Transportation

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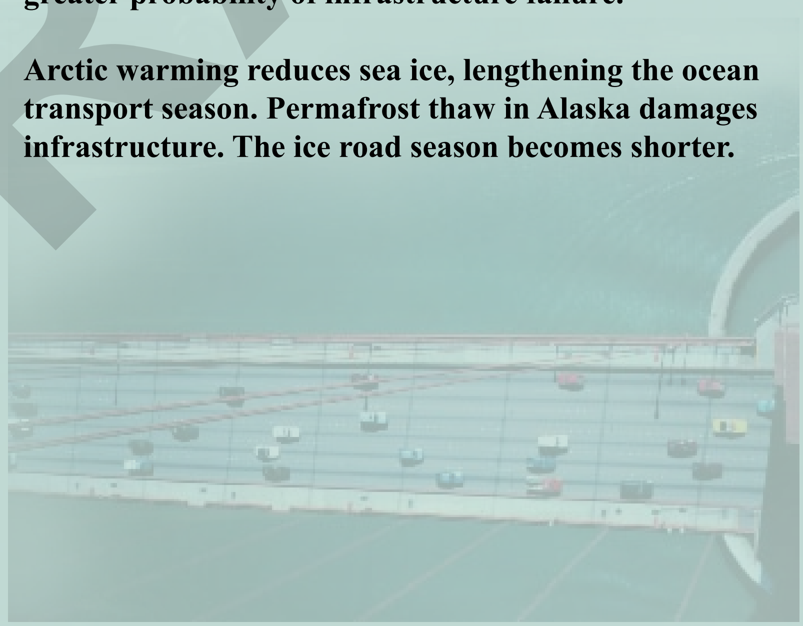
- **Increasingly intense downpours and related flooding will cause disruptions and delays in air, rail, and road transportation.**

- **The increase in extreme heat will limit some operations and cause pavement and track damage. Decreased extreme cold will confer benefits.**

- **Increased intensity of strong hurricanes would lead to more evacuations, damages, transportation interruptions, and a greater probability of infrastructure failure.**

- **Arctic warming reduces sea ice, lengthening the ocean transport season. Permafrost thaw in Alaska damages infrastructure. The ice road season becomes shorter.**



Transport across the globe, and the U.S. transport sector in particular, is a significant source of greenhouse gases. Transportation accounts for 27.2% of U.S. greenhouse gas emissions[1], more than double the percentage it accounts for globally (13.1%)[2]. So while this discussion centers on the impacts of climate change on transportation, it should be noted that transportation also has a major impact on climate.

Climate change impacts on transportation also cause disruptions in other sectors across the economy. For example, major flooding, such as that in the Midwest in 2008 and 1993, restricts travel of all types, and these restrictions, in turn, impact freight and rail shipments across the country, from moving coal to power plants to bringing chlorine to water treatment systems.

Extreme events present major challenges for transportation and such events are becoming more frequent and intense. Historical weather patterns are no longer a reliable predictor of the future. Climate change must be considered in transportation planning and design.

Sea-level rise and storm surges are projected to result in major impacts including flooding of coastal airports, roads, rail lines, and tunnels.

U.S. transportation infrastructure in coastal areas is increasingly vulnerable to sea-level rise and storm surge. With 53 percent of the U.S. population living in the 17 percent of U.S. land that is in coastal counties[3] (a population density more than three times the national average[4]). The potential exposure of transportation infrastructure to flooding is immense. And population swells in the summer months as beaches are the top tourist destination[5].

Coastal areas are projected to experience continued development pressures as both retirement and tourist destinations. Many of the most populous counties of the Gulf Coast, that already experience the effects of tropical storms, are expected to grow rapidly in the coming decades[6]. This growth will generate demand for more transportation infrastructure and increase the difficulty of evacuation in an emergency.

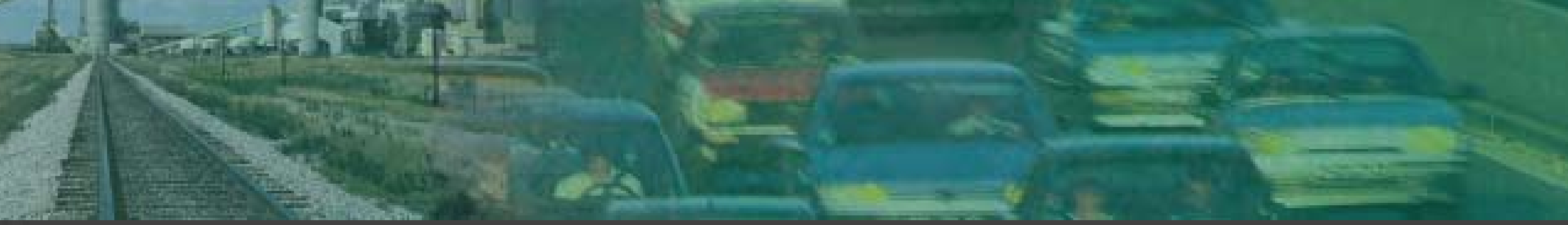
At the same time, sea-level rise will make transportation infrastructure in low-lying coastal areas even more vulnerable to extensive flooding and higher storm surges. An estimated 60,000 miles of coastal highway is already exposed to periodic flooding due to coastal storms and high waves[7]. Some of these highways currently serve as evacuation routes during hurricanes and other coastal storms, and these routes could become seriously compromised in the future.

In the Gulf Coast area alone, an estimated 2,400 miles of major roadway and 246 miles of freight rail lines are projected to be underwater within 50 to 100 years, as global warming and land subsidence combine to produce relative sea-level rise in the range of four feet[8]. Since the Gulf transportation network is interdependent and relies on minor roads and other low-lying infrastructure, the service disruptions due to sea-level rise may be even greater than these significant levels indicate[9].

Regional Spotlight: the Gulf Coast

Sea-level rise will make much of the existing infrastructure more prone to frequent or permanent inundation; 27 percent of the major roads, 9 percent of the rail lines, and 72 percent of the ports are built on land at or below four feet in elevation, a level within the range of projections for relative sea-level rise in this region in this century. Increased storm intensity may lead to increased service disruption and infrastructure damage: More than half of the area's major highways (64 percent of Interstates, 57 percent of arterials), almost half of the rail miles, 29 airports, and virtually all of the ports are below 23 feet in elevation and subject to flooding and possible damage due to hurricane storm surge. These factors should be considered in today's transportation decisions and planning processes[14].

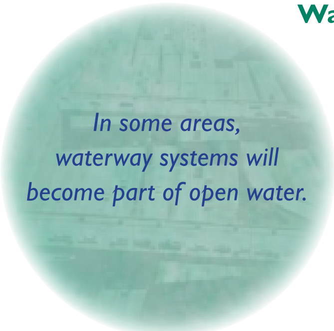
Coastal areas are also major centers of economic activity. Six of the nation's top ten freight gateways (measured by the value of shipments) will be at risk from sea-level rise[10]. Seven of the ten largest ports (by tons of traffic) are located on the Gulf Coast[11]. The region is also home to the U.S. oil and gas industries, with its offshore drilling platforms, refineries, and pipelines. Roughly two-thirds of all U.S. oil imports are transported through this region[12] (see Energy sector).



Land

More frequent inundation and interruptions in travel on coastal and low-lying roadways and rail lines due to storm surges are projected. More frequent evacuations due to severe storm surges are also likely. Many cities have subways, tunnels, parking lots, and other transportation infrastructure below ground. Underground tunnels and other low-lying infrastructure will see more frequent and severe flooding. Higher sea levels and storm surges will also erode road base and undermine bridge supports. The loss of coastal wetlands and barrier islands will lead to further coastal erosion due to the loss of natural protection from wave action.

Water



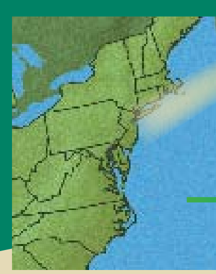
In some areas, waterway systems will become part of open water.

Impacts on harbor infrastructure from wave damage and storm surges are projected to increase. Changes will be required in harbor and port facilities to accommodate higher tides and storm surges. There will be reduced clearance under waterway bridges for boat traffic. Changes in the navigability of channels are expected; some will be more accessible (and farther inland) because of deeper waters, while others will be restricted because of changes in sedimentation rates and sandbar locations. In some areas, waterway systems will become part of open water. Some of them will likely have to be dredged more frequently as has been done across large open water bodies in Texas[13].

Air

Airports in coastal cities are often located adjacent to rivers, estuaries, or open ocean. Airport runways in coastal areas could be inundated. There is the potential for closure or restrictions for several of the nation's busiest airports that lie in coastal zones, affecting service to the highest density populations in the United States.

Regional Spotlight: New York Metro Area



With potential sea-level rise estimated under business-as-usual emissions to be up to 3.5 feet by 2080, the combined effect of sea-level rise and storm surge is projected to dramatically increase the frequency of flooding. What is currently called a 100-year storm is projected to occur as often as every four years. Portions of lower Manhattan and coastal areas of Brooklyn, Queens, Staten Island, and Nassau County would experience a marked increase in flooding frequency. Much of the critical transportation infrastructure, including tunnels, subways, and airports, lies well within the range of projected storm surges and would be under water during such events[15].

Increasingly intense downpours and related flooding will cause disruptions and delays in air, rail, and road transportation.

Heavy downpours have already increased substantially in the U.S.; the heaviest 1% of precipitation events increased by 20%, while total precipitation increased by 7%[21]. Such intense precipitation is likely to increase the frequency and severity of such events as the Great Flood of 1993 which caused catastrophic flooding along 500 miles of the Mississippi and Missouri River system, paralyzing surface transportation systems including rail, truck, and marine traffic. Major east-west traffic was halted for roughly six weeks in an area stretching from St. Louis west to Kansas City and north to Chicago, affecting one-quarter of all U.S. freight that either originated or terminated in the flood-affected region[22].

The June 2008 Midwest flood was the second "500-year event" in the past 15 years. Dozens of levees were breached or overtopped in Iowa, Illinois, and Missouri, flooding huge areas, including 1300 blocks of downtown Cedar Rapids, Iowa. Numerous highway and rail bridges were impassable due to flooding of approaches and transport was shut down along many stretches of highway and normally navigable waterways. Cost estimates are not yet available, but early indications suggests that this event will be one of the most expensive in U.S. history.

Land

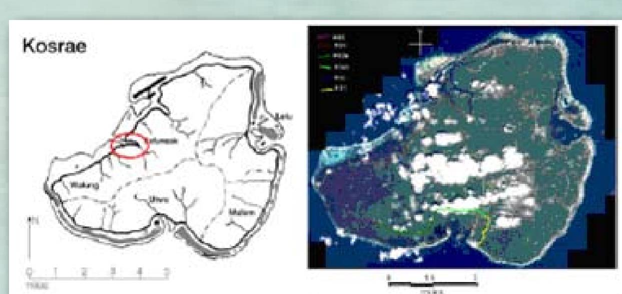
The increase in heavy precipitation will inevitably cause increases in weather-related accidents, delays, and traffic disruptions in a network already challenged by increasing congestion. There would be increased flooding of evacuation routes. Construction activities would be disrupted. There will be changes in rain, snowfall, and seasonal flooding that impact safety and maintenance operations on the nation's roads and railways. For example, if precipitation changes from snow to rain in winter and spring thaws, there will be increased risk of landslides, slope failures, and floods from the runoff, causing road closures.

Increased flooding of roadways, rail lines and underground tunnels is expected. Drainage systems will be overloaded more frequently and severely, causing backups and street flooding. Areas where flooding is already common will face much more frequent and severe problems. For example, Louisiana Highway 1, a critical link in the transport

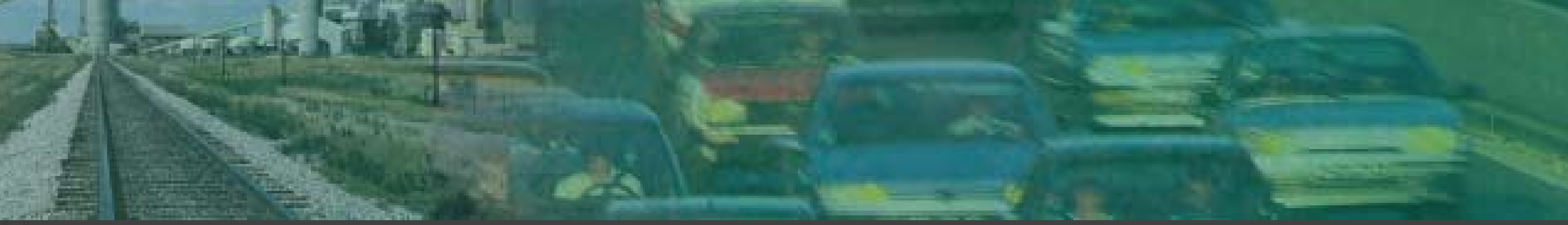
Adaptation: Climate-Proofing a Road

Completion of a road around the 42-square mile island of Kosrae in the U.S.-affiliated Federated States of Micronesia provides a good example of adaptation to climate change. A road around the island's perimeter existed, except for a ten-mile gap. Filling this gap would provide all-weather land access to a remote village and allow easier access to the island's interior.

In planning this new section of road, authorities decided to "climate proof" it against projected increases in heavy downpours and sea-level rise. This led to the section of road being placed higher above sea level and with an improved drainage system to handle the projected heavier rainfall. While there are additional capital costs for this drainage system, the accumulated costs, including repairs and maintenance, would be lower after about 15 years, equating to a good rate of return on investment. Adding this improved drainage system to roads that are already built is more expensive than on new construction, but still found to be cost-effective.



(see endnote 26)

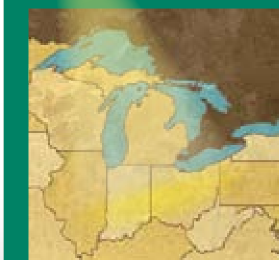


of oil from the Gulf of Mexico, has recently experienced increased flooding, prompting authorities to elevate the structure[24]. Increases in road washouts, damage to rail bed support structures, and landslides and mudslides that damage roads and other infrastructure are expected. If soil moisture levels become too high, the structural integrity of roads, bridges, and tunnels could be compromised. Standing water will have adverse impacts on road base. For example, damage due to long term submersion of roadways in Louisiana was estimated to be $50 million for just 200 miles of state-owned highway. The Louisiana Department of Transportation and Development noted that a total of 1800 miles of roads were under water for long periods, requiring costly repairs[25]. Pipelines are likely to be damaged as intense precipitation can cause the ground to sink underneath the pipeline; in shallow riverbeds, pipelines are more exposed to the elements and can be subject to scouring and shifting due to heavy precipitation.

Water

Increased delays due to heavy downpours will affect operations. As these events increase, flight delays at major airports will increase as well. Changes in silt and debris buildup resulting from extreme precipitation events will affect channel depth, increasing dredging costs.

Regional Spotlight on the Midwest



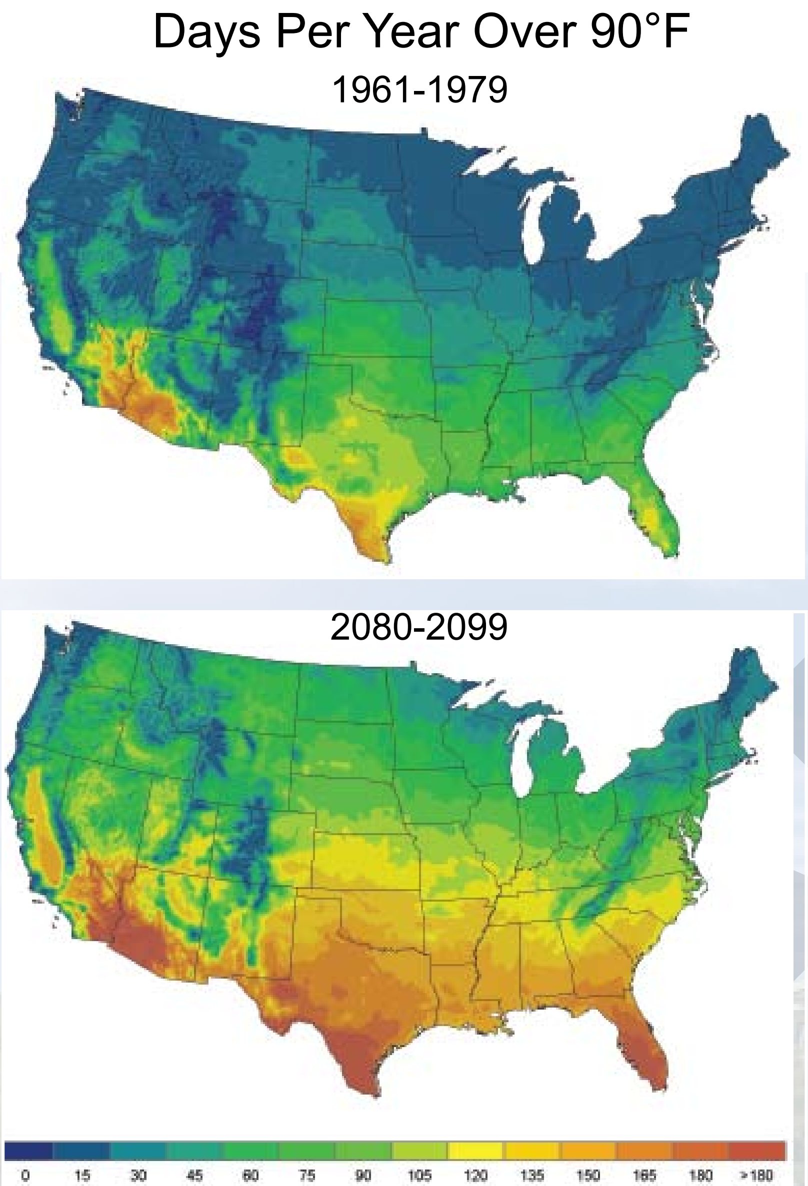
An example of intense precipitation affecting transportation infrastructure was the record-breaking 24-hour rainstorm in July 1996, which resulted in flash flooding in Chicago and its suburbs, with major impacts. Extensive travel delays occurred on metropolitan highways and railroads, and streets and bridges were damaged. Commuters were unable to reach Chicago for up to three days, and more than 300 freight trains were delayed or rerouted[23].

The June 2008 Midwest floods caused I-80 in eastern Iowa to be closed for over five days, disrupting major east-west shipping routes for trucks and the east-west rail lines through Iowa. These floods exemplify the kind of extreme precipitation events and their direct impacts on transportation that are likely to become more frequent in a warming world. These extremes create new and more difficult problems that must be addressed in the design, construction, rehabilitation, and operation of the nation's transportation infrastructure.

Air

Increased delays due to heavy downpours are likely to affect operations. Storm water runoff that exceeds the capacity of collection and drainage systems will cause flooding, delays, and airport closings. Heavy downpours will affect the structural integrity of airport facilities, such as through flood damage to runways and other infrastructure. All of these impacts have implications for emergency evacuation planning, facility maintenance, and safety[26].

The increase in extreme heat will limit some operations and cause pavement and track damage. Decreased extreme cold will confer benefits.



The maps illustrate, for example, that parts of the South that currently see about 60 days per year with temperatures over 90°F (areas in dark green) are projected to experience 150 or more days per year over 90°F (areas in orange) by the end of this century under higher emissions scenarios.

Land

Longer periods of extreme heat in summer may damage roads in several ways including softening of asphalt that leads to rutting from heavy traffic. Sustained air temperature over 90°F is a significant threshold for such problems. Extreme heat can cause deformities in rail tracks, at minimum resulting in speed restrictions, and at worst, causing derailments. Air temperatures above 100°F can lead to equipment failure. Extreme heat also causes thermal expansion of bridge joints, adversely affecting bridge operations and increasing maintenance costs. Vehicle overheating and tire deterioration are additional concerns[16]. Higher temperatures will also increase refrigeration needs for goods during transport, particularly in the South, raising transportation costs[17a].

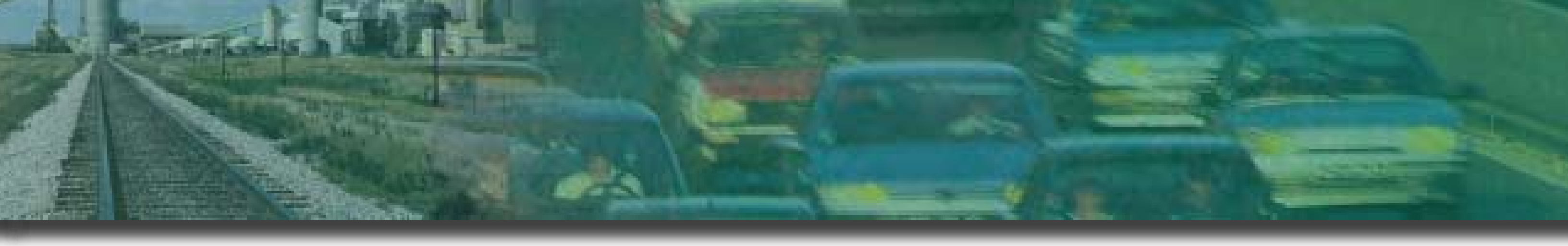
Increases in very hot days and heat waves are expected to limit construction activities due to health and safety concerns. U.S. Occupational Safety and Health Administration guidance states that concern for heat stress for moderate to heavy work begins at about 80°F as measured by an index that combines temperature, wind, humidity, and direct sunlight. For dry climates, such as Phoenix and Denver, National Weather Service Heat Indices above 90°F may be permissible while higher humidity areas such as New Orleans or Miami should consider 80-85°F as an initial level for work restrictions[17b].

Wildfires are projected to increase, threatening communities and infrastructure directly and bringing about road and rail closures in affected areas.

In many northern states, warmer winters will bring about reductions in snow and ice removal costs, lessen adverse environmental impacts from the use of salt and chemicals on roads and bridges, extend the construction season, and improve the mobility and safety of passenger and freight travel through reduced winter hazards. On the other hand, more freeze-thaw conditions are projected to occur in northern states, creating frost heaves and potholes on road and bridge surfaces and resulting in load restrictions on certain roads to minimize the damage. With the expected earlier onset of seasonal warming, the period of springtime load restrictions may be reduced in some areas, but it is likely to expand in others with shorter winters but longer thaw seasons. Longer construction seasons will be a benefit in colder locations[18].

Water

Warming is projected to mean a longer shipping season but lower water levels for the Great Lakes and St. Lawrence Seaway. Higher temperatures, reduced lake ice, and increased evaporation are expected to combine to produce lower water levels as climate warming proceeds. With lower lake levels, ships will be unable to carry as much cargo and hence



shipping costs will increase. In 2000 and 2001, water levels in the St. Lawrence Seaway were at their lowest point in 35 years, reducing vessel carrying capacity to about 90% of normal. A recent study, for example, found that the predicted reduction in Great Lakes water levels would result in an estimated 13 to 29 percent increase in shipping costs for Canadian commercial navigation by 2050, all else remaining equal.

Navigable Inland Waterways

(see endnote 8)

Lower water levels could also create problems for river traffic, reminiscent of the stranding of more than 4,000 barges on the Mississippi River during the drought in 1988. If low water levels become more common because of drier conditions due to climate change, freight movements in the region could be seriously impaired, and extensive dredging could be required to keep shipping channels open. On the other hand, a longer shipping season afforded by a warmer climate could offset some of the resulting adverse economic effects.

In cold areas, the projected decrease in very cold days will mean less ice accumulation on vessels, decks, riggings, and docks; less ice fog; and fewer ice jams in ports.

Increases in extreme heat will result in payload restrictions and could cause flight cancellations and service disruptions at affected airports.

Air

Rising temperatures will affect airport ground facilities, runways in particular, in much the same way they affect roads. Airports in some areas are likely to benefit from reduction in the cost of snow and ice removal and the impacts of salt and chemical use, though some locations have seen increases in snowfall. Airlines could benefit from reduced need to de-ice planes.

More heat extremes will create added operational difficulties, for example, causing greater energy consumption by planes on the ground. Extreme heat also affects aircraft lift; hotter air is less dense, reducing the lift produced by the wing and the thrust produced by the engine, problems exacerbated at high altitudes and high temperatures. Planes thus need to take off faster, and if runways are not sufficiently long for aircraft to build up enough speed to generate lift, aircraft weight must be reduced. Thus, increases in extreme heat will result in payload restrictions, could cause flight cancellations and service disruptions at affected airports, and could require some airports to lengthen runways. Recent hot summers have seen flights cancelled due to heat, especially in high altitude locations. Economic losses are expected at affected airports. A recent analysis projects a 17% reduction in freight carrying capacity for a single Boeing 747 at the Denver airport by 2030 and a 9% reduction at the Phoenix airport due to increased temperature and water vapor[19].

Drought

Rising air temperatures increase evaporation, contributing to dry conditions, especially when accompanied by decreasing precipitation. Even where total annual precipitation does not decrease, precipitation is projected to become less frequent in many parts of the country[20]. Drought is expected to be an increasing problem in some regions; this, in turn, has impacts on transportation. For example, increased susceptibility to wildfires during droughts could threaten roads and other transportation infrastructure directly, or cause road closures due to fire threat or reduced visibility such as in Florida and California in recent years. There is also increased susceptibility to mudslides in areas deforested by wildfires. Airports could also suffer from decreased visibility due to wildfires. River transport is also seriously affected by drought, with reductions in the routes available, shipping season, and cargo carrying capacity.

Increased intensity of strong hurricanes would lead to more evacuations, damages, transportation interruptions, and a greater probability of infrastructure failure.

More intense hurricanes in some regions are a projected effect of climate change. Three aspects of tropical storms are relevant to transportation: precipitation, winds, and wind-induced storm surge. Stronger hurricanes have longer periods of intense precipitation, higher wind speeds (damage increases with wind speed), and higher storm surge and waves.

Land

There will be a greater probability of infrastructure failures such as highway and rail bridge decks being displaced and railroad tracks being washed away. Storms leave debris on roads and rail lines, which can damage the infrastructure and interrupt travel and shipments of goods. In Louisiana, the Department of Transportation and Development spent $74 million for debris removal alone in the wake of Hurricanes Katrina and Rita. The Mississippi Department of Transportation expected to spend in excess of $1 billion to replace the Biloxi and Bay St. Louis Bridges, repair other portions of roadway, and remove debris. As of June 2007, more than $672 million had been expended.

Adaptation Strategies

Transportation planners have not typically accounted for climate change in their planning horizons or project development. The longevity of transportation infrastructure, the long term nature of climate change, and the potential impacts identified by recent studies warrant serious attention to climate change in planning new or rehabilitated transportation systems.

Planners have generally relied on weather variations of the past as a guide to the future, planning, for example, for a "100-year flood," which may now come much more frequently as a result of climate change. Historical analysis of weather data has thus become less accurate as a forecasting tool. The rapid changes in climate make it more difficult to predict the frequency and intensity of weather events that can influence transportation.

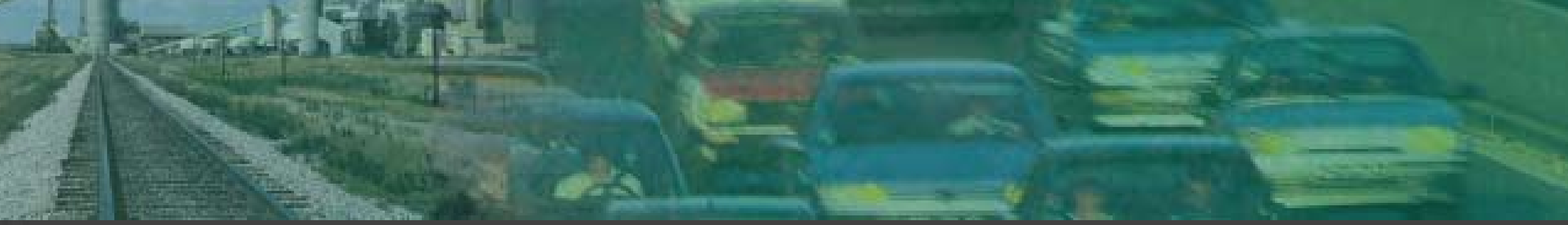
Transportation planners, designers, and operators would be wise to adopt probabilistic approaches to developing transportation projects rather than relying on the deterministic approaches of the past. The uncertainty associated with predicting impacts over a 50- to 100-year time period makes risk management a reasonable approach for realistically incorporating climate change into decision-making and investment.

Lengthening the time frames examined in the transportation planning process is a key element. The 20-year time period required under federal law for highways and transit is not sufficient to encompass the useful life of transportation infrastructure and the risks to which it will be exposed due to climate change.

Strategic examination of national, regional, state, and local networks is an important step toward understanding the risks. Communities can begin by taking inventory of their transportation assets and assessing what needs protection and factoring this into planning, using probabilistic methods. Strategic analysis can also be effective in the design of a project or the planning of a transportation network.

A range of adaptation responses can be employed by transportation professionals to reduce the risks posed by climate change. Infrastructure can be designed to withstand projected impacts or to be protected by natural or manufactured barriers. This can include development of materials and equipment that are more durable or have other desirable characteristics. Efforts can be made to enhance redundancy of critical services. Operational improvements can be developed and implemented. And infrastructure can be relocated or development limited to avoid impacts.

Planning for and adapting to climate change is an evolutionary process. Through adoption of longer planning horizons, risk management, and adaptive responses, vulnerable transportation infrastructure can be made more resilient, maintaining critical services in the face of climate stressors.



There will be more frequent and potentially more extensive emergency evacuations. Damage to signs, lighting fixtures, and supports will increase. The lifetime of highways that have been exposed to flooding is expected to decrease. Road and rail infrastructure for passenger and freight services are likely to face increased flooding by strong hurricanes even by relatively modest storm surges. In the Gulf Coast, more than one-third of the rail miles are likely to flood when subjected to a storm surge of 18 feet[27].

Water

All aspects of shipping are disrupted by major storms. For example, freight shipments need to be diverted from the storm region. Activities at offshore drill sites and coastal pumping facilities would be suspended and extensive damage to these facilities can be expected, as was amply demonstrated during the 2005 hurricane season. Refineries and pipelines are also vulnerable to damage and disruption due to the high winds and storm surge associated with hurricanes and other tropical storms (see *Energy* sector). Barges that are unable to get to safe harbors can be destroyed or severely damaged. Waves and storm surge will damage harbor infrastructure such as cranes, docks and other terminal facilities. There are implications for emergency evacuation planning, facility maintenance, and safety management.

Air

More frequent interruptions in air service and airport closures can be expected. Airport facilities including terminals, navigational equipment, perimeter fencing, and signs are likely to sustain increased wind damage. Airports are frequently located in low-lying areas and can be expected to flood with more intense storms. Eight airports in the Gulf Coast region of Louisiana and Texas are located in historical 100-year flood plains but these events will be more frequent in the future[28].

Spotlight on Hurricane Katrina:

Hurricane Katrina was the most destructive and costliest natural disaster in U.S. history, claiming more than 1800 lives and causing an estimated $134 billion in damage[29, 29a]. It also seriously disrupted transportation systems as key highway and railroad bridges were heavily damaged or destroyed, necessitating rerouting of traffic and placing increased strain on other routes, particularly other rail lines. Replacement of major infrastructure took from months to years. The CSX Gulf Coast line was re-opened after five months and $250 million in reconstruction costs, while the Biloxi-Ocean Springs Bridge took more than two years to reopen. Barge shipping was halted, as was grain export out of the Port of New Orleans, the nation's largest grain export port. The pipeline network was shut down by the loss of electrical power, producing shortages of natural gas and petroleum products. Total recovery costs of the roads, bridges, and utilities as well as debris removal were estimated to cost $15 to 18 billion[30].

Redundancies in the transportation system, as well as the storm timing and track, helped keep the storm from having major or long-lasting impacts on national-level freight flows. For example, truck traffic was diverted from the collapsed bridge that carries highway I-10 over Lake Pontchartrain to highway I-12, which parallels I-10 well north of the Gulf Coast. The primary north-south highways that connect the Gulf Coast with major inland transportation hubs were not damaged and were open for nearly full commercial freight movement within days. The railroads were able to route some traffic not bound directly for New Orleans through Memphis and other Midwest rail hubs. Because New Orleans is not as major a transportation hub as, for example, Houston, given different timing or storm track, the transportation impacts could have been worse.

Hurricane Katrina damage to U.S. Highway Bridge.

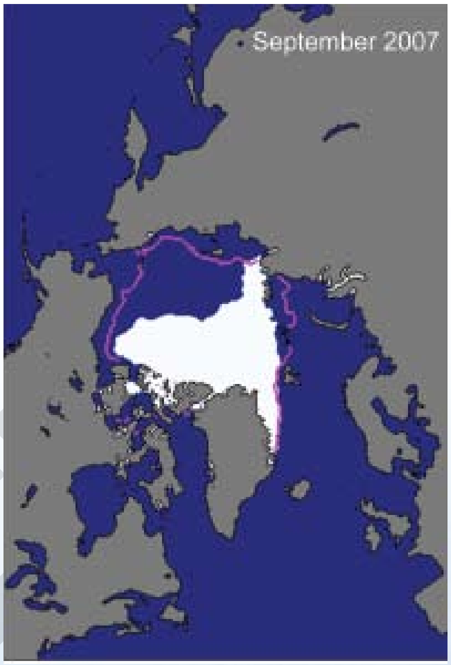
Arctic warming reduces sea ice, lengthening the ocean transport season. Permafrost thaw in Alaska damages infrastructure. The ice road season becomes shorter.

Special issues in Alaska

Alaska is warming at twice the rate of the rest of the nation, bringing both opportunities and challenges.

Warming has been most rapid in high northern latitudes. As a result, Alaska is warming at twice the rate of the rest of the nation, bringing both major opportunities and major challenges. Alaska's transportation infrastructure differs sharply from that of the lower 48 states. Although Alaska is twice the size of Texas, its population and road mileage are more like Vermont's. Only 30% of the roads are paved. Air travel is much more common than in other states. Alaska has 84 commercial airports and more than 3,000 airstrips, many of which are the only means of transport for rural communities. Unlike other states, over much of Alaska, the land is generally more accessible in winter, when the ground is frozen and ice roads and bridges are available.

Arctic Sea Ice Decline



The pink line shows the average September sea ice extent from 1979 through the present. The white area is September 2007 sea ice extent[31].

Sea ice decline

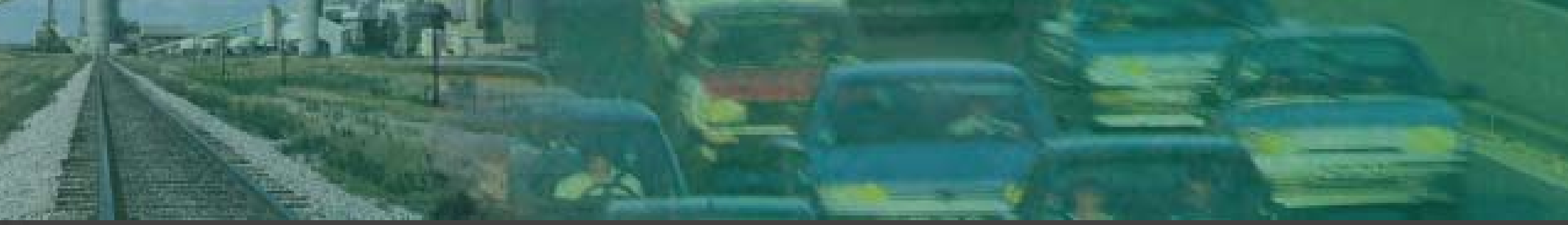
The striking thinning and downward trend in the extent of Arctic sea ice is regarded as a considerable opportunity for shippers. Continued reduction in sea ice should result in more ice-free ports, improved access to ports and natural resources in remote areas, and longer shipping seasons. For next several decades, however, warming is likely to result in greater variability in year-to-year shipping conditions and higher costs due to requirements for stronger ships and support systems such as ice-capable ships, icebreaker escorts, and search and rescue support.

Over the long term, beyond this century, shippers are looking forward to new Arctic shipping routes, including the fabled Northwest Passage, which could provide significant costs savings in shipping times and distances. However, the next few decades are likely to be very unpredictable for shipping through these new routes. The past three decades have seen very high year-to-year variability of sea ice extent in the Canadian Arctic, despite the overall decrease in September sea-ice extent. And the manner in which ice blockages control ice movement through the channels of the Canadian Archipelago may actually place more icebergs in the shipping channels of the Northwest Passage in the coming decades.

Thawing ground

The challenges warming presents for transportation on land are considerable. For highways, thawing of permafrost causes settling of the roadbed and frost heaves that adversely affect road performance, such as load-carrying capacity. The majority of the state's highways are located in areas where permafrost is discontinuous, and dealing with thaw settlement problems already claims a significant portion of highway maintenance dollars.

Bridges and large culverts are particularly sensitive to movement caused by thawing permafrost and are often much more difficult than roads to repair and modify for changing site conditions. Thus, designing these facilities to take climate change into account is even more critical than is the case for roads. Another impact of climate change on bridges is increased scouring. Hotter, drier summers have led to increased glacial melting and longer periods of high streamflows, causing both increased sediment in rivers and scouring of bridge supporting piers and abutments. Temporary ice roads and bridges are commonly used in many parts of Alaska to access northern communities and provide support for the mining

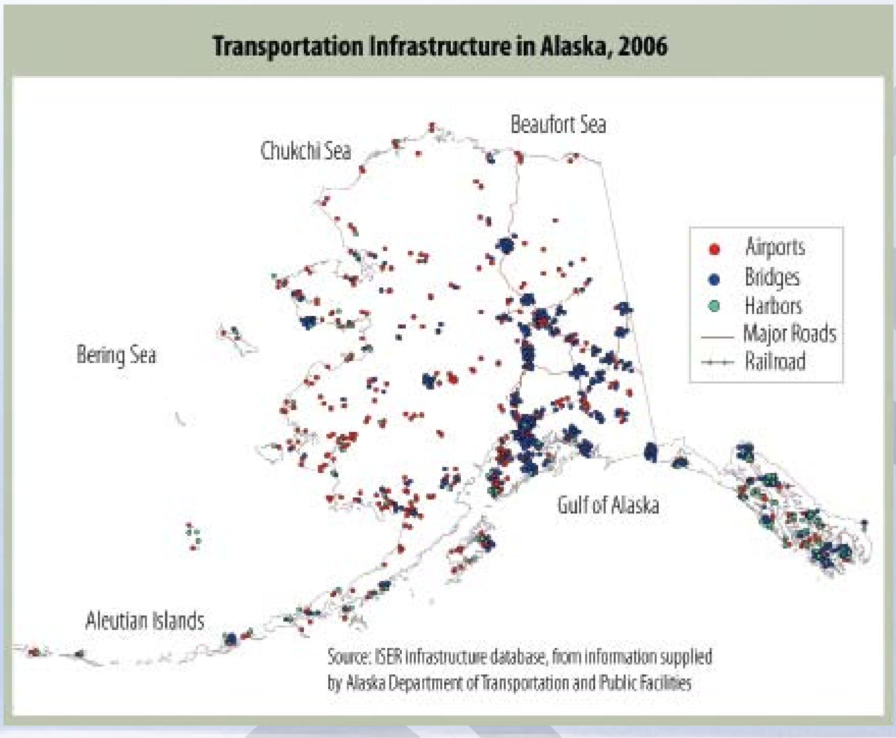


and oil and gas industries. Rising temperatures have already shortened the season during which these critical facilities can be used. Like the highway system, the Alaska Railroad crosses permafrost terrain, and frost heave and settlement from thawing affect some portions of the track, increasing maintenance costs.

A significant number of Alaska's airstrips in the southwest, the northwest, and the interior are built on permafrost. These aitstrips will require major repairs or relocation if their foundations are compromised by thawing.

The cost of maintaining Alaska's public infrastructure is projected to increase 10t o 20 percent by 2030 due to warming, costing the state an additional $4 to 6 billion, with roads and airports accounting for about half of this cost. Private infrastructure impacts were not evaluated[30].

The Trans-Alaska Pipeline System, which stretches from Prudhoe Bay in the north to the ice-free port of Valdez in the south, crosses a wide range of permafrost types and varying temperature conditions. More than half of the 800-mile pipeline is elevated on vertical supports over potentially unstable permafrost. Because the system was designed in the early 1970s on the basis of permafrost and climate conditions of the 1950 to 1970 period, it requires continuous monitoring and some supports have had to be replaced.



Travel over the tundra for oil and gas exploration and extraction is limited to the period when the ground is sufficiently frozen to avoid damage to the fragile tundra. In recent decades, the number of days that exploration and extraction equipment could be used has dropped from 200 days to 100 days per year due to warming. With warming, the number of exploration days is expected to decline even further.