LONG TERM STRATEGIC ISSUES FACING THE TRANSPORTATION INDUSTRY: DECEMBER 2010 WORKSHOP REPORT

Requested by:

American Association of State Highway
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Standing Committee on Research

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Proceedings:
Workshop on Long Term Strategic Issues Facing the Transportation Industry

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1.0 INTRODUCTORY COMMENTS

The workshop opened with greetings and introductory comments from TRB staff, leaders of AASHTO Standing Committee on Research (SCOR) and the NCHRP 20-83A principal investigator/workshop facilitator.

- *John Halikowski, Director of the Arizona DOT and Chair, SCOR:* Mr. Halikowski described the NCHRP program as being an ongoing success for DOTs, having consistently delivering many practical and useful solutions to contemporary problems. He then noted how the 20-83 series projects are different from previous efforts because of their future orientation. While acknowledging that the future may not be fully knowable, he explained that the goal of the 20-83 projects is to help DOTs prepare for as well as influence the future by taking actions today.. Finally, he reminded participants of the importance of the 20-83 projects in terms of safety, jobs and other concerns, and then introduced
- *Sandra Larson, Director of the Iowa DOT Research and Technology Bureau, Vice-chair, SCOR, and 20-83 Task Force Member:* Ms. Larson echoed Mr. Halikowski's comments and thanked the hundreds of panel members who volunteer their time and make the NCHRP program possible. She explained that in March 2008, SCOR decided to take a look at long-term research needs over a 30-50 year time horizon. NCHRP retained a consultant to conduct a scan of megatrends and held a workshop to understand the potential implications of these trends. SCOR subsequently selected and funded seven projects. Ms. Larson noted that many of these projects had started fairly recently; thus, there was no expectation that project findings and/or recommendations would be presented during this workshop. Rather, the goal of the workshop is to understand what has been learned from these projects thus far, and to solicit thoughts on additional future-oriented research needs under the 20-83 program. Ms. Larson invited participants to participate freely in the discussion, ask questions and share observations.
- *Lori Sundstrom, TRB Program Officer:* Ms. Sundstrom provided an overview of workshop agenda. She explained that although this workshop will discuss seven of the 20-83 series projects, there is an eighth project that will be conducted by FHWA and which has been put under contract. She also thanked the 20-83 project principle investigators for their willingness share their progress thus far, because this workshop was not part of their original scope.
- *Peter Plumeau, Resource Systems Group, NCHRP 20-83A Principal Investigator & Facilitator:* Mr. Plumeau emphasized that this workshop is an opportunity for participants to think outside their comfort zones. He explained that the intent of the workshop is to not only learn about the status of the 20-83 research projects, but also to begin thinking about additional long term issues that agencies may choose to address.

2.0 PANEL ON NCHRP 20-83 SERIES PROJECTS - PROGRESS AND INFORMATION TO DATE

The workshop began with a panel comprised of the Principal Investigators (PI) for each of the seven NHCRP 20-83 series research projects. The panel session began with each PI responding to a series of key questions about their projects. These responses were followed by an interactive panel-participant discussion facilitated by Peter Plumeau.

QUESTION 1: WHAT IS THE SCOPE OF YOUR NCHRP 20-83 PROJECT?

Project 1: Economic Changes Driving Future Freight Transportation, Chris Caplice, MIT	Our first objective is to provide an overview of the driving forces to help DOTs understand freight for investment planning. Our second objective is to identify how to better enable and inform freight discussions at the national, state, multistate, regional and other levels. The first deliverable was a set of expert-developed and practitioner-tested future scenarios. The second deliverable is a set of six scenario planning workshops, held in geographically and contextually diverse locations. The third deliverable is "scenario planning in a box" – a set of collateral that any practitioner can use to facilitate a scenario planning exercise.
Project 2: Expediting Future Technologies for Enhancing Transportation System Performance, Steven Popper, RAND	Our problem is to consider how DOTs can expedite the uptake of technologies and technological change. Due to the nature of technological innovation, the question is not what will happen over 40 years how DOTs can manage conditions of perpetual change. We are focusing on methods to make DOTs and other transportation agencies more effective in assessing technological trends that may affect the performance of the transportation system over the next 40 years. This means not only doing more purposeful, transportation-oriented technology assessment, but also better integrating these assessments into the planning processes as well as understanding better how to handle the inherent uncertainties.
Project 3: Long-Range Strategic Issues Affecting Preservation, Maintenance and Renewal of Highway Infrastructure, Stuart Anderson, TTI[1]	The key operative words in our project objective are merging materials and technology. The panel asked us to do this around twelve areas of change. Examples of these areas of change include technology and innovation, environment, safety, etc. We have started reviewing the literature and establishing a context around these areas of change, and will be developing some white papers and scenarios around these areas.
Project 4: Effects of Changing Transportation Energy Supplies and Alternative Fuel Sources on Transportation, Paul Sorensen, RAND	The goal of the fourth project is to think about how energy will be used in transportation over a 30-50 year timeframe, focusing on the roles of state DOTs and policy options. We have established four tasks, and we are just beginning phase 1, in which we are looking at technology issues and trends that may impact energy use. We will then develop a range of plausible energy use futures, and evaluate them relative to the roles, mandates, and funding and operations of state DOTs.
Project 5: Climate Change and the Highway System: Impacts and Adaptation Approaches, Michael Meyer, PB	This project involves synthesizing current knowledge about potential future changes to the environment. One key project goal is to develop a diagnostic framework that can help state DOTs identify more vulnerable and critical assets that may be affected by changes in climate, and to identify strategies for adapting to this change. We will also prepare guidance in specific areas on planning, maintenance, environmental analysis.
Project 6: Effects of Socio-Demographics on Travel	Our project addresses the effects of socio-demographics. Because accurate long term forecasting is difficult, the project is developing a hybrid approach using scenarios and small systems dynamics models. We have started by identifying the key

[1] It should be noted that the contract for Project 3 was executed only a few weeks prior to this workshop. Thus, the Principal Investigator was asked to respond only to Question 1 regarding the scope of the study.

Demand, Johanna Zmud, RAND	socio-demographic and external factors influencing travel demand, and our assumptions about what these will look like in the future. We then run models to illustrate various outcomes. A key challenge will involve developing strategies for DOTs based on the outcomes of our scenario tests.
Project 7: Sustainable Transportation Systems and Sustainability as an Organizing Principle for Transportation Agencies, John Wiegmann, BAH	The focus of this project is on balancing future demand for mobility and transportation services against the environment, energy, social equity and technological uptake. To define the organizing principles, we are considering things like governance structures, institutions and organizations, and models and structures for decision making. In the first phase of the project we are developing a number of scenarios that we will use to examine the implications of various organizing principles.

QUESTION 2: CAN YOU DESCRIBE FUTURE SCENARIOS FROM THE PERSPECTIVE OF YOUR PROJECT?

Project 1: Economic Changes Driving Future Freight Transportation, Chris Caplice, MIT	A scenario is not a forecast of a probable future - it is simply a plausible future. Good scenarios have a number of qualities: plausible, internally consistent, memorable, and sufficiently different from each other. We developed four scenarios for this project: **Naftastique!**, in which the world has divided into trading blocs, and North America has bonded together has formed a North American economic community; **Global Marketplace** where trade and people move freely across the globe but there is tremendous volatility; **One World Order**, in which there is a powerful international regulatory organization, like a WTO with teeth; and finally **Technology Savior** where technical advances in manufacturing, energy, and agriculture have made the United States practically self-sufficient. These are not the probable or necessarily preferred futures, but simply plausible ones that can generate discussion and debate.
Project 2: Expediting Future Technologies for Enhancing Transportation System Performance, Steven Popper, RAND	There is an essential problem with scenarios. Scenarios should not refer to specific alternative futures but rather different regimes in which many different futures may lie. The difficulty lies not in generating scenarios, but thinking through the scenarios critically and using them analytically. We need to understand why the scenarios we developed 10 or 20 years ago got it wrong. Why is the "highway of the future" always 10-15 years away?
Project 4: Effects of Changing Transportation Energy Supplies and Alternative Fuel Sources on Transportation, Paul Sorensen, RAND	At present, we haven't scenarios themselves, though our scenarios will be structured around the implications for state DOTs. We are starting by looking at all the input variables and how they interact both with one another and also collectively. We are also considering other relevant issues, such as energy independence regulation, sociodemographic and economic changes, and transportation revenue sources. All of these inputs translate into three dimensions that we're building our energy scenarios around: What is the total travel? How is that divided across modes? What is the energy source that's powering this travel?
Project 5: Climate Change and the Highway System: Impacts and Adaptation Approaches, Michael Meyer, PB	All the scenarios used in our project come to us from the intergovernmental panel on climate change, and all of the climate change modeling done worldwide is based on scenarios. These scenarios are defined along dimensions addressing population growth, economic growth, types of fuel use and other factors. In this project, we're using differences in the scenarios to identify best-case scenarios are and worst-case scenarios.
Project 6: Effects of Socio-Demographics on Travel Demand, Johanna Zmud, RAND	We have developed three scenarios at this time. In the first scenario we assume significant domestic population growth and how to accommodate this growth. The second scenario, called "Too little, too late", assumes that there is economic growth because of population growth and technology advances, but real public spending on infrastructure declines. The third scenario is called "Greenurbia", in which people being able to fulfill the needs in less environmentally damaging ways. We've been identifying key factors over the next 30-50 years, and the scenarios are defined by alternative assumptions about these factors.

Project 7: Sustainable Transportation Systems and Sustainability as an Organizing Principle for Transportation Agencies, John Wiegmann, BAH	We've developed a number of scenarios. These include: "Predictable World," based on generally held assumptions about population and economic growth and economic growth; "Crisis World" in which there is an accelerated rate of climate change coupled with slow economic growth; "Dirty World" in which there is slow economic growth, continued reliance on fossil fuels, and steady predictable rate of technological growth; and "American Renaissance" which assumes strong economic growth. Other scenarios such as "Wonderworld" and "Greenworld" are more utopian, with the former assuming major technological breakthroughs in energy and the environment.

QUESTION 3: WHAT ARE THE MOST IMPORTANT ISSUES EMERGING FROM YOUR RESEARCH?

Project 1: Economic Changes Driving Future Freight Transportation, Chris Caplice, MIT	It's important to know your objectives whenever you look at trends. In our case, because we are focused on freight movements, we are only interested in trends that may influence where freight comes from; where it goes to; how it gets routed; the total volume; and the characteristics of the products themselves (such as value density). Based on the major trends we saw, we developed the four scenarios. What distinguishes the scenarios are not the trends themselves, but how the individual scenarios/worlds react to the trends. From our initial analysis, we think the two most important factors are (1) the level of global trade and (2) resource availability.
Project 2: Expediting Future Technologies for Enhancing Transportation System Performance, Steven Popper, RAND	The question is what do transportation agency officials need to know in order to expedite the future technologies. First, technology is a means to an end therefore, it should be viewed in a larger context. Second, technology uncertainty is not a failure, but inherent in the enterprise of innovation. Third, as technology grows as a component of even traditional methods and capabilities, inherent uncertainty grows. Fourth, problems stem only in part from technical uncertainty. Often, the "failures" have to do with the nature of the organizations and cultures, not technologies. Fifth, there is a gulf between technology in planning and how it is applied in operations.
Project 4: Effects of Changing Transportation Energy Supplies and Alternative Fuel Sources on Transportation, Paul Sorensen, RAND	We've identified four key trends. First, climate issues could become increasingly important, not whether the manifestations of climate change will become evident, but rather in terms of the effects on policy. Second, major shifts in energy efficiencies and type of energy use look quite likely. Third, major shifts in transportation demand patterns are possible, and depending on the trajectories of various variables, we will see changes in the rates of growth of travel and shifts in the modes of travel. Finally, in all plausible futures we foresee the need to replace or augment current motor fuel taxes given the changes in technology.
Project 5: Climate Change and the Highway System: Impacts and Adaptation Approaches, Michael Meyer, PB	Climate change is happening now. We're going to see more and more changes like the changes we're seeing now in Alaska with permafrost and in Florida with storm surges. These changes will differ from one part of the country to another, from the intensity and amount of precipitation to sea level rise. This implies a need for more adaptive approaches, both on the design side as well as on the operations and maintenance side. We are going to have to get much more involved with risk oriented approaches to design and system management, just as we've done with assessing earthquakes and fire risks . We will need to reconsider our approaches to project design location decisions.
Project 6: Effects of Socio-Demographics on Travel Demand, Johanna Zmud, RAND	Our task is really to talk about the impacts on travel demand. Our list of trends includes economic growth, immigration rates and the uncertainty around this due to outstanding policy questions, demographic trends including fertility rates, fuel supply and prices, and vehicle technology. Some of the external drivers of these trends include information technology, transportation infrastructure, environmental attitudes, land use.
Project 7: Sustainable Transportation Systems and	The most important trends that we are looking at have to do with fiscal and financial resources, and with the locus of authority across local, state, federal and private entities, as this has implications for future revenue generation.

Sustainability as an Organizing Principle for Transportation Agencies, John Wiegmann, BAH	Trends in the spatial concentration of populations and locations of activities, the development of megaregions, and patterns and modes of intra- and inter-city travel will also be important. The rate of global warming will be a factor, as well as the development of alternative fuels is mainly a subdriver for patterns of energy use. Finally, trends in freight demand will be important because it some modes of freight transportation may not be able to absorb additional growth.

QUESTION 4: HOW QUICKLY IS CHANGE OCCURRING IN YOUR AREA OF RESEARCH?

Project 1: Economic Changes Driving Future Freight Transportation, Chris Caplice, MIT	Everything is changing rapidly - the challenge is to determine what to include and what to ignore. In looking at past predictions about fuel prices, in addition to observing that these predictions are always wrong, it is also interesting to note how they're wrong. Predictions are made based on their local environment in time projected forward - the slope of the lines predicting changes in prices reflect the slope the change in the price of fuel at the time, so there's a lot of volatility. In the long run, people simply can't predict disruptions; they tend to predict linear trends. This is why we're doing scenario planning. Ultimately, the path to the future is more important than the specific future, because you can change along the path.
Project 2: Expediting Future Technologies for Enhancing Transportation System Performance, Steven Popper, RAND	Technology prediction is not going to work. The history of technology teaches the importance of having different guesses about the future. At one point in the development of the automobile, cars had three wheels or four, were powered by steam or electric or internal combustion engines, had steering wheels or tillers, etc. We're at a similar point today with many core technology applications. Our efforts are focused on trying to address the challenge of evaluating the choices that lie before us today, given that we don't know the future and we can't forecast reliably.
Project 4: Effects of Changing Transportation Energy Supplies and Alternative Fuel Sources on Transportation, Paul Sorensen, RAND	We see a rapid pace of change. In the last decade, we've seen introduction of many new vehicle technologies such as hybrids and plugins. At the same time there's been good pace of both public and private investment in the technologies that will continue to drive change in this area. Factors that will continue to affect the pace of change include oil markets, economic growth, land use trends, policy responses to climate change, and changes in transportation financing. It's difficult to predict the future, so it's useful to look at scenarios. Also, due to the complexity and interactivity of many variables and their long time scale, it is important to incorporate more elements of qualitative reasoning.
Project 5: Climate Change and the Highway System: Impacts and Adaptation Approaches, Michael Meyer, PB	There are fairly rapid changes in terms of research approaches to climate change. But trying to forecast the future, even on a scenario basis, is very difficult. The biggest issue is scale. All the global climate change models are by definition global, and though we may have some credible forecasts at a continental or regional scale, policy makers want locally detailed information, which is called "downscaling." Downscaling is fundamental to addressing the potential transportation challenges we face. The implications of this for our research is not to get hung up on details of the forecasts, but rather to remain focused on strategies and policies, as well as on thresholds for taking action.
Project 6: Effects of Socio-Demographics on Travel Demand, Johanna Zmud, RAND	We expect that the US will look very different in 2050 than it does today in terms of where and how people live, work, and engage in other activities. The external drivers that we've talked about – fuel supply, energy technology, information technology - will impact these aspects of peoples' lives. In our approach we identify leading indicators, develop strategic assumptions about these leading indicators, build scenarios around the indications and then apply agent based simulation models to illustrate and clarify what the future may look like.
Project 7: Sustainable Transportation Systems and	One of the challenges is that some of the factors and trends that define our scenarios change slowly, while others change rapidly. One important trend to monitor from a finance standpoint is our progress towards user charging

Sustainability as an Organizing Principle for Transportation Agencies, John Wiegmann, BAH	programs. In terms of managing demand within the bounds of our economy, we need to look at trends in the financial and economic balance in terms of what the market will bear and the cost charged to users of transportation. Over the long term we're dealing with financial trends, influenced by economics and technology and other factors, of course.

QUESTION 5: HOW DOES A DOT MONITOR CHANGES IN THE POLICY ENVIRONMENT?

Project 1: Economic Changes Driving Future Freight Transportation, Chris Caplice, MIT	We need to be able to help people identify events and trends that may affect their worlds. In our project, every week we send an email to our community regarding a news event, and ask them which of the four worlds/scenarios it moves us closer to (i.e. Naftastique, etc). This helps them understand how to classify events, such as the impacts of global forces on local region, and provides them with the skills to understand the impacts of trends and events on their concerns.
Project 2: Expediting Future Technologies for Enhancing Transportation System Performance, Steven Popper, RAND	This involves two related tasks. First, we look for tools to assist in characterizing technology, not in terms of field or mechanism, but rather of where and how they will affect transportation. Second, we want to think in terms of guidelines for the assessment and use of technologies by individual agencies. We want to provide a conceptual framework for how transportation professionals can understand their roles and tasks with respect to specific technologies. Uncertainty can be managed by identifying explicitly our assumptions, which assumptions are most critical, and how shaping and hedging strategies may be developed to deal with their vulnerabilities as needed.
Project 4: Effects of Changing Transportation Energy Supplies and Alternative Fuel Sources on Transportation, Paul Sorensen, RAND	We have been thinking about this question in terms of what could be monitored rather than how to monitor. There are a number of relevant factors that we need to monitor, such as the price of oil (which influences the financial feasibility and attractiveness of some of the alternatives), evidence of climate change and how translates into federal climate or energy independence policy, changes in federal transportation finance policy, and of course trends regarding fuel and vehicle technologies and vehicle propulsion technologies.
Project 5: Climate Change and the Highway System: Impacts and Adaptation Approaches, Michael Meyer, PB	This is a difficult question to answer with regard to climate change because there is a difference between climate and weather, and we need to have appropriate responses to different types of events. DOTs are responding to more big storms and big events, but it is unclear whether these are short term anomalies or long term trends, and what does this events this mean in terms of operations, maintenance and staff? We need to identify critical assets in the highway system because there's now a higher probability that storms that cause damages. Very large scale trends may not mean that much to an individual DOT, but the fact that that scenarios are changing may an important issue. Monitoring is an essential element in detecting trends, and we also need a more risk-oriented, uncertainty-based approach for our planning activities.
Project 6: Effects of Socio-Demographics on Travel Demand, Johanna Zmud, RAND	One of our project goals is to provide the DOTs with a roadmap to monitor changes in the policy environment, and so one of our responsibilities in this project is to identify those key forces that should be monitored. Another goal of our project is to explicitly state the input assumptions that define scenarios, so that we can test our assumptions. Ultimately, we want to leave DOTs with a process for monitoring the assumptions and evaluate scenarios on an on-going basis.
Project 7: Sustainable Transportation Systems and	The difficulty that we face is that policy and regulations have complex and cumulative effects. We need to continuously monitor statistical variations in the key leading indicators, such as energy prices, air quality, deficits and

Sustainability as an Organizing Principle for Transportation Agencies, John Wiegmann, BAH	revenues at all levels of government, and energy efficiency improvements. To the extent possible, we also want to monitor the effects on travel demand and freight statistics. Finally, we need experts to evaluate the policy and regulatory drivers of these changes.

QUESTION 6: WHAT ADDITIONAL 20-83 RESEARCH SHOULD SCOR CONSIDER?

Project 1: Economic Changes Driving Future Freight Transportation, Chris Caplice, MIT	The real objective for all of our projects is to enable people to better consider the future in decision-making. We've learned a few things from our first workshop. First, it is important to play to peoples' strengths - DOTs are better at preparing than at predicting. Second, decision-makers need to be able to monitor globally, while also thinking about their local and regional needs, which is especially important in the realm of freight. A final lesson is, "show, don't tell." In terms of research, we need less emphasis on prediction and more focus on implementation. This means speeding up the adoption of scenario planning with planners. We need to emphasize robustness and flexibility in project design and we should identify and fund some comprehensive pilots that test new approaches. We should collect more longitudinal data to understand how things are changing, and finally we need an ongoing process for monitoring.
Project 2: Expediting Future Technologies for Enhancing Transportation System Performance, Steven Popper, RAND	Project has not yet advanced sufficiently to make recommendations.
Project 4: Effects of Changing Transportation Energy Supplies and Alternative Fuel Sources on Transportation, Paul Sorensen, RAND	We need research on how to bring scenario planning into the long-range transportation planning process. Another research idea would involve evaluating how we assign roles in transportation and land use, and consider whether our current institutions support our long term goals and whether our current institutions will allow us to address those goals, and whether we might want to restructure. In parallel, we need to better understand our goals and the strategies needed to achieve these goals. Often we talk about goals as means rather than ends. For example, is reducing VMT a goal, or is a means to achieve another goal? Finally, another issue is that some of the policy options such as VMT pricing face political obstacles. Are there longer terms strategies for building trust in DOTs, as a means to engage and support more meaningful debates?
Project 5: Climate Change and the Highway System: Impacts and Adaptation Approaches, Michael Meyer, PB	Risk-based analysis is a very interesting research area. Looking at best practice designs and improvements, such as looking at how the Dutch are addressing design issues, would also be a useful research topic. In addition to design, we need to understand more about effective system monitoring methods in the context of adaptive system management, with a specific emphasis on how we feed that information back into the decision-making processes. Finally, we need to be looking at the institutional side in terms of barriers and constraints.
Project 6: Effects of Socio-Demographics on Travel Demand, Johanna Zmud, RAND	Project has not yet advanced sufficiently to make recommendations.
Project 7: Sustainable	We need more study of is the potential of further devolution of authority, responsibility and accountability for

Transportation Systems and Sustainability as an Organizing Principle for Transportation Agencies, John Wiegmann, BAH	transportation. The impacts of population growth and the development of megaregions may be an interesting area for research into how to better managing our transportation system. We need to improve our models and research on the economic and travel demand effects of increased user charging because there are many components that are charges but we don't have a good understanding of the economics. Finally, we need to think about strategies for decommissioning and abandonment of facilities.

2.1 PANEL DISCUSSION

After the panelist presentations, the participants engaged in a facilitated interactive discussion with the panelists and each other. The following summarized key issues raised and discussed:

2.1.1 Rail

Workshop participants asked whether any of the projects were addressing rail, in either current or future forms:

- *Chris Caplice (Project 01):* This project is trying to remain "mode-agnostic" but recognizes that freight issues cannot be discussed without thinking of rail.
- *Paul Sorenson (Project 04):* This project is implicitly considering rail because of rail's importance to both passenger and freight transport. However, to date, the project has not explicitly addressed rail.
- *Johanna Zmud (Project 06):* This project will be looking at measures such as mode share, and will be explicitly addressing rail-related issues such as intercity travel and high-speed rail mode choice.

2.1.2 Role of DOTs

Workshop participants described the evolution of the role of DOTs from being focused primarily on building and maintaining linear infrastructure systems, to an increased emphasis on operating and maintaining infrastructure and on achieving policy outcomes such as reduced energy consumption, and they asked panel members how they though these roles would continue to evolve over the long term.

- *Steven Popper (Project 02):* This question had been raised by many DOT staff who are seeking to define agency roles and approaches. However, there are no specific predictions on how these roles would change. Several workshop participants stated that that groundwork needed to be established early on to develop political and public support for changing and evolving roles.

2.1.3 Funding Mechanisms

Participants asked for suggestions on how to use pricing as a tool to not only move toward a better future, but to finance it as well.

- *Paul Sorenson (Project 04):* This project team is seeking to identify "no-brainer" policy options that are broadly applicable across most of the plausible futures. Taking proactive steps to modify our funding mechanisms is likely to emerge as one of these options, although there is concern about the political challenges of implementing such changes. Mr. Sorenson observed that DOTs need to build greater trust and dialogue with decision-makers and the public.
- *Michael Meyer (Project 05):* This project team is examining how changes in population and other factors will affect transportation funding.
- *John Wiegmann (Project 07):* This project team is not identifying what specific future funding mechanisms will be. However, we can safely say that transportation costs will be higher, and that technology, maintenance and other costs would continue to increase.
- *Chris Caplice (Project 01):* In workshops conducted under this project, they want people to put aside budgeting and financing concerns and to instead focus on identifying priorities.

2.1.4 Scenarios and Complex Systems

One workshop participant asked about how various systems dynamics, such as the self-reinforcing nature of long-standing complex systems and the self-recovering nature of other systems were captured in the range of scenarios.

- *Johanna Zmud (Project 06):* This project team is developing scenarios that use systems dynamics models with feedback loops, in which they consider not only how input variables affect demand, but also how demand affects in the input variables.
- *Paul Sorenson (Project 04):* While this project team will be developing 10 to 15 scenarios, it will likely examine extreme and/or boundary scenarios more closely because they are more useful for exploring and understanding possible future trends.

2.1.5 Practice Relevance

Several participants asked the panel to describe the most effective way to ensure that outcomes from these projects would be used to assist executives in making improved choices. In particular, participants expressed concerns about the "blue sky" nature of the research and about the lack of commonalities in the scenarios across the seven projects, and suggested that it would be useful to have someone establish these commonalities. They also raised the issue of the evolving roles of DOTs, and how the relevance to these possible future roles could be established. They expressed some reservation about how common scenarios could be defined, given the varied focuses of the different projects.

2.1.6 Rates of Change in Technology

One workshop participant inquired about how to understand about the rate of change in technology, specifically observing that although the propulsion systems may be changing, vehicles look essentially the same as they did 50 years ago.

- *John Wiegmann (Project 07):* Regardless of the propulsion system, a certain amount of energy will be used, at a certain cost, and this probably will not have much of an impact on density and speed. There may be much more demand in the future.
- *Paul Sorenson (Project 04):* Climate change may induce policy actions designed to achieve much faster technological change. For example, in Germany, a truck toll system differentiates per kilometer rates by vehicle type based on emissions. After only a few years, this pricing policy has led to very rapid change and technological uptake. Policies are not dependent on 100% uptake of different technologies and even more moderate uptakes can have an impact.

2.1.7 DOT Workforce Training

It was observed by a workshop participant that transportation industry workers at state DOTs, at MPOs and at all levels of government are being asked to evaluate situations and issues that are significantly broader and more complex than what they were exposed to in their formal training. The panelists observed that further research into professional training relevant to these topics and issues could be warranted. One panel member observed that the issues addressed in the 20-83 projects are not formally considered in typical education/training curricula, although students are very interested in many of these issues. Another panel member observed that some graduate programs have initiated more interdisciplinary courses and studies.

2.1.8 Politics and the Policy Environment

One workshop attendee expressed concern that much of this 20-83 outcomes would not be translated or resonate with those in a position to make critical decisions, particularly those politicians who are focused on two and four years into the future, and solicited from the panel thoughts on how to get the people who make the decisions to respond to these research efforts. This perspective and concern was echoed by a number of panel members.

- *Michael Meyer (Project 05):* The most effective strategy is to simply get information out to people at all levels, from mid-level professionals to high-level decision-makers. Disseminating information about the impacts and consequences of climate change is especially critical.
- *Steven Popper (Project 02):* The issues of political backing and agency interactions are very important when technology decisions are being made. People rarely respond to significant challenges immediately, and education and time are essential. As more people understand issues, leaders find themselves being pushed to lead. It is important to use simple models when trying to convey these complex ideas.

3.0 KEYNOTE ADDRESS: "…AND I WILL MOVE THE WORLD", ALEX LIGHTMAN, CTO AND DIRECTOR, FORTUNE NEST CORPORATION

Mr. Alex Lightman, Chief Technology Officer (CTO) and Director of the Fortune Nest Corporation, and author of, A Brave New Unwired World: The Digital Big Bang and the Infinite Internet, delivered the keynote address to the Workshop.

3.1 INTRODUCTION

Mr. Lightman began his address by noting the importance of the goals of the 20-83 projects, and described how he considered it "blueprint prophesy," in which someone states how things will go, gives people the "blueprint" to make it a reality, and people then try to make it come true. He suggests that a more appropriate title for the project would have been: "NCHRP 20-83A: Long-Range Challenges and Potential Catastrophes Facing the Entire World, and Potential Solutions from the Infrastructure Community of the US Federal and State Governments." Mr. Lightman asserted that predicting the future is a function of competence, not possibility, noting the financial success of an insurance industry exemplifies just such a competency.

3.2 KEY THEMES

Key themes of Mr. Lightman's address included the following:

- *Create a "Department of Superconnectors:"* To reflect that the increased role of transportation agencies and not simply moving people and goods on a network but also supporting how people find, meet, transact and exchange, and provided new possible agency names, such as the "Department of Infrastructure," the "Department of Infrastructure and Technology" and the "Department of Superconnectors." Mr. Lightman recommended that departments of transportations should blur the lines with telecoms the FCC, and the Department of Energy. He said the "smart grid" needs federal, state, and local regulation far beyond public utility commissions' current competence.
- *Focus on Return on Investment from Infrastructure:* Mr. Lightman argued that the government's investment in the federal highway system and the internet created new industries, resulted in a commercial explosion of technologies and job-creating companies,

which further supported the ability to implement more infrastructure. Mr. Lightman emphasized the importance of analyzing and considering return on investment (ROI) analyses in order to make the case for future investment. Mr. Lightman believes that 50 years is an appropriate timeframe over which to amortize investments in infrastructure because these investments typically last for long periods of time and it is important to consider the life of the investment.

- *Address "Peak Credit:"* Mr. Lightman believes that federal, state and local finances are approaching "peak credit" and a consequent general collapse of creditworthiness. He stated that the US's creditors in China and the Gulf Cooperation Council (GCC)[2] have long term financial and investment plans and that the US needs to as well. He emphasized the importance of considering money and finance in any future plans, given the declining creditworthiness of US federal government and states. Mr. Lightman also pointed out that in a reduced credit world, there will more user fees, and less reliance on debt, and that it will be necessary for agencies to collect money directly rather than through someone else.
- *Consider Science Fiction as Inspiration:* Mr. Lightman argued that it is not sufficient to expose kids to technology, proposing instead that it is essential to provide stories that get kids excited about possibilities, and recalling Albert Einstein's quote that, "Imagination is more important than knowledge." Mr. Lightman praised science fiction for providing both vision and inspiration, citing examples of Jules Verne and H.G. Wells as inspiring the Apollo space program and atomic bomb, respectively, in their writings. He said that functionally, science fiction transmutes uncertainty about the future into a source of excitement and anticipation, and can be a means of identifying and anticipating issues. Mr. Lightman offered his own definition of science fiction: "visions of technology that people will pay for." He reminded the audience of the important of the "blueprint prophecy," which not only speculates what may happen, but also promises to reward those who realize future visions with respect and renown. He emphasized that his bids for venture capital are successful when the person to whom he is pitching says, "That's a great story."

3.3 PREDICTIONS, CONCLUSIONS AND RECOMMENDATION

As a futurist, Mr. Light offered some predictions about political and economic changes he expects to see over the next fifty years, with a focus on China and the GCC, two regions in which he has particular expertise. In the near term, he predicted that China will prohibit exports of rare earth metals to the US, which would impact the US's emerging electric car and wind power industry, and he also forecasts that the GCC countries would start buying US transportation infrastructure rather than government bonds. Mr. Lightman foresees that the China's GDP will equal the US's by the beginning of the next decade, and that as its economy continues to expand and require natural resources, China will push the US out of the Arabian Gulf. However, China will not be immune to difficulties, including internal issues associated with an aging workforce, and external issues such as attacks on its natural resource holdings. Mr. Lightman predicted that the US would eventually return to the Gulf, but that by the 2050s oil and natural gas exports from the GCC will end. However, he expects that by then we will have had sufficient time to transition to electric vehicles, powered by solar, wind, and nuclear fission and fusion and distributed using the smart grid.

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2 GCC member nations are: United Arab Emirates, The Kingdom of Bahrain, The Kingdom Of Saudi Arabia, The Sultanate of Oman, Qatar, Kuwait

Mr. Lightman encouraged participants to continue to lead forward-looking efforts, and advised that few other people were willing to consider such important issues over such a long time horizon. He offered some specific advice, suggesting that the first step in leading this change is to develop a comprehensive ROI analysis of infrastructure, both past and present, domestic and international. He encouraged the group to advocate for congressional hearings on infrastructure leadership with the goal of creating a new technological impulse similar to the space program. Mr. Lightman promoted the creation of an open source model such as the Club of Rome's "Limits to Growth Model," which was developed with MIT's Systems Dynamics Group, and to establish a standard model for the testing of different scenarios. Finally, he recommended that two books and associated videos be produced at the conclusion of the project – one book would be speculative nonfiction, similar to Limits to Growth, while the other would be a work of science fiction based on the projects findings.

4.0 SCAN OF FUTURE TECHNOLOGY AND SCIENCE ADVANCES AND POTENTIAL IMPACTS ON TRANSPORTATION: PRESENTATION OF FINDINGS, HYUN-A PARK, SPY POND PARTNERS

Hyun-A Park of Spy Pond Partners, a member of the NCHRP 20-83A project team, described how the team's first task was to a conduct a scan of science and technology advancements outside of transportation that could affect transportation 30-50 years from now. She began by discussing a sampling of past predictions about the future and the reality that emerged, as well as the question of why some of these predictions were accurate and others failed.

Ms. Park then presented a summary of the scan's key results and findings:

- *Society and Demographics:* National and international experts agreed that the aging of the population could have profound impacts on the labor force, social service provision, and even the built environment. Another population trend is the expected population growth in poorer countries and population stabilization or shrinking in wealthier countries, and many experts expressed concern about the impacts of expected economic disparities. Some of the implications were that arose from these insights are that we need to proactively look at infrastructure support for an elderly population, and that we need to consider the notion that less is better. In addition, many interviewees expect to see the further emergence of mega-regions.
- *Resource Scarcity:* Resource scarcity concerns the availability of fossil fuels, rare earth elements, water and developable land, and the competition and costs and these resources. There are many complicating questions about resource scarcity related to uncertain trendlines for resource constraints, and the implications of technology change. For example, as oil becomes scarcer we may find that it is still available but not exported as countries conserve their internal supplies, or we may see significant gains in alternative energy sources and technologies.
- *Globalization and Mobility:* "Globalization and mobility" considers the emergence of borderless economies and the creation of affinities for different areas or along different dimensions. To a certain extent, this is emerging in Europe, but not in the US. Key questions exist about the impacts of global economies on regional economies. An alternative future may involve the emergence of an "Earth culture," in which the entire world is unified without boundaries, supported by new technologies such as the scramjet that may make it possible to travel anywhere in 90 minutes.

- *Climate Change:* As stated earlier, climate change, like resource scarcity, is an area for which there was no consensus about the existence and magnitude of the problem, and the extent to which human action is a causal factor. If climate change is real and the result of human actions, change can we change the negative outcomes by changing our behavior? If climate change is real and we are unwilling or unable to mitigate it, how will we react as effects become more pronounced?
- *Useful Information:* The area of "useful information" is one in which there was consensus across almost all the experts interviewed. They observed that the past 30 years have been about our ability to capture data, and that the next 30-50 years will be about the ability to extract meaningful information from these data and converge disparate data sources. One powerful image associated with the "interest area" was the "personal brain." The vision of the personal brain is one where the individual and information are interacting in a personal way with help from technology. Another compelling vision in this area is "the internet of things," which represents the interconnectedness of devices. Critical issues in the area of useful information include the design of interfaces between and amongst persons and objects, and between objects and other objects, and the establishment of trust between people, devices and information.
- *Technology:* Technology is a general topic area that includes computers, nanotechnology, artificial intelligence, medicine, robots, and many others. To many experts, materials science seemed to hold the promise if significant impacts on the transportation sector. There was also particular excitement around the ability to integrate multiple fields, such as computing and biology, particularly with respect to the brain. Advances in robotics have and will continue to progress.

The scan report suggests how these trends and issues could affect the transportation industry and the behavior and structure of transportation agencies over time:

- *Technology:* The potential impacts of advanced technology on the transportation sector are myriad, from advancements in propulsion technology that enables commercialization of scramjets, to seamless multi-modal travel connectivity. The benefits of some of these advancements are already evident, such as the use of real-time traveler information. In addition, there may tremendous economic implications. For example, autonomous vehicles may fundamentally alter the prices for taxi services and in some places obviate the need for private vehicles.
- *Lifestyle:* A key lifestyle question raised by interviewees was whether we have reached our "mobility peak." If energy prices continue to increase will we travel less as we move toward more compact development patterns or embrace virtual reality technology? Conversely, might lower energy prices due to alternative sources or technological advances in the speed of travel result in more sprawling communities? It seems like that the future will encompass some of each of these possibilities.
- *Infrastructure:* The US transportation industry continues to shift from a "build" culture to an operating/maintenance culture. There has been little substantive advancement in materials used for transportation construction for quite some time. However, new developments may result in more durable, longer lasting infrastructure. We may find that robots are being used to do mundane or dangerous tasks resulting in lower costs. Further, in the context of conceiving of infrastructure as a system of systems, we may start to view information technology as transportation infrastructure.
- *Governance and Organizations:* It is expected that transportation organizations will need to

deal with much more complex scenarios in the future, which may require greater flexibility. A key challenge for agencies will be striking the balance between accountability and flexibility and nimbleness. Potential changes may include increased knowledge sharing and collaborative decision-making, realignment of transportation agencies with different geographic boundaries and mobility issues in mind, and integrated transportation, land use and economic development. These and other changes will have implications for public investment policy.

Additional insights flowing from the work conducted to develop the scan report include the following:

- *Predictability:* Many of the interviewees expressed skepticism about whether it is possible to predict technological, scientific and societal changes over an extended time horizon. However, we do not need to debate the possibility of meaningful prediction. Instead, we should use the information, science and the quantitative forecasting methods as best we can, informed by reasonable judgment.
- *Adaptation:* There is no question that we are in a period of rapid change with the information age, although different sectors of our society experience this change at different rates. The scope of changes we will see in the transportation field is not yet clear, but we need to consider how to adapt to these changes. Will we experience a "business as usual" future where we continue to build? Will we have to flee the earth? Will we invest in new technologies and new energy sources that maintain our quality of life on Earth?

  A present-day example of taking action now to identify and implement improvements that could potentially change our lives can be found at KAIST, the "MIT of Korea." KAIST sought to identify changes that would support greater environmental sustainability. They focused on developing light vehicles powered by inductive propulsion embedded in the roadway as the "engine" rather than a traditional vehicle that requires a heavy on-board engine. Working with the Korean government, the technology has already been implemented in some testbeds, and provides a compelling example of science and research combining with political technological and societal advance goals.

4.1 DISCUSSION OF SCAN RESULTS

- *Safety:* A participant observed that safety was not explicitly addressed in the presentation, and the question was asked as to whether this was an oversight, or if safety is assumed to be implicit in everything. Ms. Park explained that the project team started with the premise of looking outside of transportation, and we aspired to be as diverse in topics as possible. The team did not look specifically look at safety as a topic, and it did not really come up as an issue in any of the interviews. Another workshop participant observed that almost all of the concepts discussed are within our grasp, but safety and economics are two considerations that are required for any potential improvement to be realized.
- *Uncertainty:* It is important to recognize the influence of the marketplace in developing technologies, but one also has to consider market failures. For example, how does one deal with uncertain events, whether related to systems vulnerability, terrorism, or even climate change.
- *Role of Institutions:* In the useful information scenario, which promises intelligent

information about even unpredictable events, it is necessary to recognize that the provision of this information is based on having supporting institutions and organizations. Are our institutions moving us in the directions that are required to make the potential benefits of future technological improvements a reality? Is there necessary interagency coordination? It was explained that this area was addressed by team members who specifically considered the roles of institutions and the issues of cost in the decision making process.

- *Objective Analyses:* One workshop participant stated that it is important that whatever comes out of this effort be based on fact and not speculation. As an example, he cited the "folk wisdom" that fleet efficiency has improved, when in reality it really has not improved since 1987. In the context of the scenarios discussed, is it realistic to talk about a shift from building to operating and maintaining when it is projected that the population of the US will increase by 100 million people, and that 95% of travel occurs in private vehicles? Similarly, the notion that we are going to live in concentrated high density areas doesn't comport with the fact that the majority of homes built in the 1990's were located outside of urban areas. Other workshop participants observed that it is critical to recognize that different communities have different desires – some people will want to live in dense urban areas and some people will not. On a related note, it was noted that it is interesting to speculate whether increased accessibility will be provided by higher density or by electronic means.
- *Private Sector Perspectives:* One participant noted that there were few private sector perspectives reflected in the interviews, and specifically that no oil company representatives participated. It was suggested that, while they may not look 50 years into the future, these entities invest significant resources in forecasting 10 to 20 years out.

5.0 BREAKOUT GROUP RESULTS

Facilitated breakout groups, which had been convened as part of Day 1 of the Workshop, had discussed and developed responses to two principal questions:

- Based on the presentations and discussions during this Workshop, what are the 4-5 most important issues and/or challenges you think DOTs and the transportation industry will have to address over the next 30-50 years? Why?
- Considering the issues and/or challenges you just identified, think about and describe the areas or topics of research you think SCOR should prioritize over the next 2-3 years. What are the highest priorities? Why?

The following section summarizes the key responses from the breakout groups to the two primary questions, as described by a spokesperson from each of the three breakout groups. This summary reflects additional comments and questions offered by the larger group. The overall goal from the breakout groups and the subsequent discussion is to identify key near terms research topics or themes for SCOR to consider.

5.1 FINANCE ISSUES

- *Future Financing:* There was significant debate about whether the 20-83 project is the appropriate context for discussing financing issues. On the one hand, there are persistent questions about the sources of future revenues, including concerns about diminishing fuel tax dollars, and around the use of pricing policies. On the other hand, it is likely that our economy will be very different in 50 years.
- *Return on Investment / Cost Benefit Analysis:* There is a need to help people understand the

importance of investment in transportation because these investments affect employment, the environment, and our overall economy. More sophisticated return-on-investment of cost-benefit analyses can help demonstrate the multiplier effects of transportation investment across the broader economy, and can also help demonstrate cost savings resulting for near term investments. We need to think about the decision to build a 50-year bridge versus a 100-year bridge as an economic decision. More broadly, we need to consider and communicate the benefits to society at large that DOTs provide.

- *Asset Management:* DOTs have significant right-of-way assets, and it would be useful to identify means of better exploiting these assets, and perhaps having new types of asset management systems and strategies. Information is also an asset, and DOTs may be able to commercialize this information. There may be barriers and legislative hurdles that need to be addressed in order to make use of these assets.

5.2 ORGANIZATION & ROLES OF DOTS

- *Strategic Management / Adaptive Management:* The key challenge for DOTs is establishing that they are "doing the right things right." Will the focus of DOTs of the future be on providing public accessibility and mobility, across modes and land use, or will DOTs' missions be more narrowly focused? Ultimately, who are the DOTs' "users" and how can they best be served? It may be important to implement an adaptive management decision-making structure that guides the planning and investment prioritization process. Part of an adaptive approach involves tracking key indicators, and establishing responses to changes over time.
- *Serving Demand vs. Shaping Demand:* The roles of DOTs have significantly evolved over the past 50 years. In the past, estimates of demand were produced and infrastructure investments made to serve this demand. Now, in the context of financial, environmental and other constraints, DOTs find themselves need to squeeze more efficiency out of the transportation system, which can be viewed as shaping demand. What is the authority of DOTs to shape demand, and do DOTs have the tools and resources to effect desired changes?
- *Organizational Change:* In the context of ever more complex policy and investment questions being asked of DOTs, as well as technological change, some workshop participants expressed the need for more agile organizations that can be more proactive than reactive. Two different, though not contradictory, opinions were expressed with regard to overall organization changes. On the one hand, some workshop participants felt that it will be worthwhile to unify disparate government organizations in order to more efficiently coordinate responses to user needs. At present we have lots of agencies and authorities, including state DOTs, bridge authority, and local agencies that may not have common goals. Many other nations with which we trade have been consolidating their transportation agencies, and these changes are often being driven by changes in the private sector. On the other hand, some participants expressed that there will be more devolution down to local agencies. One potential problem is that local agencies do not see the value of technology, or may not have the resources or knowledge to make technology investments. Not all workshop participants agreed that organizational changes are necessary or inevitable. Rather, they suggested that better decision-making strategies would be more useful.
- *Public / Private Roles:* An important future issue will be the role of public and private entities in infrastructure provision. Increasing mistrust of government effectiveness there

has resulted in some shifts towards private infrastructure development and maintenance, though this has not been without difficulties. In addition, it was felt that it was necessary to ensure that the perspectives and insights of private entities such as shipping companies be more explicitly considered in the decision-making process.

- *Interdisciplinary / Collaborative Approach:* DOTs are increasingly tasked with challenging policy analyses such as making cross-modal comparison, and assessing the impacts of land use changes. These analyses require expertise in fields such as freight, air quality, and economic development and often involve making both qualitative and quantitative assessments. In order to answer the more complex questions posed by decision-makers and the public, DOTs need to be more internally interdisciplinary, as well as more collaborative with other agencies and other fields. In addition to the analytic challenges, there are questions about whether better decision-making will necessarily follow from more comprehensive analyses.
- *Scenario Planning:* This method can be a useful decision-support approach because it provides a range of possible answers. Given the uncertainties about the future, we do not need to be right on all the scenarios because even a few plausible scenarios can help guide decisions.
- *DOT Workforce:* There will be significant implications arising from the technological and scientific changes discussed with respect to size and skills of the DOT workforce of tomorrow, as well as on organizational knowledge management and information infrastructure. Will planners be able to use the information about of 20-83? Can we bring more young professions who may be in our positions 50 years from now into these discussions?
- *Long-term Time Horizons:* It is difficult for DOTS to look at issues with a 50-year time horizon because this long time horizon is beyond the scope of what DOT directors may want to consider. In addition, DOT management teams typically change on a much shorter time span. For these reasons, it is important that the 20-83 project engage with engineers and planners in DOTs because their tenure will frequently transcend that of their appointed executives that will be there longer than the management. Overall, there was consensus that the long time frame of the study makes it difficult to identify near term changes.
- *External Forces:* DOTs do not exist in a vacuum. And while there is a greater need for interdisciplinary work within DOTs, between agencies, and with the legislative bodies, it is also critical to understand the external realities and forces that also shape the context in which DOTs operate.

5.3 REGULATORY ISSUES

- *Changes over Time:* Most DOTs work within a regulatory framework that was established 50 or more years ago with, often not well oriented to today's problems. It is possible and useful to imagine what the regulatory regime will look like in 50 years, given that our conception of what this regime should look like may be rendered completely irrelevant by political, technological or other changes?
- *Constraints and Flexibility:* Current regulations often stand in the way of delivering projects, and impose a set of often irrational constraints, such as the preventing the expenditure of federal funds on truck stops, or restrictions on the abilities of DOTs to commercialize information or inventions. There is a need to identify these problems and work to resolve. Regulations need to be made more flexible and adaptable, perhaps incorporating

performance-based rules, and this regulatory flexibility is related to the need for DOTs themselves be more nimble and responsive to evolving policy, analysis, and financial needs.

- *Lack of Clarity:* It was observed that, in practice, there is often a lack of clarity in regulations and that different people or agencies may have very different interpretations of a given regulation. These differences may arise from the persistence of historical interpretations, the need make work plans consistent with regulations, or simply different personal perspectives. It was suggested that we need to identify and remedy non-functional or counterproductive regulations.
- *Sustainability Goals:* The notion of sustainability resonated with many participants because there is a desire to ensure that current decisions will ensure the foundations for growth for future generations. The scope of sustainability efforts cannot be limited to given state DOT, but also must consider national and international systems and demands. However, important questions remain about what a sustainable future looks like and how we achieve remain.
- *Performance Measurement:* Some workshop participants suggested that t would be useful to have sustainability performance metrics to help DOTs assess and guide their efforts. The goal of these performance measurements would be to help "tell a story" and to address the concern that current arguments for considering sustainability often do not resonate with decision-makers. However, it was also expressed that, given the advanced research nature of the 20-83 projects, the emphasis on near-term performance measurement as part of this project is misplaced.
- *Costs:* A primary challenge, if one assumes that it is more expensive today to be more sustainable, will be establishing who should bear these costs, and how these costs will be borne in the short term. It was expressed that continuing to use gas now is cheap but not sustainable, and that it will be problematic if oil costs spike and we do not have alternatives in place. We need to figure out what the future looks like and then how to move towards it.

5.4 PROJECT SCOPE AND MESSAGING ISSUES

- *Today vs. Future:* A key struggle that was implicit in workshop participants' comments was over the futuristic orientation of the 20-83 projects. Some participants felt that one of the primary challenges of all these projects is to determine whether looking at the future can be done with enough specificity to influence today's actions. Workshop participants struggled with the degree to which 20-83 project outcomes could or should focus on identifying near term actionable items, versus have a longer term, more speculative view of future research issues. Some participants were skeptical that anything useful in the near term could be produced, while other participants felt that it was premature to judge project outcomes when it is still very early in most of the individual project schedules.
- *Consistent Assumptions and Measures:* Concerns were expressed about the need for a set of logical and consistent assumptions amongst the different 20-83 projects, in order to ensure their defensibility and usefulness. In additional, there was a desire for incorporating more multimodal information and analysis into the 20-83 projects.
- *Assumption "Drag:"* Today's assumptions about how and why things work may not be applicable 50 years in the future. Unforeseen technological, scientific, economic or political changes may render today's assumptions irrelevant.
- *Project Synthesis:* There seemed to be consensus that it would be useful to develop an

additional product that would frame the goals and outcomes of the 20-83 projects. This product would review the 20-83 studies, and identify key goals, assumptions, themes and conclusions. This document could also explain the difference between scenario-based planning and predictive models. The ultimate goal of this product would be to educate people about 20-83 and distill the critical near-term and long-term implications for DOTs. It was proposed that this effort could take the form of a white paper prepared by a few qualified and objective senior individuals. This white paper would be provided to decision-makers prior to the publication of the first project report. In order to develop such a synthesis in a timely manner, it was felt that this effort needed to begin soon.

- *Target Audience:* Getting value out of these projects by carefully framing the outcomes of the 20-83 projects in terms that will resonate with CEOs and other decision-makers was emphasized. As mentioned earlier, it was also felt that there were a variety of audiences for these efforts.
- *Capacity-Building:* It was suggested that it may be useful to have several states self-select to work with consultants on implementing and testing these 20-83 notions, and then report back about what did and did not work. This would also provide an opportunity for capacity building within DOTs.

5.5 RESEARCH NEEDS

- *Scenario-Based Planning:* How can we bring scenario planning into greater practice? DOTs need to be continually considering and revising long term goals and assumptions. Given the scenario-based planning orientation of these projects, it may be more useful to come up with guidance on when and how to revise goals and assumptions, and on providing guidance to DOTs as they use these approaches and insights to develop and modify future plans. Performance measurement may not make sense when we are considering 30-50 year time horizons.
- *Return on investment:* Further research on returns on transportation investment and related cost benefit analyses were proposed. This research would address quantifying the benefits of past investments as well as developing methods of estimating the benefits of future investments. The scope of this research would necessarily be international, and would consider public as well as private sector perspectives.
- *Adaptive Management Strategies:* This research would develop adaptive management decision-making structures and strategies to guide the planning and investment prioritization process. Part of this approach would involve identification of key indicators, and proposing appropriate responses to these indicators.
- *Asset Management:* The goal of this research would be to identify means of better managing, over the short-term and the long-term, DOT assets as diverse as right-of-way and information. A key aspect of this research would involve identifying regulatory obstacles to more efficient and comprehensive asset management.
- *Sustainability:* What does a sustainable future looks like and how might we achieve this future? This research would consider the short-term and long-terms costs and benefits associated with more sustainable approaches, and consider the relevance of sustainability-oriented performance measures.
- *Workforce Changes:* In the context of persistent technological and scientific advancements, the research would consider issues of the size and skills of the future DOT workforce, and

would consider organizational knowledge management and information infrastructure.

- *Project Synthesis:* In order to effectively convey the value of the diverse 20-83 projects and outcomes to the most appropriate audiences, this effort would identify key 20-83 project goals, assumptions, themes and conclusions. It was proposed that this effort could take the form of a white paper prepared by a few qualified and objective senior individuals.

6.0 WORKSHOP SYNTHESIS, PETER PLUMEAU, RSG

The consultant team developed a preliminary synthesis of the Workshop discussions and comments for reaction and discussion by participants..

Mr. Plumeau first displayed a chart of Moore's Law, which proposes that the number of transistors that can fit on a chip will double approximately every two years, to illustrate that technological and scientific changes are a given, and appear to be on a continuously accelerating path. This notion of constant technological and scientific change was a thread through all the project research. At the same time, tremendous societal, economic, behavioral and demographic changes are also occurring. There is a concern that historical institutions, agencies and approaches are not necessarily well suited to dealing with all these diverse changes. Although scenario planning can provide a useful tool for adapting to changes, there is unfortunately often a disconnect between our desire to do scenario planning and our ability to do it right and to derive meaningful insights from our analysis.

Specific to the 20-83 series of projects, many participants observed that these projects are being conducted independent of each other, and that it would be interesting and useful to understand the implications of their results cumulatively or as a whole. People want to be able to better understand the connections between technological developments, socio-demographics change, freight, and all the other issues that have been discussed. Mr. Plumeau reported that the project team also heard concerns that that the 20-83 products may not resonate with the decision-makers, and that it may be necessary to either reframe these outputs, or target them more specifically to the engineers and planners who do the day-to-day work of the agencies, with the hope that they can use this objective information to drive changes in thinking at the top of the organizations. Another desire we heard was to be able to use 20-83 products and results to help address perceived fragmentation in authority and decision-making.

7.0 CLOSING COMMENTS

At the conclusion of the facilitated discussion on future research needs. Ms. Sundstrom and Mr. Plumeau brought the workshop to a close. The SCOR leadership offered some closing comments:

- Sandra Larson, SCOR Vice-chair, acknowledged that it is difficult to be thinking about 30-50 years in the future from a planning perspective, especially given the increasing present-day demands placed on agencies. Ms. Larson then recognized Cindy Butler's efforts to make sure all the travel and venue logistics were taken care of, and she thanked all of the task force members and workshop participants. She indicated that proceedings will be available in February and that the first NCHRP 20-83 series project report, addressing freight issues, will be published in 2011.
- John Halikowski, SCOR Chair, praised participants for the lively discussion. He reiterated that the purposes of the workshop was to give SCOR a better understanding of the current projects and help inform whether SCOR should fund additional research. He noted that this decision on future research would be made at the March 2011 SCOR meeting. Finally, Mr. Halikowski advised workshop participants that transportation agencies, confronted by

complex present-day and future issues, are potentially faced with increasing irrelevance unless they take proactive steps to anticipate the future and changes to address it.

APPENDICES

APPENDIX A

Scan Report:
Non-Transportation-Related Scientific and Technological Advances that May Affect DOTs in 30 to 50 Years
(NCHRP 20-83A, Task 1)

RSG INC.
TRANSPORTATION

Spy Pond Partners

SMART

NCHRP 20-83A Task 1 Report:

Non-Transportation-Related Scientific and Technological Advances that May Affect DOTs in 30 to 50 Years

November 2010

DATA ■ ANALYSIS ■ SOLUTIONS

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Executive Summary

The last several decades have seen extraordinary technological development. As we look forward over the next several decades we can expect this rapid pace of innovation to continue or even to accelerate. Scientists predict dramatic changes in our lives in everything from communication to medicine to transportation. Although it is difficult to accurately predict the future, experts broadly agree that we will see substantial societal changes as we adapt to accommodate an aging population, changing views on public vs. private, and increasing economic disparity. Resource scarcity, especially with respect to oil, rare earth elements, land and water, will drive us to develop new technologies to use those resources more efficiently, to replace them, and/or to access currently inaccessible supplies. Transportation technologies will improve, making it faster and easier to move people and goods around the world. Simultaneously, communication technologies will improve which may reduce the need for travel and rising oil prices may make travel and long-distance transportation more expensive. Climate change will continue to be a serious risk, although it may be mitigated by actions we take in response to other drivers such as rising oil prices. Information management advances will help us access and make sense of the increasingly overwhelming amount of information available.

All of these changes will have major implications for transportation technology, infrastructure, and management. Rising oil prices and climate change will increasingly push us to develop new, cleaner, more efficient propulsion systems. IT breakthroughs will help us deliver seamless, interconnected, multi-modal transportation infrastructure to provide efficient travel and the local, regional and global level. Autonomous vehicles will allow us to safely increase speed and capacity. Infrastructure will continue to evolve to be more multi-modal, interconnected and IT driven. Transportation management institutions will have to adapt to the changing environment by increasing collaboration and cooperation across technological, economic, and political boundaries. Public investment will become “flatter” to focus more on system-wide, multi-modal, integrated solutions.

1 Introduction

Transportation practitioners can look back with wonder at the vision of the future presented in the 1960s-era TV show Star Trek. The creators of Star Trek imagined a future in which transportation involved warp speed, transporters, and, of course, the Holo-deck — a device designed to eliminate the necessity of actual travel.

Each one of these technologies draws upon scientific breakthroughs that perhaps seemed just over the horizon 50 years before. Looking ahead 30-50 years, NCHRP 20-83 seeks to understand the implications of emerging scientific innovations and technological megatrends on state departments of transportation.

This project, a scan across the breadth of all relevant non-transportation related disciplines, addresses the scale and scope of scientific and technological change over the next 30 to 50 years. It then seeks to project the implications of these advances onto the moving target of the state DOTs of 2040-60.

In order to avoid plunging entirely into the territory of science fiction, we approached this project in close partnership with a core group of leading-edge thinkers and practitioners drawn from the forefront of their respective fields in science, technology, and engineering. These thought leaders have, through a series of informational interviews, lent their collective intellectual guidance to this project.

1.1 Purpose

The purpose of Task 1 of this project is to assemble and synthesize information from experts and futurists across a wide range of fields in order to understand what the future, and especially the future of transportation, will look like 30-50 years from now.

1.2 Contents

This document summarizes the results of Task 1 of NCHRP 20-83A, *Scan to Identify Scientific or Technological Advances Having Implications for State DOTs 30 to 50 Years in the Future,* as follows:

- Section 1 provides a brief overview of the project and the purpose of Task 1. Section 1 also introduces the organization of the report and provides a brief summary of findings.
- Section 2 discusses themes from the research that suggest areas of predicted change. For each theme or topic we offer a summary of the current state, one or more future scenarios and/or sub-themes, and a discussion of the implications of these predictions.
- Section 3 examines the implications of these predictions for transportation.
- Section 4 addresses the very idea of predictability. Section 4.1 explores the question of whether prediction of the future is even valid. Section 4.2 examines frameworks for thinking about how we adapt to change.

- Appendix A presents the research methodology and sources including how they were selected, literature sources and interview sources.
- Appendix B contains the interview guide and detailed summaries and notes for each interview.

1.3 Summary of Findings

Our research uncovered six themes of interest for the future:

1. Society and Demographics
2. Resource Scarcity
3. Globalization and Mobility
4. Climate Change
5. Useful Information
6. Technology

There is broad agreement among experts regarding emerging technologies. On key risk areas, notably climate change and resource scarcity, there is substantial disagreement. Some leading thinkers suggest that climate change and lack of oil will dramatically alter the way we live over the coming decades. Others believe that our oil supplies will be more than adequate for our needs and that the climate will stabilize without serious harm done.

In addition to predictions for the future, many thought-leaders offered observations on the difficulty and inaccuracy of long-term future predictions. While we can, to some extent, extrapolate from what we know today, it is impossible to guess at transformative breakthroughs which may occur.

2 Findings

This section presents a set of common themes from our interviews. For each theme we discuss the current state. We then present one or more predictions for the future. In some cases these predictions address different aspects of the same theme. In others, they present conflicting viewpoints about the future. We conclude the discussion of each theme by assessing the implications of the future scenarios. Sections 3.1 – 3.5 discuss social and environmental issues. Section 3.6 focuses on specific technologies.

2.1 Society and Demographics

2.1.1 Current State

Globally population is still growing with the greatest growth typically occurring in the poorest areas. Wealthier countries have stable or shrinking population. Life spans are the longest they have ever been which means average age is increasing. Economic disparity is growing – we see greater disparity than ever before between wealthy countries and poor ones, and between the rich and the poor within a country.

2.1.2 Predictions for the Future

2.1.2.1 Scenario 1: Aging Population

We will continue to see a trend toward older populations due to both low population growth and lengthening life spans. This will have implications for everything from the physical structure of our communities to transportation to work to economics. We will see a trend toward smaller, more compact living spaces that are easier for people with limited resources and mobility to navigate and maintain. We will also see smaller (physically), denser communities that put more services within easy reach for people who may not be able to travel great distances easily. In general, people do not save enough and will continue to work longer.

2.1.2.2 Scenario 2: Share More, Own Less

As communities become more compact, population densities increase and economic realities change, we will find that we can share more and need to own less. We will see an increase in services like ZipCar that allow people to share a pool of resources. We will also see an increase in systems that allow people to rent out their personal property (e.g. vacuum cleaner) to their neighbors.

2.1.2.3 Scenario 3: Social & Economic Inequality

We will see an increasing disparity between the haves and the have-nots. We will see this disparity grow not only between countries but also within them. The world cannot support a population of billions who all live like upper-middle class Americans do today. The proportion of the population that can afford such a lifestyle is likely to shrink.

2.1.3 Implications

The obstacle to progress is no longer technological – almost anything we can imagine, we can make – rather, it is societal. We need to focus less on technology for its own sake and more on what technology can help us achieve. As Scenario 3 suggests, the world cannot support a population in which everyone lives as middle- and upper-class Americans do today. As an increasing number of people around the world expect to live as they see people living in the developed world, we will have to re-evaluate our notions of what makes for a good quality of life. Perhaps it does not have to mean meat at every meal, out-of-season foods from around the world in the neighborhood supermarket, a car for every driver in the family, or regular international vacations. If we can accept sharing things we do not regularly need, as Scenario 2 suggests, perhaps we will no longer feel as much need to measure ourselves by what we possess.

2.2 Resource Scarcity

2.2.1 Current State

2.2.1.1 Fossil Fuels

The global supply of fossil fuels is able to meet current demand. Energy and fuel prices have risen steadily, but are still relatively low. The low cost of energy means that in most of the world anyone who can afford the up-front cost of a personal vehicle can then afford to operate it. Relatively affordable fuel also means goods can be produced anywhere and shipped long distances to market.

2.2.1.2 Rare Earth Elements

Rare earth elements are plentiful, although deposits are concentrated in a few locations (notably China). Supply is affected more by politics than by physical availability or accessibility of resources. Rare earth elements are critical to the manufacture of electronics including batteries (for example, the lithium in lithium-ion batteries).

2.2.1.3 Land & Water

Land has become an increasingly limited resource and water even more so. Although in many areas water still seems plentiful, we have seen an increasing number of disputes over water, particularly when a water source passes through multiple legal jurisdictions. We are also seeing some areas start to develop cities without knowing from where the water they need will come.

2.2.2 Predictions for the Future

2.2.2.1 Fossil Fuels

2.2.2.1.1 Scenario 1: We Run Out

As our supply of fossil fuels dwindles, the price of fuel (and consequently energy) will rise dramatically. Transportation will become a luxury few can afford. We will be forced to develop alternative energy sources (solar, wind, ocean, geothermal, etc.) to supply our critical needs. We will begin to reconsider globalization of our economy and distribution systems, and start to develop more localized supply chains that minimize demand for expensive fossil fuels.

2.2.2.1.2 Scenario 2: We Have Plenty

We will continue to find new sources of fossil fuels and new ways to tap known sources we have been unable to tap before. Demand may be moderated some by technological shifts driven by other factors (e.g. reduced emissions), but we will continue to have access to affordable fuel and will continue to rely on combustion engines for transportation indefinitely. Transportation will remain inexpensive and easy.

2.2.2.2 Rare Earth Elements

2.2.2.2.1 Scenario 1: We Run Out

We will run out of rare earth elements and will be forced to find new ways to either produce them artificially or to manufacture electronics without them.

2.2.2.2.2 Scenario 2: We Have Plenty

We will find new sources of rare earth elements and/or changes to the technologies that rely on them will reduce demand enough that existing supplies will be sufficient.

2.2.2.3 Land & Water

Land will become increasingly valuable and we will be forced to find ways to support a larger population on a given land area than ever before. Water resources will also become increasingly strained. Advances in desalinization may be insufficient to meet demand.

2.2.3 Implications

Disagreements among experts regarding the continued availability of critical resources such as oil and rare earth metals suggest that we will have a hard time generating the social and/or political will to mitigate risk through regulation and/or behavior changes. Instead, if those that predict supplies are at risk are correct we will see economic forces drive shifts away from dependence on these resources and will see substantial changes start to occur only after supply problems drive cost up enough to make change economically attractive. In the meantime, we are likely to continue to see access to limited resources factor heavily in politics. For example, oil access will continue to be an important factor in western relations with the Middle East and Russia and, increasingly, with Canada and South America. Access to rare earth elements will be an ongoing factor in relationships between China and the rest of the world.

2.3 Globalization & Mobility

2.3.1 Current State

We are more globally interconnected than ever before. We can freely communicate instantly with anyone, anytime, anywhere in writing, audio, and, increasingly, video. Transportation is fast and relatively inexpensive. We can travel between any two cities in a matter of hours, or at most a day and, can reach even the most remote locations with relative ease and comfort. It is no longer necessary to be an aboriginal native or a well-supplied, intrepid adventurer to stand on the shoulders of Mt. Everest, explore the polar ice caps or reach the depths of the Amazon jungle. People travel more often and further than ever before for business and pleasure. People are more likely to live far away from where they were born, grew up, or where their extended families live. They are also likely to move their homes farther and more often.

Interconnection is not limited to individuals. Businesses are headquartered where they get the best tax breaks, managed where they have access to the most educated people, produce goods where physical infrastructure is good and labor rates are low, provide services where digital infrastructure is good and labor rates are low, and market everywhere. Furthermore, they increasingly depend on one another for inputs and services.

This interconnectedness is reflected in international relationships as well. An economic downturn in the United States causes layoffs in China. A Swedish website leaks classified US government documents. A territorial dispute over a few small islands in the East China Sea puts the global supply of rare earth elements at risk, even though the supply does not come from the territory in question.

In contrast, on more regional and local scales, we are not as connected. It is often more difficult and time-consuming to travel across a region that to travel to another region, related to flawed or absent planning practices, lack of capacity for sophisticated, whole-systems implementation, and low maturity level of technologies and business models that serve multi-faceted systems required in a rapidly urbanizing world.

2.3.2 Predictions for the Future

2.3.2.1 Scenario 1: "Earth Culture"

Continued advances in transportation and communication technologies will lead to ever-increasing interconnectedness. We will progress to a borderless economy and will eventually settle on a global currency. The interconnectedness will lead to increasing conflict among local and national legal systems and will ultimately result in development of global laws. The need for and notion of "countries" will erode and we will progress towards a single "Earth culture." The new "Earth culture" will, in tandem, value the preservation of existing cultures and the creation of new ones. We may, simultaneously, see the development of "micro-states" and/or virtual nations, based not on geography but on other shared characteristics.

2.3.2.2 Scenario 2: Decreasing Mobility

We have reached or will soon reach a peak in mobility. Increasing energy costs will make long-distance travel unaffordable for most. Continued improvement in communication bandwidth and access will, simultaneously, reduce the need to travel. Business will increasingly be conducted virtually and even the need for short-distance travel (e.g. commuting between home and work) will diminish as more and more of our business and social interactions become virtual. By contrast, there will be greater short distance mobility options related to innovative systems improvement, and improved local planning that provides for walkable, bikable, transit-served accessibility.

2.3.2.3 Scenario 3: Quick-and-Easy Travel

New travel technologies will make travel even faster and easier. Scramjets will make it possible to travel anywhere in the world in just 90 minutes, making Disneyworld a day-trip from Beijing and a romantic dinner in Paris a Saturday-night date for a couple in Denver.

We will see an expansion in integrated modes of travel (such as the Chunnel or DC-to-Florida auto-trains). Auto-trains (or ferries) will connect cities across small and medium distances, making it more convenient to travel among them.

We will use airships to increase the efficiency of both short- and long-distance cargo delivery. Airships will be able to transport large or heavy loads more quickly and efficiently than ground or sea transportation currently can. They will be able to operate within cities and will open new opportunities such as off-site construction with delivery of prefabricated buildings or modules by airship.

2.3.3 Implications

Despite broad agreement that long-distance communication will continue to become faster, richer and more readily available, there are deep disagreements about whether we will become more or less mobile in the future. Proponents of the reduced mobility scenario (Scenario 2) seem to base their predictions on fears about fuel supply and economic uncertainty, while those who believe we will become even more mobile think about the question from the perspective of where technology can take us. The reality is probably a combination of the two – Scenario 3 might describe our technological capabilities, while Scenario 2 describes the economic reality.

Scenario 1 describes a utopian society not likely to actually emerge in the next few decades. Nevertheless, we can already see some of the patterns forming. Europe has already taken the step of forming a supranational government and a shared currency. The 2010 European sovereign debt crisis suggests that in order to move in the direction Scenario 1 predicts, we are likely to see the emergence of stronger supranational financial regulation to protect participants. It would be difficult to create strong supranational financial regulation without comprehensive supranational economic policy and difficult to enforce such regulation without a supranational legal system. Already we see these institutions emerging in Europe and, in the wake of the crisis, they seem likely to expand.

2.4 Climate Change

2.4.1 Current State

The world's science community now generally agrees that climate change is real and that it is mainly caused by people. We still, however, lack the political will to make a concerted, global effort to halt, reverse, or even slow down the change. In addition, we are still uncertain about the implications of climate change.

2.4.2 Predictions for the Future

2.4.2.1 Scenario 1: A Non-Issue

Climate change is happening but will not be a very important issue. Decisions that we make for other reasons will have the ancillary, beneficial effect of slowing or halting climate change. For example, as supplies of fossil fuels run low, prices will rise and we will have an economic imperative to find alternative energy sources. Since alternative energies tend to be cleaner than burning fossil fuels, the shift to alternative fuels will, naturally, slow climate change even if such slowing is not the primary driver for the shift. Climate change will not be a strong driver for lifestyle change.

2.4.2.2 Scenario 2: A Decision Driver

Climate change will continue to accelerate and its impacts will become increasingly evident. We will gather the political will to change before it reaches disaster proportions and will start to regulate carbon footprints and other climate change factors effectively. We will see some effects from climate change, but the problem will ultimately be resolved without major lifestyle changes.

2.4.2.3 Scenario 3: Reactive Adaptation

We will not gather the political will to make the changes needed to slow climate change, nor will economic or other drivers cause us to make changes soon enough. We will see serious consequences from climate change and will be forced to make major changes to adapt. For example, we will need to change engineering standards and building techniques to protect against more variable and extreme weather conditions. Agricultural techniques and locations will need to change based on new temperature and climate patterns. Populations may shift geographically as sea level rise accelerates and changing weather patterns create both new fertile growing zones and arid desert areas.

2.4.3 Implications

The world has, in the last few years, made real progress in discussions about climate change. For the first time, we have reached consensus that it is real and caused by people. However, the fact that there is a lack of clear policy on what actions should be taken suggests that it will be difficult to make concerted, global progress towards averting climate change. If we are optimistic and assume that we still have time to make changes to avoid the most serious consequences of global warming, then, in theory, we could reduce the question "to act or not to act?" to a simple payoff matrix comparing the cost of acting when it wasn't necessary to the cost of not acting when it was (on the assumption that if you made the right decision, then you come out even).

The reality, of course, is not so simple, especially because, as noted in Scenario 1, many of the actions that would address climate change also have other drivers. For example, accelerating the move to hybrid vehicles not only reduces CO_2 emissions, but also reduces demand for oil and reduces other forms of air pollution. Whichever of those concerns drives the decision to push hybrid/electric vehicles, the impact on climate change is the same. Even those experts who believe Scenario 1 would likely argue that we should take action – we should select actions which solve multiple problems, focus on those that address more immediate problems first, and target the message about why we should act to the audience. For example, develop and market the multi-modal grid infrastructure to address a range of needs and constituencies. For people who are price-sensitive, sell hybrid or electric vehicles for their lower operating costs; for people who are concerned about oil reserves, highlight how they help us reduce our oil dependence; for people who are scared of climate change, highlight their low CO_2 emissions.

2.5 Useful Information

2.5.1 Current State

Over the last few decades the amount of information available to us every day has increased exponentially. A Google search can, in seconds, turn up hundreds of thousands of sources for almost any topic. This unlimited access to information is both a blessing and a curse. While we can now find almost anything from almost anywhere, a typical search yields so much information it is hard to assimilate it, analyze it, or distinguish reliable from unreliable sources.

2.5.2 Predictions for the Future

2.5.2.1 Scenario 1: "Personal Brain"

The first application breakthrough of the information age was the spreadsheet – it allowed us to easily compile and analyze data we collected. The modern game changer is Google – it allows us to find all the information out there on a topic. The next killer app will be a "personal brain" – it will help us make sense of the overwhelming volume of information we have access to. These intelligent information systems will have an awareness of their users (who they are, where they are, what they want) and will proactively find and provide relevant information. For example, a navigation system that knows dinnertime is approaching, suggests which of your favorite places would be convenient to get to, then guides you on the most efficient route around the accident on the freeway to pick up your daughter from soccer, your son from piano, your spouse from work and your dry cleaning before directing you to the restaurant. Since it has calculated what time it will

arrive at each stop it has also made you a dinner reservation and notified your kids, your wife and the dry cleaner that you're on your way (using the "internet of things" discussed below).

2.5.2.2 Scenario 2: The "Internet of Things"

We will see the notion of interconnectedness extend from people and organizations to things. We see this trend beginning with technologies like radio-frequency identification (RFID). At present, these systems are mostly passive – they allow us to monitor a situation. In the future, they will be active. Smart objects will not only provide data when queried, they will provide active alerts or even respond of their own accord. A smart thermostat, for example, will not only turn a furnace on and off to maintain a target temperature, it might also decide based on other factors (e.g., outside temperature, humidity, current energy costs, other energy demands, presence or absence of people) whether to adjust the temperature. A wearable computer might determine when its wearer is headed home and notify the home to turn up the heat so the house is comfortable when its owner arrives. As more and more objects become smart and connected we will see the emergence of smart and connected communities. These communities will operate efficiently and be able to effectively provide comprehensive services to their citizens.

2.5.2.3 Scenario 3: Interfaces

Our current interfaces (screen and keyboard) were developed in the 1960s and have changed very little since. As we need to process more information in more places we will see a revolution in interfaces. For example, we are rapidly reaching the limits of what a dashboard-mounted screen in your vehicle can safely show you. Will we need to go to projected or windshield displays and other low-distraction means of interfacing with our cars' onboard systems? We will also see increasing sophistication in the variety and capabilities of sensors that objects (such as vehicles) use to interface with the world around them. Interfaces for telepresence and telecommunications technologies will improve immensely, aiding the adoption of telecommuting and teleconferencing and significantly reducing the need for travel.

2.5.3 Implications

From overloaded email inboxes to endless Twitter feeds to unmanageable numbers of search results, we all suffer information overload every day. An intelligent system that picked the wheat from the chaff sounds like a wonderful utopia. It does, however, raise an issue of trust. How can I trust a computer to know what I should and should not see? How does it decide? What if I don't like its decision? What happens if it misses something? How do I know it's giving me the best information, not the information sponsored by the highest payer?

Supposing that the computer makes near perfect selections and we come to trust it, we may happily spend more time on "real" tasks and less time wading through the extraneous, but what happens to the "happy accident?" Most of the time all that excess information is just that, excess, but every so often something in it catches our eye and takes us somewhere new and valuable.

2.6 Technology

2.6.1 Current State

Computers are everywhere and are increasingly interconnected. They now operate everything from our dishwashers to our communications to our cars. They continue to shrink in size while increasing in computational power, storage capacity and communication capability.

Nanotechnology is in its infancy with the no commercial applications, but is advancing towards early commercialization in a few areas, especially in medical applications.

As computational power has grown, artificial intelligence has also improved. However, machines are still essentially computational and incapable of the intuition and pattern recognition that gives human thought its power.

Dramatic improvements in medicine allow us to heal wounds and diseases that would, until very recently have been inevitable death sentences. Improved medicine has resulted in longer life spans. Although we have sequenced the human genome, this ability has not yet yielded the kind of medical advances it promises.

Early computing was, in effect, cloud computing. As computers grew more powerful we moved away from that model. Now we are in the early stages of transitioning back in the direction of cloud computing and have yet to see where it could take us.

Robots have become relatively commonplace in many settings such as on automated assembly lines, in warehouses, and even assisting surgeons in hospitals. They are starting to filter into the lives of individuals, but mostly still as novelties among early adopters (e.g. robotic vacuum cleaners).

2.6.2 Predictions for the Future

2.6.2.1 Nanotechnology

Nanotechnology is poised to take off and will yield major breakthroughs in a range of fields. It will dramatically improve medicine by allowing us to effectively deliver and target medicines and by giving us an entirely new set of diagnostic tools. Nanotechnology will also produce dramatically new types of materials for a wide variety of applications (e.g. adaptive road surfaces).

2.6.2.2 Artificial Intelligence

With recent major breakthroughs, artificial intelligence is also entering a new phase. For example, we will soon see real progress in the ability to communicate with computers using natural language and in computers' ability to reason and analyze. In addition, biotech research will inform the artificial intelligence field. As we understand more about how the human brain works, we will be able to devise increasingly sophisticated artificial intelligence that mimics human capabilities.

2.6.2.3 Biotech, Genetics & Medicine

Genome sequencing will speed up (from 15 days to 15 minutes). We will be limited only by the rate at which we can analyze the results. In addition, the number of people who have had their genomes sequenced will increase rapidly, thus improving our ability to detect patterns. As computational

power and storage capacity continue to increase we will be able to track thousands of genetic markers and proteins. These improvements will have major implications in birth decisions and in medical treatment. We will be able to easily detect and select for many more genetic characteristics. Eventually, improved genetics and the ability to analyze not only the DNA of healthy cells, but also of cancerous ones, will allow us to tailor treatments very precisely for a wide variety of specific cancers. This will also allow us to personalize medicine in other ways; for example, we will be able to train the immune system to fight off disease (or, when an auto-immune disorder has caused it to go awry, to rein it in safely).

We are also starting to sequence RNA. As our ability to do this increases, so will the benefits we derive from it.

2.6.2.4 Cloud Computing

Cloud computing is the "greatest thing people don't know about" (David Berdish). There is enormous potential to leverage its power in many complementary technology areas (e.g. genetics, biotech, medicine).

2.6.2.5 Robotics

We have made great strides in robotics and will see an explosion of applications. We will continue to see robots replace human workers in tasks that can be automated. We will also see robots appear increasingly in the everyday lives of ordinary people. As artificial intelligence, sensor technology and communications infrastructures improve robots will become increasingly autonomous. Biotech research will contribute to improvements in robotics indirectly through its impact on artificial intelligence and more directly as an improved understanding of biomechanics enables us to better mimic natural characteristics (e.g. more efficient weight-to-strength ratios). Improvements in nanotechnology may also provide materials for improved robotics.

Robots in the form of autonomous vehicles will have a major impact on our lives. Autonomous or semi-autonomous vehicles will increase the capacity of existing transportation infrastructure by making it possible for vehicles to safely travel more closely together and to efficiently manage traffic flow. They will also help wean us off our dependence on personal vehicles by making it possible to provide a fleet of inexpensive, readily available taxis.

2.6.3 Implications

We are poised for breakthroughs that could make the science fiction of only a few years ago reality. The real power will come through integrative approaches that span technologies and organizations. Many of the capabilities our experts foresee, however, pose new ethical dilemmas or increase the pressure to resolve those we are already aware of.

For example, we have for a century or more debated the ethics of genetic selection. From the crude early eugenics programs that forcibly sterilized "undesirables" to modern pre-natal genetic screening programs, we have yet to achieve consensus on where to draw the line. If, as the predictions suggest, we are mere decades away from the capability to select for a wide variety of genetic traits in early pregnancy, or even at the time of conception, we have a great challenge to decide as a society what is morally acceptable to us and what is not.

Birth decisions and genetic selection are not the only areas that present ethical challenges. We already see robots replacing human workers in some areas. That trend is sure to continue as robots grow increasingly sophisticated. In a global economy already struggling with high unemployment we will need to ensure that it remains possible for people to support themselves.

A world taken over by armies of smart, self-replicating nanobots may still sound like science fiction, but what about nanotech contamination? History clearly shows that we are neither very good at predicting what will happen when man-made substances are released into the environment, nor at preventing such releases, even when we do understand the dangers they present. As nanotech becomes pervasive we will need to be sure we can monitor and mitigate its consequences as well as gain from its benefits.

The shift back towards cloud computing raises new concerns about privacy, ownership, and data continuity. How do we decide which data should be private (and how private)? How do we ensure it remains that way? Who owns data stored in the cloud and what can they do with it? What happens to our data if a particular provider disappears?

3 Implications for Transportation

3.1 Technology

Although they have improved in speed and efficiency, vehicle, fuel, and infrastructure technologies remain largely unchanged since the advent of the jet engine. However, we now seem poised to make breakthroughs that will introduce fundamentally new approaches to the transportation sector including more integrated, sophisticated, multi-faceted systems.

3.1.1 Propulsion

While combustion engines are unlikely to disappear any time soon, improvements in battery technology are making fully electric vehicles commercially viable for the first time. If, as many experts predict, oil prices rise dramatically in the next few decades, there will be increased pressure to make major, rather than just incremental, improvements to batteries and also to develop alternative solutions such as fuel cells to commercial viability.

A breakthrough in cold superconduction could make energy-efficient maglev trains commercially feasible, particularly if oil prices rise as predicted.

In aviation, experts suggest we could see the commercialization of ramjet and scramjet technologies, making trips around the world as quick as trips to the next city down the freeway. Of course, commercial viability assumes that predictions that our oil supply is adequate to our needs hold true. If oil reserves run low and oil prices rise dramatically, scramjet travel is likely to remain accessible only to the wealthy elite, much as we saw with the Concorde flights during its lifetime.

3.1.2 Seamless Connectivity.

A breakthrough in IT and spatial design will address infrastructural and economic challenges posed by global urbanization. New connected systems will fully integrate all modes of transportation (public and private) in a seamless, open source format to provide a multi-mode, multi-service,

information technology-enhanced grid supporting the door to door trip. This new connected infrastructure will take hold in large metropolises, small communities and rural areas largely because of its cost-effectiveness, scalability, sustainability, and security benefits. It will be supported by major advances in information technology, in particular crowd sourcing, tracking, and real time data analysis. The market for the seamless mobility product will grow dramatically as urbanization increases.

3.1.3 Autonomy

As sensor technology, artificial intelligence, and robotics improve, most experts predict that we will see the advent of semi- or fully-autonomous vehicles. Autonomous vehicles would be able to react faster than humans can to changes in the operating environment and would therefore be able to safely travel closer together and at higher speeds.

3.2 Lifestyle

There are several forces that suggest we may be heading toward a transportation peak. Residents of compact, urban communities have less need for personal vehicles; the proportion of people living in such environments is increasing. A marked increase in fuel prices would make long distance travel unaffordable for many and even short-distance travel more of a luxury. Improved communication technologies obviate the need for travel to conduct business. As a result, we may have reached a mobility peak.

On the other hand, if oil prices remain stable and/or we successfully introduce oil alternatives, transportation may not become unaffordable, in which case new technologies that make travel faster and easier may actually continue to increase our mobility.

3.3 Infrastructure

We may be reaching computation closure[1] on the amount of transportation infrastructure we need, particularly for surface transportation. By allowing vehicles to safely travel closer together and at higher speeds, the introduction of autonomous vehicles could dramatically increase the capacity of our existing infrastructure. If, as some predictions suggest, we will soon reach a peak of mobility, demand for such infrastructure would decline.

Although we may be reaching a point where we no longer need to continue expanding our transportation infrastructure, we certainly need to maintain what we have. Our infrastructure is decaying and much if it is far beyond its intended end-of-life, yet we do not have the resources to do the kind of maintenance it requires. We can, however, look to nanotechnology and materials science advances to provide us with new materials with adaptable surfaces that will require far less maintenance over their lifetimes. We may also be able to look to robotics and other technical advances for less resource-intensive construction equipment and methods.

We not only need to maintain what we have, we need to adapt it to support emerging technologies. For example, we may have enough gas stations, but as we shift non-combustion-engine-based propulsion, we will need to be able to deliver energy in forms other than gasoline. Multi-modal grid

[1] Computation closure is the point at which we have the capability to continue expanding but derive no further benefit from doing so.

points will need to be installed and maintained both spatially and technologically. Autonomous vehicles will likely rely not only on on-board sensors, but also on information delivered to them from the roads themselves. That means our infrastructure will need to adapt to include the necessary sensors and communication systems.

More broadly, we may need to redefine how we define infrastructure. It is evolving to mean much more than bricks and mortar, bridges and highways. It is quickly becoming a more multifaceted "system of systems" or grid that is supported and even driven by emerging IT infrastructure and software. This new conception of infrastructure has implications for policy and business decisions regarding the emerging New Mobility market in an urbanizing world.

3.4 Governance and Organizations

3.4.1 Institutional Structures/Organization

The nature and pace of trends and innovations we are seeing have significant and potentially game-changing implications for institutional structures related to transportation decision-making and practice. In general, organizational frameworks need to work within and address increased volume and complexity combined with an accelerating pace and related lack of predictability. As such:

- Transportation-related decisions will need to incorporate and connect a wider set of sectors, disciplines, and policy areas, going beyond conventional transportation, engineering, and land use to include telecommunications; innovation; business, economic development and labor; social services; tourism; privacy; environment; urban planning; and more. In addition, our institutions will need to be more globally aligned and engaged on the policy front.

- Both decision-making and implementation will require earlier collaboration across sectors, enabling joint and multi-faceted problem and goal definition and implementation, including public-private innovation. Related to the increasing and more multi-faceted private sector role in transportation, we will need to place a greater emphasis ensuring alignment of private sector policies and practices with public goals.

- Government policy and legislation will need to address unpredictability by providing a broader, more flexible and dynamic framework that enables and facilitates multiple players achieving multiple goals. Prescriptive rules and bi-laws will give way to more general guidelines that must be met by all sectors and citizens, though this will prove challenging in terms of enforcement. In addition, new structures and technologies will provide for faster feedback loops, tracking and flagging policies and practices that hinder innovation and identifying policies and practices that support and protect quality of life, social equity and vital local and global economies.

- These new structures will employ new tools, technologies and approaches for effective, fast-paced knowledge sharing and collaborative decision-making.

- A new brand of decision-maker (both public and private) will emerge, well trained and versed in complex systems thinking and complex program management

Selected examples of these potential institutional transformations include:

- Realignment of transportation planning and operating agency structures to better match geographic mobility and travel demand patterns (e.g., Translink in British Columbia, Canada)
- Repurposing of MPOs in major urban areas to be metropolitan-level agencies that plan, fund, build and operate transportation networks to be more in sync with metropolitan needs
- Repurposing of state DOTs to focus primarily on inter-metropolitan travel and infrastructure (possible merging of DOTs across states to form mega-region agencies that can more efficiently and effectively address "real world" transportation issues)
- Integration of transportation, land use, urban development and economic development functions into unified cross-disciplinary agencies that allow more nimble response to public policy needs and issues

3.4.2 Public Investment Policy

Public investment policies will echo institutional transformations related to emerging trends and opportunities noted above. In general, spending will be "flatter" to support a wider range of modes, technologies, services and land use contexts. It will focus more concertedly on system-wide, integrated solutions, approaches and technologies that optimize operations and meet user needs for livability and security. It will also support growth of an emerging industry cluster that will supply sustainable, next generation transportation systems and infrastructure in a dynamic context. Potential examples of this transition include:

- Need to devote more public resources to planning and management of logistics/transport associated with increased dependence on local food supplies (e.g., community supported agriculture, etc.)
- Balancing increasing calls for accountability on public spending with enabling more nimble and resilient public policy and agencies
- Need to replace primary transportation revenue sources (e.g., motor fuel taxes) with other sources as use of gasoline/petroleum for transport stagnates or declines, as well as embrace cross-modal subsidization in line with both demand and smart spending
- Consideration of policies on strategic disinvestment/abandonment associated with infrastructure with very low return on investment in order to optimize spending of limited funding resources
- Need to accelerate and manage development and regulation of the nationwide Smart Grid as electrically-powered vehicles become more pervasive and the demand for electricity from the grid increases

4 Additional Insights

4.1 Predictability

Skepticism about our ability to predict the future, especially 30 – 50 years or even further out, is a common concern among the people we interviewed. Experience tells us that we are unlikely to be accurate or complete when we attempt to predict so far into the future. Furthermore, predictions are always extrapolations of what we know now, of current technology. We cannot guess at the disruptors that will fundamentally change the technological landscape. We also have so much more to learn about our world. How can we predict what new discoveries we will make or how we will use them?

The fundamental inability to predict the future has broader implications. We cannot, for example, create predictive public policy since we don't know what we will need to regulate in the future. Instead, perhaps, we should be trying to create more nimble, principle-based public policy so that we can respond faster to change and so that we have a greater capacity to encourage whole systems decision making.

The inability to predict also has enormous implications on inflexible, infrastructure-intensive areas. Transportation, for example, requires heavy investment in infrastructure. Transportation infrastructure is resource-intensive, finite, inflexible, and slow to develop. The predictive challenge leaves the transportation industry in a quandary. If infrastructure is built predictively the risk is that the predictions will be wrong, it will be impossible to repurpose the infrastructure, and the investment will be lost. On the other hand, if infrastructure is built only to meet known needs, demand will constantly outstrip available infrastructure.

Although prediction is hard, there are some tools that can help us do a better job extrapolating from current knowledge. We can use measurement as a lens for examining the past and for predicting the future. Specifically, we can look for peaks. Looking for peaks in the past can help illuminate trends and patterns. For example, the number of letters the USPS handled peaked in 1979 and has been falling ever since. We can think about future predictions in terms of peaks as well. Examining current trends and technologies can help us predict peaks that might occur. For example, steadily increasing urbanization suggests that the number of drivers worldwide will peak, despite increases in population growth and prosperity. We see that in densely populated areas (e.g. Manhattan) where travel distances are typically small and public transportation is relatively available, a very high proportion of the population does not drive. As more people move to cities, therefore, we can predict that an ever increasing proportion of the overall population will choose not to drive. If we combine a prediction that the number of drivers will peak with the trend to electric vehicles, we can also predict that the number of combustion engines worldwide will peak both because a peak in number of drivers implies a peak in the number of personal vehicles and because a shift from combustion to electric vehicles suggests that an shrinking proportion of vehicles will have combustion engines. This sequence of predictions, might, in turn, have implications in other areas (e.g. mitigation of greenhouse gas emissions).

When the capability to improve outstrips the demand for or benefit from further improvement we say we've reached computational closure. For example, at the point where we are technologically capable of displaying higher-resolution graphics then the eye is capable of detecting we will have reached computation closure for resolution. If, as in the above example, we predict that the number of personal vehicles will decrease, we will have reached computational closure for transportation infrastructure for personal vehicles – we may be able to increase capacity of the infrastructure but will derive no benefit from doing so because supply will outstrip demand.

4.2 Adaptation

Several interviews discussed frameworks for thinking about how we respond or adapt to change. Each is discussed briefly in this section.

4.2.1 Neo-Darwinism

Darwin's evolutionary pattern provides a model we can use to think about patterns of societal or economic change. From a period of stasis, we enter a period of rapid change, followed by establishment of a new order. For example, after a long period of agrarianism, the introduction of mechanization and manufacturing led very rapidly to dramatic changes in the economic and social landscape. We then reached a new economic order where the bulk of the population (at least in industrialized countries) lived in cities rather than the country and produced goods rather than food. From a period of stasis in the industrial age, we are now settling out of the rapid change that took us to the information age.

4.2.2 Desynchronization

Although we seem to follow a Neo-Darwinian pattern of societal change as a whole, in fact, different parts of society move through the cycle at different rates. For example, new technologies are typically adopted first by business, military, and industry, then by individuals and families, later by governments and other institutions (e.g. educational institutions), and only quite late by legal & regulatory systems. We especially see the effects of desynchronization in the lag between when technologies are commercialized and when they are adequately regulated. For example, biotech firms started patenting and selling seeds for genetically modified crops long before patent law had addressed what to do about unintentional patent infringements brought about by natural cross-pollination of a non-GMO farm with GMO crops from a neighboring farm. Although we can observe the impact of desynchronization in specific cases, we still do not fully understand the range of impacts and it is not clear how we can address them.

Appendix A: Methodology

A1 Methodology

A1.1 Conduct Literature Review

The first step in preparing a foundation was to synthesize information available from publications, web sites, conference proceedings, other active NCHRP 20-83 project, and other relevant sources. The project team reviewed these materials to identify issues areas to highlight, potential interview contacts and to provide a foundation for the current state of research.

A1.2 Develop Interview Guide

Based on the results of the literature review, the project team put together an interview guide to focus interviews on developing information about the current state of technology, predictions for the future and the implications for transportation.

A1.3 Build Contact List

The project team developed a preliminary contact list based on their own personal and professional contacts, prospects uncovered during the literature review, and through research of science and technology leaders.

A1.4 Panel Input

The project team conducted a conference call with the panel to obtain input based on the literature review, the proposed interview guide, and the proposed list of initial contacts to the panel. Materials were updated based on panel feedback.

A1.5 Outreach

The project team used the interview guide as a starting point to conduct discussions with the interview contacts identified during steps 3 and 4. The team also requested interviewees to propose additional contacts and, where deemed appropriate, interviewed these new contacts as well. In sum, the team interviewed 28 subjects in a range of fields including (but not limited to):

- Genetics
- Robotics
- Nanotechnology
- Engineering
- Information technology
- Economics
- Sustainability

Interview subjects have a variety of roles:

- Industry & business leadership
- Academic leadership

- Research
- Futurist

A1.6 Summarize Findings

Task 1 concluded with the project team producing this summary of findings.

A2 Research Sources

Research sources consisted of informational interviews, web-accessible video sources, a comprehensive literature review, and a supplementary review of awards for scientific achievement. The comprehensive literature review was undertaken as a first step, preparatory to the development of a working outline and research framework. This process enabled the research team to construct a list of candidate interview subjects from across the range of relevant disciplines and to ensure full coverage of the research framework.

Once identified, team members directly contacted candidate interview subjects. Participating subjects agreed to 30 minute informational interviews, conducted by project team members either in-person or by phone. These interviews were manually transcribed. Condensed interview transcripts formed primary sources for research and synthesis. Web-accessible video sources were used to augment the set of informational interviews in cases where subjects were not available within the timeframe of the project. These video sources were manually transcribed. Condensed transcripts were included among project sources. The findings drawn from all available research sources are discussed in detail in section 3.

A2.1 Selection Process

The project team employed an iterative approach to information gathering and synthesis. Team members initially conducted a literature review and identified high-quality resources addressing future trends and emerging technologies. This list of published sources formed the basis for subsequent project work and was frequently updated to reflect ongoing research. Project team members categorized each source by topic, theme, and keywords and scored each source by relevance and quality. Only sources that were sufficiently highly rated were included in the literature review. The most up-to-date index of these sources is given in *Section 2.2*.

Additionally, the research team undertook a scan of awards for scientific achievement. The awards under review included the relevant Nobels (Physics, Chemistry, Medicine), the Turing, and the Copley. On the basis of these scans, the research team further refined the initial literature review to cover certain additional topics and sub-topics.

The initial literature review provided the basis for the development of a working outline and research framework. The working framework identified key topic areas and guided the selection of candidate interview subjects. This allowed the project team to ensure an even distribution of subjects across all key topic areas. The initial set of topic areas included:

- Genetics
- Robotics

- Nanotechnology
- Engineering
- Information technology
- Economics
- Sustainability

Candidate interview subjects were assembled in a master list, based on input from all team members. This comprehensive master list was carefully categorized and scored. Each candidate interview subject was categorized by role and by area of expertise using the list of key topic areas. In addition, each candidate interview subject was scored on 6 distinct dimensions. These were:

- Public Profile
- Confidence Level
- Publications
- Transformative Potential
- Transportation Impact
- Overall Impact

Subject rankings were compiled across these dimensions and a list of preferred subjects was created. These were ranked in priority order and a first set of subjects was contacted by email and, in many cases, by phone.

All subjects were informed as to the scope and objectives of the project as well as the rationale for their inclusion on the contact list. Subjects were offered an opportunity to review all interview questions prior to the interview. Interviews were conducted in-person or by phone at the subject's convenience. In cases where a preferred interview subject was not available within the project timeframe, Web-accessible video sources were used to supplement the set of informational interviews. In addition, a supplementary set of interviews was scheduled; these will be conducted in the coming weeks.

A2.2 Literature Reviews

Team members conducted a literature review and identified high-quality resources addressing future trends and emerging technologies. This list focused on recent, influential, book-length published works. The set of sources is given in Table A1 below.

Table A1 Literature Review Summary

Title	Author	Topic	Synopsis
Tomorrow's Table : Organic Farming, Genetics, and the Future of Food	Pamela C. Ronald	Agriculture	Research scientists' assessment of GM crops: combined with organic farming, a powerful weapon against global hunger.
The Singularity Is Near: When Humans Transcend Biology	Ray Kurzweil	Biotech	Genetics, nanotechnology and robotics will redefine humans as a species.

Title	Author	Topic	Synopsis
Biomimicry: Innovation Inspired by Nature 2nd Ed.	Janine M. Benyus	Biotech	Survey of biomimicry in practice plus 10 rules for future applications.
The $1,000 Genome: The Revolution in DNA Sequencing and the New Era of Personalized Medicine	Kevin Davies	Biotech/Genetics	Implications of widespread genome sequencing.
Genome: The Autobiography of a Species in 23 Chapters	Matt Ridley	Biotech/Genetics	Cutting-edge genetic research and its impact on society.
Sonic Boom: Globalization at Mach Speed	Gregg Easterbrook	Economics	Predictions about decades following current global recession.
The Great Reset: How New Ways of Living and Working Drive Post - Crash Prosperity	Richard Florida	Economics	Predictions about societal changes following current global recession.
Who's Your City?: How the Creative Economy Is Making Where to Live the Most Important Decision of Your Life	Richard Florida	Economics	Geographic and demographic trends that shape the U.S.
The Power of Place: Geography, Destiny, and Globalization's Rough Landscape	Hans De Blij	Economics	Geographic and demographic trends that shape the global economy.
Sensible Finance for a Dynamic Economy	Amar Bhide	Economics	Critique of global economy.
Jeb Brugmann	Welcome to the Urban Revolution	Economics	Urbanism and globalization.
Tomorrow Now: Envisioning the Next 50 Years	Bruce Sterling	Forecasting	Cautions and speculations regarding future scenarios.
Shaping Things	Bruce Sterling	Forecasting	Brief history of objects and more extensive argument about future trends.
The Rational Optimist: How Prosperity Evolves	Matt Ridley	Forecasting	Planet, human population will be better off in next century than at any time previous.
The Extreme Future: The Top Trends That Will Reshape the World in the Next 20 Years	James Canton	Forecasting	Futurist's take on trends that will shape the next century.
Mind Set!: Eleven Ways to Change the Way You See - and Create - the Future 2nd Ed.	John Naisbitt	Forecasting	Insights into anticipating long-term trends from executive, author, futurist John Naisbitt.
The Future of Everything: The Science of Prediction	David Orrell	Forecasting	Survey of historic efforts to predict the future; evaluates these with coverage

Title	Author	Topic	Synopsis
			of current predictive efforts.
A Brief History of the Future: How Visionary Thinkers Changed the World and Tomorrow's Trends are 'Made' and Marketed	Oona Strathern	Forecasting	A history of futurists, inventors, visionaries with some emphasis on current practice of 'futuring.'
Thinking about the Future, Guidelines for Strategic Foresight	Andy Hines	Forecasting	A how-to book for long-term strategic thinking.
Your Flying Car Awaits: Robot Butlers, Lunar Vacations, and Other Dead-Wrong Predictions of the Twentieth Century	Paul Milo	Forecasting	Retrospective analysis of 20C forecasting with focus on accounts of inaccurate predictions.
Everyware: The Dawning Age of Ubiquitous Computing	Adam Greenfield	IT	Technological and social implications of ubiquitous computing with coverage of current tech and future visions.
In the Bubble: Designing in a Complex World	John Thackara	IT	Principles of human-centered tech design, not predictive but a popular framework.
Travels to the Nanoworld: Miniature Machinery in Nature and Technology	Michael Gross	Materials Science/Nanotech	Overview of previous generation nanotech and potential applications.
Cradle to Cradle: Remaking the Way We Make Things	Bill McDonough & Michael Braungart	Materials Science/Nanotech	Manifesto arguing for net-negative energy/waste/water lifecycles for manufactured products.
The Metropolitan Planning Organization: Past, Present & Future	TRB	Planning	Planning at the metropolitan level.
Microtrends: The Small Forces Behind Tomorrow's Big Changes	Mark Penn & E. Kinney Zalesne	Politics	Political demographer and strategist provides insights into trends shaping U.S. population.
The Next Hundred Million: America in 2050	Joel Kotkin	Politics	Migration, urbanization, will power U.S. dominance of coming century.
The Next 100 Years: A Forecast for the 21st Century	George Friedman	Politics	Conflict between global powers will continue throughout the coming century.
Wired for War: The Robotics Revolution and Conflict in the 21st Century	P.W. Singer	Robotics	Implications of next-gen robots on war and geopolitics
Robot: The Future of Flesh and Machines	Rodney Allen Brooks	Robotics	General overview of current-gen and next-gen robotics, capabilities, technologies, applications

Title	Author	Topic	Synopsis
Cyber War: The Next Threat to National Security and What to Do About It	Richard A. Clarke	Security	Survey of global cyber security risks with a focus on history and present conditions and some coverage of next few decades.
Sensible Finance for a Dynamic Economy	Bill McKibbon	Sustainability	Within a few years the effects of global climate change will be severe.
Natural Capitalism: Creating the Next Industrial Revolution	Paul Hawken	Sustainability	Sustainability trend will power business opportunities over next decades.
Worldchanging: A User's Guide for the 21st Century	Alex Steffen	Sustainability	Edited volume of 21C forecasts with eco-focus and progressive political slant.
Design Futuring: Sustainability, Ethics and New Practice	Tony Fry	Sustainability	Design manifesto argues for necessity of forecasting, sustainability to good design.
Automotive 2020: Clarity Beyond the Chaos	IBM Report on Automotive Future	Transportation	Describes the transformation of the auto industry.
Connecting & Transforming the Future of Transportation	SMART UMICH SZ	Transportation	Describes new connected infrastructure.
Colloquy on the Coming Transformation of Travel	NYSMPOs & FHWA	Transportation	Planning for the future of transportation.
Chris Leinberger	The Option of Urbanism	Urbanization	A new model of American urbanism.

A2.3 Interviews

Interviews were conducted with the objective of learning about and from the work of leading scientists, technologists, and business innovators. Respondents were prompted to discuss their own work throughout the interview, particularly in the context of scientific and technological innovation. Respondents were diverse with respect to their chosen fields, their backgrounds, and their areas of expertise. For some respondents, it was necessary to abridge, condense, or reorder the set of interview questions in order to focus on unique or particularly important issues.

Core questions included those addressing:

1) Existing and emerging trends;
2) Technologies with the greatest observed impact;
3) Technologies with the greatest potential impact; and
4) Scenarios under which these outcomes were most favorable or likely.

All respondents were prompted to address these topics with respect to their own fields or areas of expertise. To the extent possible, respondents were prompted to provide specific examples in order

to illustrate any general observations. Respondents were also prompted to consider the next 30-to-50 years of change and innovation in the context of the last 30 years. Respondents were explicitly encouraged to identify any potential implications for the transportation sector.

The set of interview subjects is provided in Table A2 below:

Table A2 Interview Subjects

Name	Focus	Title or Affiliation
John Austin	Economics	Brookings Institute
David Berdish	Sustainability	Manager of Sustainable Business Development, Ford Motor Company
Amar Bhide	Economics	Economics Author
Mike Cassidy	IT	Director of product management, Google
Carol Coletta	Urbanization	CEO of CEO's for Cities
Nancy Connery	Engineering	Infrastructure expert
Carl Dietrich	Engineering	Terrafugia founder
Gordon Feller	IT	Cisco & Urban Age Institute
Daniel Franklin	Futurist	Economist Futurist
Thomas Frey*	Futurist	Futurist
Paul Gray	Engineering	Former president of MIT (Massachusetts Institute of Technology), current professor of electrical engineering
Helen Greiner	Robotics	iRobot founder
David Gross*	Physics	Theoretical Physics, UCSB
David Haussler*	Biotech/Genetics	Professor of Biomolecular Engineering, UC Santa Cruz
Glen Hiemstra*	Sustainability	Futurist
Claire Janisch		
Alex Lightman	IT	Futurist
David Lubin	Sustainability	Esty Environmental Partners
Pattie Maes	IT	MIT, HCI expert
Dennis Meadows	Sustainability	UNH, Emeritus Professor of Systems Management
Axel Meisen	Futurist	Futurist
Gerry Mooney	IT	Director of Global Government and Education, IBM
Scott Page	IT	UMICH Complex Systems Theorist

Name	Focus	Title or Affiliation
Terry Penney	Energy	National Renewable Energy Labs
Spiro Pollalis	Sustainability	Harvard, New Cities
Jeff Rubin*	Economics	CIBC World Markets
Michael Snyder*	Biotech/Genetics	Professor and Chair of Genetics, Stanford University
Gregory Stock*	Biotech/Genetics	Former director of the Program on Medicine, Technology and Society at UCLA's School of Medicine
Nam Pyo Suh	Engineering	President, KAIST (Korea Advanced Institute of Science and Technology)
Mark Surman	IT	Chairman, Mozilla Foundation

**Indicates Web-accessible video sources were used*

Appendix B: Interviews

B1 Interview Guide

1. NCHRP 20-83A Project Overview

a) Provide a two minute summary of the project purpose and context.

2. Background

b) What are the fields, disciplines, or emerging technologies that you believe have had the most impact over the last decade (or over your career)?

b) In your view, what has been their primary impact?

c) Will these continue to define progress in the next decade? If not, what has changed?

d) What NEW technologies/innovations will be coming online in the near future?

e) How will we look back at the present era 30-50 years from now? What trends or technologies will best define our present era? (How are these different from those in Q1?)

f) On what evidence/experience/rule of thumb (e.g. Moore's Law) do you base this forecast?

g) Which technologies or innovations have been most *disruptive* over the last decade? Will these technologies continue to be disruptive over the next decade? If not, what technologies will replace them?

3. Forecasting

a) This project looks ahead 30-50 years. What is the first or most important thing we need to understand about forecasting 30-50 years into the future?

b) Over a 30-50 year timeframe, what do you anticipate will be the major trends that will have the most global or national impact? Which disciplines or technologies will dominate?

c) Will the trends you anticipate shaping the coming decade continue to be significant? (We are curious about your big-picture view.)

d) What NEW technologies/innovations that you are aware of will have impact on the end user in the next 30-50 years? On what evidence/experience/rule of thumb (e.g. Moore's Law) do you base this forecast?

e) More broadly, what national, international, or global trends (e.g. resource scarcity, climate change) do you anticipate will have the greatest impact? In what ways?

f) What do you see as the greatest opportunities for technological or scientific innovation? What are the greatest unresolved technical challenges across the sciences?

g) What are the greatest threats we will face?

h) What will be the most significant technology that most people today have never heard of? How will it change our lives?

i) What topic area is the most difficult to accurately forecast? Why?

j) What field will advance the furthest in 30-50 years? Why?

k) How will innovations within this field impact the lives of those outside of the field in the next 30-50 years?

l) Can you take us through this step-by-step?

4. Transportation

a) This project looks at the impact of innovations in science and technology on transportation in a 30-50 year timeframe. Have you considered what emerging technologies and innovations will have the greatest impact on the future of the transportation sector?

b) Where do you rank the transportation sector among the core drivers of technology and innovation at present? How do you believe this will change over the next 30-50 years?

c) What are the most significant transportation-related implications of the trends you have described?

d) What are the opportunities for closer integration of your work with the transportation sector? Are there research activities that the transportation sector can fund today or the near future that can accelerate and/or enhance the future benefits of your work/sector?

f) What would be the implications for the transportation sector if a breakthrough occurred with respect to your list of greatest unresolved technical challenges? Greatest opportunities for innovation? Greatest threats?

B2 Interviews

B2.1 John Austin

Non-Resident Fellow, Brookings Institute
Director, Great Lakes Economic Initiative

Key Messages

Global Interdependence

The over the last 20 years the world has truly become globally interdependent and interconnected. Economic and environmental decisions no longer affect just one group or nation, they inevitably affect the world. Money, information, goods, even disease all move rapidly around the world.

Neo-Darwinism & Transportation

Global economic development follows a Darwinian pattern: stasis → rapid change → new global power structures. We've undergone several of these cycles: agrarian → manufacturing → information. Transportation technologies have been important drivers to these shifts. Transportation technologies impact where people want to live, how they want to move around, etc. We need to watch for the next game changer.

Global/Multi-National Regulation

Since local/national decisions now inevitably have global impacts, we need global regimes to regulate economic, environmental and other issues with global impact. Such regulatory systems would affect global demographic, economic, and infrastructure patterns.

Transcript

From the perspective I bring – best summarized looking at economic growth & economic activity & how to understand it in the world in community & country – shaped / changed economic development trajectories. A couple categories of observation – if I were to characterize what's new about economy in last 20 years it would be era of full bore global interdependence and interconnectivity wasn't always the case w tribes and national economies. Now information, people movements, intermingling demography on global basis, reality of water on whole global regime – seeing in all dimensions. Demographic, financial, information, production of goods & services, trade & intercourse, ideas culture, media, health –pandemics can spread a million times faster – bed bugs. Demography, ethnicities, tribes cultures bouncing into each other – global challenges interdependent ecological, everything intermingling – inexorable move on one planet but has sped up & reached a head in our generation – facing reality of globally interdependent domains in this and in government and decision making – even political cultural ethnic intermingling issue, as well as climate change and environmental impacts that touch whole world.

Big game changing technologies in this road – we've had periodic and really a canon – Chuck Sable & Michael Peory on economic development – neo-Darwininsm = stasis, rapid change, new species, new overrunning of one part of world by another (e.g. we're long gone from agricultural era where made living from agriculture). Game changer that accelerated this was assembly line & vertically integrated corporate structure & vertically integrated corporations transformed – moved from farms to factories – making manufactured goods – first wave of pseudo organization – moving to small & medium size cities to work in factories- now semiconductors & internet have changed all economic transaction and again – aggregate production in a new way services to support – Peter Drucker – global urbanization – not working in factories – in offices etc research & learning ints. Global urbanization – breaking up medium. Third wave adding to urbanization global city – a

couple radical game changing technologies that facilitated each of these big steps. Next big step? I have no idea. Is there a way of changing the way things run – biometrics, materials, teleporting?

Another organizing of economy game changing emerging that affects the way growth occurs –now dealing with kick-outs of information revolution & implications of where people work, live, related needs they have – in that domain of the moment – we've seen transport technologies first lead & facilitate agricultural revolution but then manufacturing & vertically integrated corporations and now cyber revolution both leading & supporting of information age economic & social information. In addition to functionality the cyber & transportation nexus has drawn more attention to how to use enhanced functionality in those infrastructures to agglomerate communion / movement of people & ideas – enhance density & speed – all those features important until something changes the world again. People are wealthier – all transportation assets – different preferences & values of all attributes including how to transport themselves – those are lifestyle value preferences – people don't want to go to malls or drive cars, want to see high speed rail – idea of it and its existence – value.

Last thing - I'd hoped Obama could do it because trouble moving the big economic enablers – a new round of regulation of excesses of marketplace what I was hoping - was global regime on all of these domains –not many people & opportunities that could do this –reshape global governance – new global regimes on pricing & use of water & energy, trade, how support & combine those efforts – what are the global infrastructures that facilitate global growth as well as regional – if we had global (not even at national yet) national & global multinational regimes for shaping financial &trade markets, global infrastructures for commerce & people – they'd shape the market – global water, energy, carbon, global financial markets would inform how patterns of the economy would evolve =more sustainable dense metro development – that's what I fear is needed & need a global security regime – class of cultures – our culture overrunning traditional cultures – need global relationship & intercourse shaping regimes –those would inform patterns of economic development & transportation kick-outs. People like China now pivoting from replicating our growth pattern from industrial to lead in cleaning up all this mess – as state driven economy deciding unilaterally faster than we're reshaping our – doesn't deal with interconnection.

These are topics I'm fascinated with and interested in.

B2.2 David Berdish

Manager, Sustainable Business Development, Ford Motor Company

Key Messages

Human Rights

Human rights impact many issues such as energy generation, fuels, water conservation, biodiversity, connectivity, security, terrorism, and war. We need to study these issues from a human rights perspective to prepare better responses.

Cloud Computing

Cloud computing is the greatest thing/opportunity people don't know about. We need to study logistics, systems management, performance, analysis, etc. This is a critical competency to develop as soon as possible. There is enormous potential to leverage the cloud in complementary technologies including medicine, biotech and genetics. We should be putting energy into R&D in these and other technologies that could benefit from utilizing the cloud.

Interactivity

We need more interactivity among all sectors to really provide global citizens with what they want and need. Transportation will always be a driver, but top 10, not top 3. Today people's needs are really determined by auto companies, transit and urban planners. Many more sectors need to be involved.

Transcript

- Energy generation, fuels, water conservation, biodiversity, connectivity, security, terrorism, wars.
- The study of human rights would help better prepare for the above.
- Information technology– solar & hydrogen help in accessibility.
- Further study into IT cloud – logistics & systems management – understanding of systems performance, analysis = core competency we have to get sooner rather than later.
- Cloud greatest thing people don't know about and greatest opportunity.
- Also a lot of change in biotech, technology, medicine – in addition to information technology for best networks. Complementary technology for medicine, biotech, genetics etc. – ways AND means to take on emerging trends. IT is not enough – energy into complementary R & D that cloud can enhance & improve delivery.
- Transportation will always be a driver – top 10 but not top 3.
- Impact on transportation – biggest thing – transportation would really focus on the ultimate citizen. Right now because haven't addressed the other issues have auto companies, transit, urban planners determining requirement of citizens – all sectors will have to understand all the needs of different communities to see what need to do for transportation to provide citizens what they really need not just current sectors.
    - more user focus
    - more sectors involved in more things
- Experience – travel in last 5 years – UN and State Department to understand the global issues – most disruptive – internet more than anything.

B2.3 Amar Bhide

Professor, Tufts Fletcher School

Key Messages

Hard to Predict

It is very hard to predict the future. We don't know what will catch on and what won't, what will turn out to be problems and what won't. Developing predictive public policy is nearly impossible. Maybe we can create more nimble public policy that adapts faster.

The difficulty in predicting the future has an especially large impact on transportation because transportation is so heavily dependent on large, expensive, physical infrastructure. If our predictions are wrong we can't easily repurpose the infrastructure for something else. At the same time, transportation probably needs to be regulated more heavily than some other areas. Market forces might adequately regulate financial markets, but they won't regulate road safety, environmental impact, etc.

Privacy and Independence

We are moving back towards cloud computing. This has significant implications for privacy and independence. We need to have too many entities involved in the cloud with the result that it is hard to trust that our information is safe. It's hard to understand who really has access to our information. With so many entities competing in the space, it is also hard to trust that our current providers will be around long-term. Our data is not yet adequately independent of provider.

Transcript

Unqualified to answer this question – studied innovation principally focused through lens of what entrepreneurs do – opportunities of what already has been. Somebody comes up with the iPad and the rest create apps for the iPad. It's a completely unpredictable process of what things catch on or for how long they last (e.g. MySpace & Second Life went away) – today Facebook – might also vanish.

Entrepreneurs wait until it becomes a MySpace or 2nd life – until it has traction and then if it works fine, if it hasn't made enough $ it doesn't matter.

As far as public policy – a lot of interaction – greater possibilities for negative externalities – a much greater reason for laying down the infrastructure- more consequence than MySpace. With transportation it's different – if someone invents the Segway. The most famous venture capitalist said it was going to be bigger than the internet. More of a public policy issue if it's going to catch on.

Understand need to be a futurologist if concerned with public policy in the transportation sector. Those things are by & large exceptions.

Without saying there shouldn't be anticipatory policies re: transportation – incredibly hard. Not my sphere of expertise – one of those things where don't know beforehand about autos etc. – don't know whether to develop sensible public policies – who'd have known about emissions.

Policies that are more nimble or dynamic?

Reversible or irreversible - can't build roads & repurpose them for something else.

Inevitably public policy will affect the way that things evolve.

Transportation is kind of at one extreme in the degree to which it's deeply & unavoidably interwoven into public policy issues. Then there's the union issue too. The interactivity issue is huge.

My current book about financial regulation – certain parts of it like the PC industry – don't need much & world would go on fine without it. Can't do that with the auto industry. Safety, traffic laws, emission controls etc. My philosophical bent being more libertarian – let's be incredibly cautious about where we intervene & intervene where there's no other choice.

In transportation less need for regulation of shipping except at port than with airlines & automobiles. Need increases when flight increases.

Stuff is so inter-related – sales tax policy vis-à-vis internet commerce. Non-trivial. What kind of land use policies will determine urban density. Cloud and all is fine but remember the whole move to personal computers came because people didn't trust the cloud. We're going back towards it – how far we'll go it depends. I don't trust having all my docs on the cloud. The cloud requires more elaborate governance mechanisms than PCs. Used to be just 2 monopolies – IBM & AT&T. All the internet standard setting bodies. Not working well enough for me to trust the cloud and trust Google to be alive in a few years from now – only to the degree you can solve property rights & interoperability. Car is equivalent of PC. Now beginning to find there are limitations.

I started riding bike in Bombay because I didn't want anything to do with public transportation. I've never owned a car.

- privacy
- independence related to certain technologies

I'm not very helpful – triggering interesting thoughts in my mind and relief that I don't have to deal with them.

B2.4 Michael Cassidy

Google

Key Messages

Innovation in Transportation Technologies

Transportation needs to drive critical innovation. In the next 30-50 years we can expect scramjets to get us anywhere on the planet in just 90 minutes, room temperature superconductors to drive maglev trains with virtually no energy loss, autonomous cars, and sophisticated, GPS-based traffic management.

Transcript

What are the technologies and innovations that will have the greatest impact 30-50 years from now?

1. Supersonic combustion ramjet (Scramjet). A ramjet is a very powerful very fast engine. In a ramjet the airflow through the engine is compressed without a rotor or fan. A scramjet is a supersonic version, which operates on the same principle. Uses entire top of the airplane to compress air.

   Basically, it allows you to go very fast. And if you can get the plane high enough up, almost to the surface of the atmosphere, a couple things become possible. You can deal with the heat produced and you can 'skip' across the surface of the atmosphere. Takes 90 minutes in low earth orbit to reach any point.

2. Room temperature superconductor. Superconductors can conduct electricity with almost no energy loss at all. These only work today at around negative 200 degrees.

   If you can create a room temperature superconductor you could, for example, create maglev trains that operate on a closed loop. You would only have to get it up to speed, using relatively little energy, and then it would operate without friction other than air resistance.

3. Another is the autonomous car. Google is working on this.
4. Another is innovative battery technology. New lithium ion technology is emerging now.

What are the opportunities for closer integration of your work with the transportation sector?

Geolocation. Most phones have a GPS chip in them. It's creating all sorts of opportunities. You don't need any external instrumentation to measure traffic jams. You can just use the cell signal. With this information you can imagine that you can be spontaneous in managing travel behavior. You can better understand travel behavior.

Also letting you get at far more demographic information. There's even dating applications. A user can meet people, not based just on random chance. But, maybe instead because you like the same indie band or rock climbing place, etc. Lots of people will sign in.

B2.5 Carol Coletta

CEO, CEOs for Cities

Key Messages

Reconfigure Life for Changing Demographics

We are moving toward a time when people will live more densely, more compactly. They will share more and own less – from cars to houses to vacuum cleaners. We already see these trends starting – shared vehicles, smaller, later families, people living longer, more people biking, etc.

What Do We Want From Society?

We need to focus less on technology for its own sake and more on what we want out of it and how it impacts our society and communities. Assuming technology will solve our problems is not a good response. Better to decide what we are supposed to do/achieve as a result of technology.

Transcript

Hard to think out that far but appears what's happening for lots of reasons people will live more densely, more compactly, will share more, own less – everything from cars to homes to vacuum cleaners. Once get compactness & see increase in biking, increased focus on health – a lot of trends running toward smaller, later families– suggest living in more compact ways & have less need for every day every trip cars. That's generally what I see happening – the whole focus on technology to get us out of this mess – cars that drive themselves not a good response to what's really going on.

IT too often presented as "the" answer – what would really be useful is technology to signal me when I've done something good & useful & prompt this and rap knuckles when not useful – e.g. way we use resources to what we dispose of etc. Technology - environment piece of encouragement or discouragement is way underdeveloped.

Ultimately have to decide what want from society – a poor job to date. Let's think about what we WANT from technology – what we WANT from our communities – what are we supposed to do as a result of the technology.

Brought us to now – automobile, telephones, computers, now hand held devices – oddly enough letting someone else do the driving – shapeshifting our sense of time.

Trends – the one that will affect us most is aging population – how we'll need to reconfigure more and more people living longer – huge impact on the way we make our places and we want to live and the ways technologies will support that.

Social & urban – how we reconfigure life for changing demography, economy – really challenging – social science.

B2.6 Nancy Connery

Key Messages

Technology Not the Obstacle

Technology is no longer the obstacle to progress. We have made major technological advancement and have huge capabilities. Now the obstacle to progress is institutional, political and social. We need the will power to make changes. We need to be able to think beyond our own self-interest and to think of technology as a means to an end, not as the end itself.

Integrative Approaches

We need to look at integrative approaches to solving problems. We can no longer be stuck in silos. We need to look across technologies, organizations, politics. We need to bring a wider variety of expertise to bear and need to plan and implement across sectors.

3D World

We live in a three dimensional world, but really operate in two dimensions. We need to start thinking about using the third dimension more effectively. For example, can we move more transportation underground?

Transcript

The next technology gadget isn't going to solve it – we have a lot of tech but institutional factors and politics are disruptive. Tech rarely the issue – no longer a major obstacle, it's imagined to be because of cost – a question of human factors overwhelmingly across the board but particularly transport.

Not so much technology – still important to the equation – but it's important not to think of it merely as a transportation problem. Because context is too small e.g. sustainability is the org principle for transportation agencies. But sustainability is not about transportation per se. Transportation is a means to an end – not talking in relation to urban development & water issues etc outside of purview – have to think about sustainability WITH other areas & stakeholders – apply technologies to solve important questions / challenges not just a means to an end.

Got to open up the doors – mission needs to be more comprehensive.

Transportation is in fact a key driver in the problem working against sustainability – resource scarcity & disruption.

All need mobility & access – needs to be ways of transmission – if we think strictly about transport we're doomed. Technology as applied to transport systems as currently exist – not going to go any further – part of the problem – vicious cycle –root problems deeper & defined beyond their scope.

One of the big issues –obstacles not technology – in public realm human will -- insolence & arrogance to keep us from thinking beyond own self interest. It is being done elsewhere but we're in a rut – Friedman "it's morning in India". India looking at us – what happened – you're turning away from your core values – drifting pixie dust but not building high speed rail, not tackling problems – sprinkling more pixie dust.

It's got to be integrative approaches – it's not a radical notion – big companies are moving to this – Cisco & IBM working in that direction – what they're selling is integrative not the tall silos where TRB is still stuck. They've got own financing sources from DOT's & they don't want to give it up. ICT is inherently integrative –not just operational stuff but algorithms enable us to better make choices about moving around, facilities that are conveying us –but union rules work against it. Managing nuclear plans & airplanes – need to know when wobble happens not when the light goes on – to know the wobble is there via sensors & algorithms – touch the thing & adjust – things keep going – more fuel efficient – changes work rules & patterns of proprietary systems within cities – they don't want to share.

Biggest aspect of the future –the first thing we need to understand about forecasting – that we can't – the ultimate uncertainty – e.g. Axel – he would say the same thing.

Ultimately the technologies are means to an end - the ends are not well articulated – moving things down the road bit by bit but addressing the larger questions – worry about weather and water – Stephen Chu & Irv Miller from Toyota – reason we're thinking about not building cars is water scarcity – going to change the global marketplace – doomed when first flush of tough resource scarcity happens – couldn't keep going – find ways of engaging a broader network. Not a linear process – transportation has to see itself as part of solution and problem

Systems generation – young folks are hope.

In my underground engineering group human factors make the whole thing work – going back to paleo-anthropology & systems where people were addressing issues in early stages – people DID have technology – they actually did things in ancient Rome & Greece & throughout other parts of world – water management used for thousands of years – sustainability!! Built in 5000 BC and whole group in water.

They created stuff that lasted thousands of years- holy cow – this is now recognized – actually thinking about this seriously – lessons to be learned – disciplines most impact – where people completely outside of the system asked stupid questions that did not fit into their framework – expertise becomes so arrogant - caught in their framework – stifling creativity – allow them to challenge your thinking so together might make something better – I've seen this in my career where old style engineers say "oh?" Conceptual part needs to be stretched more widely against variety of perspectives – get out of own way.

Not in any way anti technology but important to ask the questions.

The other piece – applies here – maybe completely outside the realm of your audience – think about underground – a 3d approach to the world – creating systems for the future especially in concentrated urbanization – all 3 levels most judiciously – particularly with scarce resources – quality of life, island effect, impacts – transportation a big part of.

I went off to Europe (busman's holiday) where a young engineer from Swiss Institute of Technology was doing 3d modeling and bigger picture – not just promoting the underground but how to use all resources - not just space but geomaterials, geothermal – fun to hear it from someone in early 30's determined to move this idea forward – got to think about it all.

Not a matter of holding hands and kumbaya = a lot of technologies for communicating across boundaries & supporting new ideas for working in a formalized way – processes that have validity, that have work.

Bill Reid – a lot of work on sustainability – sat at his knee & listened to how it works – he's working on an international scale - more vitality – a lot stronger sense of urgency elsewhere Asia & Europe – take heart from that more momentum. Embarrassing – clear to me talking to colleague in Switzerland – they're so much farther ahead. Roman coda about underground – so much more leaping ahead.

We're starting at ground zero – remarkable things there that have been there thousands of years and more recently just part of normal life. Tunnel, subway – solved a problem – as long as it's reliable.

B2.7 Carl Dietrich

Terrafugia

Key Messages

Energy in Transportation

There is no clear path away from hydrocarbons for aviation. It will be hard to make an economic case to drive a shift to alternative energies; there are too many benefits to aviation from use of hydrocarbons (e.g. weight and efficiency).

Renewables are more viable for land-transportation, especially as batteries improve. We still need to identify the best sources. Nuclear power is a very good source if we can address proliferation risk and waste. We may even be able to develop the technology for fusion-based generators, but probably won't be commercially viable in the foreseeable future.

We Can't Predict the Future

Even those of us involved in creating leading-edge technologies cannot predict the future. Predictions are almost certain to be wrong or incomplete.

Transcript

Background

What are the fields, disciplines, or emerging technologies that you believe have had the most impact over the last decade (or over your career)?

Across the board – biotech – so much new knowledge, etc…

In your view, what has been their primary impact?

New drugs, preventive medicine, screening factors, etc., personal genetic makeup. Much remains to be discovered.

What Terrafugia is doing is pretty important – incorporated in 2006 – advent of ADSB – significant step forward, will allow much greater situational awareness inside the cockpit.

Will these continue to define progress in the next decade? If not, what has changed?

What NEW technologies/innovations will be coming online in the near future?

Carl has a PhD in plasma physics, fusion, but is mainly focused on aviation at present, so we'll focus on that.

ADSB online some places – becomes possible for people in Cessnas to have a picture in their cockpit of where other planes are – more smaller aircraft, more efficient spacing of larger aircraft.

Commercial airliners have most of this already – akin to impact of GPS. Lets little planes have same capabilities as larger planes.

Terrafugia expects to be delivering commercially in the next 18 months. Looking forward to inspiring a new generation of pilots. Airports largest underutilized transportation infrastructure. Big potential boost in GDP if we can utilize this infrastructure. Though for foreseeable future a niche industry – requires a lot of skill to fly a plane.

Most commercial airliners have an auto-land feature – eventually will see this on smaller plane. Can envision a possible path forward where technology from commercial aviation adapted into lighter aircraft, inspiring new group of pilots. Hard to predict the future. Pilot population in decline.

Would not want to speculate on the timeframe.

How will we look back at the present era 30-50 years from now? What trends or technologies will best define our present era? (How are these different from those in Q1?)

On what evidence/experience/rule of thumb (e.g. Moore's Law) do you base this forecast?

Which technologies or innovations have been most *disruptive* over the last decade? Will these technologies continue to be disruptive over the next decade? If not, what technologies will replace them?

Forecasting

This project looks ahead 30-50 years. What is the first thing we need to understand about forecasting 30-50 years into the future?
Hard to do. Whatever you come up with will be wrong or incomplete. In engineering high value on being correct – very hard to be correct.

Hard to predict even though Carl is creating a part of it.

Over a 30-50 year timeframe, what do you anticipate will be the major trends that will have the most global or national impact? Which disciplines or technologies will dominate?

Will the trends you anticipate shaping the coming decade continue to be significant? (We are curious about your big-picture view.) Yes, more so.

What NEW technologies/innovations that you are aware of will have impact on the end user in the next 30-50 years? On what evidence/experience/rule of thumb (e.g. Moore's Law) do you base this forecast?

More broadly, what national, international, or global trends (e.g. resource scarcity, climate change) do you anticipate will have the greatest impact? In what ways?
Need to think about energy policy – get that in order. Need a long-term sustainable energy policy. Energy is fundamental.

What do you see as the greatest opportunities for technological or scientific innovation? What are the greatest unresolved technical challenges across the sciences?

For aviation – hard to come up with an energy source better than hydrocarbons – need better sustainable fuels. Will be difficult to make an economic case for moving to something other than hydrocarbons for aircraft. But may be able to manufacture them… Nonetheless, lots of interest in electric aviation in general aviation.

For land transportation – batteries are certainly viable. For aviation, lots of advantages to hydrocarbons – also use of hydrocarbons has efficiency benefit – plane is lighter as it flies.

But where does the fundamental energy come from? Solar? Wind? There is potential in these. However, will probably to get more power from nuclear. Lots of potential in improved fission – need to address proliferation risk, waste.

Fusion – expects it to be doable, but unclear whether it will be economically viable in the future. It is absolutely possible to build a fusion reactor that creates more energy than it uses. It is a solvable problem, but it's not going to be cost competitive in the near future.

What needs most investment? Nuclear needs greater investment.

Energy is not an easy problem, but is what will sustain us in the future.

What are the greatest threats we will face?

What will be the most significant technology that most people today have never heard of (doesn't exist yet)? How will it change our lives?

What topic area is the most difficult to accurately forecast? Why?

What field will advance the furthest in 30-50 years? Why?

How will innovations within this field impact the lives of those outside of the field in the next 30-50 years?

Can you take us through this step-by-step?

Transportation

This project looks at the impact of innovations in science and technology on transportation in a 30-50 year timeframe. Have you considered what emerging technologies and innovations will have the greatest impact on the future of the transportation sector?

Where do you rank the transportation sector among the core drivers of technology and innovation at present? How do you believe this will change over the next 30-50 years?

What are the most significant transportation-related implications of the trends you have described?

What are the opportunities for closer integration of your work with the transportation sector? Are there research activities that the transportation sector can fund today or the near future that can accelerate and/or enhance the future benefits of your work/sector?

What would be the implications for the transportation sector if a breakthrough occurred with respect to your list of greatest unresolved technical challenges? Greatest opportunities for innovation? Greatest threats?

Focus is on energy. Has great implications on transportation. We need to focus primarily on energy. Renewables, nuclear. Also - energy storage systems – key particularly if we want to make greater use of renewables.

More emphasis should be placed on nuclear.

Example – idea of storing energy through an anchor anchoring a wind turbine in the seabed.

B2.8 Gordon Feller

Former CEO, Urban Age Institute
Director, Cisco Systems

Key Messages

The "Internet of Things"

We will see any-time-any-place connectivity for anyone. We will increasingly see connectivity with and between objects. The "internet of things" will be global, self-configuring and standardized. It will include both physical and virtual "things." The "internet of things" will provide not just monitoring but also control of the physical environment and the cloud. It will significantly impact how we transport people and information.

Smart & Connected Communities/Sustainable City Management

The "internet of things" will be a backbone that will allow for smart, connected communities. We will move away from "cities" towards "communities." These communities will have improved efficiency, better growth and improved ability to deliver services to citizens.

Transcript

- What may not show up in other interviews and therefore will be helpful – the "internet of things". Any time any place connectivity for anyone – connectivity with & between objects. Already seeing this – billions of devices connected to each other, network of networks. Based on solid technological advances & visions emerging in the physical world – network ubiquity – an integrated part of the future internet is what the internet of things is – dynamic global network infra with self configuring. Standard protocols. Physical and virtual things have identities & integrated in seamless way into information network – connect things to each other & the cloud. Virtual cloud – service universe – emergence of cloud computing & cloud tech – emergence of internet of things – change the way info & people get transported. Ubiquitous network – not just monitoring but control of physical environment. Collecting, controlling, data.

- Desk – physical object w embedded sensor w ability to communicate. Lots of work to take proprietary & obsolete systems & enable them to become internet protocol network which becomes internet layer for internet of things. E.g. desk lamps, dishwashers, cars – smartly incorporating smart objects into the infrastructure. Open source. All companies collaborating together. Just physical object w passive id is not a smart object because no embedded sensor. We're providing physical objects w ACTIVE RFID – embed a sensor & have ability to communicate – smart meters, intelligent thermostats are smart objects. We're focusing on small objects that can add a lot of intelligence to the network. By 2010 between 8 & 50 B devices of one kind or another will be available to be connected to each other. 70 – 300 % annual growth rate. Means new business models
- Not the stuff out there but what happens when you use them. Create an end to end internet protocol communications infrastructure for the internet of things. Promote open standards & interoperability & build intelligence into the network. Operations will have to be secure, reliable, scalable, resilient.
- 2nd major transition in this century is this evolution. 300 M or 400 M devices . We could see a trillion devices connected. Means where we are now – business functionality, online communications, drove the use of internet from military to business internet to consumer internet – backbone – industrialization of internet – backbone of everything becomes facilitated by internet – everything connected to everything else – the network is the platform.
- Build SMART & connected communities whole thing run on this platform – will have impact on economics, development & investment.
- We've been talking about internet in smart & connected communities – Nick did a study on benefits of SMART & connected communities – took MIT folks in to process of assigning financial & numeric benefits of planning & leveraging holistically because leveraging all services – smart & connected – improved their GDB growth, increased energy efficiency etc. Big gain for a city that decides they want to be smart & connected. Whole system. Not just transport. Citizen services menu – can deliver comprehensive services to citizens in that community – any time anyone as long as connected to the network
- In the cities where we're working – lots of complexities & conflicted priorities – if they connect to enable real time info exchange & facilitate interaction among citizens & service providers. Providing access to services now to spur the connectivity – enhanced quality of life.
- While techies working on internet of things – sustainable city management approach to ensure communities thriving
- Cisco – back office to streamline at the community level. Lots of redundancy / inefficiency – if secure & resilient – allows to communicate & collaborate across whole spectrum of community – that's the piece we're focused on. It's all happening faster than we realize. 25% annual growth in sales at Cisco – internet of things is really happening – everyone gearing up quietly to meet demand. Not just because Facebook has 500 million users – massive industrialization of the internet that will enable other applications to be possible.
- This is the big thing re: your questions – especially at local level. This is the biggest & dramatic impact – it's happening now in various ways – bus, train systems – Jannette Sadik

Khan – various asset – like all. Making the smart sensor based objects is not just an interesting convenience but a necessity.

- What we're racking our brains about is how to create transportation hubs to connect to take advantage.
- Mirrors the big changes bottom up.
- Urban communities the big focus.
- Communities instead of cities.

B2.9 Daniel Franklin

Executive Director, The Economist

Key Messages

Climate Change

We need to change but it will take big incentives and there may not be enough. It's hard to know what will happen and whether we will make the changes necessary. It's hard to predict what kind of transportation we can have without oil but will probably be either a hybrid or all-electric model.

Information Revolution & Transportation

The information revolution may drive a real shift in the notion of public vs. private. In transportation, for example, a trip may be private, but still all the information available on the public information network. Maybe we wouldn't even need to own our own vehicle, instead could use public, autonomous vehicles for point-to-point travel. Types of travel will also change with business being less of a driver because it will be possible to conduct most business from anywhere. We will still want to gather for personal/recreational/social reasons.

Transcript

I guess the obvious things that I would say – 2 huge megatrends have affected & will affect all this:

1. Climate change & impact it will have on how we live & get around
2. Information revolution & internet that affects trips we need to do and also the means of movement
3. Mass of data – ability to process it fast & meaningfully = will increasingly influence the efficiency with which all this happens.

These are my big megatrends in addition to:

4. Demography

There are questions of national policy but also merges into global policy when think of climate change – don't think of US as isolated in this respect – I would think any DOT will follow closely the experiments that different parts of the world are doing in low carbon transport, e.g. efforts to see if you can have road transport without oil. On the one hand & on other hand – if looking at 30 – 40 year. Experiments on driverless vehicles & massively better efficiency with personalized transport as well as public.

If they happen as radically as possible? People will have to live in different ways. Suppose in 30 years quaint & anachronistic to be driving your car but it's optimized for you – of any age, physical disabilities – all sorts of possible.

In a way if this was the way it happened – distinction less rigid between private & public – might be driving on private trip putting in hands of public network information – imaging the whole movement regulated in a way that currently. Fusion of public and private.

Might not need to own the car – jump into a door to door system – entirely guess work – could go in so many different directions.

Fundamental points – degree of technology – movement optimizing ability that will be around will make things possible and completely different business models . Jobs – all sorts of influences – in particular this affects jobs – look at recent trends and could imagine them being more intensified – more flexibility between home & the workplace – sorts of jobs you can't imagine today.

Trends you can see today – massive information – ability to share info – v. powerful trends already changing the way work is organized but re: transport doesn't take away the human need & inclination to gather for interaction, physical meetings, sporting.

Look at other cities across the US – corporate route a big transition mechanism. One part of the world to another.

Experiments going on now to have battery changes – that experiment with better place. I would think that would be watched closely – clearly a competitive market for fuel efficiency – big uncertainty over the model – electric only or hybrid.

Fundamental to personal or goods movement – things and people – fundamental to economic development and infrastructure that enables within & between – whoever more or most efficiently great advantages – surmounting of constraints – cost of fuels. Strategic issue – chicken & egg thing - doesn't drive policy.

Climate change – hard to know where this will end up – seems again here the pressure is as much outside us and inside when look at massive development of China & India etc – the path / trajectory – not particularly – couldn't carry on in straight line – something has to give – enormous incentives to have innovative ways of dealing with this on other hand but those might not be enough but there will be more climate change than what one would like to see & will have impact on transport.

Security - just had some good reminders – don't think in the scheme of things - can be disruptive / counter measure.

Dealing w long term investments – flexibility must be part of planning process.

B2.10 Thomas Frey

Key Messages

"Earth Culture"

As communication and mobility increase we will move towards a "borderless economy." The need for and notion of countries will erode and we will move towards a single "Earth culture" which will, in tandem, look to preserve existing cultures and to create new ones. We will see local and national laws start to break down in favor of global ones. We may, simultaneously, see the development of "micro-states" or even virtual nations.

High Efficiency/Clean Vehicles

Concerns over climate change will dissipate as we deploy increasingly clean, efficient vehicles. We will, however, see increasing conflict over public right-of-way. We will see the emergence of alternative-transportation cities and may, even, eventually tear out our freeways.

Drones

Drones will become increasingly important in civilian life – both on the ground and in the air. They will allow us to deliver goods and services ranging from on-demand, autopiloted taxis (reducing the dependence on personal vehicles), to very high-speed internet access for everyone, to highly-reliable, real-time weather, traffic, air quality, etc. information.

Desynchronization

Different elements of society innovate and adapt to new technologies at different rates: first business and industry, then families, then government and educational institutions, then law. We don't yet fully understand what the impact of such lack of synchronicity will be.

We Have a Lot to Learn

There is still an awful lot we don't know about our world. Learning more will both enable us to take better advantage of opportunities (e.g. learning more about the center of the Earth could help us predict earthquakes) and to better evaluate the risks (e.g. should we "geo-engineer" our environment?).

Transcript

Background

What are the fields, disciplines, or emerging technologies that you believe have had the most impact over the last decade (or over your career)?

In recent years I think in that in the transportation realm one of the most significant advancements has been the arrival of hybrid vehicles. As operating costs decline and the environmental side effects of transportation are reduced, this may further change our understanding and levels of mobility. On a more practical note, I think the widespread availability and permeation of GPS technology has also had a significant impact. I'm also very interested in the advancements in drone technology and their potential civilian applications.

In your view, what has been their primary impact?

Will these continue to define progress in the next decade? If not, what has changed?

What NEW technologies/innovations will be coming online in the near future?

How will we look back at the present era 30-50 years from now? What trends or technologies will best define our present era? (How are these different from those in Q1?)

On what evidence/experience/rule of thumb (e.g. Moore's Law) do you base this forecast?

Which technologies or innovations have been most *disruptive* over the last decade? Will these technologies continue to be disruptive over the next decade? If not, what technologies will replace them?

Forecasting

This project looks ahead 30-50 years. What is the first thing we need to understand about forecasting 30-50 years into the future?

Over a 30-50 year timeframe, what do you anticipate will be the major trends that will have the most global or national impact? Which disciplines or technologies will dominate?

Most significantly, I think that we will see a trend towards a more fluid society as we improve communications and mobility. This more fluid society may be marked by a "borderless economy" in which individual countries start to lose control of their abilities to regular commerce. In fact, I think overall we'll see an erosion of the notion of "countries" and a move towards a single "Earth culture" And this Earth culture will be marked both by the desire to preserve existing cultures as well as to create new cultures. This fluidity will also mean that the local and regional nature of laws will start to break down. At the same time, I think we'll see the emergence of micro nation-states, and possibly the development of virtual countries.

I believe that many of the concerns about climate change will dissipate as the next generation of clean vehicle technologies are increasingly adopted. I also think that there will be a proliferation of different types and configurations of vehicles, and that this will lead to increased segmentation and conflict over the allocation the public right-of-way. There will be a reevaluation of our car-centric infrastructure, and we'll see the emergence of the first alternative transportation cities. At a minimum we'll see the reconfiguration of public right-of-way, and at some point we may even start tearing up freeways.

I think drone technology will have a huge impact on people's lives. While this technology has been primarily deployed for military purposes thus far, it's applications in civilian realms are virtually unlimited. For example, it has been argued that the entire United States could be blanketed with internet access using only 16 drones. Non-military real-time surveillance of traffic, weather, air quality could prove to transform how we think about access to information. I can also imagine other applications of drone technology, such as providing delivery of services, via either air-based or land-based drones. For example, I can imagine automated or driverless taxis that are available

on demand. Use of air-borne drones would also extend the struggle over public right-of-way to airspace.

Finally, I think we'll see a proliferation of satellites and satellite-based technologies as we implement new and cheaper technologies for placing satellites up into orbit.

Will the trends you anticipate shaping the coming decade continue to be significant? (We are curious about your big-picture view.) Yes, more so.

What NEW technologies/innovations that you are aware of will have impact on the end user in the next 30-50 years? On what evidence/experience/rule of thumb (e.g. Moore's Law) do you base this forecast?

More broadly, what national, international, or global trends (e.g. resource scarcity, climate change) do you anticipate will have the greatest impact? In what ways?

What do you see as the greatest opportunities for technological or scientific innovation? What are the greatest unresolved technical challenges across the sciences?
I'm excited about new technologies to resist and control gravity. Such technologies would fundamentally alter not just the transportation realm, but potentially many other aspects of our lives.

What are the greatest threats we will face? Are there potential technological or scientific advances that can ameliorate these threats?
I think our greatest threat is our own ignorance. I'm amazed about how much there is still to learn about our own planet. For example, we know virtually nothing about the center of the earth. The deepest we've ever drilled was 17 miles, and that took us 22 years. But the distance to the center of the earth is something like 3,800 miles, so we've barely scratched the surface, literally. This knowledge might be highly relevant to better understanding and predicting earthquakes, which would help us not only save lives, but also make wiser development decisions.

I also wonder about the wisdom of "geo-engineering" the environment in order to address some of the problems we face. I think there's a certain portion of the humanity with a problem-solving or "fixer" impulse but, for example, I question whether even if we could control a hurricane we should.

Finally, I was recently struck by the concept of the desynchronization of society put forth by Alvin Toffler. What I understand him to mean by this is that different components of our society are moving into the future at different speeds. Business and industry are moving into the future rapidly, while families move into the future more slowly. Institutions such as governments and educational systems move even more slowly than families, and finally the law moves extremely slowly. It is unclear what the long term result of this desynchronization will be.

What will be the most significant technology that most people today have never heard of (doesn't exist yet)? How will it change our lives?

What topic area is the most difficult to accurately forecast? Why?

What field will advance the furthest in 30-50 years? Why?

How will innovations within this field impact the lives of those outside of the field in the next 30-50 years?

Can you take us through this step-by-step?

Transportation

This project looks at the impact of innovations in science and technology on transportation in a 30-50 year timeframe. Have you considered what emerging technologies and innovations will have the greatest impact on the future of the transportation sector? Which ones and why?
Although not technological in nature, I think that innovations in finance may have a great impact on future transportation development. For example, it may be useful to establish a global infrastructure bank to finance international development.

Where do you rank the transportation sector among the core drivers of technology and innovation at present? How do you believe this will change over the next 30-50 years?

What are the most significant transportation-related implications of the trends you have described?

What are the opportunities for closer integration of your work with the transportation sector? Are there research activities that the transportation sector can fund today or the near future that can accelerate and/or enhance the future benefits of your work/sector?

What would be the implications for the transportation sector if a breakthrough occurred with respect to your list of greatest unresolved technical challenges? Greatest opportunities for innovation? Greatest threats?

B2.11 Paul Grey

MIT

Key Messages

Autonomous Vehicles

We are already seeing increasingly sophisticated driver aids – sensors to provide guidance about parking, backing up, etc. This trend will continue – eventually reaching all vehicles with increasingly sophisticated degrees of assistance, eventually to vehicles capable of running virtually autonomously. This will result in the ability to travel faster.

Hybrid Vehicles

Vehicle transport will remain a hybrid electric/mechanical enterprise indefinitely. We will continue to see improvements to efficiency and power and a shift in the balance between combustion and electrical propulsion systems – eventually propulsion will be exclusively electric with combustion engines to keep batteries charged. There will continue to be new technologies for improving the efficiency and power of combustion engines. Many already exist, but the automobile industry is slow to adopt.

AI and Nanotechnology

AI and nanotechnology are set to take off. We are just now beginning to make major breakthroughs. The ability to hold natural-language conversation with machines is probably actually close. Similarly, nanotechnologies are starting to show real promise for applications such as delivering medicines within the body. For the first time labs are opening with biologists and engineers working together.

Transcript

What are the technologies and innovations that will have the greatest impact 30-50 years from now?

We are beginning to see now an array of driver aids appearing first in very high-end cars for driving, parking, backing up, warning you if you are tailgating the guy in front. These all depend on two things: the availability of significant computing power and the cost and utility of a range of sensors—optical sensors, radar sensors, a variety. That trend will eventually work its way down to cars of all values as you have seen other things do over a period of decades. Eventually these things become used much more. Probably there is currently as much computing power in a high-end car as in a laptop. Not as much RAM but as much computing power.

Beyond that, people have talked for a long time about guide rail travel. Used on one lane of a highway by people who are going long distances. Proposals for this appeared years ago. Used a mechanical link between the car and a guiderail to control speed and to control steering.

We can imagine this system in the future with an electronic link. My guess is that in the future there will not be a mechanical link, there will be solely an electronic link. This will likely permit travel at a higher rate of speed, without any direct driver control.

What trends have you observed over the past decade within your field?

I have talked about these things on the side of sensors and control applications but there is at the same time a revolution in propulsion, power generation, and utility. And what you are seeing now is increasing use of dual systems, electric drive, batteries, and mechanical drive, combustion. They are moving in the direction of a gas or diesel engine solely to keep the battery charged, with full electric propulsion.

I can say that for internal combustion engines there are enormous improvements on the drawing boards, for the future. But the automobile industry is very conservative about taking these things on. There are developments that have occurred, where folks discovered that if you inject water—just a little bit at the right time—into the combustion chamber at the same time as the gas you can increase the power output by about 30%, or see a corresponding reduction in fuel consumption. The future of vehicle transport is going to continue to be an electrical/mechanical enterprise.

What developments will have a great long-term impact on society at large?

We just dedicated a new center for integrative cancer research. It is half biologists and half engineers. The reason is that the biologists are working to understand human genome for better treatments or better diagnoses. But the engineers are working at the nano-scale to deliver the treatments. Also the overall number of electrical engineers working with biologists is very high,

especially compared to 10 years ago. It might only have been people working in AI before but it is now widespread. This will have significant implications.

Another area is AI. We have been saying that real AI is just around the corner for last 60 years. We are really no, however, getting very close to the ability to converse with a machine in a natural way. I suspect that we are close. There is a sense now, stronger than anything I've seen in the last 40 years, that we have crossed a threshold for AI.

B2.12 Helen Greiner

Founder, iRobot

Key Messages

Robot Autonomy

We are heading in the direction of autonomous robots (e.g. cars, airplanes), but need to do a great deal more work on sensing technologies (e.g. vision) and communication infrastructure.

Mimicking Biology

We currently cannot build artificial systems that approach biological systems either in computational power or in physical characteristics (e.g. strength-to-weight ratio). Biotech research will continue to be crucial to help us learn how to approximate natural capabilities.

Transcript

Background

What are the fields, disciplines, or emerging technologies that you believe have had the most impact over the last decade (or over your career)?

Connectivity and the internet.

Cloud computing. Massive storage.

In your view, what has been their primary impact?

Connectivity and the internet: Information is easy to obtain and essentially free. Communications are different more prevalent. You can easily be connected to your friends. You have information at the tip of your fingers.

Cloud computing, massive storage: The ability to use such a large quantity of information, to have and carry books in a Kindle, music on iPod.

Will these continue to define progress in the next decade? If not, what has changed?

Absolutely.

What NEW technologies/innovations will be coming online in the near future?

Cloud computing. From sharing documents etc. to sharing a point of view. Work will be more collaborative, with no need to be in same location. Much more cost effective.

How will we look back at the present era 30-50 years from now? What trends or technologies will best define our present era? (How are these different from those in Q1?)
Biotech era, knowing and understanding genetic information about us, our bodies, genetic medicine.

And of course robots: Pakbots, unmanned (aircraft?), Google cars. Hospitals now believe that they need to buy a robot to do surgery. They produce better outcomes in many cases than humans. What's going to come more and more is autonomy in robots. Not just doing things remotely.

On what evidence/experience/rule of thumb (e.g. Moore's Law) do you base this forecast?

Which technologies or innovations have been most *disruptive* over the last decade? Will these technologies continue to be disruptive over the next decade? If not, what technologies will replace them?

Forecasting

This project looks ahead 30-50 years. What is the first thing we need to understand about forecasting 30-50 years into the future?
20+ year forecasts are bunk. They do actually study forecasting. They [forecasters] miss huge things. They extrapolate from what exists. Can't predict disruptions.

There is not one shred of evidence for a singularity. Things do go exponential but then there is a period of diminishing returns.

Over a 30-50 year timeframe, what do you anticipate will be the major trends that will have the most global or national impact? Which disciplines or technologies will dominate?
Research shows 13-15 year timeframe from lab to product for robots.

New material developments, we are starting to see some different properties. For example: better energy systems, more waterproof.

Could understand what's happening in animal brains or human brains. Computers are good at search, algorithm crunching. Brains are on a totally different path, but if we can get the human architecture going we could get creativity, causality, intuitive physics so that computers and brains could not be on totally different paths.

Will the trends you anticipate shaping the coming decade continue to be significant? (We are curious about your big-picture view.) Yes, more so.
Autonomy opens up possibilities. Only believe that this phrase should be used in the context of a mission, like vacuuming (a robot can be autonomous for the vacuuming mission). These things get done automatically. This will open up possibilities.

We can add things like infrastructure that help the autonomous car. Like beacons and sensors and signals in the road that help the car. Communicating with the car.

What NEW technologies/innovations that you are aware of will have impact on the end user in the next 30-50 years? On what evidence/experience/rule of thumb (e.g. Moore's Law) do you base this forecast?

More broadly, what national, international, or global trends (e.g. resource scarcity, climate change) do you anticipate will have the greatest impact? In what ways?
World getting smaller, people have more information to hopefully make better decisions. Can instantly learn about things. But can also make the mistake of massive groupthink.

People worrying about climate change makes an impact. So much investment makes an impact.

What do you see as the greatest opportunities for technological or scientific innovation? What are the greatest unresolved technical challenges across the sciences?
Taking the great things from biology and using them – this is true for lots of different applications. For example, we don't have the strength to weight ratio that we see in biological systems, we can't easily mimic biological systems.

What are the greatest threats we will face?

What will be the most significant technology that most people today have never heard of (doesn't exist yet)? How will it change our lives?

What topic area is the most difficult to accurately forecast? Why?

What field will advance the furthest in 30-50 years? Why?

How will innovations within this field impact the lives of those outside of the field in the next 30-50 years?

Can you take us through this step-by-step?

Transportation

This project looks at the impact of innovations in science and technology on transportation in a 30-50 year timeframe. Have you considered what emerging technologies and innovations will have the greatest impact on the future of the transportation sector?
Unmanned air systems. More autonomy makes these systems safer. The appeal of these is: shortest distance between two points is a straight line. Will be led by military technology, UAV somewhat mimics this. Wouldn't put off table, for example, a FedEx autonomous vehicle. Or even unmanned.

An aside: Google's autonomous cars are robots. They are using the same technology that we are putting on the robots. Sebastien Thrun was a consultant for us in 98. He did the cleaning robot. He did the large Smithsonian project. Then he went to Stanford and eventually he hooked up with the CMU people. Sebastian said, "I can't believe that we are not funding that project."

*Flying car in Boston. (Send references).

Where do you rank the transportation sector among the core drivers of technology and innovation at present? How do you believe this will change over the next 30-50 years?
Core driver is simply people want to do other stuff while they are driving and that will put more stuff into driving.

Saw an interview with teenage girl talking about the texting while driving ban. She said: "but what will I do while I'm driving?" Very accustomed to multitasking. People will want essentially to have a personal chauffer.

What are the most significant transportation-related implications of the trends you have described?

What are the opportunities for closer integration of your work with the transportation sector? Are there research activities that the transportation sector can fund today or the near future that can accelerate and/or enhance the future benefits of your work/sector?
(Works for a robot company, a skunk works for robotics.)

Should be funding sensing technologies. Cheaper. Less false positives. Visual, acoustics, all over the map. Usually multi-modal is the best.

The other way to work on it is communication with infrastructure or with cars. Smart infrastructure. Telling the other car, I am about to pass you. A much safer way to do this.

What would be the implications for the transportation sector if a breakthrough occurred with respect to your list of greatest unresolved technical challenges? Greatest opportunities for innovation? Greatest threats?

B2.13 David Gross

Frederick W. Gluck Chair in Theoretical Physics at the Kavli Institute for Theoretical Physics of the University of California, Santa Barbara

Key Messages

New Materials, New Control

Physicists are trying to understand matter that we can create on earth out of ordinary atoms. It is the feeling of theoretical physicists that we are only beginning to explore the possible structures and phases of matter. And they will eventually become new materials. So new materials and new control. We are now able to put atoms where we want to put them. To move them around. We are able to create materials in empty space by optical lattices of laser beams - at whose nodes we can place atoms, move them around, change the forces between them and create a whole variety of new materials. Both for basic science, to study fascinating phase transitions, or for technological miracles.

Theoretical Biology

Biology means studying living matter. Theoretical physicists are moving in because there is so much data and so many questions. Two examples where physicists are moving in: One is genomics.

We have the genome decoded. All of that data, we should be able to figure out what's going on. One way I like to put this is: can one tell the shape of an organism by looking at its DNA? 100 years from now we will say: here is a genetic sequence, draw a picture of the animal. I have a feeling that might be possible in 100 years. The second area is consciousness, neuroscience. Here physicists try to ask difficult questions like how do you construct a model of self-organization that is responsible for memory, like the kind memory we have - not computers, and consciousness? This is after all the century of biology. Will physics continue to be important? The answer is *yes*.

Quantum Computing

Attracted some of the brightest people. In quantum physics, mathematics, condensed matter physics. Both in designing the hardware and software of a computer that is based not on classical physics but on quantum physics. Quantum computers can have in some cases exponentially more power than classical computers and can help us overcome the apparent obstacles to ever-increasing computer power. The problem is that quantum systems are always in contact with the environment. And the environment immediately de-coheres the quantum state.

Transcript

We have learned a lot in the last 50 years. In the last 50 years: Completed a journey of 1000s of years. Constructed an understanding of the building blocks of all matter. And we understand the forces the 3 forces that act within the atom and the nucleus. Achieved Democrates' dream of understanding the flow in terms of structure of point-like objects. Have identified all the elementary particles we've seen and also their cousins. And the forces that act on them. Astronomy, astrophysics, almost all of the history of the universe mapped. Learned to control matter in all its phases down to the nanometer scale. Manipulations at the quantum level. But the focus is on what we don't know. The most important product of knowledge is ignorance.

Within the next ten years we will detect dark matter in the laboratory. And we will produce it in the laboratory, in particle accelerators. What about dark energy? Dark energy is a very strange kind of a thing. We probably know what it is, it's what we call vacuum energy. It's a kind of energy that pervades the universe yet doesn't act like an ether. It has very strange properties. If you have ordinary stuff, that energy will depend on your reference frame. With dark energy, we don't expect this. For this to be the case, it must have negative pressure. It acts like anti-gravity. We observe this by noticing that the universe is expanding more rapidly, is accelerating. We call this Einstein's cosmological constant. But it may be something else. We don't know if the universe will accelerate forever.

Quantum mechanically, a vacuum is a very complicated dynamical medium. In quantum physics the hard job is to understand the vacuum. Particles are little ripples of quantum fields, living in the vacuum. By any calculation we get huge quantities of vacuum energies, but what we observe seems to be 120 orders of magnitude smaller. This is a great problem for the future.

There is a beautiful generalization of ordinary space called superspace, and of ordinary geometry called super symmetry. And here the question is "is physics super-symmetric?" Are there quantum dimensions? This question we will answer in the next decade. We think. Because of the large hadron collider.

I hope they may discover the super-world, in effect discovering quantum dimensions of space and time. Studies of string theory have led us to question space and times, have suggested that space/time is sort of an emergent concept. So what is behind space/time? Now we just beginning to get hints.

***Applications**:*

Condensed matter physics is trying to understand matter that we can create on earth out of ordinary atoms. It is the feeling of theoretical physicists that we are only beginning to explore the possible structures and phases of matter. And they will eventually become new materials. For example, one material that we are very excited about is graphene. Simply a single layer of graphite that you find in ordinary pencils. These are carbon atoms. This has remarkable properties both theoretical and eventually technological applications.

So new materials and new control. We are now able to put atoms where we want to put them. To move them around. We are able to create materials in empty space by optical lattices of laser beams - at whose nodes we can place atoms, move them around, change the forces between them and create a whole variety of new materials. Both for basic science, to study fascinating phase transitions, or for technological miracles.

One of them is quantum computing. Attracted some of the brightest people. In quantum physics, mathematics, condensed matter physics. Both in designing the hardware and software of a computer that is based not on classical physics but on quantum physics. Instead of representing bits as either 1s or 0s as we do in our classical computers, or up and down arrows, we use quantum concepts of quantum spin which can be in a coherent state of up and down. So a q bit can be in a super-position of up and down, so until you do a measurement it is neither up or down. Quantum computers can have in some cases exponentially more power than classical computers and can help us overcome the apparent obstacles to ever-increasing computer power. The problem is that quantum systems are always in contact with the environment. And the environment immediately de-coheres the quantum state.

Theoretical biology. Biology means studying living matter. Theoretical physicists are moving in because there is so much data and so many questions. Two examples where physicists are moving in:

One is genomics. we have the genome decoded. All of that data, we should be able to figure out what's going on… it's all in the genome. Can you make the theory of evolution really quantitative? Predictive? You can now do experiments on viruses. Let them mutate and develop a quantitative theory. One way I like to put this is: can one tell the shape of an organism by looking at its DNA? 100 years from now we will say: here is a genetic sequence, draw a picture of the animal. I have a feeling that might be possible in 100 years.

The second area is consciousness, neuroscience. Here physicists try to ask difficult questions like how do you construct a model of self-organization that is responsible for memory, like the kind memory we have - not computers, and consciousness? Can make a machine with free will? Can we do experiments? Can one measure the beginning of consciousness in an infant? Everyone would

agree that at this stage, a fetus is not conscious. And everyone would agree that a teenager is. So what happens in-between? Somewhere a consciousness-switch is flipped? It might be useful to focus on the transition. Is it discontinuous? Or is it continuous?

Physicists have learned that you can learn a lot by studying the different phases of matter and concentrating on the nature of the transition from one phase to another, even if they don't understand the nature of the laws governing them. You might study this transition for different species, different populations. You would of course have to figure out what it is that you are measuring. This is after all the century of biology. Will physics continue to be important? The answer is yes.

B2.14 David Haussler

Professor of Biomolecular Engineering, University of California Santa Cruz

Key Messages

Birth Decisions

Right now we can only do embryonic genetic testing for a very small number of diseases and these tests are relatively invasive. As our knowledge of the genome increases and our ability to separate fetal DNA from maternal DNA improves we will be able to non-invasively test for a wide-range of traits. Parents will be able to be much more selective about the characteristics of their children.

Cancer Treatment

As our ability to recognize genetic mutations that lead to cancer and, especially, to understand the genetics of tumors themselves improves we will win war on cancer. We will increasingly understand the role genetics plays in cancer and be able to identify which treatments will work for which patients.

Immunology

Genetics will heavily influence immunology. We will be able to train the immune system to fight diseases more effectively.

RNA Sequencing

RNA sequencing is the next big thing to focus on. Combining DNA and RNA sequencing will be very powerful.

Transcript

Background

What are the fields, disciplines, or emerging technologies that you believe have had the most impact over the last decade (or over your career)?

Computing power.

In your view, what has been their primary impact?

Growth in sequencing is faster than Moore's law.

But the Web was not really designed to distribute this volume of data. The cloud is necessary to distribute these data. Data centers are the right scale.

Will these continue to define progress in the next decade? If not, what has changed?

The best way to store DNA is as DNA, not as electronic/magnetic bits. You would rather have the DNA, not our stored data.

There are complementary biological interactions, our machines interact very directly with DNA. One challenge is indexing these data. Google does a good job with text. But DNA data is another story. You need to have a historic index, also something like a functional index. You want to exploit the fact that most of the DNA is common. Store only differences. But we can't compress yet relative to a standard.

What NEW technologies/innovations will be coming online in the near future?

Birth decisions and personalized medicine. If you accept the fact that we will be able to sequence genomes and we will understand more than we do now what are the applications social implications. #1 is diagnostics that relate to birth decisions. Several options currently to get tested. Right now invasive. If you are at risk of passing on a devastating disease you can currently do pre-implantation diagnostics. Currently only 1 or 2 tests. Could potentially do this as a whole genome. Right now we do not understand this area well enough to make these decisions.

Right now 1/1billion of the blood cells in a mother are actually fetal-derived. We could use these to do this non-invasively. Could do this early in pregnancy. Also 3% of cell-free DNA is fetal-derived. This can be sequenced and diagnosed. For example Down's syndrome can be tested for in this way. Paternally-derived mutations are useful. Mother's are confusing to these methods. So are vanishing (vanished twins).

We can focus these efforts by first sequencing the parents fully, that will help you zero in on what risks to look for.

Cancer is an example of a disease that you would do lots of sequencing from the same individual. We started to study this by looking for genes that are associated with cancers. Now we are finally starting to look inside the DNA of the tumor itself, of the cells. We see rearrangement of DNA, which creates novel genes. These you can find in various cancers, most famously in leukemia. Just errors in copying or tiny little point mutations can cause cancer. We are now starting to think that about cancer not as something that happens to you once. But as something that is a longer process. Mutations explain why cancers recur and have resistance. But the good side is that we can understand treatments in these terms, targeting specific genes upon which the tumor is dependent.

Computational cancer genomics is active work, ongoing work. We see similar genomic legions that we can use to classify and sub-classify, and sub-sub classify cancers. There are hundreds of thousands of questions that you can ask about these cancers. We want to organize these data along pathways through which these genes interact with each other. A good example is p53 a crucial point in these pathways for many tumors. We see these pathways as including changes that have the overall net effect of tumors protecting itself by including genes that make cells grow and prolong cell life.

How will we look back at the present era 30-50 years from now? What trends or technologies will best define our present era? (How are these different from those in Q1?)

On what evidence/experience/rule of thumb (e.g. Moore's Law) do you base this forecast?

Which technologies or innovations have been most *disruptive* over the last decade? Will these technologies continue to be disruptive over the next decade? If not, what technologies will replace them?

Forecasting

This project looks ahead 30-50 years. What is the first thing we need to understand about forecasting 30-50 years into the future?

Over a 30-50 year timeframe, what do you anticipate will be the major trends that will have the most global or national impact? Which disciplines or technologies will dominate?

Will the trends you anticipate shaping the coming decade continue to be significant? (We are curious about your big-picture view.)
The future is a combination of genome sequencing and RNA sequencing. The problem with the RNA is that you're not seeing if something is knocked out. But the combination of the two is really powerful. Complementary RNA is a great way to go for looking at these things. But early detection is probably the biggest gain.

One really important role is in picking patients who will respond to a treatment during drug trials.

What NEW technologies/innovations that you are aware of will have impact *on your field* in the next 30-50 years? On what evidence/experience/rule of thumb (e.g. Moore's Law) do you base this forecast?
There are interesting ways that people are training the immune system to attack the cancer. Genomics is going to be a revolution in immunology, perhaps more than cancer.

Believes we are going to win war on cancer such that there is a big impact on overall mortality. You're going to start to see in a couple years that we can treat this cancer now. Sure it's only three percent but then we see another subpopulation. Then in 10 years this starts to get really hot. Then you could see this going really mainstream.

More broadly, what national, international, or global trends (e.g. resource scarcity, climate change) do you anticipate will have the greatest impact? In what ways?

In your field, what do you see as the greatest opportunities for technological or scientific innovation? What are the greatest unresolved technical challenges across the sciences?
It is not a technical bottleneck. It is a knowledge-based bottleneck. We really do not understand how genes work. They are extremely complicated and we cannot translate changes in genome to changes in the cell. That is a gap we cannot cross. We have technology gaps now but we are confident we can make progress. Less confident about these knowledge gap.

One thing that happens in cancer is that there are lots of mutations, passenger mutations that are just along for the ride. We need to work to identify the driver mutations that are responsible for the original tumor.

What are the greatest threats we will face?

What will be the most significant technology that most people today have never heard of (doesn't exist yet)? How will it change our lives?

What topic area is the most difficult to accurately forecast? Why?

What field will advance the furthest in 30-50 years? Why?

How will innovations within this field impact the lives of those outside of the field in the next 30-50 years?

Can you take us through this step-by-step?

Transportation

This project looks at the impact of innovations in science and technology on transportation in a 30-50 year timeframe. Have you considered what emerging technologies and innovations will have the greatest impact on the future of the transportation sector?

Where do you rank the transportation sector among the core drivers of technology and innovation at present? How do you believe this will change over the next 30-50 years?

What are the most significant transportation-related implications of the trends you have described?

What are the opportunities for closer integration of your work with the transportation sector? Are there research activities that the transportation sector can fund today or the near future that can accelerate and/or enhance the future benefits of your work/sector?

What would be the implications for the transportation sector if a breakthrough occurred with respect to your list of greatest unresolved technical challenges? Greatest opportunities for innovation? Greatest threats?

B2.15 Glen Hiemstra

Key Messages

Climate Change

Climate change is going to have a major impact on the world. We will see far more variable weather. We may fall into a negative cycle where global warming triggers the release of more naturally existing methane which in turn exacerbates global warming. We will need to adapt our environments to this change.

Fossil Fuel

As we run low on fossil fuels energy prices will increase. This will affect how we move around and how we build our communities. We will need to provide alternatives to fossil fuels but will also probably reduce our need to travel. We will should no longer talk about "alternative energy" sources. Tapping these sources is no longer an alternative – we don't have any choice. We need to be looking at the potential of wind, ocean, sun and other non-fossil power sources.

Aging Population

As life spans increase and the population ages we will need to adapt to their needs. We will see impacts in a range of areas including housing, transportation (especially in areas that are spread out, not pedestrian friendly and have little in the way of public transit systems), workplace (people will be both be able to work longer and need to in order to support themselves).

Online Communities

The prevalence of online communities will continue to grow. We will see significant changes in many areas including business and education as a result. The growth of online communities will also impact areas like transportation – as more and more tasks can be done online, people will have less need to move around.

Robotics

Robots will become increasingly integrated into everyday life. We will see them replace many humans in the workplace although it is not clear at this point whether this will free more people up to do creative work, or will result in more people doing menial, low-paying work. We will also see robots in many other areas (e.g. autonomous vehicles which may obviate the need for personal vehicle ownership).

Nanotechnology

Nanotechnology has the opportunity to revolutionize the materials available to us.

Hidden Pollution

We are at significant risk from pollutants we don't even realize yet we are putting into the environment. We often think the pollutants are either not getting into the environment or are getting it at such dilute levels that they are non-toxic. We are beginning to realize, though, that toxins accumulate and, while they may be non-toxic or in non-toxic quantities at the point where they leach into the environment, they concentrate in various ways (e.g. as they progress up the food chain) and become toxic.

Religious Divisiveness

Religion is an uncomfortable issue for most people. Globally we still have very substantial religious divides and as communication increases there is increasing potential for serious conflicts to arise as a result.

Transcript

Forecasting

Over a 30-50 year timeframe, what do you anticipate will be the major trends that will have the most global or national impact? Which disciplines or technologies will dominate?
Unquestionably, climate change and global warming is going to lead to more variable weather, and will have all sorts of local, national, and global implications.

Increasing energy prices and the end of cheap oil are also going to have significant impacts, not only how we move around, but also on the shape of our communities and how we inhabit these spaces. We will need to provide people with more alternatives to fossil fuels for transportation because these fuels will become too expensive, and this will necessarily lead to a reconsideration of how we approach our built environment. And you can see that in some regions, change in this direction has already begun.

The aging of the population is going to be a significant challenge that will impact many different aspects of our lives and communities. The baby boom generation is becoming older, and will find that they no longer want to maintain large homes that only one or two people live in, so the housing market is going to have to produce products that are attractive to people in this life stage. In addition, it will be necessary to provide affordable housing to older people who will be living on more limited incomes. On a related note, it will be interesting to see the dynamics of workforce participation as the population ages as well, because it is almost certain that people will continue to work until they are older, primarily because people are not saving enough to support themselves in retirement.

The transportation realm will also be impacted as ultimately up to 25% of the population probably will not need to travel as much. Notwithstanding higher rates of older workforce participation, there will be lots of older people who are not working, either because of retirement, disabilities, or mobility limitations. It will be a challenge to accommodate people will lower mobility in regions that are very spread out and don't provide good transit service or pedestrian-oriented communities.

I think we'll see immense growth in the development of and participation in of online communities. Currently, there are very popular and massive participatory environments and multiplayer games in which people are literally living second lives. Companies, products and services are moving into these realms and setting up virtual places which now function as testbeds for trying out new ideas and developing new ways of thinking in marketing. I also think that immersive virtual environments will have all sorts of other applications. In particular, I think these environments could revolutionize education at all levels: elementary education, higher education, and corporate training.

What do you see as the greatest opportunities for technological or scientific innovation? What are the greatest unresolved technical challenges across the sciences?
I see lots of opportunities for reconfiguring the physical spaces in which we choose to live. I think there are opportunities to create interesting, compact places for people of all ages to live. I also

think that we'll see the emergence of new modes of transportation, such as automated vehicles that shuttle people point-to-point.

I think we'll see that robots become integral parts of all aspects of our lives, and the rise of robots will be similar to the rise of computers. Robots will play a diverse set of roles, from assisting humans, to replacing segments of our workforce. In fact, I think we tend to underestimate the degree to which automated work process and systems such as robots will replace human labor. It's estimated that as many as 20 million jobs in the US alone might be replaced by automated work processes. One question is: what people will do? Will this lead more people to be able to participate in creative work, or it result in more people doing low skill, low pay work?

Nanotechnology will be an area of tremendous and significant innovation and opportunity. Manipulating matter at the atomic scale will provide us with the ability to create materials with entire new properties unlike anything that has existed before, as well as create extremely small or even extremely large objects that could be applied to an immense number of challenges.

Finally, there are untold opportunities to develop alternatives to fossil fuels, but we need to figure out how to do this quickly – within the next couple decades. I like to say that alternative energy isn't an alternative anymore because it's not an option – we have to use develop new forms of energy. It's interesting to me that the leading solar nation in the world is Germany, which isn't exactly known for its sunshine. But Germany has demonstrated that if you create the right kind of energy policy you can develop new energy technologies that are cleaner, safer and longer lasting. In addition, wind and ocean energy sources are largely untapped, and we should be figuring out how to exploit these energy resources over the coming decades.

What are the greatest threats we will face? Are there potential technological or scientific advances that can ameliorate these threats?

I worry that we underestimate the impacts of climate change, and that the changes we experience will be very significant. For example, we could easily get caught in a negative feedback loop where global warming leads to the release of more and more naturally stored methane, which is twenty times worse than carbon dioxide when it comes to global warming.

The issue of "hidden pollution" is a long term threat, specifically as it relates to water and air quality. For example, fire retardants are now put in all sorts of products during the manufacturing process, and it's clear that these chemicals are leeching into our water system. Although the levels in our water are currently deemed to be safe, it has recently been discovered that these chemicals accumulate in animals, particularly at the higher end of the food chain, to the point that they do become toxic.

It's a sensitive topic, but religious divides continue to dominate the global scene and businesses need to recognize this as a challenge. This divides have existing for a very long time, but with the advent in instant communication, rapid travel, and personal access to powerful weapons, we need to be more actively addressing these divides. Unfortunately, talking about religion often makes people very uncomfortable.

Finally, I fear that too many people place emphasis on being "right" rather than being "happy" and that this can lead to poor long-term decision-making.

Transportation

This project looks at the impact of innovations in science and technology on transportation in a 30-50 year timeframe. Have you considered what emerging technologies and innovations will have the greatest impact on the future of the transportation sector? Which ones and why?

We'll see the emergence and adoption of automated or robot navigated vehicles that will function in a sense as personalized transit, providing people with point-to-point travel without needing to own a car. I can imagine fleets of these wandering around cities. At the same time, current and future generations will grow up in a world of the internet and virtual augmented realities, and this will be highly consequential for how people choose to live, work, and travel.

B2.16 Claire Janisch

Biomimicry Expert and Lecturer, CEO GeniusLab, South Africa

Key Messages

A Beneficial Footprint

Talk today mostly focuses on how to be less bad for our world. Instead, we should be thinking about how to actually be beneficial. We can use biomimicry and an integrated systems approach to optimize conditions conducive to life. For example, instead of toxic chemical pigments, maybe we can learn to color surfaces by creating microscopic textures similar to those on the feathers of brightly colored birds. We could combine self-assembly (a la ant colonies) with 3D printing and use locally available materials so all we'd have to transport would be the designs. We can look to solar energy and electrochemistry to move beyond batteries and current dirty energy sources. We are even experimenting with teleportation and the electron level, maybe that will develop into something we can use.

Transcript

Every time I do my bio mimicry – do range of product process & systems & talk about how would nature move people.

1. Environmental awareness & need to reduce carbon
2. Shift from being less bad to how can we actually created beneficial footprint rather than less bad – become a living city
3. Poverty also

Overall Pollyanna – going to be better.

Shift to integrated systems approaches to solving challenges – that links to biomimcry – understand systems far more in a way that can be applied to human apps especially in cities.

"Life's Principles" or "nature's principles" = use conditions conducive to life- optimize rather than maximize – interdependence – she'll send them along – benign manufacturing, free energy – all the

principles applied to cities becomes powerful re: enabling innovation – enhances rather than destroying – more well adapted to planet rather than maladapted.

Read Bert Bras paper – apply to info, solar energy, carbon to feedstock, big impact on systems approach applied to cities – impact from extraordinary techs like leap from old fashioned computer.

More info based, decentralized – help people move as well as manufacturing.

Push the GeniusLab limits – realize can get to levels of teleporting and torsion field – being done at electron scale & Russian research – field propulsion – could suddenly mean a quantum leap in way we move rather than.

Movie the fly – get teleported with the fly. Aware of extraordinary options for movement based on alt energy – being able to teleport – hope that starts coming in – does make sense but cracks the understanding of boundaries & borders – how go through a border & have passport stamped.

Potential – 3 dimensional printing combined = rapid prototyping – where it can be in the future – send a blueprint & have itself assemble – no need to transport goods – just the information – combine self assembling with benign composites & need fewer resources – combine with 3d printing – not transporting but making with locally available materials – abundant & benign. CO2 becomes a feedstock – it's a feedstock for almost everything in nature.

Nano tech – how nature creates color using nanostructures – feather on bright bird – pure keratin & brown – reflect structure= 3 dimensional printout of a car – use C02 as feedstock 7 final reflects the color so don't have to paint – gets intriguing. Also can have stuff that changes color. Also potential to do everything based on DNA chains - any potential.

Level of looking at way insect exoskeleton & inside all made out of same material with different shapes. Eg packet of crisps – metal for impact resistance – stick them together and the unable to be recycles – instead get the nanostructure & can self assemble.

New ways of attaching, propulsion. Whalepower.com – bumps of fin enable to turn tight circle – tested on wind turbines – operate in low & turbulent winds – just used on planes - & got 32 % reduction –by changing the shape. Golden ratio – pax – 10 – 85% energy & 75% reduction in sound – available already – if just applied to trains or planes huge impact.

Incremental jump or teleportation.

New ways of storing & capturing energy- decentralized – every windowpane an energy/solar system – living water –photons – sudden dramatic change in capturing & storing energy. Not even using batteries but chemicals, electrochemistry.

So much happening in that space if doesn't have revolution we as humanity have to feel we're idiots. So far developed. Bacteria convert metals to energy.

Movement . Whole movement driven by understanding superorganisms –eg ant colonies – self organizing rather than top down hierarchical – intelligent system design – but who is the intelligent system designer (as opposed to policy maker)

Teleportation has to be level of high consciousness – need to know that we are all one and of the same substance so same laws can't apply – we are all made of energy and matter comes together based on concentrated observation – can't combine current dept of transport.

Run based on information and service – nature maintains itself by turning itself over – the action of digestion is happening no matter who's in place – it's how Ford can become a transport company.

Nature – always look at function if looking for a solution – the functions trying to meet are there eg access to resources – always diverse, decentralized, distributed – never centralized with production line. What is DOT – how can those services be supplied – how can they ensure that service is being provided – people need to achieve that thinking – you are not important – you are an adventurer.

In many circles people believe the evil empire already exists – it prevents people from knowing they can teleport.

You don't want to be self empowered if government provides everything need - you as individual have to accept going to have someone in power – don't know how to inspire self empowerment – most systems designed for lowest common denominator – search for alternatives.

Whole movement – Juan – people network for common good – got to be a combo of self empowered people coming together - not the people in DOT – either enable self empowerment – blessed unrest – Paul Hawken - combine all the movements in the world – only just connect the dots of all the existing willing passionate people. Enabling self organization & finding out where the gaps of . Like new mobility only on level of the cosmos – playing catalytic connecting role important thing to do – connectors & enable rather than do it all ourselves.

2 different answers – if groups of people hold a vision it will self organize. If no vision of what going towards, reaction won't get there. Power of holding w own observation an imagined alternative future is absolutely vital otherwise it's a mishmash - clear vision of where you want to be – highly self organized based on diversity – large principles of it rather than specifics.

Set of clear principles as vision – get transcendental meditators.

Other level – enable systems thinking – nobody is taught systems thinking – could be enabled to think in 6 dimensions – embrace from a young age – really interdisciplinary systems thinking if want to be effective planner at all – need to be discovered.

B2.17 Alex Lightman

MIT Media Lab

Key Messages

Predicting Peaks

We can look at history through the lens of measurement to identify peaks. E.g. the number of letters handled by the USPS peaked in 1975. We can use the idea of peaks to think about the future. E.g. what will peak first, the demand for processing power or our technical ability to keep up with Moore's Law? Applying the idea to transportation, we will see peaks in both the number of internal combustion engines and the number of drivers. The number of combustion engines will peak because we'll start to shift to other technologies – as the number of electric vehicles increases, the number of combustion engines will decrease. As we continue the trend to urbanization the number of drivers will start to decrease. In very high population-density areas, personal vehicles are no longer an effective way to get around. Already 30% of Manhattan residents have no driver's license.

Computation Closure

Computational closure is the point at which for some task there is no benefit derived from more computational power (processing speed, bandwidth, memory, etc.). We will hit computation closure for many applications. For example with graphics (video games) we will hit computation closure at the point where resolution outstrips our physical ability to perceive. At that point we might be technologically capable of increasing resolution but will gain no advantage from doing so. We may be reaching computation closure for transportation. Other technologies (e.g. high bandwidth communication) will decrease the need to travel. Similarly as the number of drivers peaks and starts to decline we will no longer need to continue expanding the infrastructure for personal vehicles. The introduction of autonomous vehicles will also impact the need for personal vehicles – a fleet of readily available, inexpensive, autonomous taxis, for example, would make car ownership unattractive.

Transcript

What are the technologies and innovations that will have the greatest impact 30-50 years from now?

You can think about the future in terms of predicting peaks. A good reference is a book called The Measure of Reality: Quantification in Western Europe, 1250-1600 by Alfred W. Crosby. (Describes peak functions and argues that the reason Europe grew and conquered was because they developed a mania for measurement).

It is useful to look at the future through the lens of measurement and to identify peaks. For example: the number of letters handled by USPS peaked in 1975, declined after that.

This is connected to concept of computational closure. Computational closure refers to the point at which for some task there is no benefit derived from more computational power/processing speed/bandwidth/ram/etc. So after a period where you need more and power/processing speed/bandwidth/ram/etc. then just don't need that much anymore.

This is related to an interesting debate: Which will run out first, the market demand for processing power or the technical ability to keep up with Moore's law?

For example, with video games there are only so many more doublings of resolution possible before limit of perception is reached. It is similar for bandwidth and latency.

Similarly, for maps and resolution, we may have reached computational closure with maps as transportation aids. Possible that we have reached a peak of computational closure.

We may have reached what I will call Transportation Closure.

We will hit peak number of internal combustion engines. Perhaps 5000 of these vehicles are electric now, perhaps 2-9 million by 2050.

We will see a peak in car ownership.

This will be hugely influenced by delivery of 100 megabits per second (mbps) connectivity to 100 million households. This is 4G—real 4G. The Whitehouse is trying to do this. If uncompressed HD video is exchanged, it only takes 19 mbps; 100 mbps will reduce the marginal growth of the need to travel.

Meanwhile, potholes and maintenance needs will grow and grow and grow because of lack of state and local funding. People will be discouraged from driving it will be so bad.

An interesting book in this context is Where Good Ideas Come From: The Natural History of Innovation by Steven Johnson.

Johnson points out that the ocean is largely lifeless. Yet there is a lot of life near coral reefs. Reef ecology is diverse; coral reefs use limestone and wave energy like a factory for creating ecology to support marine life. This is, in a way, similar to cities. Cities are exponentially greater at developing ideas. As our economy is increasingly based on ideas, more and more people are going to want to live in cities. And, for example, in cities more and more people will not have licenses. 30-something% of people in Manhattan don't have licenses.

(Also: all animals have about the same number of heartbeats. Bigger animals' hearts beat slower while smaller animals' hearts beat faster; since bigger animals live longer than smaller animals, all animals have about the same number of heartbeats over their life-spans.)

What areas of science are going to have the biggest impact?

Well, I recommend $20 Per Gallon: How the Inevitable Rise in the Price of Gasoline Will Change Our Lives for the Better by Christopher Steiner. It suggests that we will have a completely different society.

Also Google is researching fully autonomous vehicles. The result of this might be that one year there are a million taxi drivers. Then, the next year there are 1000. Imagine a city where taxis are like 20 cents a mile because you're not paying for a driver; the economics are changed entirely.

I recall that for the T in Boston, a study of the No.1 bus found the cost of a person's time is about $9 an hour while on the bus, but it rises to about $28 dollars an hour while waiting for the bus.

Jessica Scorpio—her company Getaround offers the opportunity for a member's personal car to be rented, using an online system, to other members. For people who just might need a couple hundred dollars, for example for a mortgage payment, it might be a lifesaver. Getaround might contribute to getting us past peak vehicles.

Similarly, for high-speed rail in CA, trains for any place where there are long distances, it just doesn't make sense to use trucks… or cars.

What will be the impact of, for example, Nanotech or other emerging technologies?
It will not be a big driver compared to IT/ICT and energy.

The 30-50 year timeframe is precisely the timeframe of the singularity. Ray Kurzweil predicts will occur when computers are more 'intelligent' or computationally powerful than humans and then there is no way to predict what happens after that, even for writers of science fiction.

To understand this I recommend a book called The Watchman's Rattle: Thinking Our Way Out of Extinction by Rebecca Costa. She argues that our society is exhibiting levels of complexity and gridlock similar to that of others before they crashed.

B2.18 David Lubin

Key Messages

Personal Brain
The first killer app of the information age was the spreadsheet. The modern killer app is Google – the ability to locate and access massive amounts of information about anything. The next killer app will be analytical – a personal brain that will be able to make the mountains if information currently available usable and manageable.

Sustainability
Sustainability is going to become an increasingly critical driver. We will have to decarbonize the economy. There will be major innovations in fuel cell technology which will change our thinking about low carbon energy. We already see companies focusing on risks related to climate change and resource availability. That will increase. Historically we have seen the personal and/or societal benefits of new technologies but have failed to see the environmental downside. Transportation is a case in point – current transportation systems are destructive. We will have to get better at managing unintended societal and environmental consequences.

Longer Lifespans
Genetic technology will make individualized medicine a reality. This will have major impact. Our ability to extend the human life span will increase dramatically. We need to think seriously about the impacts of extending life. It will create huge moral, ethical and social dilemmas. What happens in situations of disparity? Scarcity?

Transcript

Background

What are the fields, disciplines, or emerging technologies that you believe have had the most impact over the last decade (or over your career)?
Telecom, wireless. Internet, advanced communication. Mobile communications.

In your view, what has been their primary impact?
To make information accessible at any time, any place, to any person. Enhanced entertainment, decision-making, productivity.

Will these continue to define progress in the next decade? If not, what has changed?
They will, but incrementally - more implementation, more integration. More intelligence and automation. These will make most use of wireless mobility.

Other technologies will dominate in next decade.

Next decade is energy and carbon – decarbonizing economy. Maturing of long RD cycle on energy and increasing awareness. That will change priorities.

What NEW technologies/innovations will be coming online in the near future?
Many of course. Fuel cell technology will be the big innovation of the next decade. It will change in a big way our thinking about low carbon technology.

How will we look back at the present era 30-50 years from now? What trends or technologies will best define our present era? (How are these different from those in Q1?)
We will look back at this decade and say "I can't believe they were so focused on entertainment while earth was in peril." Look back with regret.

One trend is: business productivity tech morphing into personal/entertainment tech.

Next round is shifting from business and personal productivity to sustainability.

On what evidence/experience/rule of thumb (e.g. Moore's Law) do you base this forecast?
Evidence: watching flow of capital in financial world. Big flow towards new processes, towards these new technologies. At the same time, big changes in how companies perceive risks. Companies perceive big risks related to climate, resource availability.

Which technologies or innovations have been most *disruptive* over the last decade? Will these technologies continue to be disruptive over the next decade? If not, what technologies will replace them?

Forecasting

This project looks ahead 30-50 years. What is the first thing we need to understand about forecasting 30-50 years into the future?
Multiple forecasts. Figure out multiple scenarios. Scenario planning. For example: will developed or developing countries be at center of global power. Many endpoints. How do you know which path you're on? Sign posts.

What NEW technologies/innovations that you are aware of will have impact on the end user in the next 30-50 years? On what evidence/experience/rule of thumb (e.g. Moore's Law) do you base this forecast?
More intelligence, more interactive intelligence, true whether looking for nearby Chinese restaurant, getting a mortgage for your home, or business-related decision. That's going to happen. That's coming, it's real.

Change: as much over next 30 as last thirty. Greater capacity to analyze, now information overload.

The killer app was the spreadsheet. Now killer app is Google. Next 10-30 years the killer app will be the personal brain, personal Google. This means usable information.

What do you see as the greatest opportunities for technological or scientific innovation? What are the greatest unresolved technical challenges across the sciences?
Solving problem of growth in the world economies? Making growth sustainable. Balancing desire for growth with consequences. Historic dynamic: Personally and societally, consequences are good and bad, but environmentally, consequences are bad.

What field will advance the furthest in 30-50 years? Why?
Gene science / genetic medicine will advance the furthest in the next 30 years. About the same age, almost to the year as the PC. The core individualized medical therapies are only a little teeny bit real but will probably create profound changes. The potential to change the human lifespan in significant ways. Going to create enormous ethical social moral dilemmas.

Lifespan's been creeping along 60, 70, 80 can you imagine the impact of the power to extend that out to 120, 140? Imagine that in a scenario of disparity, or scarcity.

Where do you rank the transportation sector among the core drivers of technology and innovation at present? How do you believe this will change over the next 30-50 years?
Big drivers are need to decouple growth from consumption of natural resources. Solve energy, water, air, problems.

Transportation systems as they are currently structured are destroyers. Transportation systems are a major problem that society will have to crack. Old model of mobility is an example of how

people were so fixated on the positive consequences, they never dreamed the negative consequences would be so serious.

Can transportation make a big contribution to making cities work better? Cities are going to have to be more productive than they are today.

Managing unintended societal costs is going to have to become part of the responsibility of governors and producers, of business. The balance otherwise becomes so imbalanced, it impedes your ability to grow.

The development of the past has created so much decay, so much waste, so much degradation, that it is impossible.

B2.19 Pattie Maes

MIT Media Lab

Key Messages

Interfaces

Current interfaces (keyboard/monitor) were developed in the 1960s and haven't changed much. We will need big changes to interfaces in the future. For example, as we increase on-board sensors in a vehicle, we need to be able to provide information to the driver in a way that isn't distracting (e.g. projection, windshield displays).

Intelligent Information Systems

We now have enormous amounts of information available, but it we need to make it easier to work with. For example, systems with awareness of their users: who they are, where they are, what they want. Also, proactive systems (e.g. navigation systems that proactively tell users where to go, how to get there, adapt to changing conditions).

Transcript

What are the fields, disciplines, or emerging technologies that you believe have had the most impact over the last decade (or over your career)?

The internet, of course. The internet will continue to impact things in big ways. In particular, through new interfaces. Current interface (example: keyboard/monitor) basically invented in 1960s and hasn't really been changed. Information systems have been advancing but interfaces have not.

Her work is about making it easier to access information and to work with it. Intelligent information systems, systems with awareness of users intentions: who they are, where they are, what they want.

For example: Traffic systems that will proactively tell you where to go, how to get there. Systems that take a more active role in pushing information to users

She also works on physical interfaces, augmented reality, projection, and information overlays onto physical world, private and shared.

More and more information is available. There are more and more sensors, more and more data.

Her work is more about proactively pushing relevant information to users. Others are more about extracting new data from new sources.

For example: A WA state company has agreements to harvest GPS location data from UPS and from USPS. Use this for traffic.

Similarly, Google's ad model is very context-based. That whole idea is going to influence what we get in a mobile environment, not just online. Now Google is going to start to make a lot of money by leveraging physical context.

What needs to be developed to make this happen?

Well, one problem people are now facing is: How can you provide info without distracting people while driving. Some possibilities are: projecting information or using windshield displays. Increasingly there will be more intelligent things like that.

This will require: 1) novel displays, 2) progress in computer vision, and 3) the power to compute these scenes in real time.

But in the more distant future you will see more intelligent systems, systems that drive themselves i.e. autonomous vehicles. And at the same time, more and more data. For example, a scenario where every car can talk to every other car.

At this time, however, data is not networked very much. The Google GPS example is just the very first, not very much done yet.

You could change all sorts of things that way. Not just traffic, but sharing vehicles. The entire system can be optimized and made more efficient automatically.

What are the technological barriers you face in your work?

We need advances in computer vision. In (computer) intelligence. Her background is in AI.

Ultimately we will develop systems that can reason and understand people's goals. Progress is a gradual thing but the ultimate situation is one where you just have a lot of autonomous vehicles.

What are some potential applications?

New technologies will bring new markets – socially networked systems for transport, social changes related to sharing and mobility.

There will be enough intelligence in the cars to be able to say: I want to go here… I am in a hurry… I will pay this much. And the vehicle meets the conditions. No driver necessary, but like taxis.

Also, safety applications. Vehicles aware of the driver's state - tired, etc.

Also, roads with embedded sensors. Car would automatically slow down given driving conditions. Perhaps based on road surface conditions. With nanotech you would have materials that can adapt and change.

Other contacts and references

Bill Mitchell's lab (Seoul City Scooter). Same idea as bicycles in EU cities (and MN) but with scooters/cars. Bilbao is where they are building this car. (S.P.)

Ryan Chin / Kent Larson.

B2.20 Dennis Meadows

Key Messages

Infrastructure Maintenance

Our transportation infrastructure is aging. We don't really need to expand the infrastructure, but we need to maintain what we have. We cannot afford to do that so we must find ways to reduce the cost of infrastructure maintenance to 10% of current costs. We also need to look at how the infrastructure needs to change to meet new demands – especially as we shift from oil to electricity for propulsion.

Resource Scarcity

We have already reached our peak oil production. As oil becomes scarce we can expect prices to rise dramatically. Before prices peak we will need to shift to non-economic (i.e. government managed) methods for distribution. Democratic societies will not tolerate a situation where only the wealthy can afford fuel.

We also need to come up with technologies for making high-efficiency engines that don't rely on rare-earth elements. These resources exist in very limited quantities and China controls most of them.

Lifestyle

We have come to take virtually instantaneous transportation for granted. We can get in our personal vehicles and travel long distances rapidly, comfortably and on our own schedule. As infrastructure deteriorates, oil becomes scarcer and climate change forces us to restrict CO2 emissions further we will need to change our expectations – rely more on public vs. private , recycle more, etc.

Transcript

Background

What are the fields, disciplines, or emerging technologies that you believe have had the most impact over the last decade (or over your career)?

In the past decade, the electronics and telecommunications fields have probably had the greatest impact, though I think we people also tend to underestimate the extent to which advances in synthetic materials and plastics have transformed our lives. When I started my career, cars were

primarily made out of metal – now much of a car is made of plastic. 90% of all plastics ever produced have been produced since 1960, and oil is the key ingredient in the production of the plastics. In addition, 80%-85% of all oil consumption has occurred since 1970. These two trends, the proliferation of plastics and the availability of oil have had immense impact on vehicles and how we use them.

Distributed intelligence has also fundamentally changed transportation. For example, when I was a teenager I could take my car engine apart and put it together it would still run. It's impossible to do this now because so much of the vehicle operations are computer controlled, and the microprocessors are distributed throughout the car. This makes the system much more complex.

Finally, I think that advertising has had big impact. The design, refinement and promotion of messaging has

Forecasting

Over a 30-50 year timeframe, what do you anticipate will be the major trends that will have the most global or national impact? Which disciplines or technologies will dominate?

There's good reason to believe that oil production has peaked, and will start to fall. In fact, the German think-tank Energywatch estimates that by 2030, oil production will be half of current levels. Given the enormous influence of oil in transportation sector, this will have a tremendous impact. Assuming that as oil becomes scarce, prices will inevitably go up. But long before price gets to extremely high prices, we'll shift to non-economic methods to allocating oil, such as government mandated and managed rationing. This is because most democracies will not tolerate $20 for gallon gas because only the rich would be able to afford. But there may be bigger issues than running out of oil. For example, in terms of the globalization, I have more concerns about currency battles.

Climate change is also going to have an enormous effect on transportation sector in two ways. First, it will make us much more concerned about C02 emissions, and second, the impact of climate change will be disruptive to our use and maintenance of transportation infrastructure.

Finally, I think that there are larger trend with our expectations about travel. With transportation there, are at least three primary issues: First, what is the volume of transport as measured in person miles or tonne miles? Second, what is the mode of this travel, such as auto or train or truck? And third, what is the convenience? It is this third factor that has fundamentally changed. We've become used to instantaneous transport. In the old days people, might journey from their far away home location twice a year to town. Now, people just jump in car and zip down. Our convenience expectations have changed phenomenally, and it seems to me that inevitable this is going to reverse. Expectations, lifestyles, habits are going to have to change. Recycling is going to become much more important.

What are the greatest threats we will face? Are there potential technological or scientific advances that can ameliorate these threats?

Sometime during the next 30 years, there's a high probability of a major solar surge, which will wipe out all electrical grid, and probably disable most vehicles. I think this is a good area for

research, in terms of identifying what this would do to transport infrastructure. Are there things we can do to mitigate? Do we need to redesign systems? What backup systems should we have? I also think that eroding infrastructure is a big threat. By every indicator, our transportation infrastructure is crumbling, and at some point, you start having failures. But given the economic situation of the country, I don't see us starting a major infrastructure investment program. We need to come up with ways of rebuilding so that the costs are one-tenth of current costs. In addition, most people are facing a period of declining income, and this will reflected in transportation choices and tax income.

Transportation

This project looks at the impact of innovations in science and technology on transportation in a 30-50 year timeframe. Have you considered what emerging technologies and innovations will have the greatest impact on the future of the transportation sector? Which ones and why?

In term of greatest impact, I think developing radically less expensive ways for maintaining infrastructure will be essential. I don't think the amount of infrastructure needs to go up. We need to maintain our infrastructure, and we need to shift to a greater reliance on public rather than private sector means. I also think it's important to note the whole set of issues that goes along with the shift we're seeing to electricity as a power source for our transportation system. One thing we need to do is to find ways to do high efficient motors without use of rare earth elements – at present China controls over 90% of rare earth materials. The Japanese have developed methods for building high efficiency motors without using rare earth element.

B2.21 Axel Meisen

Chair of Foresight, Alberta Research Council

Key Messages

Transportation Paradigm Changes

We could leverage Zeppelin/air ship technology to transport increasingly large amounts of cargo by air. This has several advantages: quiet, can operate in cities, can transport heavy/large cargo.

We could increase auto/train integration to provide drive-on train transportation for many more short- to mid-distance trips. Similar to the Chunnel, people could drive onto the train in one city, then off in another. This would reduce the need for intercity highways and allow better management of inter-city traffic.

Autonomous or semi-autonomous vehicles will improve efficiency and capacity of transportation infrastructure.

Transportation Infrastructure Materials

Improved materials for constructing transportation infrastructure will simplify maintenance. Infrastructure will last longer, maintenance will be simpler. Construction methods will also get simpler.

Transportation Demand

Improved IT infrastructure will change our transportation patterns and needs. Today it is still necessary for most people to travel into the city center to work. Increasing communications capabilities will render that unnecessary. This will reduce the number of vehicle-miles traveled and will change patterns of travel frequency and distance.

Security

We continue to face security threats to our transportation hubs. We have a long way to go to close these vulnerabilities.

Transcript

- We'll see emergence of different form of transportation -- a significant impact on other road & currently used: airships - well suited for transportation of heavy goods over both long & short distances – time not primary determinant. "blimps" Zeppelins. Never received much attention not because of Hindenburg but no serious military need for them. All aerial transportation is really result of military needs- true for both fixed wing & rotary wing. Need for transporting heavy loads - the ability to do it by road & current conventional air is quite limited. A place for airships to do this – can operate in urban environments – don't need landing strips – quiet – would have a role not only in moving goods (can envisage things like constructing houses offsite & transporting to their destination). Not constrained by height of bridges & tunnels. If that were to come about could actually play useful role in construction of world infrastructure- transport bridge members.

- We'll likely see the advent of autos being transported by rail in part – cars on rail – essentially trains that function like ferries that transport so people can go from one place to the other without having to drive from city to city. Chunnel connecting England to France – drive auto onto rail car and drive it off. Many cities where that's quite reasonable – not transcontinental but typical trip length order of 3 – 5 hours quite suitable. Required integrate rail and auto system which is quite doable and would relieve highway congestion significantly. Energy implications – very energy efficient to move by train rather than driving

- More conventional – we'll see advent of more guided autos maybe not driverless but where can sit back & don't have to steer & it'll take you from a to b. It'll need a new infrastructure but well within our reach with very beneficial results on accidents and lessening congestion – avoid bunching that takes place when cars are driven by people.

- Major need for improving existing & building new roads = way we build & upgrade roads will be overtaken significantly by developments in the future. In Northern reaches of US – kind of asphalt & construction for roads – last for 10 yrs without refurbishing. Fiber based construction materials.

- Whole matter of better, longer lasting infrastructure and better ways of replacing it. It's very complicated and labor intensive how roads are built – to build a foot of highway requires many hands and that will likely change.

- Last thing – issues related to security – unfortunately terrorism of one form or another. Our whole transport system – not just airline system is very vulnerable – particularly of ports & port facilities- really know what's being transported in containers – not much imagination to see people of certain mind creating problems – security from that perspective- a social sciences problem affect on transportation if not handled properly.

- Lastly # of vehicle miles we drive will change substantially because nature of work is changing. – compelling necessity to go into the city centers to work in big office towers will not disappear but will lessen. Rockefeller center – 60k people go there & leave every day – less reason to do this – not out of their homes - much more electronically using parallel systems – will have significant impact on needs – kinds of distances people.

- Changes will reshape cities the way we know it.

B2.22 Gerry Mooney

General Manager, Global Government and Education, IBM

Key Messages

Reprioritization of Transportation Modes

Green technology and green concerns will cause a reprioritization of transportation modes. Cars will give way in favor of trains and other mass transit. Tele-presence tools will also reduce demand for travel, especially given how onerous and expensive it has gotten.

Long-Term Transportation Planning

We can plan for 20-30 years out and need to because of the lead time required to implement a major transportation project. It is not, however, so easy to get those plans implemented because of the huge up-front cost and long lag time before benefits are realized. As a result we will probably fail to make big changes and will probably fail in high-speed rail investment. Job and industry creation (not climate change) will be primary drivers for transportation development and will likely happen outside of the US (e.g. in China).

Information

The omnipresence of smart phones makes enormous amounts of data available in real-time both for and about users. We can use that data to understand where everyone is. We will see it used more and more for transit applications in a variety of vehicles.

Transcript

Green tech & green concerns are going to cause reprioritization of transportation modes. In future & past here in US heavily invested in highways & cars – they'll drop in favor of trains & mass transit. When thinking about impact of collaboration pools – E.g. Cisco's telepresence –these tools will help

take demand out of traditional transportation systems – if Cisco continues to invest in their tech – could see a shift in terms of planes & need for going to & fro into collaboration tool infrastructure for doing better & more high quality telepresence to cut down on need for trips. Put this sooner rather than later: travel more & more of an ugly experience – the airlines are giving you less, more onerous, expensive, violence – opening for Cisco to do telepresence – may see all of a sudden demand taken out of the system both city to city & international basis – over certain duration of travel time & hassle degree.

Re: actually running the systems left – more info & analytics about streamlining & interconnecting the systems so better connection & better info for the user.

Can we plan 30 years out? Interesting – if talked to Bob Yarrow or Tom Wright – any large infrastructure – a several decade process –planning, funding , implementation, operating – perfect (e.g. tunnel from NJ to NYC)– government just said sorry I'm out – how many years it would take to dig the tunnel = issue of long term planning more difficult especially for big projects because of price tag – v. concerned – I'll predict the country is going to fail on high speed rail investment. States won't be able to. While we can plan over 20 or 30 year horizon, climate we're in now for big changes in transportation are going to become more difficult – not the political will to do these kinds of projects at this point. Maybe if tied to jobs.

You should get Tom & Bob

Re: end user – getting better & better (e.g. iPhone, iPad, smart phones) – ability to use as input to understand where everybody is in the system – how pick up data – less expensive ways – data in real time rather than batch – people getting cleverer & cleverer = info for optimizing system & informing end user – now hitting the knee in the curve – accelerating – a lot coming out from that – not a lot of huge capital invest – existing modes will use it more & more – transit & cars.

Climate change won't be the prime mover- it's going to be job creation & industry creation – China has decided they're going to create an industry around the electric vehicle – creates high quality jobs – Chinese in China – will pick 10 or 12 cities – start an internal biz of developing electric vehicles – already figuring out charging stations, where put them in cities etc – enough annual production to drop price point & start exporting. Taking advantage of climate change to get people into electric cars but investment is creating new industry for places like china – what they proved on high speed rail – top down – leapfrog existing competition – put the amount of critical mass investment – technology will leap forward both re: individual design to scaling & manufacturing to create an industry – critical mass to go in entrenched tech in countries like the US and rapid adoption.

A lot of things going for cleaner fuels (e.g. air quality) - whoever can drive to scale and work out the issues related to quality of vehicles – there will be a new industry that will rise up and it's all about Chinese seeing as able to create new industry – high quality jobs to export.

Up to this point transportation has been pretty much a laggard in terms of driving technology. I think as we move into these new areas – it's the opportunity of creating a new industry that will make or break. E.g. airlines – may become least innovative because demand could start to drop off –

high speed rail – more by other economies than our own because willing to make the investment. Cars eventually gets to alternate clean energy vehicles – less advancement in combustion & tipping point re: driving that & all infrastructure required becomes either a limiter or an enabler depending on the investment – countries thinking about if going to really have electric vehicles really take off have to have more investment in smart grid – where are the charging stations, shopping at mall, your car bill goes to you – smart grid.

New Mobility industry

In countries like the US, we could see a flip re: public vs. private trans. As certain techs become more mass scale as customer experience gets better on public trans – a shift away from individual but higher quality better use of public trans – demographic of more people in urban areas – urban footprint more dense – less people in rural areas – a flip in terms of more innovation, more adoption, more use of new modes/ higher quality public transportation – less use of cars etc.

My frustration with USDOT is real lack of imagination – we need to be really looking more starting at end point and designing towards that so some of emerging countries is where innovation is going to come from.

Talk to John Inglish – one of more forward thinking guys – when he goes looking for innovation – takes an international trip a damning statement about us. Has been flying around the world for a number of years looking at innovation – his perspective. He's brought his innovation from other parts of the world. Innovative guy – forward thinking.

Can you send me the notes – speech at TRB – sounded good.

B2.23 Nom Pyo Suh

President, KAIST

Key Messages

Scarcity of Resources

Our primary battery technology today depends on lithium. Worldwide there are only 10 million tons and with China's recent limits on export, prices have gone up 2-3 times in just the last year. This is a very real limitation on the ability to decrease oil reliance by increasing the degree to which cars rely on electricity for power. We need to look at alternative technologies such as the ability to send power over a gap.

Environment is the Driver of Change

We hear a lot about running out of oil, but we actually still have a lot of reserves (e.g. Brazilian sea). We need to reduce oil dependence more because of environmental impact. We have to reduce CO2 emissions dramatically in the first half of the century. Even oil-rich countries such as the UAE are looking to alternative energy sources – UAE is building two large nuclear power plants.

Transcript

What are the technologies and innovations that will have the greatest impact 30-50 years from now?

We look at the issue a very different way. We start by asking what are the major issues humanity has to deal with in the 21st century.

Among major issues we see four major drivers:

1. Energy
2. Environment
3. Water
4. Sustainability

In relation to these drivers we (KAIST) have done a lot of different things. In relation to transport, the main thing is the need to eliminate CO2. We need to decrease emissions 50% by 2050. We wanted to address this challenge.

We decided to develop an electric car, with no internal combustion. We first looked at what others are doing. We looked at all the companies doing something like this.

When you look at this area you notice that batteries are heavy, expensive, large, and they take up space. Usually we would then ask how much cheaper, smaller, and lighter can they be?

If we can reduce these by 50% then we are doing well, but even then costs are still very high. This is true for lithium polymer and lithium ion batteries. Supplies of important materials are limited. Some claim there are large supplies in Afghanistan. But there are only 10 million tons worldwide. Sources include Bolivia, Peru, some in US, some in China. Some claim it is plentiful in seawater… But if you put the output of all of these in all cars you exhaust all of the world's available lithium. With China limiting exports costs have gone up 2-3 times over a year ago.

We are thinking about this in a very different way. So we are thinking about, what are the constraints that will determine the future of transportation? So we developed a system to send a large amount of power over a 25 cm gap. This allows us to eliminate, or shrink the size of, the battery significantly. (I was at Massport; they are very interested in working with this technology.) In urban areas the entire city can have this system. On highways it can have 30-40%

It is also good for the battery's life. If you decrease a battery's charge all the way, it limits the life of a battery. Frequent charges and distributed networks make it possible to avoid this.

The basic tech can be applied to many things. The KTX train could be an application. If we replace the mechanical contacts and catenary line we can go much faster. The electric contact limits speed. And we could also use smaller tunnels. We can do this because it is possible to draw electricity from below without contacts.

(The is true for a refrigerator, or perhaps a robot. Massport wants to apply this to aircraft. Also, we are talking to Seoul City who buys 1000 busses each year. These run on reserved part of the road, only for buses. This makes implementation much easier. Hopefully we can find many applications.)

Once you impose this additional constraint on the overall system – green – things become very interesting. We just created a new graduate school, a graduate school for green transportation. There is lots of money for these projects. Over 70 million dollars…

What are the opportunities for closer integration of your work with the transportation sector?
We have already built semi-autonomous cars. Say you have three, four, or five cars? You only need a driver in the first one. The distance between vehicles can be adjusted automatically based on speed. The driver in the second car doesn't really have to do anything.

We do need communication, IT, etc. but when you think about: "why do things really need to change?" the real driver is energy and the environment.

For example, if Korea builds just two more power plants we will not have to import 30 billion gallons of oil a year. UAE is building 4 1.5 GW nukes even though they still have a lot of oil. They are worried that people will not need this oil. Not that they will run out. What if nobody buys oil anymore? If we can have a vehicle that does not need oil, then no one will want to buy it. So as a result they are investing in new technologies. We are very closely tied to Abu Dhabi. We have a contractual obligation to build up their research university to a high level. We have all sorts of new projects and faculty.

My feeling is as far as availability of petroleum we have quite a bit of deep sea Brazilian oilfields? The real driver is the environmental impacts not scarcity of petroleum.

B2.24 Scott Page

Associate Director, Center for the Study of Complex Things, University of Michigan

Key Messages

Social Inequality
We see increasing social inequality. The reality is that the world cannot support a population of billions who all live like upper-middle-class Americans. We need to identify what is really needed for a good quality of life (do we really need out-of-season foods from all over the world? Lots of travel? Etc.) and try to make that available to everyone. We need to look at innovative ways to improve quality of life without placing additional burdens on scarce resources.

Educational Innovation
The IT revolution has really changed how we learn. Information is no longer a scarce resource. We have free access to more than we can possibly process. Now we need better tools for making sense of it.

Transcript

When I think about disciplines and technologies that have biggest impacts on me obviously it's information revolution – literally the case that the reason to be at the university was to be physically close to the information – be IN the library – TOUCH the journals – limited to collection & what had been published – working paper series – seemed unfair – schools with big budgets have access to what's currently happening. Now world completely change everything there to access all

the time and universities & academics put everything they do on the web – course notes, summaries of research – ability to learn things is so much easier. But problem is the fire hose and sorting through. Downside – everybody spends 2 hours a day dealing with email – so much information passing back & forth – hard to get space to sit around & think. 1985 – 2010 entered information age and amazing things but didn't figure out how to deal with overload – individually acting as filter. It will be more sophisticated in 10 years. Driving car without a steering wheel. Most disruptive – these technologies haven't been as disruptive as you'd think. E.g. office – store books. Now I can work anywhere yet I work in an isolated office.

Increasingly convinced how architecture & space changes things – physical buildings & roads makes it hard to have massive disruptive change. Technology to change things at the margin –easier to site, send presentations. I give a lot of talks and travel a lot. Great – used to have travel agent – they'd arrange for me and I'd have to pick up ticket. Etc. now on line. Now give talk – make transparencies – now all elaborate stuff, videos, webinars. I went to teaching company course – video tape – learn how to present better on video. THE TEACHING COMPANY – professors give courses. Really great learning experience. They're still working on model of DVDs watching on TV.

How's it going to play out – in field I know best – educational world – 20 months talking about diversity. What's going to change a lot – a lot more structure to what sort of information is out there – not much interactive stuff.

On the floor – connect Play games – like Wii – reads body movements – think about combining reading body move w voice rec software – if I'm cooking dinner – interacting with screen – haven't beat eggs long enough! Question – anything routinized where doing a particular thing will replace or you will be in a feedback situation where you'll be corrected – learning is HUGE.

Write on chalkboard – made mistake.

Know that practice nb in terms of practicing knowledge & skill – create things that enable people to accumulate practice. If had a coach. See next decade more & more software to enable us to get better. Also more & more Google & Yahoo based on search behavior & what we do – product ads in response to all this info. Going to see people developing products that work thru the fire hose. On top of that. – what concerns me – look at trend to increasing income & wealth inequality and coincident increasing segregation by class – worries me – even as get all this great info. What is it people need to live a fulfilling life in terms of resources – money, energy. Mean I have to travel, have a big house? Food from all over? Multiply by 10B – are there ways to structure things so fulfilling lives can be achieved without huge resources. No way to have a world where everyone lives like suburban Americans – accounting on that.

Have to think about with kids – construct a life go to school with all rich smart kids – what understanding – sensitivities bred in school – don't know anybody with hardship.. Pull in that direction – people who are making big decisions about direction people should go & these people are isolated elite who've lived these isolated lives is there going to be any sense of buy in even if elite think doing the right thing. E.g. mayor DC & superintendent of schools do great things – got voted out of office. Without involving people in the decisions.

THREATS: Global equality has to occur or opportunity within & across countries otherwise planes flying into buildings –not safe happy place – rich people walling themselves off.

INNOVATION standpoint – can we use new technologies to equalize the world? One of 2 things – either technology has to allow us to live fulfilling lives without resources or give us more resources or both. That's the challenge.

MEDICAL RESEARCH – mapping from DNA and types influenced by environment you're in. Belief 20 years ago – drug to fix. Now much deeper understanding – an incredibly complex mapping – people want so much to be healthier – want diseases cured – a lot of $ & effort going into pharmaceuticals- not sure how different it's going to be

SO INTRIGUING – military – very high ups – all sat with both feet on floor with backs straight stared straight ahead – made themselves into well disciplined people – all in good shape, alert, no alcohol – together – in a regimented environment where things expected of them. Human freedom yet culture part of what we do like exercise, meditation so don't have obesity epidemic.

The "Rational Optimist" – we have a population boom, going to die from nuclear attack but it's gotten better & better. Even low income folks now have better access. Upper end oh my goodness.

Part of me wants to be optimistic – where should the optimism lie. Have to not see technology or medical breakthroughs as an end in themselves – goal to enable people to live interesting happy fulfilling lives. Studies show people who got promoted one level higher lived a lot longer. Those things – want a world in which people can live interesting sets of life experiences & treat one another well

Really funny - need lots of good ways to teach math – how ensure innovation? How ensure nimbleness dynamism. How do we leverage the stuff we learn in order to help people learn to do the things they want to do better. If think of "cognitive elite" crowd. Lots of people have high need to be intellectually engaged all the time. Different sets of things that bring them joy – how enable people to find and pursue passions to just be happy – it's not along going to do it. We're willing to say it's a dysfunctional community or behavior but at same time loathe to compose our own cultural behavior norms on others – as much as this tech and bio breakthroughs continue= bumping up against ethical questions.

How much quality of life – Haiti – a lot of people living lives they really liked then lack of capital makes it impossible to resurrect lifestyles. At end of day see it as every second a bunch of kids are born – all this potential – think of the lives we're leading & how fulfilling & interesting – why couldn't everyone lead lives like this? If my life were dependent on returns – sell books – can't do that. But as economist - aggregation phenomenon –how much would one person have to produce – some unequal distribution of income to have resources & activities & activities that mean something to us. My wife & I - buy local, buy the best we could afford for our house. Now switch. For house either last and give to kids or something that is either recycled or can recycle quickly – minimize resources used. IF someone builds a table and it will last 100 years. High quality of life – indiscriminately local. Any new local product – try it by sheer joy – but then watch – if feel like the local co is learning / adapting in acquiring human capital, continue to frequent, maybe they should

be doing something else – don't feel as compelled to support someone. Sylvios pizza – getting better – now it's fantastic

Trying to encourage people to use all these things to make stuff that's better but hard thing is learning to do stuff with research.

B2.25 Terry Penney

Laboratory Program Manager
National Renewable Energy Lab

Key Messages

Resource Scarcity, Population Growth and Aging

We are already putting enormous pressure on our natural resources. Continued population growth and increase in quality-of-life expectations will dramatically increase this. We see pressure in many areas including oil, water and rare earth elements. Aging populations will also exacerbate these pressures.

Miniaturization

We will see increasing miniaturization of everything. Nanotechnology will have huge implications.

Medical Science

We will see huge advances in medical science. We'll be able to replace whole parts when they aren't working. This will, among other things, contribute to increasing life spans and population growth.

Oil Prices

As oil reserves run out oil prices will go way up making travel prohibitively expensive. This will drive increasing dependence on virtual communications.

Transcript

2A – at first I put stuff I've worked on over the years and then realized the real biggest impact is IT – when I started at NREL we still had pink slips – now everyone has voice mail. The whole progression of phone in pocket, miniaturization. At Google – all had noses in computer AT THE MEETING! Asking deeper & deeper questions – IT & the speed at which we're able to analyze computationally is # 1 on the list – Moore's Law profound impact.

I remember Encyclopedia Britannica – now on shelf because can't throw away but totally outdated – Kindles. Are books the thing of past?

Film – hard drive failure – not backed up. Both good and can stab if not up to it. Huge vulnerability.

New technologies – now but more norm later is 24 – 7 global workforce. Around the world all working on it so by time get it next day more groups have worked on it by time I get it the next day – that's where we're heading with computation & optimization.

We'll look back: those assholes they ruined with inefficiencies energy that was coming out of wall and so much $ on cleanup & we didn't get population under control – will force us to look back & wonder how we were so inefficient.

We're going to live longer so it's going to be a mess

Evidence / rule of thumb: when fill car up $1k a fill up and save 26 k for gas $ in retirement years. People say not going to be $10 a gallon – but I say it's 10 times what it was 30 years ago. Then they go back to spread sheet – then gallon of gas - $10 which is 1K per fillup – if it goes faster like Moore's Law even worse.

Disruptive – IT and miniaturization – chip in my brain – makes me think clearer. Chips – Brain research – nano science, material science.

Equations for blood flow are like traffic flow – cardiac arrest – log jammed.

First thing to understand for 30 – 50 years. Not going to predict the right thing and not far enough. People under predict rather than over predict.

Committed my time to oil & oil displacement because it's going to run out – going to be higher & higher price – it'll still be there but will be too $$.

If plot population trends & global population for world –worldwatch – eating at rate of 3 earths and soon 10 earths – waste and novelties to solve that – designer crops, food, etc, just like designer fuels. Going to give big wakeup call – using natural resources – China last week – Chinese fishing boats off coast of Japan – held hostage China said no more earth magnet almost shut Toyota down. China is buying up natural resources & at some point going to run out & someone's going to dominate.

Trends shaping future decade – nano everything & material science – chemical & molecular level materials by design, nano scale, surface, biology, efficiency, superconnectivity, what enables that is high performance computing – 200 terawatts 10 years ago – where is physical limitation to how fast can compute

Social trend or problem –what are people going to do? What is the opportunity for employment? How to educate workforce of future because job doing now –have 100 times the work used to do with equipment –analyze in a few minutes. That whole thing re: speed of computers, design more efficient, worldwide – a son of a bitch to even have a job. Worry about kids

Minor which could be major trend – as get old service jobs for older people – a lot of interactions – people are going to live

Some of the trade schools – spas, beauty, entertainment big – a different kind of job skills – in UMICH cannot continue to increase fees & take out huge loans – not sustainable unless let inflation go – don't see how colleges will continue the trend – where we go with education

That was broadly what international/national global education, scarcity natural resources e.g. raw materials – probably not running out of lithium.

Greatest opportunity – as learn more & more & use computers to optimize, that's going to be greatest asset & challenge. In future I should be able to design a car exactly to what I want – customized to what I want and delivered to me tomorrow with all things I want without dealership. We been working on "virtual car" here and let out 20 M of work where designing entire battery pack w fundamental, pack design & how going to fit in the car – see that with engines, crashworthiness, tire design – at some point will put it all together and do the whole car.

Threats – depleting Earth's natural resources by 3 – 3 times capacity & if don't come up with designer pill, don't have enough natural resources. Global warming not an issue not 30- 50 years (that's 100 years).

Most accurately forecast –currency –what are things going to cost – whole economies of disparate haves & have-nots – disparate workforces not going to be solved over night – a world currency to get to a steady level – tremendous pressures for haves & have-nots.

Water a big issue – drinking but confident technology to desalinate salt water, food.

What field will enhance the furthest – medicine & drugs – replacement parts – what will be available to those people – living to 130. In next 30 – 50 years huge increases because of designer drugs being found because of computer power – cross pollination to get real data.

MRI runs NREL as government contractor – design matrices of pinpoint injectors into little test tubes at 1000 a shot – thousands of examples of combinational thing – what will & won't work. 1000 things at a shot – how quickly can use the computer with artificial intelligence – mix chemicals together to see what they do. Hard part is human subject testing – FDA approved – medicine really hot. Also leads to foods .

My favorite – transportation – I was really pleased we have an impact on getting autos cranked up on hybrids. I said to my boss if in 10 years can have a hybrid car in the show room wouldn't that be great? Electrification & what's made it possible. Why GM could do it today & not 10 years ago it's miniaturization of electronics. Second is energy storage – still a long way to go. Probably will be a fuel cell world in 50 years from now. Electrification will be niche vehicles. Most transportation folks aren't thinking about what you're saying = will you even need / want a car – gas price, cost of insurance. Congestion, taxes, people will seek out other ways. Node to node order up what you need is the way it will be not the way it is today- this will happen sooner than 30 – 50 . Auto ind slow. I hope they'll adopt. I can probably design if enough $ but why would you. 30 – 50 is a little on the near side for that kind of scenario. It's 20 years since the hybrid program. Look at how small a step we've taken in 20 years – maybe way too aggressive – I think because oil stimulus because of world demand is behind panacea about electric vehicles, We have a Mitsubishi 100% electric – same as volt & I've been driving around to see if I can tolerate –it's so unpredictable – 35 – 100 mile range. Think in near 30 – 50 won't just turn over and go all electric – it'll be a niche – typical diesel & gas for those who can afford. Price signal so high it will be neutralized to the right niche whether transit or other. Need to electrify highways generated by renewables – smart grid with smart houses and smart transportation – sustainable living – communities of the future will generate and net energy & food & waste flow will be contained in that space – all jurisdictions will say have to build this

2 more quickies – virtual connectivity – more & more meetings with multi-screen TVs linked to other facilities. Brought to mind – cars or vehicles but what about airplanes – cost of flying – will we be able to afford that? Maybe boat but may be 20 – 30 k to get to Hawaii – cost of plane flight a whole new story so virtual connectivity will weave into the equation –will make travel unnecessary = work at home like virtual avatar – second life.

Might be able to run a company virtually, production going on all over the world – more like 50 than 30 years – I shoot high because most people shoot low. But like in 3 A anybody that forecasts is a dumbass.

B2.26 Spiro Pollalis

Harvard GSD

Key Messages

Resource Scarcity

We will have to adapt to resource scarcity on a variety of fronts, especially land and water. Already we are building cities we cannot provide water for. Land scarcity will have big impacts on many areas including urbanization and transportation. Our current modes of transportation take up a lot of space. Current vehicles are dangerous and resource intensive. So far we haven't been very successful at coming up with alternatives but we will need to.

Transcript

Background

What are the fields, disciplines, or emerging technologies that you believe have had the most impact over the last decade (or over your career)?

The internet. Computing power, and communication technologies.

In your view, what has been their primary impact?

I believe we don't really *do more* but we can communicate so much better, faster, more high quality, and with more people. I really do not believe we are much more efficient than we used to be. Almost everything we do we could have done many years ago. In fact we waste so much time. But communication is so much more powerful. This has changed how we work, who we work with. The world is in fact small.

When we first added computers, we did not see them as enabling communication. I wanted modems and people said why do you want that?

Will these continue to define progress in the next decade? If not, what has changed?

Of course, but it is really too hard to say what will happen.

What NEW technologies/innovations will be coming online in the near future?

You never know, I do not believe that I have ever successfully predicted these things. It is very difficult. My attitude is not to try to predict, it is to adapt. You know, when Islamabad was planned in the 1960s the clients said "why do you design for roads? Cars are almost finished. Very soon we

will travel only by helicopter. Doxiadis (the planner) said, maybe that's true, but today we have cars. So I plan for cars and later we can plan for helicopters. I believe this was correct.

How will we look back at the present era 30-50 years from now? What trends or technologies will best define our present era? (How are these different from those in Q1?)
The beginning of the internet and of course, urbanization.

On what evidence/experience/rule of thumb (e.g. Moore's Law) do you base this forecast?

Which technologies or innovations have been most *disruptive* over the last decade? Will these technologies continue to be disruptive over the next decade? If not, what technologies will replace them?

Forecasting

This project looks ahead 30-50 years. What is the first thing we need to understand about forecasting 30-50 years into the future?
The main issue is our cities and the resources of the planet. These are the important things. Overpopulation and social issues among those who have the means and those who have not. These are the important issues, not technology. It doesn't matter for example that my computer will be very small, or whether I wear it or not, or where or how I wear it or if I look at a screen. We already have Bluetooth and we will see things in a similar way but these are not really important things.

Over a 30-50 year timeframe, what do you anticipate will be the major trends that will have the most global or national impact? Which disciplines or technologies will dominate?
Urbanization, scarcity of resources and land. Climate change does not worry me that much. But I am worried, especially, about scarcity of land and space. Climate change, I am less worried about.

Will the trends you anticipate shaping the coming decade continue to be significant? (We are curious about your big-picture view.)
We see these already and will see them increasingly in the future.

What do you see as the greatest opportunities for technological or scientific innovation? What are the greatest unresolved technical challenges across the sciences?
Overpopulation, urbanization, water scarcity, land scarcity, other resource scarcity. These are challenges. Also transportation. Not so much long-distance transportation. This is not really the problem. Short distance transportation. Within cities. Cities have become so big that it is very difficult to move around.

There are projects for new cities that are being built where they do not know how they will provide water there. And I mean really they do not know. The clients say you have to rely on the site. On the water you have on the site. But then you realize, there is no water on the site. You have a small catchment area but not really anything.

This is a technical and a social problem. It becomes dangerous to treat it as a social problem. We want to see it as a technical problem because technology provides optimism. You think that you can solve the problem.

Climate change is very serious, but it is not that serious. Climate change can be faced if can just capture a little bit more of the energy from the sun.

Transportation

This project looks at the impact of innovations in science and technology on transportation in a 30-50 year timeframe. Have you considered what emerging technologies and innovations will have the greatest impact on the future of the transportation sector?

This is relatively easy to answer, I think. First of all transportation is long distance and short distance. Long distance is not really the problem. The problem is short distance. First of all we have to look at the means of people when we are looking at solutions in the US these are very different that when you are looking at many other countries.

But it is hard to envision. We are trained to think a certain way so we can only say maybe bicycling is the solution, maybe a power assisted bicycle is the best that we can do until we have teleporters.

The point is transportation within the cities, this is the great difficulty. The cities cannot afford to have the large cars that we drive today. And these small cars, the electric cars, foldable cars, they are not economically viable. And the social dimensions are complex. They are applicable to certain societies but not all.

Where do you rank the transportation sector among the core drivers of technology and innovation at present? How do you believe this will change over the next 30-50 years?

Actually it is very central, it will be very central. The lack of space and transportation are closely connected. These are key issues that define innovation. Transportation consumes a lot of space right now. Again, I am talking about the inner city. And innovations there need to be really quick. We already see innovations there, attempts to put transportation on a different layer or level, for example. So far these things have failed. So how can these things exist on the same plane. Vehicles are the problem. Vehicles are fast, they are aggressive, they are strong. If they hit you they damage you. So there is an incompatibility between vehicles and people.

Again, highways are different.

This problem will have a spatial solution.

In 1979 I was working in Venezuela. During a long drive to the mountains we drove in many cars to the hills, in a convoy. And I remembered thinking in a convoy of 10 jeeps, why do we all have to steer? Why do we waste time and energy to actively drive all the cars?

B2.27 Jeff Rubin

Former Chief Economist, CIBC World Markets

Key Messages

Returning to Local

We are never going to literally run out of oil, but we will run out of the cheaply available supplies. As oil gets more expensive we're going to find other ways of doing things. Especially, the economy

will stop being so global and will return to a much more local orientation. The amount we save in wages by sending manufacturing far away will be mover than overcome by the cost to move raw materials and finished goods there and back. The switch to a local economy will not be driven by regulation, but rather by the decisions individual consumers and business make based on price. If we are too resistant to this change, though, we could see a long series of oil-price-driven boom-bust cycles.

Transcript

Over the next 30-50 years, what do you anticipate will be the major trends that will have the most global or national impact?

Because I'm an economist and I believe in the power of prices, I believe that we're going to change. I believe that a global economy, where we move resources all around the world to be assembled by the cheapest labor force and then be shipped to the other end of the world—that's not a rational way of doing business in a world of $150-a-barrel oil. What we're going to see is a whole reengineering of our economy, and while we're going to make a lot of sacrifices in terms of our past energy consumption, we're going to find that our new smaller world has a lot of silver linings. And in a lot of ways it is going to be more livable and sustainable than the old oily world we're leaving behind. Peak oil will be an agent of change, and much of that change will be positive, not negative.

While we can't do anything about triple-digit oil prices, there's a whole lot we can do to make sure that when we encounter triple-digit oil prices, they don't have to be so devastating as in the past. We have to reduce, in effect, oil per unit of GDP, and the way we do that is to go from a global economy back to a local economy because a global economy is an extremely oily way of doing business. And that switch isn't something that the Federal Reserve Board or US Treasury or the Bank of Canada or the European Central Bank is going to put in place; that is going to be the aggregate result of all the micro decisions that consumers make about what we eat, where we live and how we get around. I think triple-digit oil prices will lead us to make the right decisions on those fronts, and the result will be a very different economy than the economy we know.

What's surprising is how many sectors of the economy see [my] book as pretty optimistic, particular when it comes to the return of some long-lost manufacturing at the local level. And that's a subject of as much interest in Barcelona and Lisbon as it was in Seattle or Toronto. I think the other part of the book that resonates well in different places is the return to a local and regional focus; that's of as much interest in Europe as it is in North America.

What are the greatest threats we will face?

Of course the world will never run out of oil in the literal sense. There are some 170 billion barrels of the stuff trapped in the Alberta tar sands, and over 500 billion barrels more in the Orinoco tar sands in Venezuela. And if we suck them dry, there are billions more barrels of oil in shale, just as there is natural gas.

I think what's happening is that economists are beginning to realize that, yes, the supply curve—meaning, the higher the price of oil, the more oil we'll find—has a big problem in that much of the new oil that we'll find, like tar sands or deep water, we won't be able to afford to burn. Economists'

responses will be that $150 oil will give us new forms of supply but that those prices will send a lot of motorists to the sidelines. Sure, we can produce 4 or 5 million barrels a day out of the Athabasca tar sands or Venezuela's heavy oil, but the prices to produce it translate into $7-a-gallon gasoline. Can we really afford to burn that? They are starting to understand that depletion is more an economic term than a geologic term because we not going to hit the absolute limit of oil supply; as we're keep drilling towards the bottom of the barrel, it's going to get too expensive to bring out what's left.

We already saw that when oil got to $147 a barrel, it was cheaper to make steel in the US than it was to bring it in from China. China had to import iron ore from Australia or Brazil, make it into steel and ship it back. There's only an hour and a half of labor time in making a ton of steel. What you save on wages you more than lost on bunker fuel. The other question is, how strong is the economy going to be and how much steel will the economy consume? That's going to depend in part on how readily we transition to this local economy. Because if we don't…if we stay with the oil-based global economy, then we're just going to go back into an endless series of oil-induced recessions; the economy recovers, but very quickly oil gets back up to $150 a barrel and bang, we go back into recession. Oil drops back to $40 a barrel, we recover but only temporarily. That's a future I think we have to avoid. And the way to avoid that is to abandon the model of the global economy because it just doesn't make sense in a world where transport costs will be so dear.

We all might have liked the pump prices that came with $40-per-barrel oil during the recession, but we shouldn't expect much to be flowing out of the gas pumps at that price. Even deep-water oil, like at BP's ruptured Macondo well in the Gulf of Mexico, doesn't work at that price, to say nothing of mining bitumen in Alberta and processing it into synthetic crude. If you doubt that, just look at what happened in the Alberta tar patch when world oil prices plunged during the recession. Some $50 billion of planned investment was cancelled literally overnight.

Have you considered what emerging technologies and innovations will have the greatest impact on the future of the transportation sector? Which one(s) and why?

First of all, I think what's happening in the Gulf is going to raise the environmental bar, not just for deep water but also for shale gas[2]. There are a number of environmental issues surrounding shale gas drilling and we're going to find that many jurisdictions may not be as open to shale gas development as the industry believes, particularly when it comes to contamination of ground water.

Secondly, we can substitute natural gas for oil for a whole lot of things, and we have. For furnaces, for power generation, as a feedstock for petrochemicals—we can make that substitution. But oil packs four times the energy density of natural gas and that's why oil is our transport fuel. Yes, there's 130,000 natural-gas-powered vehicles in the United States, but out of a vehicle stock of 245 million, that's not going to do the trick. So the Pickens plan[3] doesn't mean anything until we can use natural gas as a widespread transportation fuel, and we're a long way off from doing that.

[2] Shale gas is natural gas produced from shale. Shale gas has become an increasingly important source of natural gas in the United States over the past decade, and interest has spread to potential gas shales in Canada, Europe, Asia, and Australia (http://en.wikipedia.org/wiki/Shale_gas).

[3] On July 8, 2008, T. Boone Pickens announced a major energy policy proposal, called the Pickens Plan. The plan promotes a radical reduction in the United States' dependency upon foreign energy, particularly oil provided by nations in the OPEC cartel. Although the plan calls for

Do you have suggestions on what further research could benefit transportation to expedite the impacts of your research?

What I say about the Pickens plan is the same thing I say about growing corn to feed our gas tanks and a lot of other stuff; instead of learning how to turn cow shit into high-octane fuel, we have to learn how to get off the ropes. In other words, the adjustment has to be more on the demand side than on the supply side. I'm sure that's not a message that North Americans want to hear, but it's the message that $7-a-gallon gasoline will deliver loud and clear in the near future.

B2.28 Michael Snyder

Chair of Genetics, Stanford University

Key Messages

Improvements in Gene Sequencing

We are seeing very rapid improvement in our ability to sequence genomes. We will get to the point where we can sequence a genome in about 15 minutes. The limiting factor will be our ability to analyze it. We are also seeing very rapid reductions in the cost to sequence genomes, dramatic improvements in error rates and a rapid increase in the number of people who have had their genomes sequenced. All of these will give us the ability to understand the impacts genetics better. We will be able to track thousands of genetic markers, proteins, etc.

RNA Sequencing

We will be able to sequence RNA and look at the thousands of proteins it codes for. We will track thousands of proteins and metabolites.

Transcript

Background

What are the fields, disciplines, or emerging technologies that you believe have had the most impact over the last decade (or over your career)?

Increase in storage, computing power. Invested about 1billion in initial effort to sequence human genome.

Will these continue to define progress in the next decade? If not, what has changed?

Sequencing will be rate limiting, currently takes about 15 days. Then up to 1 month to get a 'read' to point where you can interpret sequence. Expect to get sequencing down to 15 minutes, this is claimed to be coming soon. Then the analysis becomes rate limiting, figuring out how to make sense of your sequence.

What NEW technologies/innovations will be coming online in the near future?

Cost of sequencing is down 10x every 18 months, this is better than Moore's law. Now down to 20k. Also seeing exponential growth in the number of individuals who have had their genome sequenced.

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introduction of various alternatives to oil, including wind and solar, its major component is the conversion of the nation's commercial transport sector away from OPEC diesel to natural gas (derived mainly from shale gas) (http://en.wikipedia.org/wiki/T._Boone_Pickens#The_Pickens_Plan).

Forecasting

Will the trends you anticipate shaping the coming decade continue to be significant? (We are curious about your big-picture view.)

Coming down the road, we are looking at RNA sequencing, and looking at protein levels for all your proteins, 1000s of proteins. Also for metabolites. What's coming down the road is the ability to follow DNA microarrays, proteins, 1000s of things. Thousands of markers. The thought about what you are trying to do is to use something the size of an iPhone to do this, a mass spectrometer could do this in this, perhaps by pricking finger, drawing blood. With some of the new machines, not this small, you can definitely follow thousands of markers.

Within your field, What do you see as the greatest opportunities for technological or scientific innovation? What are the greatest unresolved technical challenges across the sciences?

I expect genome sequencing to reach 1billion people in few years. Average error rate is about 1-2% Expect to reach the Xprise threshold of 0.00001% shortly.

Certain diseases out there like sickle-cell anemia are very easy to track through genetic histories. Other genetic diseases are not well understood. Most diseases out there are very complex. Diabetes, schizophrenia, obesity, even traits like height. Best way to tell height? Look at heights of parents. Looking at diabetes, the genetic contribution now looks like 7%. Or alternatively environmental and genetic interactions.

B2.29 Gregory Stock

Key Messages

We Control Our Evolution

Genetic science will allow us to take control of our own evolution. We will alter ourselves as much as we've altered the world around us. We will be able to select our children's genes, reverse aging, extend life spans, and more. There will be huge opportunities as we begin to blur the lines between therapy and enhancement, between treatment and prevention, and between need and desire. We will not only be able to select for the traits we want in our children, we will be able to add them.

Transcript

What are the fields, disciplines, or emerging technologies that you believe have had the most impact over the last decade (or over your career)? What do you think has been their primary impact(s)?

There have been two recent and unprecedented revolutions. The first is the silicon revolution, which is in essence taking inert silicon and breathing into it a complexity that rivals or surpasses the complexity of life itself. The second is the genomics revolution, which is really an outgrowth of the silicon revolution. Current research, in in-vitro fertilization, in gene therapy, and in other areas are laying a foundation for literally changing the path of human evolution.

Over the next 30-50 years, what do you anticipate will be the major trends that will have the most global or national impact? Which disciplines or technologies will dominate?

Advances in biological sciences will be most significant to us in the future because we're biological creatures, and what we do with our biology will shape our future. In essence, we will seize control of our evolutionary future. We will have the ability to choose our children's genes, which will have immense social impact and raise difficult ethical dilemmas. Biological enhancement will lead us into unexplored realms, eventually challenging our basic ideas about what it means to be human.

A generation away, there will be profound changes as we start to modify ourselves. For example, we may be able to reverse aging, allowing us to extend our life span to 150 years of more. We may find ourselves more actively managing our emotions. I think we are going to alter ourselves every bit as much as we've changed the world around us and its going to happen a lot sooner than people imagine.

In medicine, there will be a big shift towards preventive medicine as we can identify all the risk factors that we have as individuals. But a big question is who will pay for all of this? And how will we understand all this information? Understanding and communicating all this knowledge will be the IT challenge of the next generation. We're going to have deal with immense amounts of new knowledge. We as humans may be 99.9% the same as each other, but we care most about the little bit of difference between us because we compete with each other. We are going to have to come to grips with all of the implications associated with the differences that we know about.

What do you see as the greatest opportunities for technological or scientific innovation? What are the greatest unresolved technical challenges across the sciences?

We're human, and we will want to use new biological technologies to improve our lives.

For example, germ line engineering – which is the manipulation of the genetics of the egg or sperm to modify future generations - will have tremendous consequences. There will be huge opportunities as we begin to blur the lines between therapy and enhancement, between treatment and prevention, and between need and desire.

We've already begun down the path of pre-implantation genetic diagnosis, which is embryo screening. It's been done for about 10 years. What we'll find is that the avoidance of disease through these technologies is going to become increasingly commonplace as in-vitro fertilization becomes easier, and as the range of genetic testing is increased. This will become even more challenging part as we start to see tests for things that are not strictly disease related, like personality and temperament.

The final stage in this revolution will be direct germ line interventions. There is the possibility of adding an extra chromosome or chromosomes to achieve desired traits. This sounds like science fiction, but there are artificial chromosomes, rudimentary ones, that have already been put in tissue culture in human cells. How this evolves remains to be seen. It's likely that initially these interventions will not be heritable because people will not want their children to pass on yesterday's technology – they'll want the latest version or release. The software analogy is very appropriate.

I think when future humans look back on this era, they will remember this time as when we laid the basis for their societies. Genetic engineering - the ability to rework our own genetic blueprint – has never before happened in the three and a half billion years of life on Earth. I think that we will also begin to inhabit space and the universe. Again, for 3 ½ billion years, all life has been constrained to this thin film around the surface of this planet. Finally, I think that true artificial intelligence, where nonliving things resemble the complexity of life, will be tremendously consequential.

What are the greatest threats we will face? Are there potential technological or scientific advances that can ameliorate these threats?

Banning technologies would be a tragedy. It's not that there aren't dilemmas – there are. But when people start to ban things, it simply shifts development elsewhere, drives the developments things from view, makes these new technologies available only to the wealthy, and ultimately denies us the information to make wise decisions.

However, I also think that it's easy to become seduced by the technologies, and to lose touch with the basic rhythms of our biology and our health. In the midst of all these amazing technological advances, there's also a counter revolution underway, which involves an interest in remedies from the past. But even this resurgence of interest in past knowledge, which some people like to brand as non-science, is driven by computer and information technology as well.

B2.30 Mark Surman

Director, Mozilla Foundation

Key Messages

Decentralized Innovation

An increasingly interconnected, open-source world fosters innovation. It no longer takes a huge investment to get something started. Instead, you can start small, work with commodity pieces to assemble a new, customized innovation. Open edges make integration with existing components easy. In this new, low-friction environment the standards that make interconnection possible become the infrastructure. We see this maturing on the internet but it could apply in the physical world as well, for example with telephony service, robotics, etc. That being said, the network effect does lead to natural monopolies so it is important to find ways to fragment power to foster new opportunities for innovation.

Transcript

Where have we been where next – been: web has had most impact & internet – "Culture" & tech have been intertwined – look at both – trends that come out are lower friction for innovation – smaller capital can start something – see that from everything from Facebook or Google starting literally in garages & becoming huge generators of wealth or Tessla or local motors – open source cars – also means decentralized – where ideas come from is the edge, more diverse also see huge growth in interconnectedness of all these things. Just because want something massively scaled and interconnected to other elements doesn't have to be massively engineered – eg API's can do it & build own innovations & build on top of those systems – how to hook into those systems & extend them. Low friction, distributed, open edges & ability to extend. Less centrally controlled economy –

ability for new people to come up quickly more fragmentation of power – information technology & hints on how it starts to emerge in science capital intensive. When get to things that WERE capital intensive – ingenious recombination of commodity parts – spirit of the web is the "maker" movement – all based on how innovate on top of commodity parts so even things that are hardware based are low friction. In Barcelona – Banzi –invented Arduino – video of his talk – good transition into future – traditional engineering background but found that electrical engineering schools didn't teach anybody anything but started to build hardware that people could just tinker with – hacker spaces, specifically about things we think most vaunted like robots something anyone can play with – these as new learning AND new innovations environments. Cheap robotic microcontroller – can extend with commodity sensors – cheap to work with but core guts are all open source – build your own version for own purposes.

Another example of decentralization – making most industries more web-like – village telco – anyone to set up small phone company using internet wifi stuff – build customized versions – off the shelf get stuff for slum or conf or neighborhood – on decentralized basis as in Facebook – have bigger systems that can hook into and extend and connect to rest of world.

Even if not looking at decent & low friction, missing out on what's happened & what's about to happen.

Standards & ability for people to interoperate become as important as infrastructure so the standards BECOME the infrastructure – it gets built by everyone – find ingenious ways to extend it.

Projecting out 30 – 50 yrs – that trend will continue barring major social calamities – decentralized infrastructure, communication.

Degree to which virtual & physical / locative tech becomes central part of this – past less than 5 years – GPS connected to everything that happens in cyberspace – decentralization trend connecting to locative.

Re- fictioning like Gibson spook country – cyber space disappears & turns up volume – virtual is viewed on the physical – goggles. Locative stuff is connected a fourth dimension of data – us, info, historical records. Lends itself to obvious & non obvious dimensions that could impact transp. Manage different flows & demands – interesting to look at whether that trend toward physical & virtual – benefits play out thru innovation or control

Open government data – government saying can get citizens playing with data. – if enlightened government – people thinking of how to add value, how things moving around – other central authorities.

Different from past technologies – hopefully get that creativity that comes on the decline end because don't need amt of central decision and capital invest up front – it's expensive to become the dominant tech – requires a lot of existing power – if it's cheaper, not necessarily the case to have stasis & conservatism.

Visually instead of linear, more nodal, fractal process & in that a lot of diversity in terms of creativity. Not just creativity at point of decline.

Fragmentation of power needed – network effects do lead to natural monopolies – interesting in terms of where power sits they're not because people have other pieces of the fractal that have other parts of the ecosystem – a real self interest in maintaining the openness & fragmentation because nobody owns the whole stack.

Scary part of see stasis & consolidation is if they all consolidated.

APPENDIX B

Overview of the NCHRP 20-83 Project Series: Long-Range Strategic Issues Facing the Transportation Industry

Resource Systems Group, Inc.

NCHRP 20-83 Project Series

Long-Range Strategic Issues Facing the Transportation Industry

Project Overviews

November 2010

Contents

NCHRP 20-83 Project Series: Long-Range Strategic Issues Facing the Transportation Industry

BACKGROUND

The transportation industry will face new and emerging challenges in the future that will dramatically reshape transportation priorities and needs. The American Association of State Highway and Transportation Officials (AASHTO) recognizes that research can help ensure that transportation practitioners are equipped to deal with future challenges facing the industry over the next 30 to 40 years. These challenges may derive from the impacts of major global trends, such as climate change, changes in the cost of fuels, and new technology, and from domestic trends, such as changing demographics and lifestyle expectations, changes in land use patterns, and limitations in current transportation finance methods. AASHTO has allocated $5,000,000 to examine longer-term strategic issues both global and domestic that will likely affect state departments of transportation (DOTs) and directed $1,000,000 to each of the following projects: (1) Potential Changes in Goods Movement and Freight in Changing Economic Systems and Demand; (2) Framework for Advance Adoption of New Technologies to Improve System Performance; (3) Approaches to Enhance Preservation, Maintenance, and Renewal of Highway Infrastructure; (4) Effects of Changing Transportation Energy Supplies and Alternative Fuel Sources on Transportation; and (5) Potential Impacts of Climate Change on Transportation Infrastructure and Operations, and Adaptation Approaches.

The 2008 report, "Long-Range Strategic Issues Facing the Transportation Industry" prepared by ICF International, presents a framework for this effort and identifies future issues and trends, which may create new challenges for the transportation industry, based on a literature scan of work conducted by futurists, demographers, economists, and other experts. Research conducted for this project will focus on a longer timeframe (30 to 40 years) than is typically examined in NCHRP projects. Although some of the future challenges facing the transportation industry are emerging today, the goal of this research is to look beyond and focus on the longer term consequences.

Independently, and in combination, these trends may have significant implications for the transportation system. Many of the trends and forces affecting the future are interrelated and the crosscutting linkages between trends and forces that will affect transportation in the future will be examined. Thus, research conducted for this project will consider the following two goals: (1) anticipate the future issues that may be approaching so that transportation agencies are better prepared to respond to new and emerging challenges; and (2) explore visions of what the future should look like, so that transportation agencies can help shape the future through their decision-making.

The specific research projects underway as of November 2010 include the following:[1]

- 20-83(01) Economic Changes Driving Future Freight Transportation
- 20-83(02) Expediting Future Technologies for Enhancing Transportation System Performance
- 20-83(03) Long-Range Strategic Issues Affecting Preservation, Maintenance, and Renewal of Highway Infrastructure
- 20-83(04) Effects of Changing Transportation Energy Supplies and Alternative Fuel Sources on Transportation

[1] See http://144.171.11.40/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2628 for additional information.

- 20-83(05) Climate Change and the Highway System: Impacts and Adaptation Approaches
- 20-83(06) Effects of Socio-Demographics on Travel Demand
- 20-83(07) Sustainable Transportation Systems and Sustainability as an Organizing Principle for Transportation Agencies
- 20-83(4A) - Multi-Modal Connectivity Options for a Future Seamless Transportation System

The following pages provide brief overviews of the objectives and elements of each project. The last page presents a comparative timeline for each project.

NCHRP 20-83(01) - Economic Changes Driving Future Freight Transportation

OBJECTIVE

The objective of this research is to provide decision-makers with a critical analysis of the driving forces behind high-impact economic changes and business sourcing patterns that may affect the U.S. freight transportation system. This analysis will better enable informed discussions of national, multistate, state, and regional freight policy and system investment priorities.

Performing Organization: Massachusetts Institute of Technology

Principal Investigator: Christopher Caplice

Due: July 2011

PHASES

I. Catalog and assess driving forces, points where systemic changes occur, leading indicators, and critical dependencies, and their relative importance to future freight patterns. [Phase I not to exceed 25% of project effort.]

II. Identify representative plausible scenarios of driving forces and their impacts on future levels and patterns of freight movement, fully articulated to enable "what-if" discussion of consequences, opportunities, and threats. [Phases I and II not to exceed 60% of project effort.]

III. Identify consequences for policy and management strategy for stakeholders (e.g., DOTs and others); means for realizing, accommodating, or managing under alternative scenarios; and uncertainties and risks associated with policies and management strategies. [Phases I through III not to exceed 90% of project effort.]

IV. Present project results in compelling ways to encourage and guide responsible officials to institute appropriate policies and management strategies (for example an effective multimedia presentation for communicating future freight challenges to stakeholders, abstracts for DOT CEOs, and outreach and communication activities).

NCHRP 20-83(02) - Expediting Future Technologies for Enhancing Transportation System Performance

OBJECTIVE

The objective of this project is to develop a process that transportation agencies can use to identify, assess, shape, and adopt new and emerging technologies to achieve long-term system performance objectives. The process should reflect relevant trends in technologies and their applications and help transportation agencies anticipate, adapt to, and shape the future.

Performing Organization:
RAND Corporation

Principal Investigator:
Steven Popper

Due: December 2011

PHASES

I. Catalogue and assess possible technological trends, in all relevant fields, that could impact the performance of the transportation system over the next 10 to 40 years.

II. Describe typical system performance objectives that transportation agencies could be expected to use in the future. System performance objectives should be applicable to the entire surface transportation system and should foster a proactive approach to managing and operating the transportation system. These objectives should address an array of system performance outcomes, including, but not limited to safety, multimodal mobility, and reliability. In addition, the objectives should address outcomes impacted by the performance of the transportation system, including environment, energy, and the sustainability of the transportation system. Objectives should consider both systemwide performance and the experience of the individual traveler.

III. Identify the barriers commonly faced in identifying, assessing, shaping, and adopting innovative technologies and describe approaches to address these barriers. Consider the challenges to advancing change and innovation among transportation operators, including institutional constraints, private-sector concerns, financial constraints and objectives, the role of standards, and multi-agency coordination across modes. Consider the transportation users' acceptability of new systems operations approaches, including issues such as privacy, new pricing mechanisms, and other relevant considerations.

IV. Develop and document a process to identify, assess, shape, and adopt technologies that contribute to transportation system performance objectives across all surface transportation modes. Of particular interest are the results of research efforts that may lead to a relevant technology but may not produce a directly implementable product. The process should: (a) inform investment decisions by maximizing return on investment; (b) consider research, development, and technology from industries outside transportation; (c) leverage promising processes used in other industries for innovation and knowledge transfer (e.g., translational medicine); (d) facilitate coordination among agencies and help identify roles and responsibilities for the review of a particular technology; and (e) accommodate technologies that offer alternatives to physical travel (e.g., telecommuting, on-line shopping).

V. Evaluate the process' practicality and sustainability and summarize the results of the evaluation.

VI. Present the project results in compelling ways to encourage and guide responsible officials to institute and sustain appropriate policies and management strategies.

NCHRP 20-83(03) - Long-Range Strategic Issues Affecting Preservation, Maintenance, and Renewal of Highway Infrastructure

OBJECTIVE

The objective of this research is to develop guidance for transportation stakeholders on emerging materials, tools, approaches, and technologies that could be used to deal with long-range (30 to 50 years) highway infrastructure maintenance, preservation, and renewal needs and ensure satisfactory system condition and performance.

Performing Organization: Texas A&M Research Foundation-TTI

Principal Investigator: Stuart Anderson

Due: June 2013

PHASES

I. **Scenarios and Impacts:** This phase will identify the factors and future trends that could influence infrastructure maintenance, preservation, and renewal and assess the likelihood and impact of various scenarios on future needs.

II. **Vision Development:** This phase will (1) identify and examine potential of new materials, tools, approaches, and technologies for meeting future needs for maintaining, preserving, and renewing the highway infrastructure and (2) develop a vision for a future, sustainable highway infrastructure. Potential barriers to the identified materials, tools, approaches, and technologies will be discussed.

III. **Guidance and Communication:** This phase will develop (1) guidance for transportation stakeholders on the use of potential materials, tools, approaches, and technologies for enhancing system maintenance, preservation, and renewal consistent with the described vision and (2) communication packages to convey the vision, objective, and products of this research to current and future transportation stakeholders. This phase will also identify future research efforts that are required to expand the findings of this project and to serve as a guide for further research opportunities.

IV. **Deliverables:** This phase will prepare and submit project deliverables, including a final report that documents the entire research effort, communication packages, and other items identified in the research plan.

NCHRP 20-83(04) - Effects of Changing Transportation Energy Supplies and Alternative Fuel Sources on Transportation

Performing Organization:
RAND Corporation

Principal Investigator:
Paul Sorensen

Due: January 2012

OBJECTIVES

The objectives of this research are (1) to determine how the mandate, role, funding, and operations of DOTs will likely be affected by future changes in long-term energy supply and demand and (2) to identify strategies and actions that can be used by the DOTs to plan and prepare for these effects.

PHASES

I. Identify and assess driving forces, leading indicators, critical interdependencies, and their relative importance to future energy use and alternative fuel scenarios. Document the results in Interim Report 1.

II. Develop representative scenarios regarding the future use of energy and alternative fuels that may result from the driving forces identified and described in Interim Report 1. Document the results in Interim Report 2.

III. Prepare a detailed analysis of how the mandate, role, funding, and operations of DOTs will likely be affected by various plausible future energy supply-and-demand scenarios. Identify short- and long-range actions and strategies that DOTs can use to plan, respond to and otherwise manage under each scenario, and an assessment of the potential risks associated with those policies and management strategies. Document the results in Interim Report 3.

IV. Present project results in compelling ways to encourage and guide responsible officials to institute appropriate actions and management strategies. These could include executive summaries, briefing materials, multimedia presentations, and similar products to communicate future energy challenges and appropriate planning strategies to senior DOT executives and other stakeholders.

NCHRP 20-83(05) - Climate Change and the Highway System: Impacts and Adaptation Approaches

Performing Organization:
PB Americas

Principal Investigator:
Michael Meyer

Due: March 2012

OBJECTIVES

The objectives of this research are to:

I. Synthesize the current state of worldwide knowledge regarding the probable range of impacts of climate change on highway systems by region of the United States for the period 2030-2050

II. Recommend institutional arrangements, tools, approaches, and strategies that state departments of transportation (DOTs) can use during system planning, design, construction, operations, and maintenance to adapt infrastructure and operations to these impacts and lessen their effects

III. Identify future research and activities needed to close gaps in current knowledge and implement effective adaptive management

NCHRP 20-83(06) - Effects of Socio-Demographics on Travel Demand

Performing Organization: NuStats

Principal Investigator: Johanna Zmud (RAND)

Due: March 2012

OBJECTIVE

The objective of this research is to determine how socio-demographic factors are likely to affect travel demand over the next 30 to 50 years and to identify strategies and actions that can be used by policymakers in state and local transportation and planning agencies to plan and prepare for alternative future scenarios.

The focus of the research should be on understanding the fundamental relationships between social and demographic factors and travel demand, and how these relationships might change over time. These factors may include diversity, gender, birth rates, aging population, wealth and income, immigration, regional migration and employment patterns, rural versus urban populations, and the size and structure of households and families. The research will also examine the relationships between human factors and other variables affecting travel demand such as new technology, alternative fuels, economics and the economy, climate change, land use, and development patterns. In addition, it should identify opportunities for incorporating the results into the planning and decision-making process.

PHASES

I. Develop the catalog of potential socio-demographic drivers that might affect individual travel behavior and aggregate travel demand and assesses best current practices for incorporating socio-demographic variables in travel demand forecast models.

II. Further refine both of these by looking at gaps in data sources, knowledge and practice and indicates recommended socio-demographic driving forces. The information is synthesized to craft early draft scenarios along with the parameters for simple systems dynamics models. This information is used to illustrate research (Phase III) to test our scenario assumptions and our conceptual model (i.e., the research plan).

III. Execute the research plan, with results used to refine the scenarios, their underlying assumptions and the systems dynamics models.

IV. Specify the future scenarios, complimented by the systems dynamics models. The team will identify regional settings for applying the scenarios. Agent-based models will be run in the regional settings over short time scales to simulate in greater detail what a transportation network might look like under those conditions specified in the scenarios.

V. Draw implications for state DOTs (i.e., how to apply) and how to use (i.e., develop strategic responses to the possible scenario outcomes). Key indicators will be identified — serving as a signal for conducing additional research if important changes are detected in a trend.

VI. Develop and execute a plan for dissemination of the research findings. Produce the final report.

NCHRP 20-83(07) - Sustainable Transportation Systems and Sustainability as an Organizing Principle for Transportation Agencies

Performing Organization: Booz Allen Hamilton

Principal Investigator: John Wiegmann

Due: April 2013

OBJECTIVE

The objective of this research is to provide a framework for transportation agencies to use to identify and understand the future trends and external forces that will increasingly put pressure on their ability to carry out their responsibilities to (1) meet society's evolving demand for transportation services and (2) meet society's emerging need to operate on a more sustainable basis. The framework will also provide a means for agencies to assess their future capacity to meet society's demands, and provide or identify tools and approaches that agencies may use to assist them in making changes they deem appropriate and necessary to meet rapidly changing needs and conditions.

PHASES

I. Describe future scenarios and the difficulties, challenges, and opportunities that will likely require transportation agencies to make fundamental changes in the how they deliver transportation services in a manner that contributes to a more sustainable society. Document the results in Technical Memorandum 1.

II. Assess the current and future ability of transportation agencies to support a sustainable society. Describe and assess the necessary evolution of linkages and relationships between transportation agencies and their partners and stakeholders. Identify barriers that may prevent transportation agencies from delivering transportation services in support of a sustainable society. Provide examples of transportation agencies that are well positioned to meet these future challenges or take advantage of future opportunities, with a focus on practices or approaches that are transferrable to other agencies. Document the results in Technical Memorandum 2.

III. Inventory benefits achieved from business models, best practices, and lessons learned from other organizations, industries, or sectors (not limited to domestic transportation agencies) that have successfully adapted to rapidly changing external conditions. Document the results in Technical Memorandum 3.

IV. Describe plausible future roles and responsibilities of transportation agencies that deliver transportation services supporting a sustainable society. At a minimum, describe the organizational schemes, legal authorities, governance structures, and funding elements needed, as they relate to a broad vision of the mission(s) of a transportation agency. Document the results in Interim Report 1.

V. Develop analytical tools and processes for agencies to use to track relevant trends, and to evaluate their current ability to meet future challenges or take advantage of pending opportunities in a manner that supports a sustainable society. Provide tools and approaches that transportation agencies can use to implement the framework. Document the results in Interim Report 2.

VI. Submit a final report and outreach materials that present the project results in compelling ways to encourage and guide responsible officials to institute appropriate actions and management strategies. These could include executive summaries, briefing materials, multimedia presentations, and similar products to communicate to senior transportation agency executives and stakeholders. Develop an outreach plan to facilitate adoption of

results. The "look and feel" of these products should be coordinated with other projects in the 20-83 series.

NCHRP 20-83(4A) - Multi-Modal Connectivity Options for a Future Seamless Transportation System

Performing Organization: University of Southern California (under FHWA)

Principal Investigator: Sven Koenig

Due: November 2013

OBJECTIVE

Significant advances have been made in the procurement and provision of real-time information that would be required for the effective control of a transportation system. Yet, this information is mostly used in centralized transit system design and operation or congestion pricing. These efforts have limited success addressing congestion in most American cities, which have a dispersed demand due to a lack of single high density business and residential centers.

The research objective is to harness emerging information technologies in an innovative use of computational thinking to develop a new type of decentralized transportation system, the Transportation Market, capable of real-time allocation of resources. The premise is that an intelligent use of traffic information will help users make decisions that will tap into unused vehicle capacity, radically transforming the way people use transportation systems.

The proposed Transportation Market is based on developing new intelligent systems that require both the exploitation of a large amount of traffic data to find good coordination policies and an understanding of the transportation system with human and man-made components. The research project will create a distributed system for negotiating routes and prices between consumers and providers of transportation in real-time. In particular, the research will create a networked market for transportation in which consumers and providers of transportation negotiate with each other to determine routes and prices.

For this purpose, the research will develop auction mechanisms and game theoretic models that will use traffic data in local automated computation which will allow services and pricing to respond directly to consumer demand. This raises research issues in distributed optimization, mechanism design, machine learning, agents and user interfaces, computation of large scale equilibria, and planning under uncertainty. In addition to developing the Transportation Market, a key research direction is to understand its impact on the transportation system and how to regulate this market.

This research has the potential to radically transform the means that people commute and view scarce transportation resources in the next 30 to 50 years. As the workplace is moving further out of a core central business district, the need for the development of a fully centralized transportation system becomes more essential to meet the lifestyle preferences and changing socio-econo-demographics of the next century. This research has the potential to spur the migration toward real-time coordination, as well as to the development of new ITS technologies to meet the future demand for transportation.

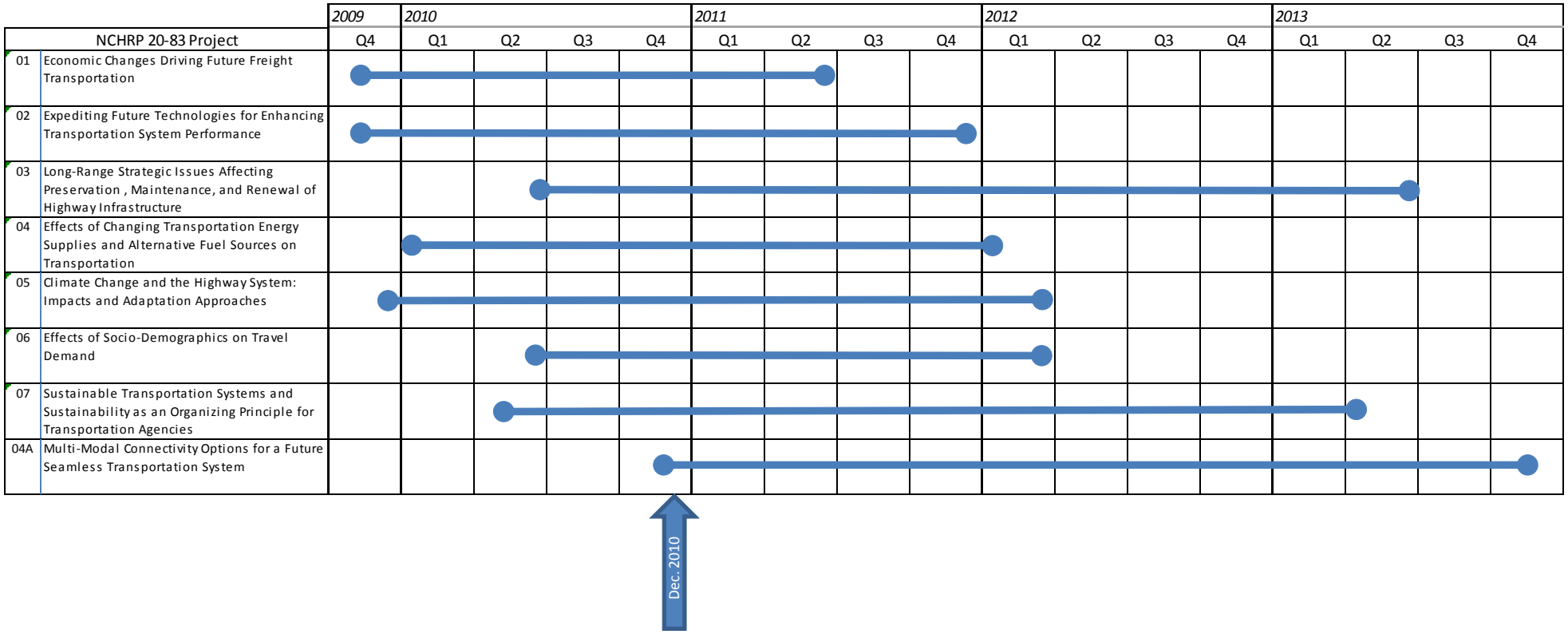
A fully functional and integrated Transportation Market has the potential to effectively price idle transportation resources to improve the mobility of the general population. A wide adoption of the Transportation Market has the potential to transform the landscape for transportation, which

would require new methods for the design of and coordination with fixed lines, multi-modal, and hybrid transit systems. A Transportation Market model can be used for other transportation needs, such as long distance travel, freight, and shipping.

The auction and bidding mechanism of the Transportation Market present an innovative financing mechanism of transportation resources. Also by promoting a more efficient use of the existing transportation capacity, this research could help address important environmental considerations of the transportation sector. The Transportation Market can radically transform transportation systems by 1) more efficiently utilizing available transportation resources, thus reducing costs; 2) reducing congestion and pollution by increasing the average number of passengers per vehicle; 3) making more transportation options available to consumers, and 4) increasing the number of transportation providers by facilitating the entrance to the market.

The primary deliverable of this project is the simulator which will contain modules that replicate the transportation market. The simulator will be a model of the transportation system of the future (within 30 to 50 years). The open access design of the software will facilitate other researchers to use it as a platform for their own work and will make it feasible for private companies to use it as a basis for commercialization and implementation of the system for use in the transportation market within the desired 30 to 50 years.

NCHRP 20-83 Project Series - Comparative Project Timelines



APPENDIX C

Workshop Agenda

National Cooperative Highway Research Program Project 20-83

Workshop on Long Term Strategic Issues Facing the Transportation Industry

Wednesday, Thursday
December 8, 2010 8:30 a.m. – 5:00 p.m.
December 9, 2010 8:00 a.m. – 11:00 a.m.
Conference Room 101
William M. Keck Center
500 Fifth Street NW
Washington, DC 20001

AGENDA

Day 1 – December 8

8:30-8:45	Opening Remarks & Charge to Participants	John Halikowski, AZDOT Sandra Larson, IA DOT
8:45-9:00	Overview of Seminar Agenda, Format & Goals	Peter Plumeau
9:00-10:30	Panel on NCHRP 20-83 Project Issues & Findings to Date: ▪ Christopher Caplice - *Economic Changes Driving Future Freight Transportation (01)* ▪ Steve Popper - *Expediting Future Technologies for Enhancing Transportation System Performance (02)* ▪ Stuart Anderson - *Long-Range Strategic Issues Affecting Preservation, Maintenance and Renewal of Highway Infrastructure (03)* ▪ Paul Sorenson - *Effects of Changing Transportation Energy Supplies and Alternative Fuel Sources on Transportation (04)* ▪ Michael Meyer - *Climate Change and the Highway System: Impacts and Adaptation Approaches (05)* ▪ Johanna Zmud - *Effects of Socio-Demographics on Travel Demand (06)* ▪ John Wiegmann - *Sustainable Transportation Systems and Sustainability as an Organizing Principle for Transportation Agencies (07)*	Peter Plumeau, Moderator
10:30-10:45	Break	
10:45-12:00	Panel (continued) & Facilitated Discussion, Questions & Answers	Peter Plumeau, Moderator
12:00-1:00	Lunch Keynote Speaker – Alex Lightman, Director, Fortune Nest and	

	Author, Entrepreneur & Futurist	
1:00-2:15	Presentation – Results of Scan of Future Technology & Science Advances with Facilitated Q&A	Hyun-A Park & Peter Plumeau
2:15-3:15	Breakout Session: ▪ Implications of Presented Issues for DOTs, by Topic/Category (One Breakout Group per Topic/Category) ▪ Identification & Prioritization of Research Needs	Group Facilitators
3:15-3:30	Break	
3:30-4:45	Breakout Session continued	Group Facilitators
4:45-5:00	Day 1 Closing Remarks	Chairs and/or Facilitator
5:00	Adjourn	
Evening	Reception & Dinner	Keck Center Atrium

Day 2 – December 9

8:00-8:15	Summary/Synthesis of Day 1 Results & Overview of Day 2	Peter Plumeau & Hyun-A Park
8:15-9:45	Breakout Reports with Facilitated Commentary from 20-83 Panel	Peter Plumeau, Facilitator
9:45-10:00	Break	
10:00-10:45	Summary/Synthesis of Seminar Results and Recommendations for Priority Research Issues (with Facilitated Discussion)	Peter Plumeau & Hyun-A Park
10:45-11:00	Closing Remarks	Sandra Larson IA DOT, Chair
11:00	Adjourn	

APPENDIX D

Workshop Attendees

Workshop on Long Term Strategic Issues Facing the Transportation Industry
December 8-9, 2011

Attendees

Name	Affiliation
Michael Brown	Virginia DOT
Cynthia Butler	Transportation Research Board
Mara K. Campbell	Missouri DOT
Gerry Chaput	Ontario Ministry of Transportation
Rick Collins	Texas DOT
B. Ray Derr	Transportation Research Board
Debra Elston	Federal Highway Administration
Monique R. Evans	Federal Highway Administration
Michael Fitch	Virginia DOT
John S. Halikowski	Arizona DOT
Amir N. Hanna	Transportation Research Board
Christopher J. Hedges	Transportation Research Board
John Horsley	AASHTO
David L. Huft	South Dakota DOT
Crawford F. Jencks	Transportation Research Board
Christopher W. Jenks	Transportation Research Board
Timothy A. Klein	Research and Innovative Technology Administration
David Kuehn	Federal Highway Administration
Sandra Q. Larson	Iowa DOT
Calvin Leggett	North Carolina DOT
James T. McDonnell	AASHTO
Tommy E. Nantung	Indiana DOT
Charles W. "Chuck" Niessner	Transportation Research Board
Oman, Ellen	Washington State DOT
Harold R. "Skip" Paul	Louisiana DOTD
Glenn E. Roberts	New Hampshire DOT
Floyd Roehrich	Arizona DOT
Robert E. Skinner, Jr.	Transportation Research Board
Nanda Srinivasan	Transportation Research Board
Lori Sundstrom	Transportation Research Board
Steve Takigawa	California DOT
Mary Lynn Tischer	Federal Highway Administration
Michael Trentacoste	Federal Highway Administration
John Tunna	Federal Railroad Administration
Stuart Anderson	Texas A&M University

Name	Affiliation
Robert Bertini	Research and Innovative Technology Administration
Christopher Caplice	Massachusetts Institute of Techology
Joe Castiglione	Resources Systems Group, Inc.
Kim Fisher	Transportation Research Board
Gary Frederick	New York State DOT
Edward T. Harrigan	Transportation Research Board
Bill Hyman	Transportation Research Board
Barbara Ivanov	Washington State DOT
Randy Iwasaki	Contra Costa Transportation Authority
Linos Jacovides	
Stephen Lawe	Resources Systems Group, Inc.
Andy Lemer	Transportation Research Board
Alex Lightman	MIT
Perry Lubin	Spy Pond Partners, LLC
Gary McVoy	New York State DOT
Michael Meyer	Georgia Institute of Technology
Mark R. Norman	Transportation Research Board
Hyun-A Park	Spy Pond Partners, LLC
Peter Plumeau	Resources Systems Group, Inc.
Steven Popper	RAND Corporation
David Reynaud	Transportation Research Board
William Rogers	Transportation Research Board
Paul Sorenson	RAND Corporation
Ted Trepanier	Inrix, Inc.
John Wiegmann	Booz-Allen & Hamilton, Inc.
Johanna Zmud	RAND Corporation