Potential Impacts of Climate Change on Freight Transport

By **Harry Caldwell, Kate H. Quinn, Jacob Meunier, John Suhrbier, and Lance Grenzeback**

Introduction

This paper presents the results of a preliminary scan of potential impacts that global climate change may have on the movement of freight, examining implications for the physical facilities and infrastructure and also the patterns or demand for the shipment of freight. Climate change scenarios used by the National Assessment Synthesis Team in preparing its *Climate Change Impacts on the United States* report suggest that during the course of the 21st century the temperature on Earth is likely to warm in the range of three to 10 degrees Fahrenheit. As a result, evaporation will increase, ice melt and precipitation will intensify, sea levels will rise, and weather patterns are expected to become more variable.

In the United States, as in other countries, these kinds of effects resulting from climate change could have important impacts on the movement of freight by all modes: road, rail, air, and water. While some of the effects of global warming on freight transport are likely to be positive, such as fewer delays and crashes attributable to snow and ice in wintertime, others are likely to be negative, such as more frequent flood and storm damage to long-established port facilities. Mitigation can be accomplished by far-sighted planning and steady, long-term investments.

After a brief overview of the current state of the nation's freight transport system, this paper summarizes likely impacts on freight transport that could result from climate change-related environmental changes that are projected to occur over the next 100 years.

Freight Movement in the United States

The United States freight transport system comprises a vast network of roads, airports, railroads, waterways, terminals, ports, and pipelines. This network includes 161,000 miles on the National Highway System, 46,000 miles of Interstate Highways, 3.8 million miles of other roads, 800 major airports, 170,000 miles of freight railroads, 26,000 miles of navigable waterways, 10,000 commercial waterway terminals, and 1.4 million miles of oil and gas pipelines. Many of these facilities, especially intermodal ports, are sited in low-lying coastal areas, reflecting the historical importance of water access to the movement of freight. In the future, however, their location may prove as much a liability as an asset, since many global climate change models forecast an increase in flood frequencies and elevations.

To describe the movement of goods over the transportation network, several sources and types of freight data are available. One such source is the TRANSEARCH® database, which includes all domestic moves by truck, rail, air, and water, and is linked to a set of commodity-specific forecasts. Based on this source:[1]

- The nation's freight system moved 14 billion tons of domestic freight valued at \$11 trillion over 4.5 trillion ton-miles in the year 2000. Figure 1 shows the share of tons, ton-miles, and revenue dollars for each mode.

- Trucks moved 78 percent of the nation's domestic freight tonnage, generated 60 percent of its ton-mileage, and accounted for 88 percent of its dollar value, the highest percentage in each category. Trucks moved 11 billion tons valued at $9.5 trillion over 2.6 trillion ton-miles in 2000.

- Rail moved 16 percent of total domestic freight tonnage, second to truck. Rail moves tended to be longer in distance than truck moves and therefore accounted for a proportionately higher share (28 percent) of ton-miles. Rail moves also tended to involve lower-value commodities than truck, so rail represented a proportionately lower share (six percent) of total domestic freight value. Rail moved two billion tons valued at $600 billion over 1.2 trillion ton-miles in 2000.

- Air represented a negligible share of tonnage and ton-miles, but a disproportionately high share of value, five percent. Airfreight tends to be very light and valuable.

- Water (e.g., river barges and coastal and lake steamers) moved six percent of tonnage, 15 percent of ton-miles, and one percent of value. These figures cover only domestic waterborne tonnage. Like rail, water moves tended to be longer in distance and lower in value than truck moves. Domestic shipping moved one billion tons valued at $138 billion over 540 billion ton-miles in 1998.

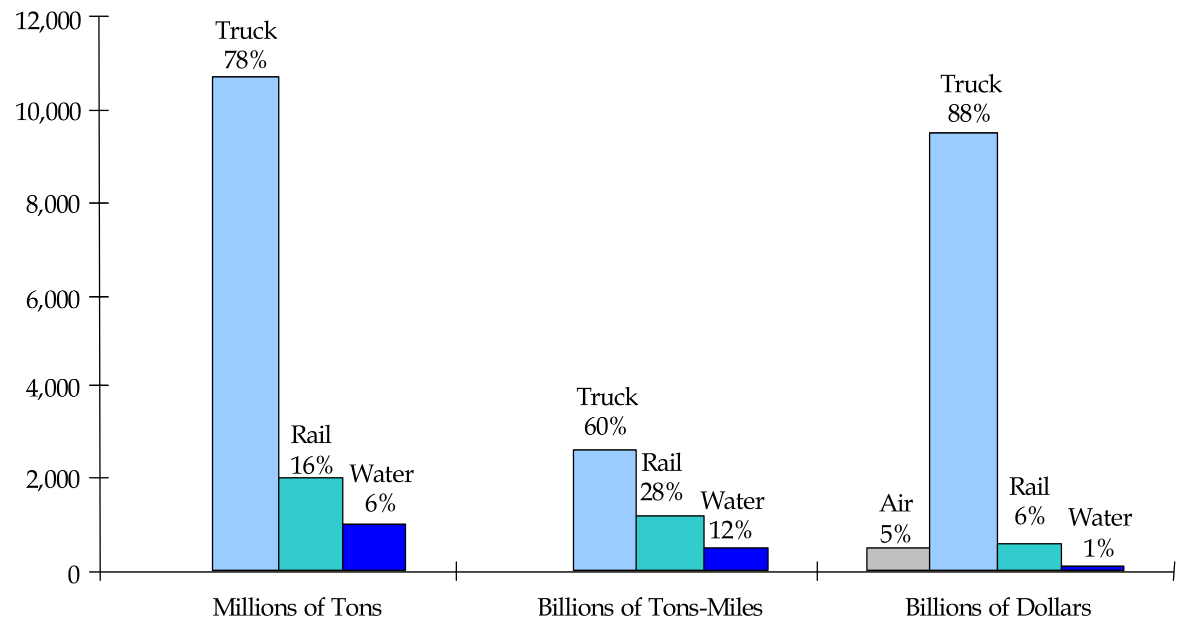

Figure 1. *U.S. domestic freight movement, year 2000. Source: Reebie Associates' TRANSEARCH and U.S. DOT Freight Analysis Framework Project, unpublished data.*

A useful source for data pertaining to international waterborne commerce is the U.S. Army Corps of Engineers (USACE) Navigation Data Center which compiles statistics on freight moved on United States waters. According to the USACE, in 1999 foreign waterborne commerce (imports and exports) totaled 1.3 billion tons valued at $631 billion. While comparable statistics for foreign airborne cargo shipments are not readily available, the Bureau of Transportation Statistics Reports that 13 of the top 50 foreign trade freight gateways by value of shipments were airports, with a combined value of $426 billion.

Each of the four freight modes offers certain advantages and disadvantages in terms of cost, speed, reliability, visibility, and security, with shippers buying freight services that best fit their specific shipping needs. Figure 2 shows the spectrum of freight transport services with the approximate cost per pound and key service characteristics. For example, package and express shippers favor air and truck because these modes offer the fastest and most reliable door-to-door service for lightweight shipments. The cost is high, but customers are willing to pay for the high quality of the service. In contrast, shippers of bulk commodities like coal, grain, and petroleum prefer to use water or rail. These modes offer less speed and reliability, but provide transportation at a far lower unit cost, which makes these commodities affordable across the nation. Figure 3 compares average trip length by mode. Average trips are longest for air at 1,070 miles, followed by rail (617 miles), water (511 miles), and truck (247 miles). Figure 4 compares average value of cargo by mode, showing the very high value of air cargo compared to freight shipped by other modes. Cargo shipped by air is valued at almost $61,000 per ton, compared to $890 per ton for truck, $304 per ton for rail, and $131 per ton for water.

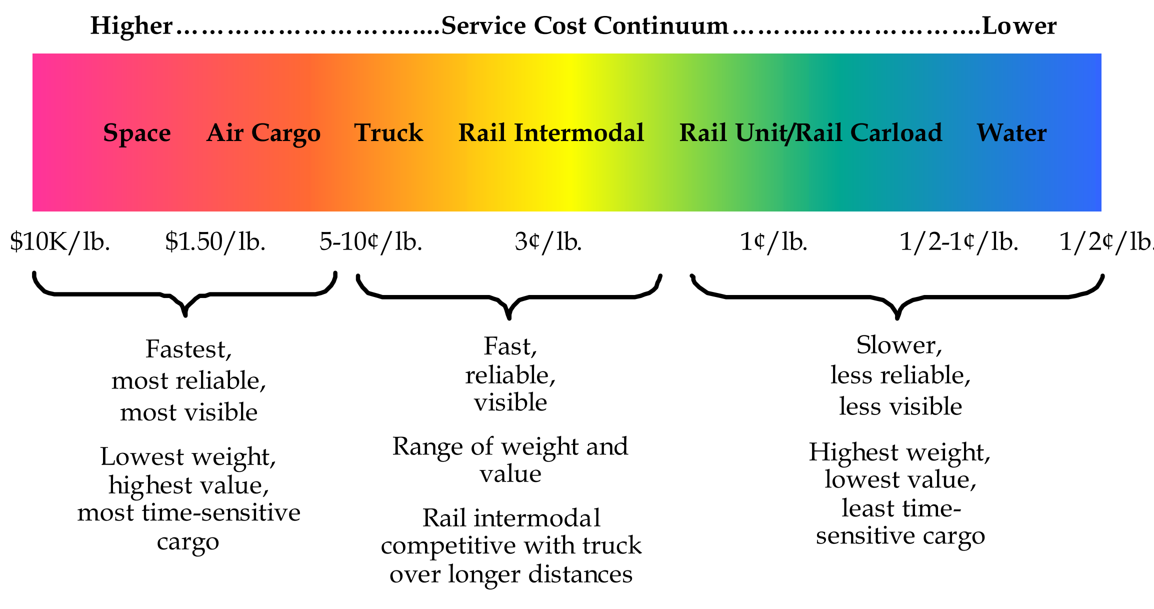

Figure 2. *Freight transportation "service spectrum."*

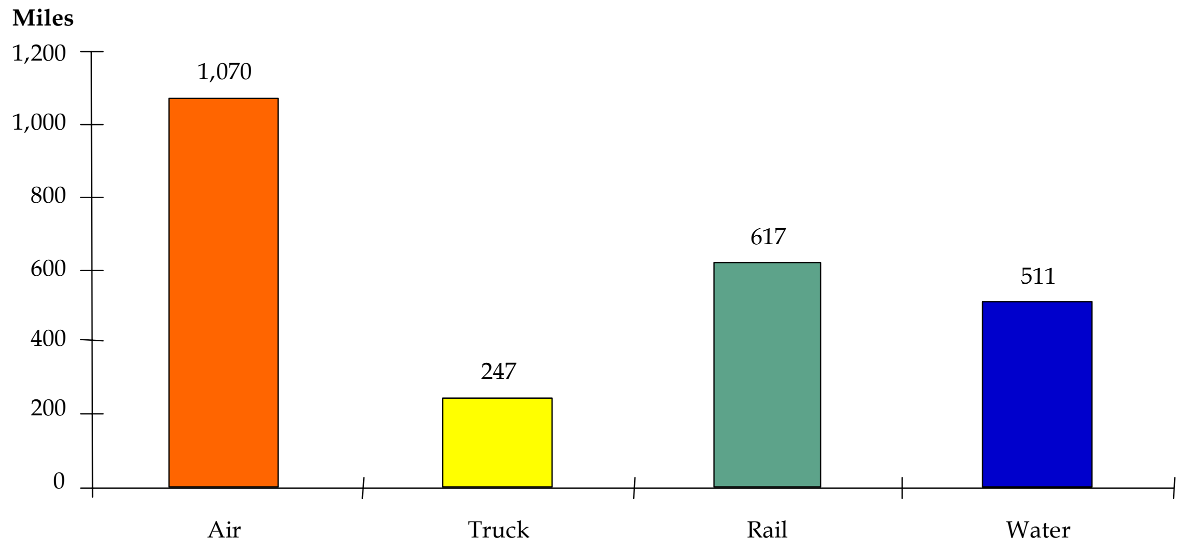

Figure 3. *Average length of trip by mode in miles, year 2000. Source: Reebie Associates' TRANSEARCH and U.S. DOT Freight Analysis Framework Project, unpublished data.*

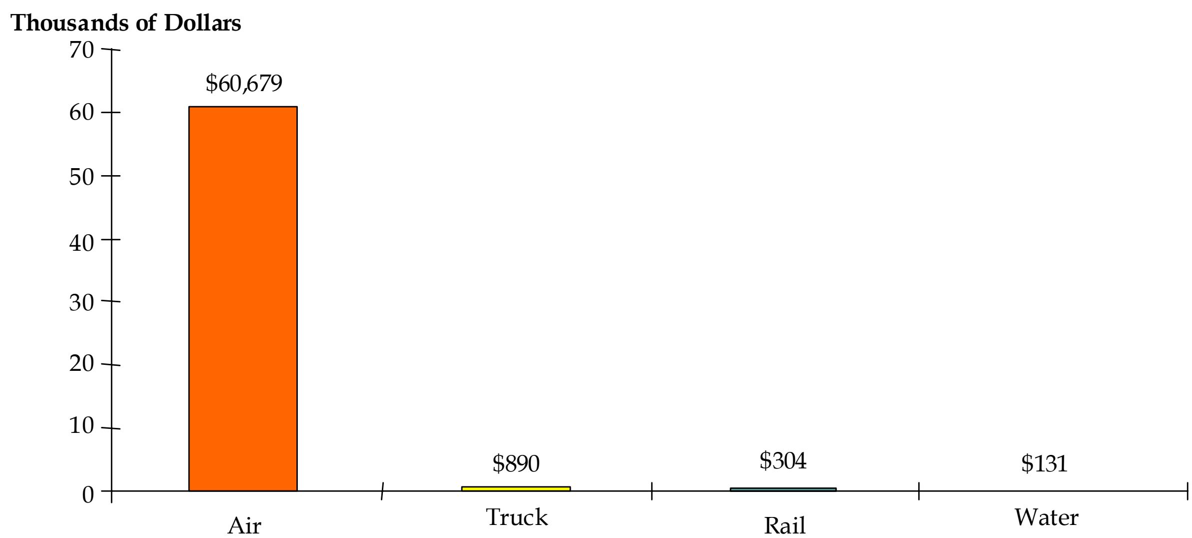

Figure 4. *Average value per ton of cargo, year 2000. Source: Reebie Associates' TRANSEARCH and U.S. DOT Freight Analysis Framework Project, unpublished data.*

In examining the potential impacts of climate change on freight transport, it also is useful to examine the growth in freight movements over time. Freight always has been an important underlying driver of the economy. This continues to be the case today, especially with the increasing globalization of national economies.

Demand for freight transport in the United States has grown rapidly in recent years. Over the past four decades, domestic freight movements by air, rail, road, and water have increased nearly two and a half times, reaching a record 3.8 billion ton-miles in 1999 (Figure 5). Over the same period, the combined (real) dollar value of inbound and outbound freight flows crossing United States land and sea borders has increased tenfold (Figure 6). If one takes a truly long-term perspective on imports and exports, the increases become even more impressive. Between 1860 and 2000, the real dollar value of inbound and outbound commodities – excluding those moving by air – increased 136 times (Figure 7).

This growth is projected to continue into the future. Based on the U.S. DOT's Freight Analysis Framework, the value of cargo handled by the United States transportation system is projected to reach $30 trillion per year by 2020. Air and truck modes will experience the fastest increases. Domestic air cargo tonnage is projected to nearly triple. Trucks are expected to move over 75 percent more tons in 2020, and to capture a somewhat larger share of total tonnage. International trade is estimated to grow faster than domestic trade, presenting particular challenges to United States ports and border gateways.

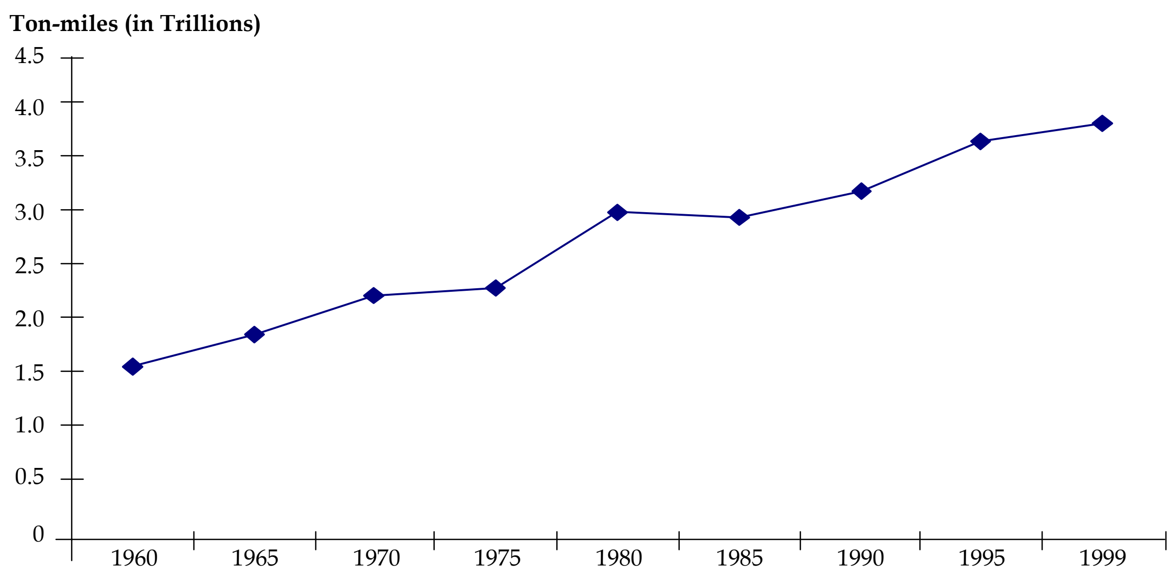

Figure 5. *Domestic freight movement, 1960-1995. Source: Bureau of Transportation Statistics, National Transportation Statistics 2001 (Washington, D.C.: U.S. Department of Transportation, 2002).*

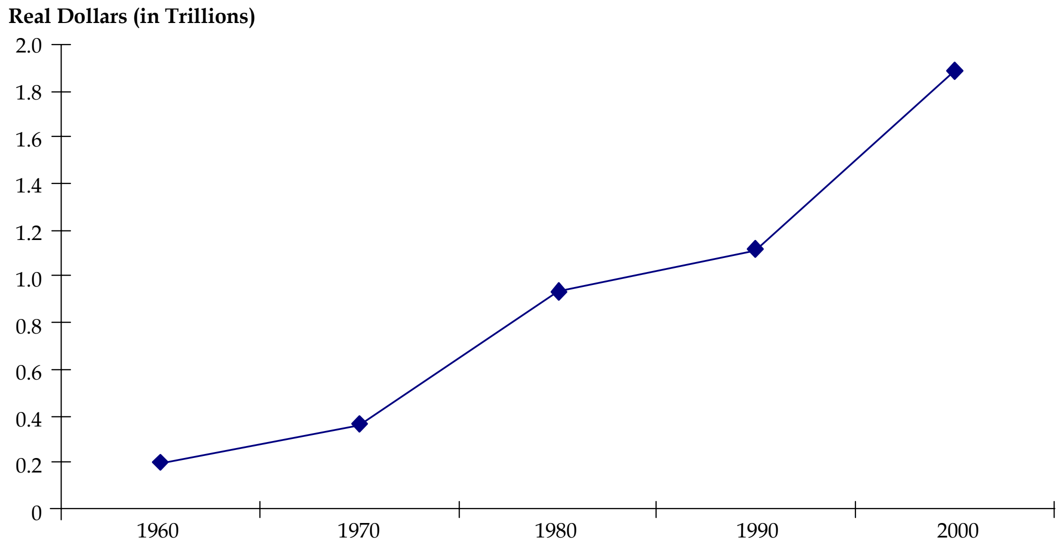

Figure 6. *Merchandise imports and exports (combined), 1960-2000. Source: U.S. Bureau of the Census, selected Statistical Abstracts of the United States, 1971-2001.*

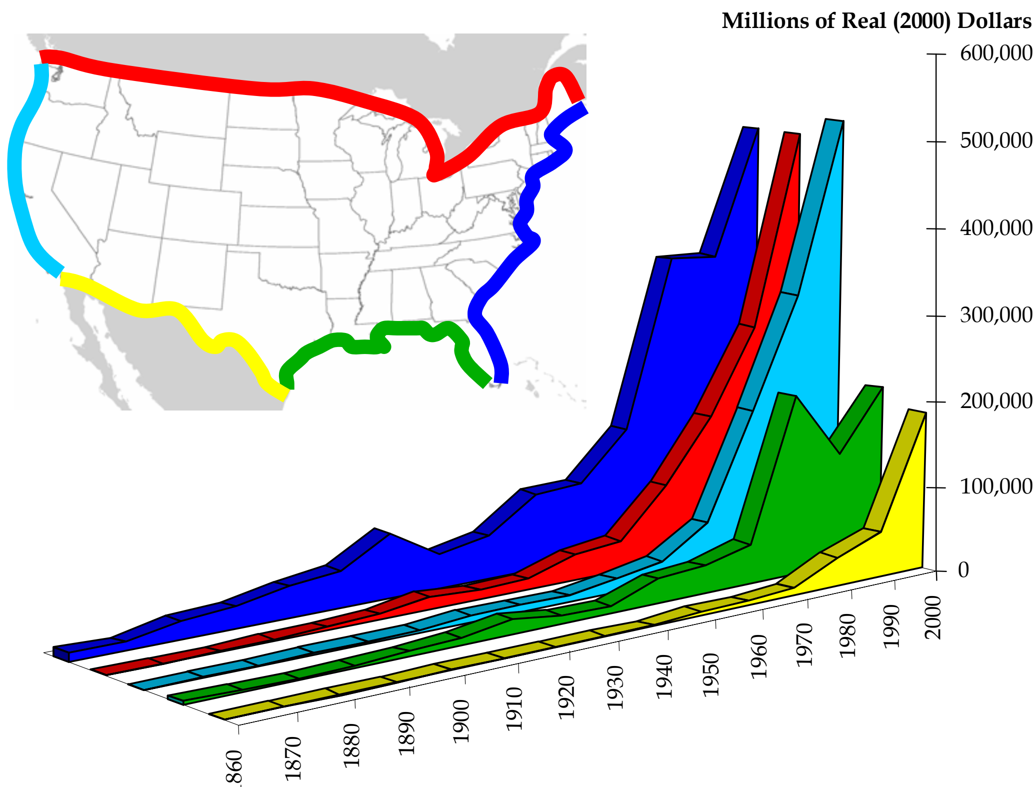

Figure 7. *Growth in value of imports and exports from 1860 to 2000 by U.S. coast and border regions. U.S. Bureau of the Census, Historical Statistics of the United States, Colonial Times to 1970, Series U 264-2 U.S. Bureau of the Census, Statistical Abstracts of the United States, 1971 – 2001.*

A Changing Climate

Developing an understanding of the impacts of climate change on freight transport first requires an understanding of how different regions within the country may be affected by long-term changes in climate. While estimates vary, a general consensus has emerged within the scientific community that temperatures worldwide could rise by three to 10 degrees Fahrenheit by the year 2100. This would constitute a rapid acceleration of the warming trend that began in the twentieth century. Indeed, a nine degree increase over the next 100 years would be roughly equal to the increase since the peak of the last ice age 18,000 years ago.

Generally speaking, regions that now experience the coldest temperatures, such as Alaska, will see the greatest warming. Higher temperatures will cause evaporation rates to increase as well, which is likely to reduce soil moisture during the warm season in many parts of North America.

Continuing a trend already observed in the late twentieth century, weather patterns are projected to become *more variable* as a result of global warming. In some areas, overall precipitation is projected to increase, although not enough to offset the increase in evaporation. Across the United States, precipitation is likely to occur in heavy, extreme events (downpours and snowstorms). Winter snowfall and periods of extreme cold are very likely to decrease, while the frequency of very wet and very dry conditions is likely to increase.

Sea levels, which are already rising at a rate of one foot per century along the mid-Atlantic and Gulf coasts due to polar ice melt and thermal expansion, are very likely to rise one to three feet by 2100. However, most models project that the water level of the Great Lakes is likely to *fall* three to six feet due to increased summertime evaporation. This would constitute a net loss of about 15 percent of the Great Lakes' water supply.

Floods and forest fires are likely to become more frequent and severe. Crop and forest productivity (especially hardwood) will probably increase in some areas, but the increases may not persist through the century if temperatures rise too high or too quickly. Changes in the distribution of plant species are also likely, affecting crop and forest diversity and productivity.

Impacts on Transport

The impacts of global warming on freight transport are likely to result in changes in the origins from which freight is shipped and also affect the design, safety, operations, and maintenance of the physical infrastructure used to move freight, with water and temperature the main agents of change.

Physical Infrastructure – Water-Related Impacts

A greater number of extreme weather events – hurricanes, snow storms, ice storms, floods, etc. – will increase damage to infrastructure used for the movement of freight. Each year, state and local transportation agencies spend an estimated five billion dollars repairing roads, bridges, and other infrastructure damaged by snow and ice.

The most serious and costly water-related impacts of climate change are likely to be coastal flooding that would result from increased flood frequencies and flood elevations. The risk of damage to low-lying port facilities, locks, airports, roads, rail lines, tunnels, pipelines, ventilation shafts, and power lines is particularly great because of the large number of fright facilities – international gateways in particular – that are concentrated on the Atlantic, Pacific, and Gulf Coasts and along inland waterways (Figure 8).

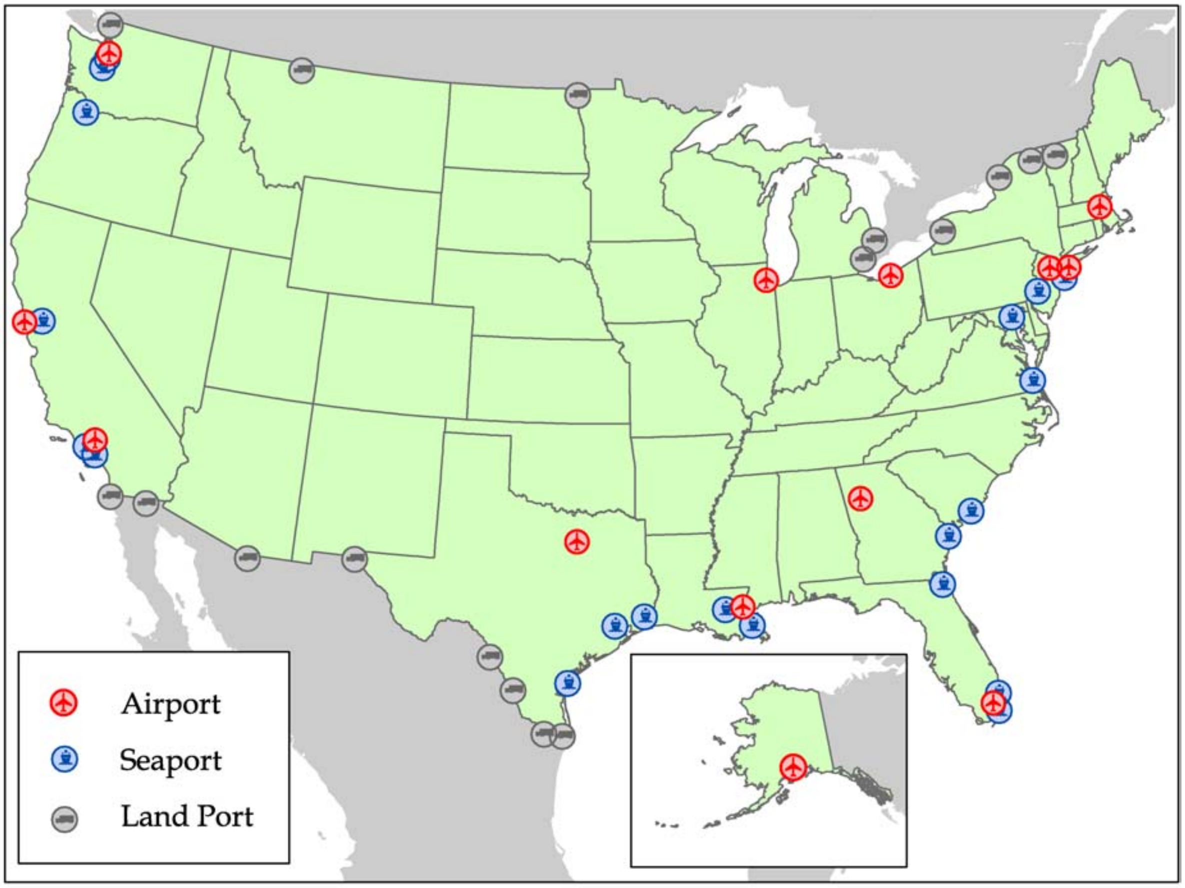

Figure 8. *Map of top United States foreign trade freight gateways by value of shipments (Year 1998). Source: Bureau of Transportation Statistics, National Transportation Statistics 2000 (Washington, D.C.: U.S. Department of Transportation, 2001), 66-67.*

The transport infrastructure of low-lying port cites, such as New York, Boston, Charleston, Miami, New Orleans, Texas City, San Jose, and Long Beach, could be particularly at risk. For example, New York's La Guardia Airport, which is less than seven feet above sea level, already maintains a dike and pumps for floodwaters. Newark International and John F. Kennedy International Airports are about 10 feet above sea level. In 2000, JFK was the country's largest foreign trade gateway measured by value. Building higher retaining walls around flood-prone airports is generally not a viable option, as these would interfere with aircraft takeoff and landing.

At least four New York tunnels – the Lincoln, the Holland, the Queens Midtown, and the Brooklyn Battery (the longest continuous underwater vehicular tunnel in North America) – are also potentially subject to flooding, depending on the extent of sea level rise and storm surges. Several key freight rail facilities in New York City are also vulnerable to the effects of rising sea levels and storm surges, including the Greenville Yard, the Harlem River Yard, the Oak Island Yard, and the Express Rail Terminal. In all, New York City has nearly 600 miles of waterfront, nearly all of which could face flood and storm damage.

Transportation facilities on the Gulf Coast are already prone to storm surges and flooding. On an annual basis, Louisiana, Florida, and Texas are the top three states in the nation in terms of the damage they suffer due to hurricanes and floods. Given the large number of facilities on the Gulf Coast dedicated to oil and gas production, distribution, and processing, the impact of climate change on United States energy supply could be dramatic. Two-thirds of the nation's imported oil shipments enter through facilities in Texas and Louisiana. These same two states produce one-quarter of the nation's domestic oil and gas supplies from 4,000 offshore production platforms.

Inland freight facilities are also at risk (Figure 9). River flooding, rainstorms, and snowstorms are likely to affect key roadways, rail lines, and intermodal terminals. Chicago, the nation's largest rail hub, is projected to suffer more frequent extreme weather events, although the effects of these may be mitigated by milder winter weather.

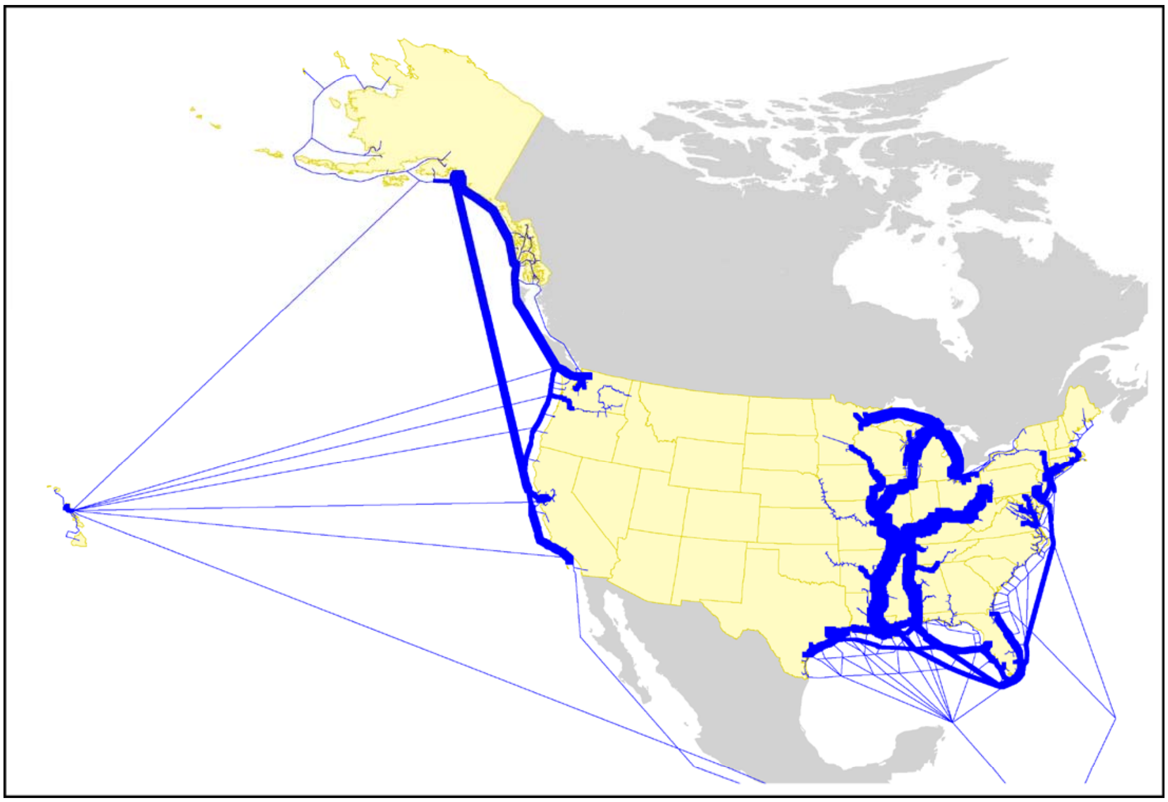

Figure 9. *Map of inland and coastal water-freight flows, year 2000. Source: Reebie Associates' TRANSEARCH and U.S. DOT Freight Analysis Framework Project, unpublished data.*

The impact of climate change on the Great Lakes and St. Lawrence Seaway could be particularly dramatic. On the one hand, milder winters could lengthen the ice-free shipping season by several weeks, increasing vessel utilization and reducing the costs of ice-breaking. On the other hand, falling water levels on the lakes will decrease water depths, necessitating shallower draft vessels, and therefore less tonnage capacity per trip. Per *inch* of lost draft, a 740-foot ocean going vessel loses 100 tons of capacity, and a 1,000-foot bulk carrier loses 270 tons of capacity. By some estimates, Great Lakes shipping costs could increase by 30 percent due to decreased water levels resulting from climate change. Past instances of low water levels on the Great Lakes hint at the seriousness of the problem. Most recently, in 2000, low water levels forced carriers into "light loading," reducing their cargo tonnage by five to eight percent.

Harbor and channel dredging, the usual means of mitigating the effects of low water levels, will not be easy in the Great Lakes; deepening channels below the 27-foot project depth will require an authorization and appropriation from Congress. It will also have serious environmental impacts, because in some areas lakebed sediment is contaminated with mercury, PCBs, and heavy metals that if disturbed will become suspended in the water. In others areas, rocky bottoms will require blasting. On the St. Lawrence Seaway, the problem of decreasing draft will be no less acute, especially if the level of the Great Lakes falls as the level of the Atlantic rises. The decreasing disparity between water levels in the Great Lakes and the ocean would cause the flow of water through the seaway to diminish, and with it its ability to "self-scour." If lake levels fall as much as some predictions suggest, a modal shift from water to rail or truck would be likely. While this might be good news for road and rail haulers, the maintenance costs on highways and rails would likely increase, given the heavier and bulkier loads traditionally carried by barge.

Rising ocean levels and declining flows could also pose problems on the Mississippi River system, which handles a large percentage of the country's bulk commodities, such as grain and coal. The result would be more water diversions and salt intrusion, and possibly the disappearance of much of the Mississippi Delta. This would necessitate a new shipping outlet to the Gulf. Droughts and floods would also disrupt traffic on the Mississippi. In 1988, low water levels prevented the movement of 800 barges in the river for several months. In 1993 and 1997, flooding again disrupted barge traffic and prevented ships from reaching the port of New Orleans for several days.

Global climate change is likely to require reengineered freight facilities that are better able to withstand storm surges and flooding. For example, stronger, higher, corrosion- and scour-resistant bridges will be needed in areas subject to storm surges and salt water contamination. Lift-on/lift-off port facilities may replace roll-on/roll-off port facilities in harbors that experience unusually large tidal variations. Protective structures and water removal systems will be needed for road and rail tunnels subject to flooding. Global warming also could necessitate changes in the *location* where new infrastructure is built. For example, if the origin of farm and forest product shipments shifts as their optimum growing regions change, demand for new roads and rail lines would also shift.

Physical Infrastructure – Temperature-Related Impacts

The temperature-related impacts of global climate change are also likely to be significant. At northern latitudes, permafrost degradation is a major concern. In Alaska, melting permafrost is already causing entire stands of trees to list at odd angles, a phenomenon that Alaskans have dubbed "drunken trees." The softening ground is causing pavement and tarmac to buckle, disrupting some freight movements moved by road, rail, and air. Because frozen pavements are less susceptible to damage by trucks, they are legally allowed to carry 10 percent heavier loads. Warmer winters will reduce the time this exception is permitted. The impact will be felt most acutely in Alaska, which relies heavily on the structural integrity of frozen roads and has a freight rail network less than 500 miles long.

In contrast, ocean borne freight moving at far northern latitudes may benefit from rising temperatures. Perhaps as early as 2015, the Northwest Passage may be sufficiently free of ice during the summer months to allow container ships and oil tankers to take the Arctic route rather than the Panama Canal, saving nearly 5,000 nautical miles of travel. For vessels that are too wide to fit through the Panama Canal, the lure of the Northwest Passage will prove even stronger.

At lower latitudes warmer temperatures are also likely to have important consequences for freight movement. While warmer winters could reduce the need for salting and plowing, thus increasing pavement life, impact of wider temperature swings and more frequent freeze/thaw cycles, which are likely to cause buckling and heaving of pavement, rail lines, and pipelines, will be far greater. Very warm temperatures (above 90 or 100 degrees Fahrenheit) can cause "sun kinks" in rail lines and "blowups" along cement pavement expansion joints. In the summer of 2002, for example, a passenger train derailment outside Washington, D.C. that injured 100 people was blamed on heat-stressed rails, which expanded to the point that pressure forced them out of alignment. It is common for sun kinks to suddenly appear ahead of a train, leaving engineers with no time to stop. As a precautionary measure, CSX, the owner of the track, imposed temporary speed restrictions on the line. Such restrictions could become more common if summertime temperatures frequently climb into the 90s, increasing the risk of track distortion.

Global climate change is likely to increase demand for reengineered freight facilities that are better able to withstand heat. For example, deliberately heating rails to more than 100 degrees before they are installed, a common practice in Florida, makes them less susceptible to distortion. New roadway construction techniques and materials could also be used to prevent pavement blowup.

Safety, Operations, and Maintenance

Climate change is likely to affect freight-related safety, operations, and maintenance in a number of ways. More frequent icing and extreme weather events could significantly reduce safety while increasing delays and maintenance costs. Today, approximately 16 percent of commercial vehicle crashes occur on wet or frozen pavement. Snow and ice control accounts for 39 percent of road operating costs, costing state and local agencies over $2.3 billion annually. In 1999, fog, snow, and ice were the most frequent causes of non-recurring traffic congestion, accounting for nearly one-quarter of all delays in 1999. If precipitation in the form of ice rather than snow becomes more common, maintenance costs could rise. More frequent freeze/thaw cycles could similarly drive up the cost of operations and maintenance.

Warmer summer weather will also have important implications for safety, operations, and maintenance. First, it will make the need to refrigerate perishable goods all the more critical. Second, it will reduce engine combustion efficiency. This will place a particular burden on air carriers because aircraft will require longer runways or lighter loads. Third, on extremely hot days it will preclude certain maintenance efforts that require prolonged outdoor exposure.

If there is a general push to reduce carbon dioxide emissions, the fuel efficiency of heavy- and light-duty trucks could come under closer scrutiny. This could affect both long-distance haulers and urban delivery companies. Cargo planes and other aircraft could also be subject to tighter environmental regulation; at high altitudes, aircraft emissions have a greater impact on ozone levels than emissions on the ground.

Water operations are likely to become more expensive and less reliable. Not only will an increase in extreme weather events create more frequent disruptions in service, it will cause sediment shifts in channels, increasing requirements for dredging. Rising sea levels will reduce bridge clearances and the effectiveness of roll-on/roll-off port facilities at high tide. "RO-RO" facilities, such as those at the ports of New York/New Jersey, Baltimore, and Jacksonville, are used primarily for loading and unloading shipments of automobiles, farm equipment, and military equipment.

Finally, the timing and demand for freight services is likely to shift as a result of global climate change. For example, coal shipments may decline as cleaner forms of energy are substituted. This would have serious consequences for the freight railroads, which carry virtually all of the coal mined in the U.S.. Coal accounts for 41 percent of tonnage moved by rail and about one-quarter of the revenues of Class I railroads. Heating oil and liquid natural gas shipments might also decline as winter heating needs lessen. In contrast, agricultural shipments are likely to rise as longer growing seasons make multiple harvests in a single year more common. Timber shipments (particularly hardwood) may also rise. The spatial pattern of agricultural production is also likely to change, causing demand for freight transportation in some regions of the United States to increase and in other regions to decline.

Conclusion

This preliminary scan suggests that the impacts of climate change on the transport of freight could be quite significant, influencing both shipping patterns and the facilities used to move this freight. Intermodal freight facilities and shipping routes located in coastal areas are particularly vulnerable. However, pavement design and maintenance requirements could change in any part of the country that is subject to an increase in the number of freezing and thaw cycles.

Rising temperatures are likely to change the mix of maintenance costs. In existing snow-belt states, precipitation may fall less frequently as snow and more frequently as sleet or freezing rain. In Sun Belt states, excessive summertime heat could have an effect on maintenance activities. Rising sea levels and an increase in extreme weather events could reduce reliability and threaten transport facilities in low-lying areas. Indeed, all modes of freight transport – road, rail, air, and water – are vulnerable to the effects of global climate change. If industries continue to move in the direction of just-in-time production and distribution, the economic consequences of disruptions in the transportation system become more acute.

An important question is how the transportation community responds to these potential changes. Based on the results of this initial scan, more intensive and focused freight transportation research is merited to better understand both the magnitude and the distribution of climate change impacts. At the same time and while still acknowledging the uncertainty in transportation-specific impacts that currently exists, selective initial policy and design changes can be made immediately. The knowledge and technology necessary for the freight sector to adapt to climate changes already is available. Moreover, given the time frame of the projected changes, adaptation strategies can be incorporated into normal life-cycle replacement plans. New or expanded intermodal freight facilities can be located in areas that are less vulnerable to the anticipated effects of climate change. Similarly, a bridge slated for replacement but also facing the possible threat of increased ocean storm surges could be rebuilt on the same location but several feet higher and of stronger materials. Alternatively, the possibility could be investigated of building on higher ground a few hundred yards inland, thereby diverting the road away from the coast.

In summary, it is not too early to begin incorporating the effects of climate change projections into freight planning. With foresight, the nation's freight transport network can continue to provide safe, reliable service regardless of what transformations are in store.

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[1]The data and forecasts reported were prepared for Cambridge Systematics, Inc., for use in the 2002 *AASHTO Freight Rail Bottom-Line Report*, by Reebie Associates using Reebie's TRANSEARCH® database and the DRI/WEFA/Global Insights economic forecasts.

Mr. Caldwell is the Chief of Freight Policy for the Federal Highway Administration, responsible for developing policy and legislative strategies to promote freight and international trade transport. He conducted the readiness assessment of North American transport systems for international trade, and authored the US borders program in TEA-21. He recently completed drafting comprehensive freight productivity strategies for TEA-21 reauthorization. Mr. Caldwell works closely with regional trade transport coalitions, and speaks frequently throughout North America on issues of trade transport, economic development, and institutional reform.

Kate H. Quinn is the Assistant Division Administrator of the Federal Highway Administration's Indiana Division Office. Formerly, she was part of the Freight Policy Team in Federal Highway's Office of Freight Management and Operations.

Jacob Meunier, Ph.D. is an Analyst of Cambridge Systematics with experience in transportation planning and policy-making. He specializes in freight policy and intermodal planning, transportation demand management, and alternative transportation systems. Dr. Meunier has contributed to a number of studies and reports for the I-95 Corridor Coalition, the Federal Highway Administration, the American

Association of State Highway and Transportation Officials, the Federal Transit Administration, and the National Park Service.

John Suhrbier is a Principal of Cambridge Systematics. Much of his work has focused on the effects of transportation investment and operations on the natural and human environment, with particular emphasis on the relationships between transportation and air quality. He has worked with the Federal Highway Administration's Offices of Planning and Environment, the U.S. Environmental Protection Agency, the American Association of State Highway and Transportation Officials, and states and urban areas throughout the country. Current and recent work involves global climate change, particulate matter and air toxics, air quality conformity, the Congestion Mitigation and Air Quality Improvement Program, safety conscious planning, and support for the Transportation and Community and System Preservation Pilot Program.

Lance R. Grenzeback is a Principal and Senior Vice President of Cambridge Systematics. His practice is in the areas of transportation policy, planning, and economics. He specializes in freight policy and intermodal planning, transportation operations and Intelligent Transportation Systems (ITS), and economic development. For the Federal Highway Administration and U.S. Department of Transportation, Mr. Grenzeback is advising on the development of a National Freight Productivity Program and Transportation Equity reauthorization. He is studying national freight flows, developing freight-modeling tools, and analyzing policy and financing options for the Freight Analysis Framework project. Mr. Grenzeback has recently directed the I-95 Corridor Coalition Mid-Atlantic Rail Operations Study and American Association of State Highway and Transportation Officials first Freight Rail Bottom-Line Report.