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Climate Change Impacts on Transportation in the Midwest

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At the request of the U.S. Global Change Research Program, the Great Lakes Integrated Sciences and Assessments Center (GLISA) and the National Laboratory for Agriculture and the Environment formed a Midwest regional team to provide technical input to the National Climate Assessment (NCA). In March 2012, the team submitted their report to the NCA Development and Advisory Committee. This white paper is one chapter from the report, focusing on potential impacts, vulnerabilities, and adaptation options to climate variability and change for the transportation sector.

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Contents

Introduction

This paper assesses current literature on potential impacts of climate change on transportation systems in the Midwestern region of the United States. Four sections follow: First, a brief synopsis of recent research on general transportation impacts is offered. Second, we examine current climate projections for different parts of the Midwest in order to assess relative levels of risk for transportation impacts associated with climate change. Third, an assessment of ongoing transportation adaptation measures is presented. Finally, gaps in knowledge and research needs are discussed.

Transportation and Climate Change

Changes in temperature and precipitation associated with climate change can have different effects on different modes of transportation. Summaries of these effects may be found in Jaroszweski, Chapman and Petts (2010), Koetse and Rietveld (2009), Meyer and Weigel (2011), Meyer, Amekudzi and O'Har (2010), the Panel on Adapting to the Impacts of Climate Change (PAICC, 2010), Hodges (2011) and Schwartz (2011). This section briefly summarizes current thought on ways in which climate change may affect the following modes of transportation: surface transportation (i.e., roads and highways), rail, water and air.

Air

Temperature change: Warmer air temperatures can affect takeoff performance and cargo capacity by reducing the amount of lift generated by the wing of an airplane, increasing the time required to achieve a given altitude. However, there is little knowledge about the extent to which temperatures are, or may be, the limiting factor in cargo capacity or takeoff performance at airports in the Midwest.

It is important to note that climate change may produce some benefits, as well as negative consequences. In the case of air travel, it may be that warmer temperatures during winter months would benefit airports that have to deal with snow and ice removal.

Precipitation change: Changes in precipitation can affect air traffic in several ways. Heavy precipitation can overwhelm airport drainage systems and inundate runways, particularly for airports built in floodplains or other low-lying areas. An increase in the frequency of heavy precipitation events could therefore lead to more airport closures. In addition, heavy precipitation can degrade aviation system operations, resulting in delayed takeoffs and landings.

Fire: Wildfire can disrupt air traffic by reducing visibility and by degrading engine performance. Places experiencing an increase in hotter and dryer conditions may be more susceptible to wildfire.

Extreme weather: Tornadoes, severe thunderstorms and heavy winds can halt airport operations, and in some cases cause physical damage to airport facilities.

Water

River traffic can be disrupted by high water levels following heavy precipitation that increase flow velocities and make navigation difficult. Changes in the frequency of heavy and prolonged precipitation may therefore reduce the volume of river barge traffic. On the other hand, falling water levels in the Great Lakes have reduced the carrying capacity of cargo vessels in recent years, and climate change could exacerbate this trend.

Rail

Temperature change: Rising temperatures may lead to material stress, including buckled rails.

Precipitation change: Increases in heavy precipitation events could flood low-lying tracks, forcing temporary closure of low-lying rail lines.

Surface transportation

Temperature change: Increases in temperature, and particularly in the frequency of extreme heat events, could increase material stress on pavement and bridge expansion joints, necessitating more frequent maintenance.

Precipitation change: Changes in precipitation patterns could affect surface transportation in three ways. First, an increase in heavy precipitation events can lead to flooded roadways. Second, increased runoff creates faster stream currents which can erode bridge piers, a condition known as bridge scour. Third, precipitation generally degrades system performance, resulting in longer travel times and more crashes.

Extreme Weather: Tornadoes, severe thunderstorms and heavy wind can disrupt highway travel, and heavy cross winds can make long bridges unsafe. The Mackinac Bridge connecting the Upper and Lower Peninsulas of Michigan has experienced accidents due to wind, and the Mackinac Bridge Authority often must close the bridge to all traffic during spells of severe weather.

Comparative risk

Current peer-reviewed literature on climate change impacts in the Midwest does not provide a basis for quantifying the costs of impacts such as material stress, flooded roadways, bridge scour and disruptions to barge traffic. However, current projections can be used to assess relative risks associated with different types of impacts in different subregions of the Midwest. The projections described in Kunkel (2011) are the basis for this section.

Extreme heat

The number of days with a temperature greater than 95 degrees is a good indicator of the risk of pavement and rail buckling. North American Regional Climate Change Assessment Program (NARCCAP) projections for the years 2041-2070 show an increase of more than 20 days each year for almost all of Missouri, including the Kansas City and St. Louis metropolitan areas, as well as for southern Illinois, southern Indiana, and the Cincinnati metropolitan area. Northern portions of the Midwest, including the Minneapolis, Milwaukee, Chicago, Detroit and Indianapolis metropolitan areas, are projected to have increases of less than 20 days per year exceeding 95°F. These projections suggest that heat stress on rail and pavement may be of particular concern in Missouri and the southern portions of Illinois and Indiana.

Changing precipitation patterns

Flooding risk

Takle (2010) maintains that precipitation levels in eastern Iowa have increased over the last 30 years:

> *Using these tools, we see that eastern Iowa has experienced increased precipitation of 1 to 2 inches in spring (April through June) over the last 30 years. This is consistent with increases throughout the central U.S. since about 1976 (Groisman et al. 2005). There also is increased intensity of extreme events in the warm season. Groisman et al. (2005) report a 20 percent increase in the most intense 0.3 percent of precipitation events in the central U.S. over this period. By contrast, there has been a slight decrease in the frequency of light or average precipitation events (CCSP 2008). Records from Cedar Rapids (IEM 2008) show that there were 14 days from 1901 to 1950 that had three or more inches of daily total precipitation. Between 1951 and 2000, this number rose to 23 days. Over the last 113 years, annual precipitation in Cedar Rapids has increased by about 9 inches, from 28 to 37 inches. Increases have come in both the warm season and cool season, with the cool season precipitation currently being about 50 percent higher than a hundred years ago. The Cedar Rapids record agrees with the regional trend of increased precipitation since 1976, but the Cedar Rapids upward trend started much earlier. So although it is hard to argue that this locale's increase in annual total precipitation is due to anthropogenic effects of the last 30 years, models suggest this existing trend will continue. The increase in number of days with intense precipitation, by contrast, has increased in the latter part of the 20th century, which is consistent with changes attributable to anthropogenic effects (p. 112).*

A conference held at St. Louis University in November 2008 drew together several scientists who study climate change effects on streamflow. Although the papers presented at this conference were not peer reviewed, several agreed that flooding is becoming more frequent in the Mississippi River basin (Kriss, 2009; Pinter, 2009) or that flooding is likely to become more frequent under climate change scenarios (Wuebbles, Hayhoe and Cherkauer, 2009; Pan, 2009).

Current NARCCAP projections show a continuation of several of these trends through the middle of the 21st century. The entire Midwestern region is projected to see increases in precipitation in winter, spring and fall.

Moreover, the number of days with more than 1 inch of precipitation is projected to increase throughout the Midwest. NARCCAP simulations for the period 1971-2000 indicate that most of the area south of the Missouri-Iowa border (an area extending as far as Columbus, Ohio) experienced about 6-8 days per year in which precipitation exceeded 1 inch. NARCCAP projects an increase in heavy precipitation days for the period 2041-2070. In the Mississippi River basin between the Quad Cities and LaCrosse, Wisconsin, the mean number of days per year with precipitation exceeding 1 inch is projected to rise by 1.5 to 2 relative to the period 1971-2000; the rest of the basin between St. Louis and Minneapolis is projected to have an increase of 1.0 to 1.5 days.

These projections suggest an increased risk of disruptions to navigation on the Ohio, Mississippi and Missouri Rivers. In addition, the projected increase in heavy precipitation throughout the Midwest suggests additional risk of temporary flooding of rails and roadways. With higher return frequencies for heavy precipitation events, the design carrying capacity of many culverts and hydraulic structures may be insufficient to prevent rail, highway, airport and other infrastructure flooding.

The observations and projections cited above are consistent with the conclusion of Pryor, Kunkel and Schoof (2009) that "the most common cause of flooding is intense and/or prolonged storm precipitation (Nott, 2006). Given the increase in intensity of extreme precipitation events, an increased risk of flooding seems likely."

Snow

NARCCAP projections indicate rising winter precipitation over much of the Midwest, suggesting a rising risk of transportation system disruption caused by snow and ice. Monitoring regional changes in snow removal budgets and planning accordingly may be one simple and effective adaptation option that can be taken by state and local transportation authorities.

Great Lakes water levels

Wang et al. (2010) report that water levels on the Great Lakes dropped in the 1990s, resulting in significant transportation impacts in the Great Lakes region:

> *From the late 1990s to the early 2000s, the volume of lake ice cover was much lower than normal, which enhanced evaporation and led to a significant water level drop, as much as 1.3 meters. Lower water levels have a significant impact on the Great Lakes economy. For example, more than 200 million tons of cargo are shipped every year through the Great Lakes. Since 1998--when water levels took a severe drop--commercial ships have been forced to lighten their loads; for every inch of clearance that these oceangoing vessels sacrificed due to low water levels, each ship lost US$11,000-22,000 in profits.*

There is considerable uncertainty regarding future water levels on the Great Lakes. Angel and Kunkel (2010) report that an output of 565 model runs from 23 Global Climate Models were applied to a lake-level model. Under the A2 ("high emissions") scenario, median changes in lake levels were -.41 meters; under B1, the median drop was -.25 meters. However, the range in lake levels projected by the various models was considerable, leading to high uncertainty about future lake levels.

Hayhoe et al. (2010) note that expected increases in precipitation may offset increases in temperature, leading to uncertainty about water levels, at least by the middle of the 21st century: "Competing effects of shifting precipitation and warmer temperatures suggest little change in Great Lake levels over much of the century until the end of the century, when net decreases are expected under higher emissions."

The Wisconsin Initiative on Climate Change Impacts (WICCI 2011) notes that the Great Lakes have historically experienced both high water and low water decades. According to WICCI, climate change could potentially create both high and low water decades that exceed normal decadal variations. The report suggests that ports and marinas may need to take the possibility of greater fluctuations into account when designing and building new infrastructure. In addition, WICCI posits that lower water levels could force cargo vessels to carry lighter loads.

According to Cruce and Yurkovich (2011), "Great Lakes shipping is very sensitive to lower lake levels as an annual mean or during periods of seasonal variation." A 1,000 foot vessel loses 270 tons of capacity per inch of lost draft, which equates to about $30,000. Low water levels between 1997 and 2000 forced shippers to reduce cargo tonnage by 5% to 8%. According to Cruce and Yurkovich, research conducted by Millerd (2007) at Wilfrid Laurier University indicates that falling water levels are expected to increase operating costs by 1.9% to 7.4% by 2030, with costs projected to rise to between 13.3% and 26.7% by the end of the century. Subsequent research by Millerd (2011) places the estimated cost at between 5% and 22% by 2030. Cruce and Yurkovich also argue that falling water levels could damage port and marina infrastructure and increase dredging costs.

Cruce and Yurkovich note, however, that less ice on the St. Lawrence Seaway could present opportunities to shippers; since the 1980s, the annual amount of time in which the seaway is closed because of ice has dropped by about 10 days per year. A reduction in lake ice may partially offset some of the challenges associated with varying water levels. Warmer conditions, reducing lake ice, could result in more navigable days, which would benefit shippers.

Ongoing adaptation efforts

Chicago: The City of Chicago has a Climate Action Plan (CAP) (City of Chicago, 2008) which largely focuses on mitigation efforts. In particular, most of the plan elements related to transportation emphasize greenhouse gas reduction, including measures to promote transit-oriented development and alternative modes of transportation. However, the CAP explicitly addresses climate change impacts on transportation, noting that an increasing frequency of heavy precipitation events is likely to result in traffic delays and damage to infrastructure.

The bulk of adaptation measures related to transportation in the Chicago CAP involve stormwater management. The CAP calls for increased use of permeable paving surfaces, rain gardens, rain barrels and landscaping to reduce storm runoff. The City's Green Urban Design (GUD) plan includes measures to modify alleys to reduce runoff, and dozens of alley modifications have been implemented thus far.

Wisconsin: The Wisconsin Initiative on Climate Change Impacts (WICCI) released a report in 2011 which addresses potential impacts on both surface transportation and water transport. The report anticipates an increase in the frequency of transportation infrastructure damage and temporary flooding as a result of more frequent incidents of heavy rain.

The WICCI report highlights 2008 flooding on the Baraboo River as an example of vulnerability to high water conditions. According to the report, "the Wisconsin Department of Transportation is conducting a review of the vulnerability of the entire interstate highway system as a result of flood-triggered closures of I-39, I-90, and I-94 at the Baraboo River in Columbia County. Engineers will weigh the costs of flood-proofing stream crossings and embankments against the economic costs of temporary closures...."

In addition to stormwater impacts, the WICCI report also notes the need for additional research on potential material stress. In particular, WICCI suggests that projections of changes in freeze-thaw cycles could be used to predict changes in the useful life of concrete, with maintenance measures adjusted accordingly.

As in the Chicago CAP, the major adaptation elements related to transportation in the WICCI plan are those that address stormwater runoff. WICCI recommends open space preservation, Low Impact Design (LID) methods for paved surfaces, and green roofs to reduce runoff.

Iowa: The Iowa Climate Change Impacts Committee (ICCIC) was formed by an act of the Iowa General Assembly. In January 2011, the ICCIC issued a report on potential climate change impacts for Iowa.

The ICCIC report indicates that precipitation in Iowa has increased over the last 100 years and that the number of intense rain events has also increased. The report further asserts that certain places such as Cedar Rapids have seen greater increases than the state as a whole. In addition, the report states that streamflows have risen in recent years, and reports that streamflow projections conducted by researchers at Iowa State University indicate that increased precipitation could result in a 50% increase in streamflow in the Mississippi River basin. ICCIC concludes that these findings suggest that the risk of flooding is rising.

The report does not focus extensively on the relationship between climate change and transportation infrastructure, but it does note that higher temperatures increase the risk of road buckling and that increased precipitation and stream flow would increase the risk of washed out roads and bridges.

Michigan Department of Transportation:

MDOT has conducted an analysis of potential challenges related to climate change and has developed a menu of potential responses. MDOT staff presented their analysis at an April 2011 webinar conducted by the Transportation Research Board of the National Academies (Johnson, 2011).

The main areas of concern for MDOT are the possibility of more intense storms and hotter, drier summers. Methods for adapting to more intense storms include using larger hydraulic openings for bridges, armoring of ditches to prevent erosion, installation of higher capacity pumps to ensure that drainage systems are not overwhelmed, and use of intelligent transportation systems (ITS) that help motorists adapt to changing traffic conditions. Methods for adapting to hotter and drier summers include intensifying monitoring of pavement conditions during extreme heat periods and encouraging more night work to prevent premature cracking.

Federal Highways Administration (FHWA):

FHWA is undertaking at least two initiatives to help Midwestern states prepare for challenges associated with climate change. These include updated flood frequency hydrographs and peer learning events.

Precipitation Frequency Analysis: State departments of transportation use precipitation frequency graphs to develop design standards for culverts and other hydraulic structures. These design standards are promulgated by a state DOT to ensure that adequate drainage capacity exists for roads built in the state. Basing design standards on current precipitation frequency data is an important adaptation measure because using updated information reduces the risk of road closures or infrastructure damage due to heavy precipitation. Unfortunately, in some parts of the country, rainfall maps have not been updated for decades.

FHWA is currently conducting a pooled fund program through which state DOTs can contribute funds to update precipitation estimates (Transportation Pooled Fund Program, 2011). In the Midwest, contributors to the pooled fund include the transportation departments of the following states: Colorado, Iowa, Kansas, Minnesota, Missouri, Nebraska and South Dakota. The study uses updated information from NOAA to determine annual exceedance probabilities (AEP) and average recurrence intervals (ARI) for durations ranging from 5 minutes to 60 days and for ARIs from 1 to 1,000 years. Point estimates will be spatially interpolated to a spatial resolution of approximately 4 km × 4 km.

Peer Learning: FHWA hosts peer learning events for Metropolitan Planning Organizations (MPOs) and state departments of transportation. An exchange held in May 2011 included MPOs and DOTs from the Midwest.

The final report from these sessions includes input from state and local planning officials (ICF International, 2011). Representatives from MPOs identified county hazard mitigation planning efforts as a vehicle for climate change adaptation planning. Barriers to adaptation include the lack of inter-agency collaboration and the lack of localized climate data.

The state DOT session focused on the possibility of more frequent heavy precipitation events, which could cause more bridge scour, and which could also make current culverts and drainage systems inadequate. Presenters stated that more frequent incidents of heavy precipitation could overwhelm drainage systems, leading to an increased risk of roadway flooding.

One presenter argued that an asset management approach to infrastructure maintenance and design should be considered an effective adaptation measure. Transportation asset management consists of continually monitoring the condition of assets such as roads, bridges and culverts using geographic information systems (GIS) and other tools. Assets considered critical to system performance are identified, as is the required level of service. These considerations inform investment strategies and long-term funding strategies.

By conducting peer exchanges such as these, FHWA is providing technical assistance to state and local planners who will be making adaptation decisions for transportation systems. Transportation asset management and integration with hazard mitigation plans are two useful ideas to come from the Indianapolis sessions.

Research needs

Three main research needs emerge from the foregoing summary. First, there is a need to quantify impacts of climate change on transportation for the Midwest region, and for specific communities in the Midwest. Second, there is a need to model the effectiveness of adaptation options. Third, there is a need to integrate uncertainty into decision making about adaptation options.

Quantifying impacts

Although there is a qualitative understanding of the types of impacts that might exist under climate change scenarios, there is little peer-reviewed literature that quantifies transportation impacts in the Midwest. The area of Midwestern transportation that has had the most quantitative analysis has been Great Lakes shipping, where researchers have been able to measure likely changes in cargo capacity due to falling water levels.

Analysis at this level has not been performed for surface transportation or rail in the Midwest. For example, it is reasonable to conclude that an increase in the number of days per year over 95°F will increase material stress on pavement and rail. A useful next step would be to quantify the potential damage in terms of a pavement condition index, useful life or cost of maintenance.

To pick another example, it is reasonable to expect that flooding of roadways may increase due to changing precipitation patterns. But it would be useful to quantify the impacts in terms of vehicle miles of travel (VMT) or vehicle hours of travel (VHT). Tallying the cost of lost shipping days on the Ohio and Mississippi Rivers would also be of benefit.

Adaptation effectiveness

There is now a rich literature on adaptation measures being undertaken. But there is a strong need for additional work that models the effectiveness of different adaptation options. In particular, there is a widespread understanding of the connection between stormwater management and transportation, with a realization that reducing runoff can also reduce flooding on roadways. Needed is a way to measure the effectiveness of different options. Modeling the effectiveness of different options, including permeable paving surfaces, open space preservation and rain gardens, would allow a more robust cost-benefit analysis, which would inform policy and planning at the local level.

Uncertainty

The presence of uncertainty raises serious problems for decision makers. The issue of water levels on the Great Lakes is a good example. There is much uncertainty about future water levels, and there is even a possibility that water levels could rise during some years of the next century. Given the uncertainty, how can decision makers determine optimal adaptation strategies?

An approach to risk management known as Robust Decision Making (RDM) has entered the literature on transportation and climate change. The concept was introduced to the study of climate change adaptation by Lempert and Schlesinger (2000), who drew a distinction between prediction-based approaches and "robust" approaches to risk management. Predictive approaches attempt to determine the most likely scenario, and to design a management response that optimizes outcomes under a specified condition. By contrast, the RDM approach is useful for situations in which there is "deep uncertainty" about future conditions. In such a situation, according to Lempert and Schlesinger, the best solution will be one that provides acceptable outcomes across a wide range of possible scenarios. In RDM, the use of mathematical models to project outcomes under different scenarios is a key tool.

Schwartz (2011) applies this approach to the study of transportation adaptation, arguing that robust strategies "encompass structural, operational, and institutional options." Schwartz describes RDM as an approach that incorporates multiple views of the future, uses robustness across multiple scenarios rather than optimization as a decision criterion, and allows iterative ability to assess and adjust to vulnerabilities. Schwartz uses as an example a coastal community facing a rise in sea level and storm surge. Even if a reasonable degree of confidence exists with respect to the long term trend, the timing and amount of sea level rise remains highly uncertain. In this situation, the most robust strategy may not be to simply retrofit all existing assets. Rather, a more cost-effective approach may be to continually monitor changing conditions, rebuilding only critical assets when sea levels reach a critical height.

Another example of a possible application of RDM to transportation planning is the uncertainty over water levels in the Great Lakes. Although many models project falling water levels, the range of projections is so great that it would be risky to make major investment decisions based on optimization for a single scenario. Given the deep uncertainty, it may be rational for designers of ports, marinas, and perhaps even cargo vessels to consider performance across a range of possible water levels. Additional research on performance of adaptation measures across a range of scenarios would give policy makers the tools with which to evaluate proposed options.

Conclusions

Following is a summary of key impacts, with an assessment of the level of confidence associated with each.

Medium Confidence:

- There is a rising risk of disruption of Mississippi River navigation. Given that flooding impacts are already significant, have grown in recent decades, and are projected to continue growing, the assignment of medium confidence to these impacts seems reasonable.

- There is a rising risk of temporary flooding of roads and rails due to both riverine flooding and ponding. This assessment is based on recent increases in the frequency of intense precipitation events, projected increases in the frequency of intense precipitation events and projected increases in winter and spring precipitation in the Mississippi River basin.

- There is a rising risk of disruption to Great Lakes navigation due to variability in water levels. Recent economic impacts of falling water levels have been well documented, and projections indicate that variability is likely to increase over the next century.

- Warmer temperatures will increase rail and expansion joint stress and decrease pavement life.

- Warmer temperatures will create more difficult conditions for construction labor.

Low Confidence:

Although it is reasonable to hypothesize that the following impacts may occur, there is currently insufficient quantitative data with which to assess the likely severity of these impacts:

- Warmer air temperatures and increased frequency of extreme weather and heavy winds may disrupt air traffic.

- Faster stream currents caused by an increase in heavy precipitation events may result in increasing severity of bridge scour, which could affect both rail and highway travel.

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