Systemic Impacts of Climate on Transportation

Workshop held by the

Office of the Secretary of Transportation
U.S. Department of Transportation

at the
National Highway Institute, Arlington, VA

October 11-12, 2012

Contents

Overview

The "Systemic Impacts of Climate Change" workshop held October 11-12, 2012, organized by the US Department of Transportation (USDOT) Office of the Secretary of Transportation (OST) examined the effects of climate change on the performance of national transportation systems. The two-day workshop was intended to summarize research on systemic impacts of climate change, identify gaps in current research, and determine areas where additional exploration might be fruitful.

This report summarizes the content of the workshop. The first day consisted of presentations, broken into the following sessions:

- Sectoral impacts of climate change
- Regional impacts of climate change
- Integrated studies of adaptation
- Transportation system effects case studies

On the second day, participants engaged in group discussions that focused on climate change impacts and effective adaptation strategies for urban infrastructure, passenger travel, and freight systems.

Background

Beth Osborne, Deputy Assistant Secretary for Transportation Policy
Arthur Rypinski, USDOT

Systemic impacts of climate change are those that affect the performance or scope of the transportation system. These impacts affect transportation operations, planning, and infrastructure design, and may influence national-scale estimates of transportation costs. They fall into three general categories:

1) changes in transportation systems induced by climate-induced changes in the economy or society
2) changes in system capacity or reliability induced directly by climate effects, and
3) changes in system capacity or reliability induced indirectly by damages to infrastructure

On October 5, 2009, the President issued Executive Order 13514. This order seeks to organize the national effort on climate change adaptation and to ensure widespread and complementary programs across the US government. The executive order states that Federal agencies will participate actively in a new US Interagency Climate Change Adaptation Task Force that is developing domestic and international dimensions of a national strategy for adaptation to climate change. This strategy will contribute to the knowledge, capacity, and resources to effectively respond to climate change.

The National Climate Assessment (NCA) is a statutory program that integrates, evaluates, and interprets the findings of the U.S. Global Change Research Program (USGCRP); analyzes the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity; studies current trends in global change, both human-induced and natural; and projects major trends for the subsequent 25 to 100 years. Previous assessments were completed in 2000 and 2009, and the next assessment will be released in 2013. The 2013 report has been drafted, and it identifies about 140 key messages, each supported by traceable accounts. Traceable accounts document the process used to come to the conclusion in the key messages and allow the reader to link to data and resources.

Weather events affect the efficiency of the nation's transportation systems, and transportation system failures affect everyone. The USDOT is exploring these effects for several reasons:

1) The new transportation bill, Moving Ahead for Progress in the 21st Century (MAP-21), has an increased emphasis on performance measures of the transportation system. USDOT is exploring how weather affects the performance measures outlined in the legislation.
2) By identifying the range of impacts that may result from climate change, USDOT can better determine effective initiatives for adaptation
3) Studying the systematic impacts will improve understanding of the economic costs and benefits of climate change.

Sectoral Impacts

This session addressed the impacts of climate change on different sectors that affect or are affected by transportation, including agriculture and grain transport, water levels and irrigation, urban infrastructure, and energy transportation.

Agriculture

Margaret Walsh, USDA

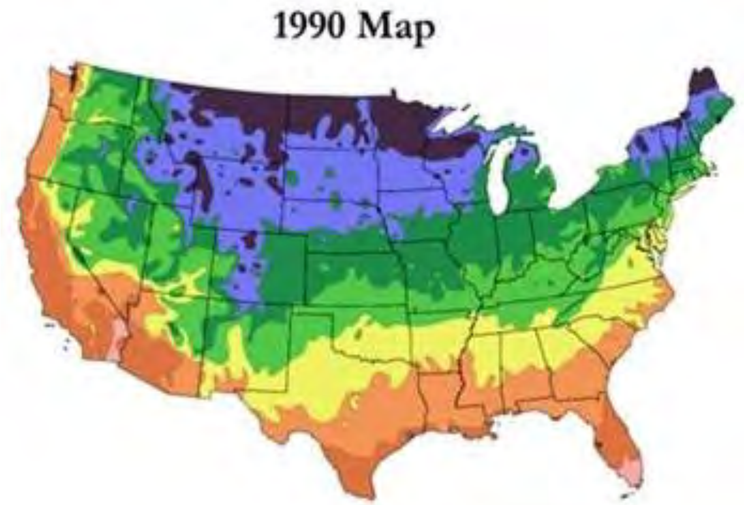
The Climate Change Program Office at US Department of Agriculture (USDA) is providing technical input to the NCA and is developing its own report of impacts of climate change on agriculture.

Climate change has and is expected to continue to produce several direct effects, including changes in temperature and precipitation and the frequency of extreme weather events. The growing season has lengthened, and the number of frost days has diminished (though frosts do not necessarily arrive later). The optimal growing regions for specific crops have been shifting north since 1990. New locations are becoming hospitable for certain crops, while others no longer provide optimal climate conditions for the given produce (see image on page 6).

Animal husbandry has been affected by increased summer heat stress, leading to greater mortality, lower productivity, and lower pregnancy rates, and to milder winters, leading to decreased animal mortality. The indirect effects of climate change have affected agriculture as well. Changes in temperature and precipitation influence lifespan and occurrence of weeds, insects, disease, and wildfire.

Despite these changes, agriculture is a highly adaptive sector. Farmers can make annual or seasonal changes to their crops and livestock and can gradually accommodate changes in climate. They can shift their planting dates or tilling practices, or select cultivars with different maturation qualities or water needs. Farmers can shift to livestock with greater tolerance for high temperatures, humidity, and pest resistance. As other producers begin adapting successfully, competitive pressures and the power of example will shift the behavior of all farmers towards these economically and environmentally efficient and effective practices.

Over the next 25 years, climate change will have both positive and negative consequences for agriculture. However, the balance of consequences is expected to be negative for most crops and livestock. Climate change will exacerbate pressures associated with weeds, disease, and insects, and it will increasingly compromise the ability of ecosystems to provide necessary services to agriculture, including water quality and quantity. Adaptive actions offer the potential to capitalize on emerging opportunities and to minimize the costs associated with climate change, but these actions depend on farm-level costs and benefits, perception of risk, and access to actionable information.



Source: After USDA Plan Hardiness Zone Map, *USDA Miscellaneous Publication No. 1475*, Issued January 1990

Source: Re-colored version of the 2012 USDA Plan Hardiness Zone Map

As agriculture and transportation are affected by climate change, agricultural production patterns throughout the nation will shift, including:

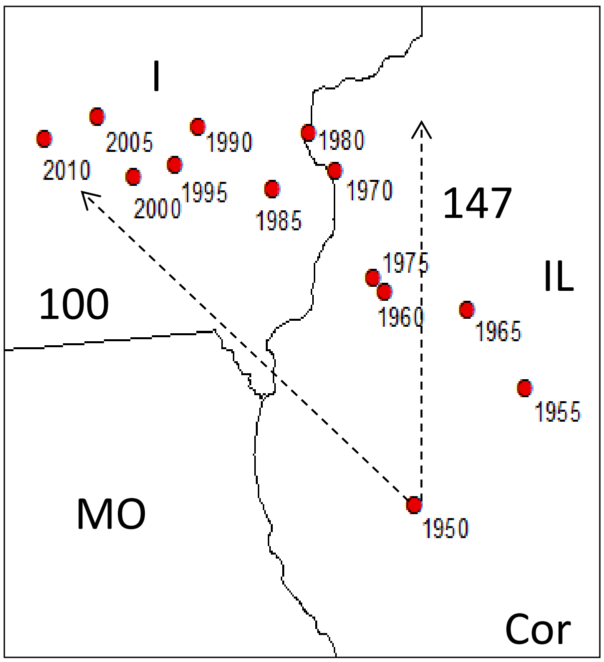
- Easier movement of vehicles on dry land (with drought)
- Changes in international trade patterns
- New irrigation where water resources permit
- Changes in feasible locations for crops and livestock
- Changes in consumption patterns
- Damage to trade goods
- Increased need for emergency distribution of food

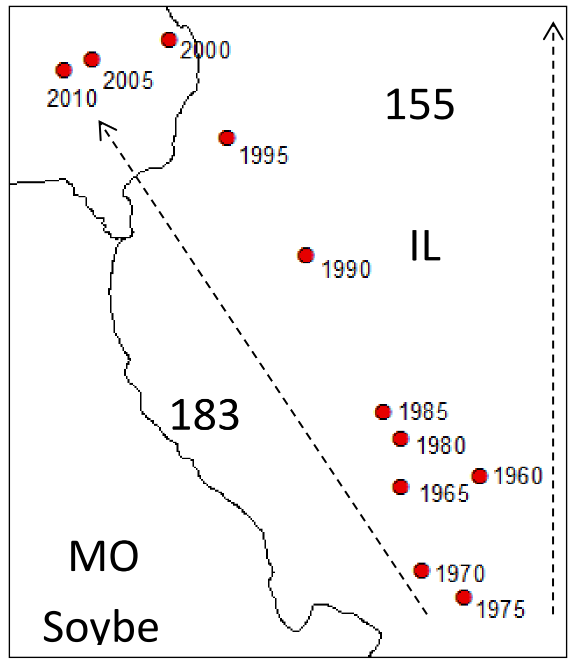
Grain Transport

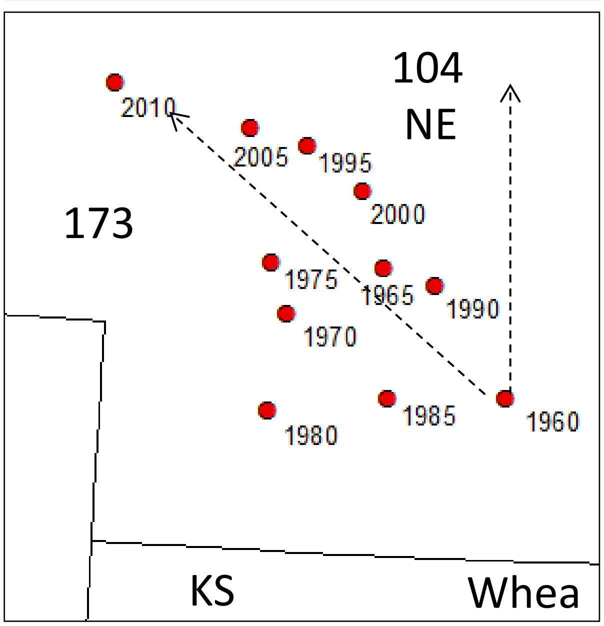
Witsanu Attavanich, Rutgers University and Kasetsart University

Climate change may shift the demand grain places on the national transportation system due to impacts to yield, water, navigation, and seasonal effects both domestically and internationally. Transportation demands for grain have been slowly moving northward and are projected to increase, especially as corn displaces wheat in some parts of the country.

Demand for rail is projected to increase in the northern regions, which may necessitate that many components of the rail infrastructure be upgraded and expanded along the routes serving areas with higher levels of production. This includes routes from Minnesota and North Dakota to Pacific Northwest ports; New York to North Carolina; Colorado to Idaho; Minnesota to New Mexico and Oklahoma; Nebraska to California; Pennsylvania to Virginia; South Dakota to Texas Gulf ports; and Michigan to Atlantic ports.







Production Weighted Centroid 1950-2010

Source*:* The Effect of Climate Change on Transportation Flows and Inland Waterways Due to Climate-Induced Shifts in Crop Production Patterns, Texas A&M

Transportation by truck is also projected to increase in many regions. Road infrastructure may need to be expanded and upgraded to accommodate the additional truck traffic from the areas where grain supply is expected to increase, such as roads in rural areas along the Upper Mississippi River in Minnesota;; routes in northern parts of Ohio leading toward the Great Lakes ports at Toledo; and roads in Ohio, Pennsylvania, and New York leading toward Atlantic Ports at Norfolk, Virginia.

In addition, the Upper Mississippi River is likely to receive higher grain transportation shipments due to the predicted increase in grain supply from Minnesota and North Dakota. Enlarging or improving conditions of locks and dams in that segment may be necessary if this occurs.

Water Levels

Jeff Arnold, USACE

USACE global change adaptation work includes coastal and inland hydrology. Coastal concerns include vulnerabilities and possible adaptation measures for harbors, intracoastal waterways, beach and other shoreline protections, storm damage reduction defenses, environmental restoration sites, and other projects. Inland concerns include dams, reservoirs, inland levees, hydropower production facilities, and flood risk reduction structures and operations.

Because climate change will affect human interaction with water, coastal and inland operations are at some risk from some type of climate change effects. USACE is working to characterize those climate change threats, the vulnerabilities of coastal and inland projects and programs, and the capacities to adapt these projects and programs to current and future climate change effects. The general approach at USACE is called “decision scaling” the climate change questions. Decision scaling links the insights provided by bottom-up analyses with the information from climate models, and informs decisions and risk assessments. The process identifies climate impacts that may cause problems and then uses climate models to estimate whether those changes are likely. One can evaluate the decisions they’re already making, and then identify which decisions have climate sensitivities and react or adapt accordingly.

USACE is developing a framework and set of measures for reporting our progress against the climate change threats and the effectiveness and efficiency of our adaptation actions to counter them. This type of evaluation reporting is crucial for both internal USACE program functions and for external reporting to Congress and our stakeholders since we want to know and demonstrate that our characterizations of the threats are correct and our actions to reduce vulnerability and enhance resilience have been worthwhile.

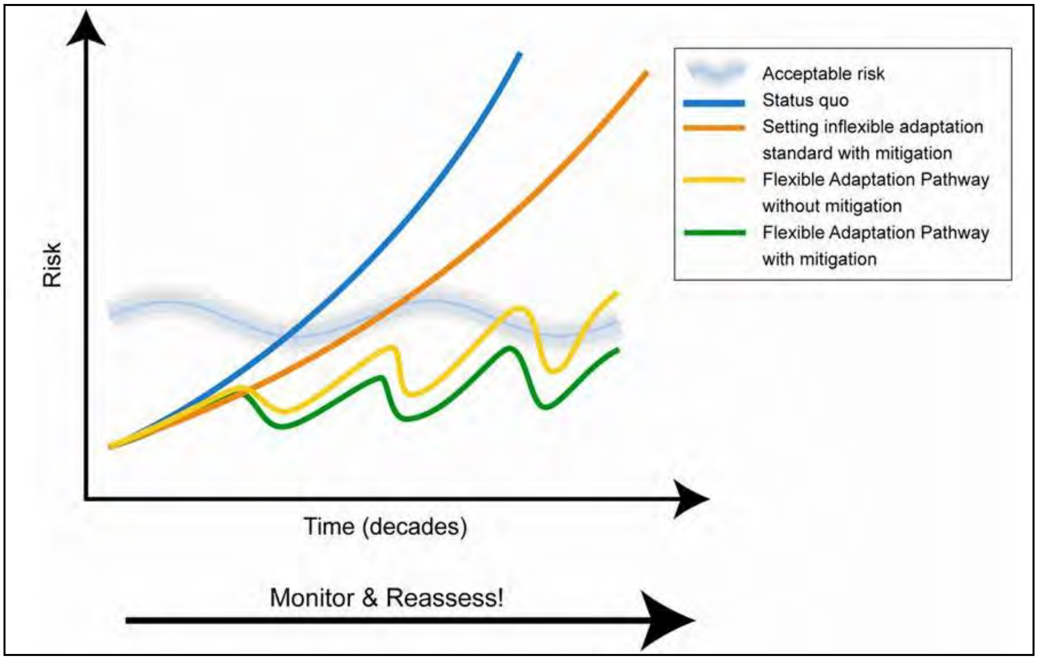
Urban Infrastructure

Mike Savonis, ICF

US population is highly concentrated in urban areas. In 2010, 84 percent of the population lived in cities or suburbs. Urban areas have both higher travel demand and more extensive transportation infrastructure than rural areas. A greater proportion of the personal transportation needs of urban populations are met by higher occupancy services such as those provided by bus, rail, and ferry transit and through intermodal integration leading to higher density of infrastructure.

Urban systems provide critical energy, clean water, transportation, and communication services to residents, each of which depends on its infrastructure, and suppliers. These services are highly interdependent, and they rely on each other to fulfill their roles. For example, energy sources power the transportation system, but the energy system also requires transport of raw materials and final products, such as coal, natural gas and petroleum. Interruption of any part of these interdependent services can cause unforeseen ripple effects, affecting the health, economy and quality of life of urban residents.

Disruptions of service lead to direct impacts on citizens, businesses, service providers, and business-to-business activities. Urban areas can explore intervention options to enhance the resilience of their infrastructure systems. Some cities, including New York City and San Francisco, have begun to develop plans for adapting to climate change, including sea level rise.



Adaptive Urbanization – Climate Risk Management in Cities, Flexible Adaptation Pathways, and Interactive Mitigation and Adaptation

Source: US Department of Energy (DOE), *Climate Change and Infrastructure, Urban Systems, and Vulnerabilities*

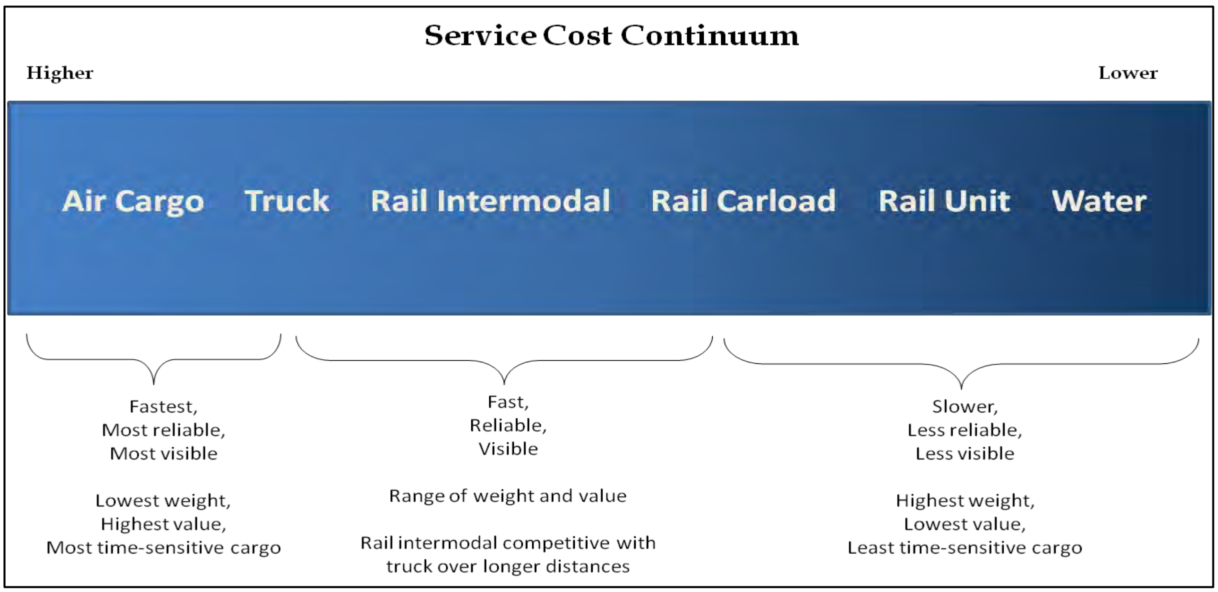
Urban areas should focus on making adaptive changes that adjust over time. One approach to adaptive urbanization is Flexible Adaptation Pathways (see figure), which recommends adaptation actions that evolve over time as understanding of climate change improves, so that urban planners concurrently reflect local, national, and global economic and social conditions when developing adaptation actions. Urban decision-makers should understand how climate change is likely to affect the critical services they provide, and the time and resource requirements, including costs and benefits, of potential interventions to develop appropriate adaptation strategies to improve system resilience. As the figure indicates, monitoring and reassessment should occur throughout, and that adaptation and mitigation strategies will interact.

Transportation and Energy

Austin Brown, NREL

Energy commodities comprise nearly 40 percent of all ton-miles in freight. Coal makes up more than 50 percent of all rail-ton miles as well as 10 percent of water ton-miles. Changing fuel prices and fuel efficiency impact which mode transports the different energy commodities.

Most mode choice decisions are made on the properties of the freight to be transported, including the cost, weight, and distance the goods need to be moved. For example, 31 percent of trucking costs are attributable to fuel costs, while fuel costs make up just 18 percent of expenditures in rail. If fuel costs increase, freight may shift towards rail. However, trucking will likely dramatically increase its fuel efficiency in the coming years, which may shift the cost advantage towards using this mode over rail. These scenarios examine the possible mode shifts from “low carbon futures” and “fuel price futures”.



Source: Brogan, J.J.; Brown, A.; Fischer, M.J.; McKenzie, E.; Vimmerstedt, L.; Vyas, A.D.; Witzke, E. (forthcoming). *Transportation Energy Futures Series: Freight Transportation Modal Shares.* Prepared for the U.S. Department of Energy by National Renewable Energy Laboratory, Golden, CO.

Regional Impacts

The speakers in this session addressed the identified potential regional impacts of climate change with a focus on sea-level rise and changing temperature and precipitation levels.

Sea-Level Rise

Kevin Knuuti, USACE

Global warming, cooling, and the associated rise and fall of sea level are cyclic. Throughout the twentieth century, global mean sea level rose at a rate of approximately 1.7mm per year. Many researchers believe the rate of sea-level rise may be increasing beyond what would have occurred due to the natural cycles of the earth. Though current research has not yet been able to quantify what percentage of current global mean sea-level rise is due to natural processes and what percentage is due to human behavior, it is commonly accepted that anthropogenic activity is likely to increase the rate of global mean sea-level rise in the future. Projections by the Intergovernmental Panel on Climate Change (IPCC) in 2007 estimated between 0.09 meter and 0.88 meter increase in sea level between 1990 and 2100, though some more recent estimates have estimated potentially greater sea-level rise. Given the uncertainty of sea-level rise projections, planning organizations may find it desirable to plan for a range of scenarios. The NCA report on sea-level rise projections recommends considering a range of potential sea-level rise scenarios with endpoints ranging from 0.2 to 2.0 meters of global mean sea-level rise by 2100.

In addition to global mean sea-level rise, sea-level rise in particular local areas is also affected by the relative increase in water levels due to movements of the earth's crust and a range of other factors. Just a small increase in sea level may dramatically affect the amount of storm surge in a given area, as the relationship between sea level and storm surge is nonlinear.

Regional Scenarios

Laura Stevens, CICS-NC/NOAA

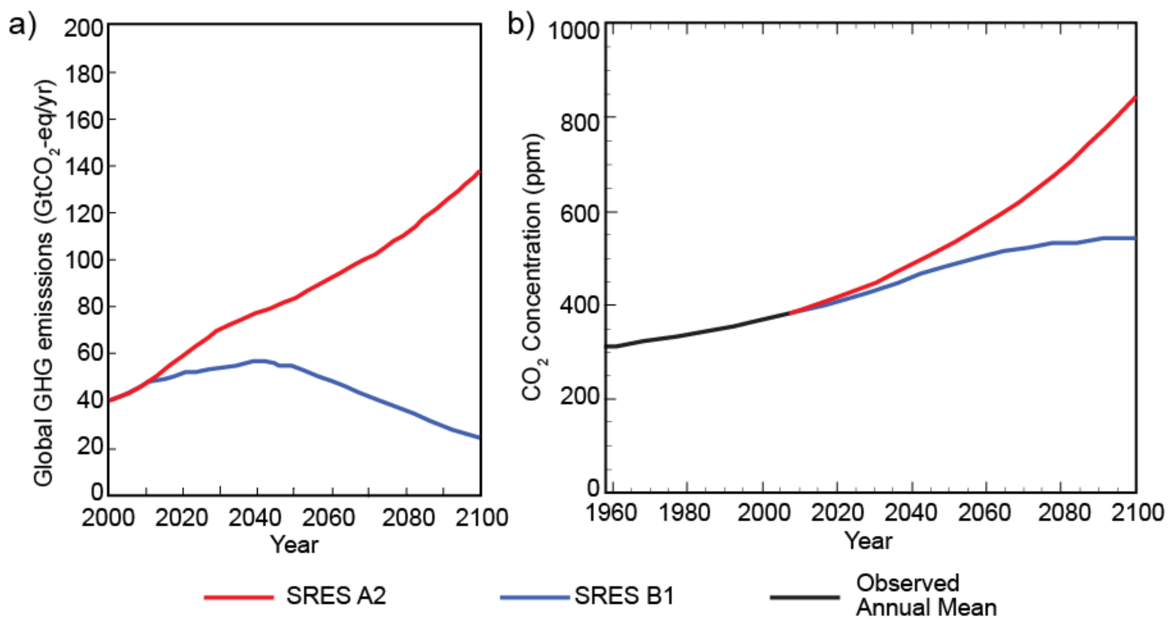
Nine "Regional Climate Trends and Scenarios" documents have been produced as technical input to the NCA). These documents include a survey of recent historical climate variability and change, as well as two scenarios of potential conditions for 25 to 100 years into the future, for eight regions of the United States.

Significant climate factors include:

- Drought (meteorological, agricultural, hydrological)
- Floods (melting snow pack, heavy rainfall)
- Winter storms (snow storms, ice storms)
- Convective storms (downbursts, heavy downpours, lightning, hail, tornadic winds, flash flooding)
- Heat waves
- Cold waves
- Hurricanes

Recent historical studies of climate demonstrate that annual mean temperatures have increased significantly since 1895, with the exception of the Southeast "warming hole". Annual precipitation has also exhibited a general upward trend over the past century.

Looking at future climate projections, an ensemble of climate models were used to simulate temperature and precipitation changes, under the IPCC A2 and B1 emissions scenarios. While A2 assumes a continued rapid increase in greenhouse gas emissions, B1 assumes a rise and a then plateau and decrease in overall emissions. These scenarios were created by models with consideration of both physics and socioeconomic factors, assessing population growth and movement. The A2 and B1 scenarios were developed in 2007, but national emissions are already outpacing the increase demonstrated in the A2 model.



Source: IPCC, [Projected greenhouse gas emissions and carbon dioxide concentrations]

Temperatures are simulated to increase under both scenarios, but more rapidly for the high emissions (A2) scenario. The number of days over 95°F is simulated to increase, while the number of days below 32 °F is simulated to decrease. These scenarios indicate that the wetter regions of the country may have more precipitation in the coming century, while the drier regions could continue to get drier.

The full set of results from this study is slated to be published as National Oceanic and Atmospheric Administration (NOAA) Technical Memoranda in January 2013, and key information will also be included in the third NCA Report.

Integrated Studies of Adaptation

This session reviewed existing USDOT adaptation pilots and studies. Federal Transit Administration (FTA) and Federal Highway Administration (FHWA) are currently funding research on climate and transportation, including the FHWA Climate Change Vulnerability Assessment Pilots and the FTA Climate Change Adaptation Assessment Pilots.

Gulf Coast Study and FHWA Adaptation Pilots

Robert Hyman, FHWA

Climate change has implications for the planning process, asset management programs, and for project-level design considerations. Adaptation has become recognized as an important climate issue along with mitigation. However, relatively few State Departments of Transportation (DOTs), metropolitan planning organizations (MPOs), and cities have moved past very general high-level vulnerability assessments to implement adaptation projects. FHWA seeks to help its partners understand how to conduct and act on these assessments through the Gulf Coast Study and Climate Change Vulnerability Assessment Pilots.

Gulf Coast Study

To better understand potential climate change impacts on transportation infrastructure and identify adaptation strategies, the USDOT is conducting a comprehensive, multi-phase study of climate change impacts in the Gulf Coast region. Home to a complex multi-modal network of transportation infrastructure and several large population centers, this region plays a critical national economic role in the import and export of oil and gas, agricultural products, and other goods. The study is sponsored by the USDOT's Center for Climate Change and Environmental Forecasting in partnership with the US Geological Survey (USGS) and is managed by FHWA.

Phase 1 of study was completed and published in 2008, and Phase 2 is scheduled to be completed in 2014.

Climate Change Vulnerability Assessment Pilots

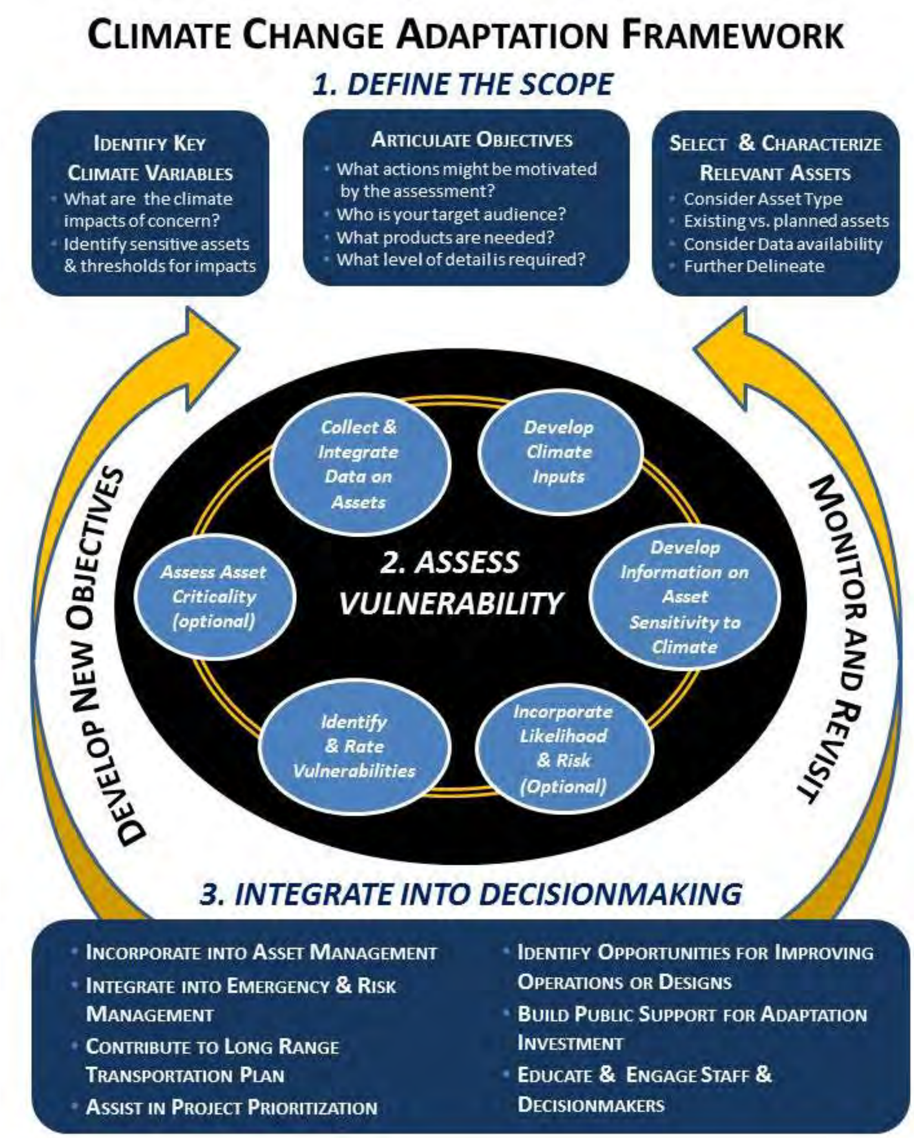
This assessment pilot program aims to develop a framework State DOTs and MPOs can use to consider climate change vulnerability and risk in transportation decision-making at both the system and project levels.

Five agencies participated in the pilot program:

- Oahu MPO
- Virginia DOT
- New Jersey DOT
- Washington State DOT
- San Francisco Bay Metropolitan Transportation Commission

FHWA developed a Climate Change Adaptation Framework based on the Gulf Coast Study and the assessment pilots that identifies three main steps in the adaptation process:

1) **Define the Scope** –Identify climate variables, articulate assessment objectives, and characterize relevant assets
2) **Assess Vulnerability** – Collect and analyze data on the scale, risks, and likelihood of climate impacts to the identified assets
3) **Integrate into Decision-making** – Use results to inform Long Range Transportation Plans (LRTPs), asset management, improvements in operations, project prioritization, and other aspects of the transportation decision-making process



Source: Federal Highway Administration

FTA Climate Adaptation Pilots

Brian Alberts, FTA

The FTA Climate Adaptation Pilots advance the state of practice for adapting transit systems to the impacts of climate change. The pilots assess the vulnerability of transit agency assets and services to climate change hazards and develop initial adaptation strategies.

The seven participating agencies include:

- Georgia Tech, in partnership with the Metropolitan Atlanta Rapid Transit Authority
- Los Angeles County Metropolitan Transportation Authority
- Chicago Transit Authority
- Central Puget Sound Regional Transit Authority
- Texas Transportation Institute in partnership with Island Transit, Hillsborough Area Regional Transit authority, and Metro
- San Francisco Bay Area Rapid Transit District
- ICF Inc. in partnership with Southeastern Pennsylvania Transportation Authority and Delaware Valley Regional Planning Commission

These pilots identify how transit providers can adapt to climate change, assess lessons learned for other transit providers, and develop a network of peers with which to collaborate on adaptation strategies.

Climate Change and Transportation Priorities

James H. Lambert, University of Virginia

Researchers at the University of Virginia (UVA) addressed the influence of climate scenarios in long range transportation planning in a collaborative project with the Virginia Department of Transportation, the Hampton Roads Transportation Planning Organization, and the Hampton Roads Planning District Commission. The study identified how climate can influence the public involvement process and long-range transportation planning. The study demonstrated how combining climate with other factors such as economy, regulation, technology, wear and tear, and ecology, can lessen or compound effects.

Building on forecasts of climate change nature and extent in Hampton Roads, the study developed a systematic approach to modeling and analyzing scenarios of varying climate and non-climate conditions. The process for developing these models is outlined below:

1) Study the regional LRTP
2) Identify climate conditions
3) Build scenarios that mix conditions of climate, technology, economy, etc.
4) Assess which are the influential scenarios
5) Focus modeling and analysis on influential scenarios
6) Repeat process for priorities of assets, traffic analysis zones, projects, and policies
7) Interpret results with implications for the LRTP

The UVA study showed the implications for priorities among 150 projects, mixing climate and non-climate conditions. The framework developed has informed transportation planners' use of climate change data to influence decision-making and priority-setting for the projects, assets, multi-modal policies, and traffic analysis zones in the LRTP. The framework has been implemented in software workbooks available from the University of Virginia.

	Scenarios (one or more conditions)				
	S1. Scenario 1	S2. Scenario 2	S3. Scenario 3	S4. Scenario 4	S5. Scenario 5
Conditions					
Climate Conditions					
Increase in sea level rise	☑	☑	☑	☑	☑
Increase in storm surge	☑	☑	☑	☑	☑
Increase in precipitation	☐	☐	☐	☐	☐
Increase in stormwater	☐	☐	☐	☐	☐
Increase in storm frequency	☐	☐	☐	☐	☐
Increase in days below freezing	☐	☐	☐	☐	☐
Increase in extreme heat days	☐	☐	☐	☐	☐
Increased occurrence of drought	☐	☐	☐	☐	☐
Non-Climate Conditions					
Economic recession	☐	☑	☐	☐	☐
No further increase on federal government debt cap	☐	☐	☐	☐	☐
Increased wear and ear on public infrastructure	☐	☐	☑	☐	☐
New technology for maintenance / inspection	☐	☐	☐	☐	☐
Increase in traffic demand	☐	☐	☐	☐	☑
Increase in area tourism	☐	☐	☐	☐	☑
Population growth	☐	☐	☐	☐	☐
Energy shortage	☐	☐	☐	☐	☐
Changes in land use regulation	☐	☐	☐	☐	☐
Increased infectious desease occurrence	☐	☐	☐	☑	☐
Increased loss of forest and plant life	☐	☐	☐	☑	☐
Increased mortality of native animal species	☐	☐	☐	☐	☐
N/A	☐	☐	☐	☐	☐
N/A	☐	☐	☐	☐	☐

More information can be found in [“Climate change influence to priority setting for transportation infrastructure assets”].

Transportation Systems Effects Case Studies

The case studies focused on the impacts of climate change on various transportation modes, including aviation, roadway operations, and trucking. As temperature and precipitation patterns change, the institutions that plan, operate, and maintain these modes will be challenged to adapt to the new conditions.

Aviation and Weather Delays

Tom MacPhail, Federal Aviation Administration

Weather affects the capacity of the National Airspace System (NAS), which is the system that controls flight patterns throughout the US and a large portion of the world's oceans. Weather-related delays cause about 70 percent of all air traffic delays, and in regions where traffic demand approaches the system's capacity, any loss of airspace and airport capacity to weather will produce delay which can, if it occurs at the wrong place or time, cascade throughout the NAS.

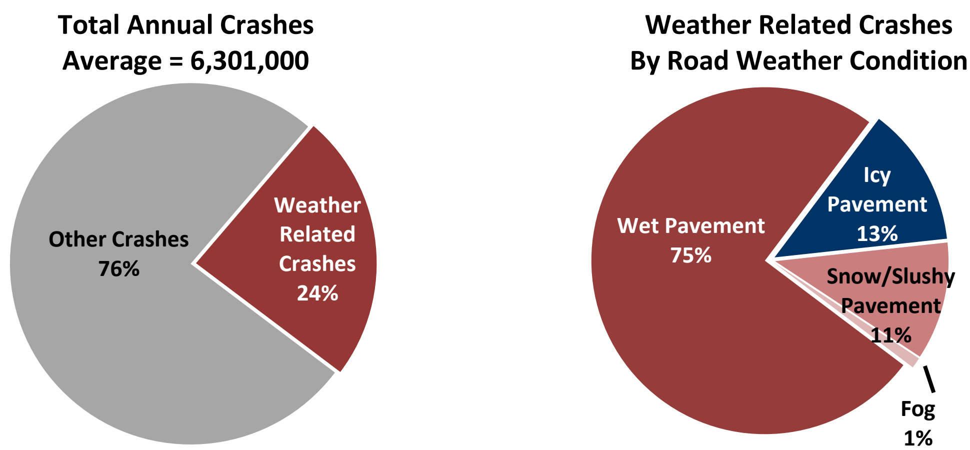
Weather represents lane blockages in the sky, producing "no-fly" zones and then jammed "parking lots" on the ground (airports). Traffic flow management initiatives are implemented to balance flight demand with capacity by slowing down or reducing air traffic access to airspace or airport destinations. Weather often produces counter-intuitive impacts on air transportation. Minor weather issues can result in excessive, far-reaching delay when it impacts high-density airspace while a well-forecast major storm often reduces traffic volume (due to cancellations) with an overall effect of less delay for those flights electing to continue. Airlines have shown less risk tolerance in the face of major storms in the past few years especially when adverse weather impacts a major urban area like the New York metropolitan area. It has become common for airlines to preemptively cancel flights rather than delay them to avoid having stranded passengers or aircrafts out of position to meet their later flights.

Adding additional traffic to the NAS will increase the impact of today's weather. Similarly, any future change in the frequency or severity of weather could exacerbate the impact of this additional traffic. The Federal Aviation Administration (FAA) is presently developing NextGen, a new air traffic management system that is expected to expand NAS capacity and better integrate weather information into flight planning. NextGen promises to decrease the impact of weather on air travel by increasing NAS capacity and making it "elastic" to the inevitable impact of weather. By improving the quality and availability of weather information to NAS users and traffic planners, flying operations can become better able to preemptively plan mitigation strategies.

Road Transportation and Weather

Paul Pisano, FHWA

Highway operations, safety, and infrastructure are affected by adverse weather. Extreme weather events and climate change have significant economic and transportation impacts. Highway delays from snow, ice, and fog cost $11.6 billion each year. And adverse weather conditions are overrepresented in crash statistics, accounting for 24 percent of all crashes, and yet occurring less than 10 percent of the time drivers spend behind the wheel. The US is working to slow climate impacts by adopting a proactive approach to highway operations and management. Developing management strategies today that enable operators and users to respond to weather impacts will put them in a better position in the future, under alternate climate regimes. For example, improved real-time and forecasted weather information for road users and the use of advanced decision support tools can be developed to accommodate fluctuating temperatures, as well as changes in precipitation type, frequency and intensity.



Source: Road Weather Management Program, Table: Weather-Related Crash Statistics (Annual Averages)

The highway operations system is based on current weather conditions. As conditions change, FHWA has begun to explore responses to climate impacts in the following sectors: system maintenance, operations, travel behavior, and freight transportation. Increased exposure to hazardous driving conditions increases the need for timely, accurate, and relevant traveler information to enable more efficient and safer decision making. For example, an increase in the magnitude and duration of severe heat waves may induce dynamic or seasonal restrictions for trucks during times of high heat, reducing acceptable freight weights or speeds. Improving current freight and traveler information systems will enable the freight community to proactively manage their actions under these varying conditions.

Climate impacts will manifest themselves as specific weather events as well as long-term trends. The scale, frequency, and intensity of weather changes will affect how operation agencies are organized and function. Over the next few years, FHWA will to document climate-sensitive decisions of transportation operators and users, and then enhance or modify the current systems and services to make more improve these decisions and minimize the impacts. Operations organizations are also beginning to develop more formal ways to incorporate risk and uncertainty into operations.

Trucking and Weather

Mike Johnsen, Federal Motor Carrier Safety Administration

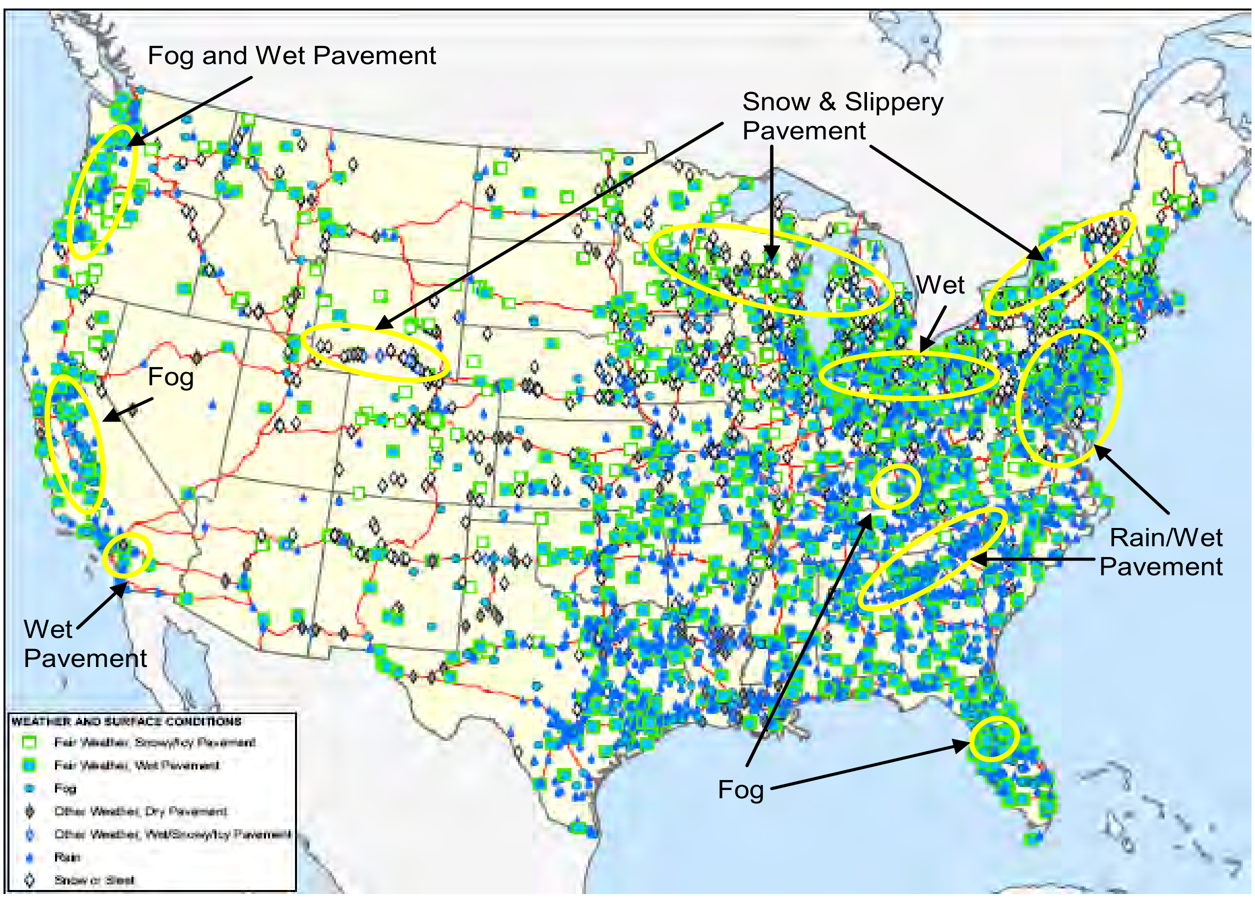
In 2011, the Federal Motor Carrier Safety Administration (FMCSA) published "Weather and Climate Impacts on Commercial Motor Vehicle Safety," outlining how past and existing weather conditions impact commercial motor vehicle (CMV) safety and how climate change might affect CMV safety. The report found that approximately 16 percent of all fatal CMV crashes are associated with adverse weather, and fatal crashes for CMVs occur at higher rates than crashes for all vehicles. Weather affects trucking through loss of traction and control, stress or damage to vehicle components, reduced visibility, and vehicle instability in high winds.

Climate change implications for CMVs include:

- Severe or abrupt weather events, which can increase crash risks
- Changes in agriculture production, increased flooding, and droughts can impact shipping patterns and modes
- Decreases in snow could reduce crashes, but increases in ice storms could offset those crashes prevented by the decrease in snow.

Weather can influence CMV safety, and while the overall number of weather-related CMV fatal crashes is fairly small, climate change may increase those crashes. However, more research is needed to determine the risk of a crash during various weather conditions and what FMCSA's response should be if those risks warrant increased involvement. FMCSA will explore the actual risks involved with severe weather.

Locations of Fatal Crashes Involving CMVs by Weather Event



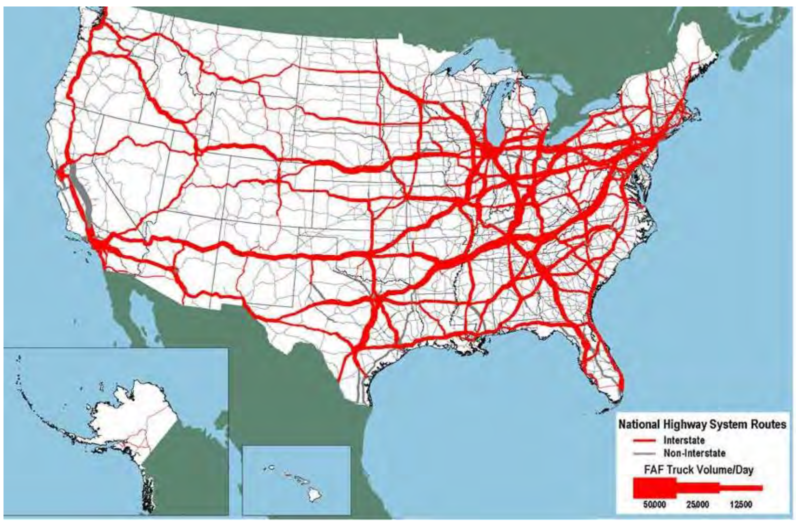
Source: Weather and Climate Impacts on Commercial Motor Vehicle Safety, FMCSA

Discussion Sessions

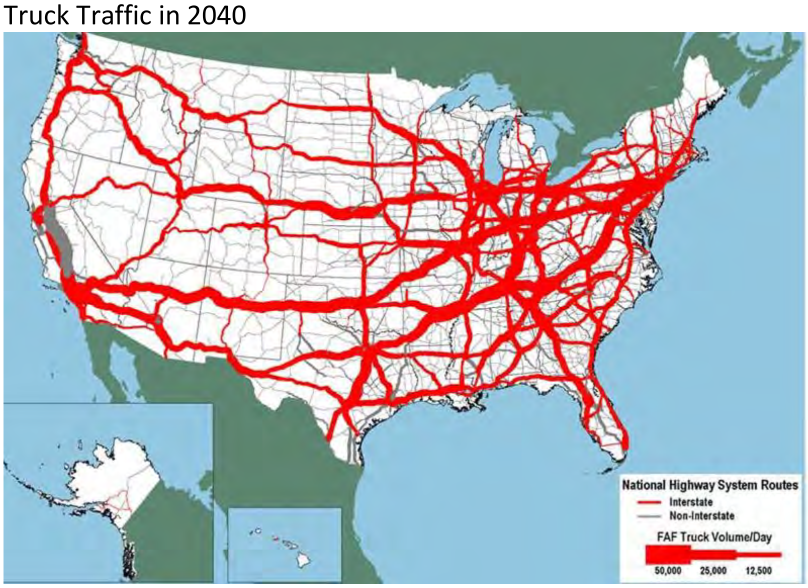
Overview

The systemic impacts of climate change are expected to affect planning and infrastructure design as well as maintenance and operation of existing transportation systems. If the future unfolds like the past, the coming years will yield a US with a larger, wealthier population with increased freight and passenger movement.

Truck Traffic in 2007



Truck Traffic in 2040



Source: USDOT, FHWA Office of Freight Management and Operations, Freight Analysis Framework, Version 3.1, 2010.

The second day of the conference was spent on group discussion, prompting participants to share their experiences and recommendations on future research and opportunities surrounding both impacts of climate change and effective adaptation strategies.

Themes

Several themes emerged as participants speculated how urban infrastructure, freight, and travel patterns may change in coming years, and how climate change will influence or be influenced by these developments. The discussion below summarizes some of the points made by participants.

Population Shifts – Shifts in where people live could change travel patterns and demand throughout the country. If past population shift patterns continue, people will continue to move to regions with temperate climates. Water availability and electricity will continue the shift of the population to the Southwest. Disadvantaged populations will have to move to regions with smaller climate effects, such as those less likely to experience extreme heat or cold or extreme, acute weather conditions.

One of the most dramatic population shifts of the last century has been the move from rural to urban. This increased concentration of people in cities has climate change implications. In most major US cities, the best land in urban areas has already been developed. As rural to urban migration continues, development must expand to higher risk areas, such as flood plains. As these areas increasingly experience the impacts of climate change, they must develop mechanisms to protect vulnerable populations living there.

In addition, as people move to cities, the demand for sidewalks, roads, and transit infrastructure will increase. Conference participants questioned if the shift toward urban centers and steps taken to accommodate this shift would increase and compound the impacts of climate change.

Cultural Shifts – Changes in American culture may also affect transportation patterns and demand in coming years. A significant increase in the number of people teleworking could reduce vehicle miles traveled (VMT). The aging of the Generation X and Y, who drive less than the generations before them, could affect VMT as well, as could the retirement of the baby boomers.

Mode Shifts – As climate change impacts increase and change the cost or efficiency of different transportation modes, travelers may shift to more convenient modes to accommodate their trips. For example, if more flights are grounded for weather delays, travelers may choose rail as a time-efficient alternative. If gas prices continue to rise, more travelers may choose to use transit. Participants noted that the transportation system must become more resilient to mode changes. If gas prices spike and demand for buses drastically increases, systems must quickly adapt to meet this need. If possible, systems could try to forecast these mode shifts and prepare accordingly.

Similar shifts may occur for freight transportation as well. Climate events impacting one mode can affect other transportation networks as well. For example, if a rail transit system is crippled by inclement weather, transportation will shift to buses or personal vehicle traffic on roads. Not all freight systems can easily shift operations in an acute weather event. While trains or trucks may reroute, ships are more limited by the set of waterways that lead from their origin to their destination. Potential effects of increased flooding or drought may pose large challenges to freight moved along waterways.

Comprehensive Adaptation and Recovery– As cities work to protect their infrastructure, through construction of levees or through storm water design, planners face the challenge of mitigating local risks while not transferring or compounding the risk upon other neighboring areas. Cities and towns within a region affected by disaster are often in competition for resources both in preparedness, response, and recovery (including funding resources). Participants questioned if natural disasters and their recovery product a set of winners and losers.

As climate impacts increase in frequency and intensity, planners must decide to what extent infrastructure in vulnerable areas should be rebuilt and restored and what implications these decisions have for populations that were or continue to live in high risk areas. The least advantaged households often experience the greatest impacts of climate effects. Participants discussed if planners should accommodate these populations and questioned how to do so.

Paying for Adaptation and Recovery – As climate impacts damage existing infrastructure and transportation assets such as trucks and trains, cities and States must work to repair and rebuild, and to restore services. Communities can try to rebuild in a way that protects them from similar future storms or conditions. However, this can be challenging within the constraints of existing disaster recovery relief funding. Federal Emergency Management Agency (FEMA) funds mandate that infrastructure is restored to its condition prior to the emergency. Similarly, FHWA Emergency Relief Program, which assists in the repair or reconstruction of roads damaged through natural disasters, typically constructs roadways to match their previous design. Roads road can only be rebuilt differently if the changes are economically feasible. Planners can make assumptions of increased storms or of seal-level rise when developing feasibility studies, for these impacts are likely to further damage the roadway in the future if it is not improved.

Not all climate impacts permit use of FEMA or recovery funds. In order to cover these additional costs, participants discussed increasing fees for infrastructure use. While it is standard practice to charge for transit, only some bridges and highways currently levy fees.

Rail Infrastructure Vulnerabilities – Plans for infrastructure repair or new development should consider climate forecasts in their plans. Many rail routes run along coasts and rivers, areas that are particularly susceptible to the impacts of climate change. Rail must run along flat land, which is why so many rail lines are situated along waterways. However, this poses challenges to how rail can react to climate change and opportunities for possible reroutes. However, many rail lines that have been abandoned in the last century have been "railbanked," in which the rail company permits the removal of train ties and the construction of a multi-use path along the right of way (ROW) with the stipulation that they may reinstate rail to the ROW in the future. Should coastal routes become unusable, rail companies may reclaim some of their corridors throughout the country.

Railroads are typically privately owned and maintained. Representatives from these companies were not present at the conference, but participants suggested making more of an effort include the rail carriers in future climate change adaptation discussions.

Technology and Increased Efficiency – Technological advances have both increased and hindered the population's ability to effectively adapt to climate change. As many office tasks have become increasingly digital, much of the population can now work at home. If weather impacts prevent workers from traveling to the office, these people can complete tasks from their personal computers. However, if an area loses power or phone access, these same employees are unable to work at all.

Advanced communications technology improves citizens' ability to react to acute weather events and climate change as real-time forecasting and alerts can be effectively broadcasted. In addition, this technology allows for a mutual exchange of information, as those within or affected by adverse weather events can better inform officials of the current condition of their community as well as their individual needs.

Technology plays a role in the transportation systems themselves as well. Many transportation modes are working to develop new technologies to improve both energy efficiency as well as cost and time efficiencies: marine technology is increasing the speed of ships; General Electric and Electro-Motive are forming strategies to meet new emissions standards in locomotives; and the DOE has invested millions in the development of a SuperTruck, a truck with highly efficient engine systems and vehicle technologies that meet prevailing emissions and regulatory requirements. Freight sensor technologies are improving, better gauging the temperature and vibrations within cargo containers. Transportation faces the same challenges to improving efficiency as other sectors, specifically large upfront costs. These improvements may become increasingly important if fuel costs continue to increase.

Conclusion

The USDOT has a formal responsibility in adaptation planning, and is engaged in a series of exercises. The "Systemic Impacts of Climate Change" workshop provided an opportunity for information sharing of current research on climate change impacts on different transportation modes as well as research on how the effects of climate change on different sectors may change transportation demand.

Appendix A: List of Attendees

Full Name	Company/Organization
Abkowitz, Mark	Vanderbilt University
Allen, Catherine	EPA
Arnold, Jeff	USACE, Institute for Water Resources
Arnold, Robert	USDOT FHWA
Attavanich, Witsanu	Rutgers University
Broad, Catherine	USDA Office of Procurement and Property Management
Brown, Austin	NREL
Bryan, Jeff	USDOT Volpe Center
Bush, Kevin	US Council on Environmental Quality (CEQ)
Camp, Janey	Vanderbilt University
Cantral, Ralph	USGCRP
Chipman, Peter	USDOT RITA
Cohn, Jesse	USDOT Volpe Center
Constantine, Elena	Metropolitan Washington Council of Governments
Corley, Richard	USDOT Maritime Administration
Cuddy, Thomas	USDOT FAA
Daniels, Amy	US Forest Service, Research & Development
DeFlorio, Josh	Cambridge Systematics
Denicoff, Marina	USDA, Agricultural Marketing Service
DesRoches, Susanne	Port Authority of New York & New Jersey
Dorney, Christopher	Parsons Brinckerhoff
Fine, Alisa	USDOT Volpe Center
Flood, Michael	Parsons Brinckerhoff
Gazda, Walter	USDOT Volpe Center
Graff, Robert	Delaware Valley Regional Planning Commission
Grasty, Katie	USDOT
Gustave, Mirna	USDOT Volpe Center
Habic, Elizabeth	Maryland State Highway Administration
Hodges, Tina	USDOT FHWA
Holsinger, Heather	USDOT FHWA
Hyman, Robert	USDOT FHWA
Johnsen, Michael	USDOT FMCSA
Kafalenos, Robert	USDOT FHWA
Klima, Kelly	Center for Clean Air Policy
Knuuti, Kevin	USACE
Kramer, Casey	Washington State Department of Transportation
Kumar, Ashwin	Climate Institute
Lambert, James	University of Virginia
Lawson, Linda	Self-Employed
Lovaas, Deron	Natural Resources Defense Council

Lupes, Becky	USDOT FHWA
MacDonell, Margaret	Argonne National Laboratory
MacIsaac, James	USDOT NHTSA
MacPhail, Thomas	FAA/NextGen, Aviation Weather Division
Maples, John	US Energy Information Administration
McCalla, Margaret	NOAA
Metcalfe, Matt	Booz Allen Hamilton
Mittelholtz, Camille	USDOT
Osborne, Beth	USDOT, OST
Partowazam, Kevin	USDOT FAA
Pippin, Anne	CEQ
Pisano, Paul	USDOT FHWA
Ritchie, Emilee	Booz Allen Hamilton
Roth, Alex	US DOT FRA
Sand, Stephanie	Booz Allen Hamilton
Savonis, Michael	ICF International
Schneir, Sydney	USDOT FRA
Schwartz Freeburg, Andrea	USDOT FAA
Serassio, Helen	US CEQ
Singletary, A.J.	Airlines for America
Stevens, Laura	Cooperative Institute for Climate and Satellites - NC (CICS-NC)
Taijeron, Sabrina	Office of the Federal Coordinator for Meteorology (OFCM)
Tyson, Alexandra	USDOT OST
Walsh, Margaret	USDA Climate Change Program Office
Zhu, Charles	Center for Climate and Energy Solutions

Appendix B: Acronym List

Acronym	Organization
CMV	Commercial Motor Vehicle
DOE	Department of Energy
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FTA	Federal Transit Administration
IPCC	Intergovernmental Panel on Climate Change
LRTP	Long Range Transportation Plan
MAP-21	Moving Ahead for Progress in the 21st Century
MPO	Metropolitan Planning Organization
NAS	National Airspace System
NCA	National Climate Assessment
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
OST	Office of the Secretary of Transportation
USACE	US Army Corps of Engineers
USDA	US Department of Agriculture
USDOT	US Department of Transportation
USGCRP	US Global Change Research Program
USGS	US Geological Survey
VMT	Vehicle Miles Traveled