Chapter 14

Transportation

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Executive Summary

The Southwest transportation network includes major freeways, rail corridors of national importance, and major port- and border-crossing facilities. Recent passenger-travel trends suggest that vehicle ownership and per capita vehicle miles traveled (VMT) may have stabilized across the Southwest, which may be partly attributed to the economic recession as well as transportation planning strategies such as pricing, transit service improvements, managed lanes, and changes in land-use configurations. However, the Southwest appears poised to show gains in rail-freight traffic due to imports of foreign products, often in containerized cargo or bulk materials.

The following key messages highlight major climate issues facing the Southwest transportation sector:

- Many transportation infrastructure projects, currently in planning, design, or construction, do not necessarily address the potential effects of climate change. As climate change effects begin to manifest, design and operational vulnerabilities of these transportation system elements will appear. (high confidence)

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- Alternative-fuel vehicle sales steadily increased throughout the Southwest until 2008. Yet, hybrid and alternative-fuel vehicles constitute less than 5% of the total passenger vehicle fleet in the Southwest. Increased heat events, which are confidently projected for the region, may increase vehicle air-conditioner usage and emissions and decrease fuel economy. (high confidence)
- The seaports of Los Angeles and Long Beach comprise the largest port complex in the United States and handle 45% to 50% of the containers shipped into the United States. Direct impacts of projected climate changes (such as sea-level rise and flooding) to California ports, include more frequent dredging of harbors and channels, realignments of port infrastructure—such as, jetties, docks, and berths—relative to rising waterline. (medium-high confidence)
- Extreme heat events, projected to increase during the course of the next 100 years, can shorten the life of pavements. Roadway deterioration will have an impact on all trade—including local trade circulation—that occurs between the Southwest and other U.S. regions, and trade between the Southwest and Mexico. (medium-low confidence)
- Increased precipitation intensity, which some studies project for the Southwest region, is associated with reductions in traffic safety, decreases in traffic efficiency—such as speed and roadway capacity—and increases in traffic accidents. (medium-low confidence)

14.1 Introduction

The transportation system in the Southwest comprises a number of major freeways, more than 514,000 lane-miles of rural roads, and more than 350,000 lane-miles of urban roads (FHWA 2011). Rail corridors of national importance and major port and border-crossing facilities also serve the region. Recent national statistics show about 484,000 million vehicle miles traveled (VMT) in the Southwest in 2008, roughly 16% of the national total (BTS 2008). After a number of years in which per capita VMT increased rapidly throughout the United States, per capita passenger VMT in the Southwest tended to be relatively stable or even declined during the late 1990s. Yet, in certain parts of the Southwest total VMT continued to increase.

Increased transportation activity combined with an expanding economy until about 2007 and increased electricity generation significantly contributed to the long-term rise in total CO_2 emissions generated by fossil-fuel combustion. In 2009, transportation uses accounted for about one-third of the total CO_2 emissions generated by fossil fuels (EPA 2012). California's transportation-related CO_2 emissions, which are higher on average than most states, were close to 40% of the state's total CO_2 emissions (California Air Resources Board [CARB] 2008), while Colorado's transportation-related emissions account for about 24% of the state's greenhouse gas (GHG) emissions (Climate Action Panel 2007). Despite increased numbers of "clean" vehicles and reduced tailpipe emissions of traditionally regulated pollutants, the proportion of total GHG from transportation increased slightly from 29.1% in 1990 to 31.2% in 2009 (EPA 2012). This may be attributable to increased VMT.

This chapter begins by describing current trends in passenger and freight transportation in the Southwest. The chapter then reviews the potential effects that climate change may have on transportation infrastructure, on the movement of passengers and goods, and on the risks to infrastructure integrity. A concluding overview examines the uncertainties associated with estimating future climate impacts and how these uncertainties, coupled with the timescales upon which infrastructure decisions normally are made, complicate adaptation planning and management.

14.2 Passenger Transportation Trends in the Southwest

While the Southwest states vary in their approaches to reducing GHG, all rely on a similar suite of options that include increased use of cleaner and more efficient vehicle technologies, new incentives to encourage people to change their travel behavior, and cleaner burning fuels. The U.S. Environmental Protection Agency (EPA) sets emissions standards for motorized vehicles nationally; however, the state of California has passed its own legislation regulating vehicle GHG emissions. The California standards are stricter than the national standards and were subsequently adopted by Arizona and New Mexico.[i] There also have been changes in vehicle fleet composition over time.

The success of hybrid-electric and alternative-fuel vehicles has been notable in the last decade. Not unexpectedly, California has led the way in terms of sales: one in four hybrid vehicles sold nationwide between 2003 and 2007 were purchased in California (Figure 14.1). Alternative-fuel vehicle sales steadily increased throughout the Southwest until 2008. While electric vehicles comprise a quarter of the total alternative-fuel vehicles registered in California, their share remains negligible in other Southwest states, where cars using an ethanol-fuel blend tend to dominate the alternative-fuel vehicle market. Although these figures are encouraging, hybrid and alternative-fuel vehicles constitute less than 5% of the total passenger vehicle fleet in the Southwest.

As fuel efficiency rises, the cost of driving declines, which historically has increased travel. Recent trends, however, suggest that vehicle ownership and per capita VMT may have stabilized across the Southwest (Figure 14.2), likely aided by the economic recession but also helped by transportation planning strategies such as pricing, transit service improvements, managed lanes, and changes in land-use configurations. Drops seen in the late 2000s in registered new hybrid vehicles, vehicles owned per capita, and vehicle miles traveled per capita are likely to be largely due to the effects of economic recession.

14.3 Freight Movement in the Southwest

Freight transportation includes both pick-up and delivery services and the movement of goods into and out of a region. Pick-up and delivery services include package-delivery services, such as UPS and Federal Express, as well as waste and recycling pick-up. Over the past thirty years, increased use of lean supply chains, "just-in-time" manufacturing, and Internet shopping has increased the demand for this sector. Broadly speaking, truck delivery is generally more efficient with respect to VMT and CO_2 emissions than having shoppers make individual trips to commercial centers. Nationally, pickup and delivery freight is expected to grow with increased use of delivery services (Golob and Regan 2001).

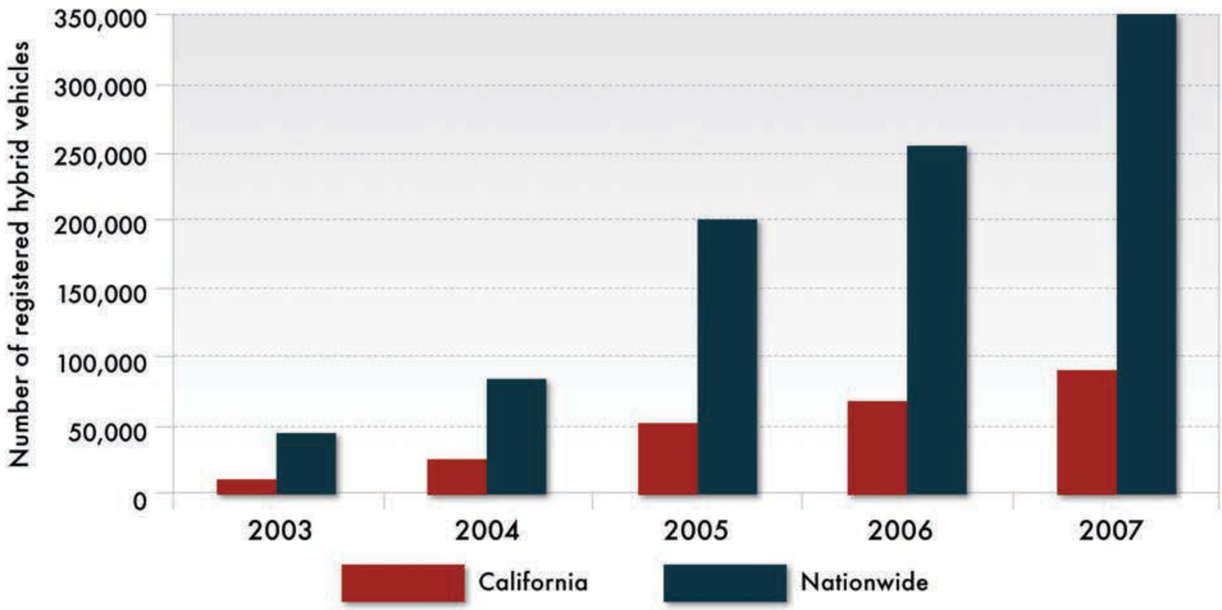

Figure 14.1 Number of new registered hybrid vehicles in California and throughout the United States. Source: RITA (2008); state transportation statistics.

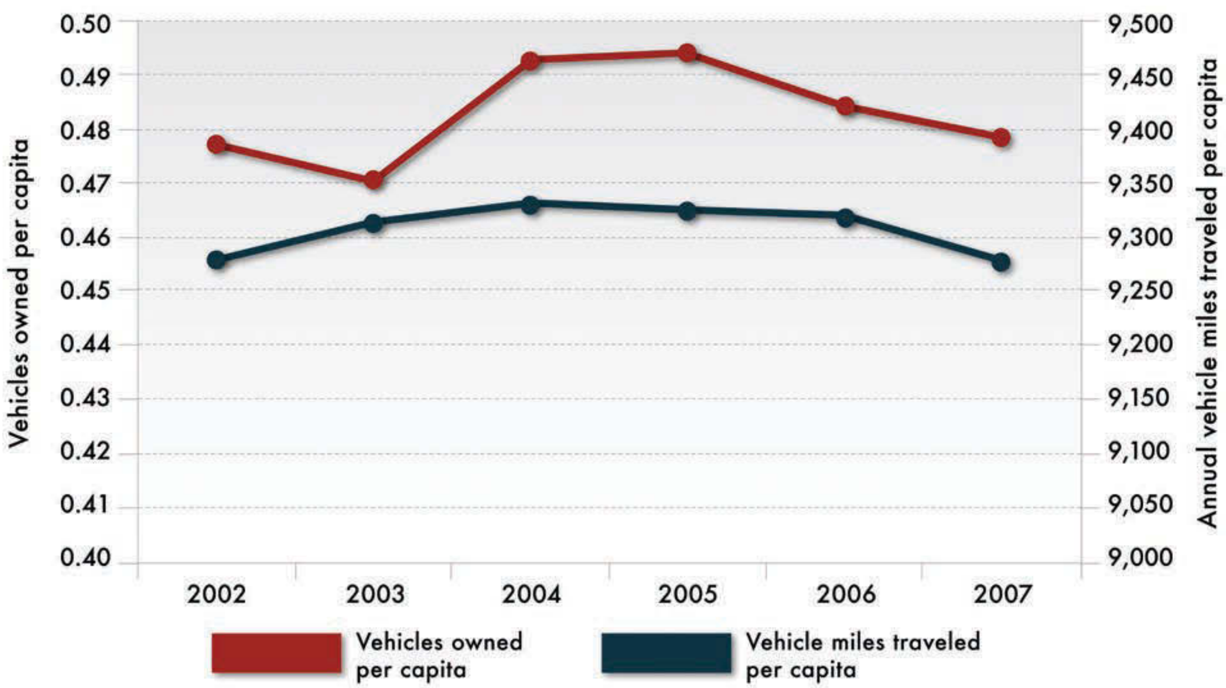

Figure 14.2 Per capita vehicle ownership and annual vehicle miles traveled in the Southwest. Source: RITA (2008); state transportation statistics.

Transportation services distribute Southwest-produced agricultural, commodity, and manufactured goods across and outside the region. Freight export volumes moved by the trucking sector have stayed reasonably constant over the last three decades. Economic conditions currently suggest that export cargo volumes will increase (WTO 2011), which may in turn increase use of rail for cargo, particularly for non-time-sensitive items such as empty containers, waste, and recyclable materials.

The Southwest is poised to show gains in rail-freight traffic due to containerized and bulk foreign imports. The volume of this cargo grew dramatically between 1990 and 2008 (WTO 2011). In 2010, the value of goods imported by the Port of Los Angeles was estimated at $293.1 billion, compared with $32.7 billion in goods imported by land into California from Mexico the same year.

Foreign imports are typically transported from a seaport or across a land border to an intermodal terminal, handling facility, or distribution center from which the goods are then distributed throughout the United States. The seaports of Los Angeles and Long Beach comprise the largest port complex in the United States and handle 45% to 50% of the containers shipped into the United States. Their regional and national importance is illustrated by the 2002 lockout at the Port of Los Angeles, which is estimated to have cost the U.S. economy $1 billion per day (Cohen 2002). Of the containers unloaded at the Port of Los Angeles, 77% leave California; roughly half of those leave by rail and half by truck transport (Heberger et al. 2009). As both fuel prices and the cost of CO_2 emissions rise, a propensity for using rail is likely to emerge (Siikavirta et. al. 2008; TEMS 2008). However, diversion of large amounts of cargo from trucks to rail is not likely to happen in the immediate future due to railway congestion and the mature state of freight movements via truck.

The Southwest also trades goods within the United States. Domestic freight uses the same transportation network as international freight and is subject to the same surface transportation rates and policies. Domestic freight is also intertwined with foreign trade in that many of the raw materials and equipment needed in domestic production are imported from other countries.

14.4 Impacts of Climate Change

Climate effects will vary by location within the Southwest. Sea-level rise is expected to be a significant issue for California, for example, while potential changes in temperature and precipitation would pose significant challenges for Arizona and Nevada. The force of these effects will be highly variable, but nonetheless will result in significant costs to infrastructure (Cambridge Systematics 2009). This section reviews the types of direct and indirect impacts to transportation services that are likely to emerge as a result of sea-level rise, extreme heat events, and increased precipitation intensity.

Direct impacts

FLOODING. Flooding of coastal infrastructure, coupled with increased intensity of storm events and land subsidence, poses the greatest potential threat to surface transportation systems in California (NRC 2008). Without the adoption of adaptive measures, a sea-level rise as great as 4.6 feet (1.4 meters, as projected in the high-emissions scenario; see also Chapter 9) would expose California's transportation infrastructure to the flooding of nearly 3,500 miles of roadways and 280 miles of rail lines (Heberger et al. 2009). The rate at which sea-level rise is projected to increase represents one of the "most troublesome aspects of projected climate change" (Knowles et al. 2009, 1).

Coastal regions of California bear the majority of this risk, with vulnerability split roughly equally between the San Francisco Bay Area and the Pacific Coast (see Figure 14.3). Among the areas affected, communities of color, low-income populations, and critical safety, energy, and public health infrastructure would be disproportionately affected. While coastal erosion has also been identified as a significant problem in California, the statewide flooding risk exceeds that of erosion (Heberger et al. 2009).

a)

Major Highways Influenced

RTE	Traversable Length (mi)	Flooded Length (mi)	Percent Inundated	RTE	Traversable Length (mi)	Flooded Length (mi)	Percent Inundated	RTE	Traversable Length (mi)	Flooded Length (mi)	Percent Inundated
1	656	62.79	9.57%	78	194	0.11	0.06%	169	24	0.14	0.60%
4	192	0.08	0.04%	80	204	5.55	2.72%	183	10	5.30	53.02%
5	796	0.94	0.12%	82	52	0.18	0.35%	200	3	0.06	1.98%
9	39	0.00	0.01%	84	96	6.72	7.00%	211	5	3.12	62.46%
12	116	4.79	4.13%	90	16	0.14	0.89%	217	2	0.55	27.43%
13	10	0.20	2.03%	92	28	3.85	13.75%	218	3	0.61	20.24%
22	15	0.74	4.92%	101	807	62.22	7.71%	237	11	2.78	25.31%
29	106	2.60	2.45%	103	2	1.22	60.79%	255	9	5.47	60.81%
35	53	0.18	0.34%	109	1	0.77	77.06%	260	2	1.38	68.85%
37	21	15.26	72.65%	112	2	0.03	1.27%	280	59	1.28	2.17%
39	56	1.38	2.46%	114	1	0.57	57.32%	380	3	0.37	12.30%
47	3	0.83	27.54%	116	46	2.08	4.52%	405	72	1.09	1.51%
54	8	0.34	4.28%	121	33	2.10	6.37%	580	76	5.78	7.60%
55	18	0.16	0.87%	128	121	2.38	1.97%	605	27	0.36	1.33%
61	7	3.85	55.04%	129	14	1.62	11.59%	680	71	1.66	2.34%
73	7	0.01	0.17%	131	4	1.07	26.78%	710	22	0.62	2.80%
75	13	1.02	7.85%	133	9	0.05	0.52%	880	45	9.56	21.24%
76	53	0.02	0.04%	152	105	0.40	0.38%	980	2	0.07	3.43%
77	0.4	0.13	32.74%	156	25	1.98	7.93%				

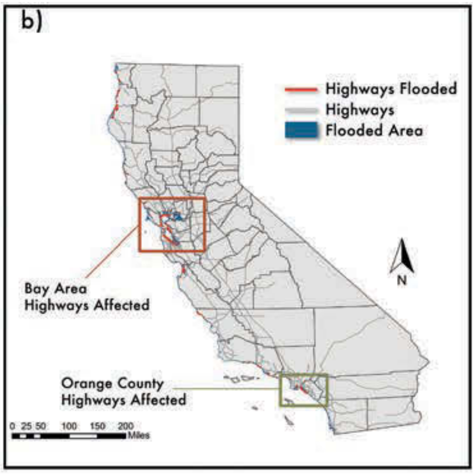

Figure 14.3 California highways affected by 140cm of sea-level rise. Source: Heberger (2009), Knowles (2009), Pacific Institute GIS data downloads (http://www.pacinst.org/reports/sea_level_rise/data/index.htm).

Flooding on the region's roadways will damage the physical infrastructure and require increased maintenance (Heberger et al. 2009). Inundated roadways will obstruct freight by delaying deliveries and forcing changes in route (CCCEF 2002) and disrupt international and domestic supply chains that depend on reliable delivery of goods.

Both flooding and rising sea levels can change coastal ports by creating deeper water. Deeper water allows vessels with deeper hulls to safely navigate a channel. While deeper water also leaves less clearance under bridges, most bridges over shipping lanes are already set high in order to accommodate large ships (Titus 2002; Heberger et al. 2009). However, the Golden Gate Bridge could block large vessels if sea level were to rise by four to five feet (Perez 2009). In addition, increases in storm surges would increase siltation and require more frequent dredging of harbors and channels; storm surges would require bridges to be built stronger and possibly higher to accommodate higher tides (Titus 2002); and bridges and port infrastructure would need additional protection from corrosion as the salt concentration and water levels change (PIANC EnviCom Task Group 3, 2006).

Other needed changes include port infrastructure realignments relative to the waterline, such as to docks, jetties, dry/wet/cargo docks, berths, and other port facilities, and modification of roll-on/roll-off operations to correct for new deck heights (Caldwell et al. 2000). Advancing saltwater in upstream channels may also change sediment location and create sandbars that can obstruct safe navigation (Titus 2002). To maintain safe channels, dredging will have to increase and pilots will need access to updated seafloor mapping.

Summer melting of Arctic ice may allow for a longer Arctic shipping season. The usability of the Northwest Passage for commercial marine shipping is highly uncertain and at best is predicted to vary year to year. But Canada's International Policy Statement predicted in 2005 that the Northwest Passage would be sufficiently ice-free for regular use during summer as early as 2015. Arctic shipping lanes would provide a route that is 5,000 nautical miles shorter for Asia-to-Europe trade than would a route passing through the Panama Canal. Vessels too large for the Panama Canal may be attracted to the Northwest Passage as an alternative to truck or rail transport across the United States. The use of the Arctic shipping lane rather than unloading in California and trucking across the United States would reduce cargo volumes in California ports (Pharand 2007). This change in demand could lessen the vulnerability of California ports, but it would also reduce economic activity in the region's transportation sector.

EXTREME HEAT EVENTS. Extreme heat events affect the duration of roadways and infrastructure. Extended periods of heat can shorten the life of and deteriorate pavements, force thermal expansion of bridges (thus delaying bridge operations and impacting their attendant maritime commerce), and deform the alignment of rail lines. Roadway deterioration will have an impact on all trade—including local trade circulation—that occurs between the Southwest and the remainder of the United States as well as trade between the Southwest and Mexico.[ii]

High temperatures can force rail lines out of alignment in what are called "sun kinks." Such a condition was responsible for injuring 100 people in a passenger train derailment near Washington, D.C., in 2002. The CSX Corporation, a freight transportation provider and owner of the rail line, initiated temporary speed restrictions after the incident, which slowed supply chains. These rail slowdowns could become more problematic as the frequency of extreme events due to climate change occur (Caldwell et al. 2000).

CHANGES IN PRECIPITATION. Changes in precipitation—specifically changes in intensity, frequency, and seasonality—also represent a significant threat to the Southwest transportation infrastructure. Compared to temperature, precipitation changes are more difficult to predict because precipitation is highly variable and localized. However, published studies tend to agree that while most of the Southwest is unlikely to see increases in total annual precipitation (Seager et al. 2007), increased precipitation intensity is likely (Alpert et al. 2002; Groisman et al. 2004; Groisman et al. 2005).

Increased precipitation intensity likely will result in one of more of the following: decreases in traffic demand; reductions in traffic safety; and decreases in the efficiency of operational features, such as speed, capacity, or travel-time variability (Table 14.1). Not surprisingly, severe weather events both decrease traffic demand and increase traffic accidents. Studies show traffic demand (measured by traffic volume) can change by anywhere from 5% to 80% due to severe weather events (e.g., Hanbali and Kuemmel 1993; Maze, Agarwal, and Burchett 2006).

Table 14.1 Potential impacts of precipitation events on transportation operations in the Southwest

Change in Precipitation	Impacts on Land Transportation Operations	Impacts on Marine Transportation Operations	Impacts on Air Transportation Operations
Increase in precipitation intensity and stormwater runoff	• Increased delay • Increased traffic disruption • Reduced safety and maintenance	Increased delay	• Increased delay • Increased stormwater runoff, causing flooding, delays, and airport closings • Impact on emergency evacuation planning, facility maintenance, and safety management
Increase in drought conditions	• Increased susceptibility to wildfires, causing road closures and reduced visibility	Impacts on river transportation routes and seasons	• Increased susceptibility to wildfires causing reduced visibility
More frequent strong hurricanes	• Interrupted travel and shipping • More frequent and more extensive emergency evacuations	Increased need for emergency evacuation planning, facility maintenance, and safety management	• More frequent interruptions in air service

Source: NRC (2008)

Depending on the level of planning and preparation undertaken by transportation providers, climate change may substantially and directly impact transportation operations as well as transportation infrastructure. For example, although a submerged jetty can be replaced or reconfigured, until this work is completed, it can no longer support the mobility of goods. Failing infrastructure cannot fulfill the role for which it was designed. Without advance planning to address and adapt to weather conditions that could reduce or limit infrastructure capacity, key infrastructure is at risk of being substantially less available. Table 14.2 summarizes the range of expected direct impacts to transportation infrastructure of climate change.

Indirect impacts

VEHICLE EMISSIONS. Heat events in the Southwest may increase air-conditioner usage in vehicles, which may bump up the total emissions. The U.S. EPA's Supplemental Federal Test Procedure (SFTP) for air conditioning (SC03) shows that total vehicular emissions increase 37% when air conditioning is turned on while driving, while fuel economy drops as much as 43% in a high-fuel-economy vehicles and 13% in conventional vehicles (Farrington and Rugh 2000).

Table 14.2 Potential impacts of climate on transportation infrastructure in the Southwest

Climate Change Factor	Impacts on Land Transportation Infrastructure	Impacts on Marine Transportation Infrastructure	Impacts on Air Transportation Operations
Sea-level rise and more frequent heavy flooding	• Inundation of roads and rail lines in coastal areas • More frequent or severe flooding of underground tunnels and low-lying infrastructure • Erosion of road base and bridge supports • Bridge scour • Loss of coastal wetlands and barrier shoreline • Land subsidence	• Reduced effectiveness of harbor and port facilities to accommodate higher tides and storm surges • Reduced clearance under waterway bridges • Changes in navigability of channels	• Inundation of airport runways located in coastal areas
Rising temperature and increase in heat waves	• Thermal expansion on bridge expansion joints and paved surfaces • Concerns regarding pavement integrity (e.g., softening), traffic-related rutting, migration of liquid asphalt • Rail-track deformities	• Low water levels • Extensive dredging to keep shipping channels open	• Heat-related weathering and buckling of airport and runway pavements and concrete facilities • Heat-related weathering of vehicle stock
Increase in precipitation intensity	• Increased flooding of roadways, railroads, and tunnels • Overloaded drainage systems • Increased road washout • Increased soil-moisture levels affecting structural integrity	• Changes in underwater surface and buildup of silt and debris	• Impacts on structural integrity of airport facilities • Destruction or disabling of navigation aid instruments • Damage to runway, pavement drainage systems, and other infrastructure
Increase in drought conditions	• Increased susceptibility to wildfires that threaten transportation infrastructure directly • Increased susceptibility to mudslides	• Reduced river flow and shipping capacity	• Increased susceptibility to wildfires that threaten airport facilities directly
More frequent strong hurricanes	• Increased threat to stability of bridge decks • Increased damage to signs, lighting fixtures, and supports • Decreased expected lifetime of highways exposed to storm surge	• Damage to harbor infrastructure from waves and storm surges • Damage to cranes and other dock and terminal facilities	• Damage to terminals, navigation aids, fencing around perimeters, and signs, etc.

Source: NRC (2008) and Karl, Melillo and Peterson (2009).

ECONOMY. The indirect economic effects of climate change on transportation infrastructure might include the shifting of production centers for agriculture, forestry, and fisheries. While some predictions show that climate change would increase U.S. agricultural production overall, some parts of the country likely would benefit more than others, such as areas at higher latitudes (see Chapter 11). Geographic shifts in the agricultural, forestry, and fishery industries would necessitate shifts in transportation routing patterns as well, prompting the need for new infrastructure. Southwest agricultural exports may decrease and imports may increase (Reilly et al. 2003). There may also be downward cost effects on the food chains of local and regional agriculture (NRC 2010).

On a larger scale, changes in international imports and exports of agricultural products may shift seaport traffic (Caldwell et al. 2000; NRC 2008; Koetse and Rietveld 2009). Major storm events may also require evacuations of coastal areas, which could disrupt normal trade flow. In the short term, product shortages and supply-chain disruptions could increase costs for shippers, carriers, retailers, manufacturers, and others reliant on the normal flow of goods (Ivanov et al. 2008).

If the major ports in California cannot handle their usual volume due to climate-caused damage, delay, or obstruction, ports in Oregon and Washington (or elsewhere) may need to be used instead. Such a diversion could tax smaller ports and their transportation network, and add travel time to the movement of goods throughout the United States. Diverting cargo to ports in Canada or Mexico—also an option—would hurt the economies of the Southwest and the United States (MARAD 2009).

HEALTH. Indirect health effects associated with added transportation infrastructure stress have been less emphasized in the literature, yet are critically important. Transportation serves as an essential component that both defines and responds to housing and settlement patterns. This relationship determines access to goods and services. Thus, when climate change alters the environmental context of human populations and settlements, the transportation system is also altered. Forecasting these health effects hinges on predicting both the type and magnitude of environmental change and their associated impacts on human populations, settlements and the transportation system. Disadvantaged and elderly populations, who are traditionally under-served by their transportation systems, are likely to be hardest hit by climate-change effects (see detailed discussion in Chapter 15 about the effects of climate change on the health of human populations in the Southwest).

14.5 Major Vulnerabilities and Uncertainties

There are many uncertainties associated with estimating future climate impacts. These uncertainties, coupled with the timescales on which infrastructure decisions are normally made, complicate responses. For example, new infrastructure construction can take as long as twenty years, with much of that time in the planning and engineering phases. Many transportation infrastructure projects already underway (in planning, design, or construction) were developed under priorities different than those of today and did not necessarily consider climate change. As the effects of climate change begin to manifest, the design and operational vulnerabilities of the transportation system will appear.

Disruptions to the transportation system

Disruptions to the transportation system, whether caused by climate change or other factors, have major economic effects on transportation system users. Climate change has the ability to impact all modes of passenger and freight transportation, including roads, bridges, tunnels, rail, public transportation, air transport, the vehicles that use these facilities, and the energy sources (gas, electric, etc.) that fuel them. Higher fuel and power consumption and the potential disruption of fuel and electric supplies cause prices to rise. Disruptions may prevent some trips from being made altogether. Most critically, when individuals can't get to work, they lose productivity and wages. For example, the system-wide transportation damage caused by the 1996 flash floods in Chicago prevented some commuters from reaching Chicago for up to three days (NRC 2008). Disruptions within a single link (for example, the collapse of the I-35W Mississippi River Bridge) can have ramifications on congestion levels throughout an urban area. Other, longer-term ramifications include relocation costs for households that need to follow the jobs, which further stress transport networks designed for lower demand and lead to increased congestion.

Studies of economic impacts of climate change have mainly focused on the costs of rebuilding infrastructure and costs related to freight movement. The economic impacts to passenger travel, even basic estimates of time lost, have not been actively researched. The key variables necessary to quantify economic impacts are loss of human life, economic productivity, and relocation costs. Other damages are difficult to quantify or estimate, such as breaks in social networks and families, anxiety, and stress. All such social and economic changes can have health implications. While short-term effects may be relatively easy to quantify, long-term effects are more important. The magnitude of the economic consequences will depend on the links within the disrupted network, the properties of both the transport network (including levels of redundancy), transport demand (the amount and location of desired travel), and the duration of the event (including recovery and rebuilding time).

The international goods movement system relies on goods supply and demand, international collaboration, physical and natural infrastructure, and favorable economic conditions. For example, the shipping community foresees climate change to be an issue but does not have the capacity to adequately predict and proactively combat its effects (see also Chapter 9).

Ports are a major intermodal connection, transferring containers and bulk goods from ships to trucks and railways. Ports comprise the harbor, berths, terminals, cranes, and surface transportation connections. Harbors must allow safe passage of ships. Larger ships require that the harbor allow deep draft vessels. Height of bridges is also a factor in safe ship passage. Once moored in the berth, another limiting factor is the size of the port cranes. Cranes are located on the port terminals and extend over ships to pick up and lower containers. The cranes must be large enough to reach across an entire ship. Increasing ship size therefore drives port infrastructure development. A consequence of larger container ships is the transformation of international shipping from a linear system to a hub and spoke system (Notteboom 2004; RITA 2011): cargo ships increasingly service only a few ports (called *load centers*) per region, with smaller vessels then distributing goods regionally. To increase their competiveness and likelihood of becoming a regional load center, ports are making large investments such as dredging to increase their water depth, buying larger cranes, constructing new terminals, and raising bridges to add to ships' height clearance.

Part of the competitive strategy of American ports is to promote the use of green technology and environmentally sustainable practices at their facilities. Planning for climate change, however, has not been a primary concern during port infrastructure development (IFC International 2008). As climate effects are felt, other routings and ports may become more competitive, for example, the Panama Canal (as well as the Northwest Passage, discussed previously). Opened in 1914, the Panama Canal connects the Pacific and Atlantic Oceans and now facilitates the passage of forty vessels a day (Autoridad del Canal de Panamá 2011). Even though only 25% of the world's fleet can fit through the canal locks, 4% of global trade and a much higher percentage of all U.S.-destined trade pass through the Panama Canal (Rosales 2007). The canal is currently undergoing an expansion that will allow the larger cargo ships to traverse the canal and unload cargo on the U.S. East Coast rather than on the West Coast. In anticipation of this diversion of cargo, East Coast ports are investing in their facilities (e.g., dredging, raising bridges, building new terminals) but with little planning for climate change (IFC International 2008). One study found that the cost of investment in Arctic-capable ships that could use the Northwest Passage to move between Japan and Newfoundland, Canada, would be recovered, but the investment would be uneconomical if the trip were extended to New York (Somanathan, Flynn, and Szymanski 2007). There is high uncertainty involved with potential use of the Northwest Passage for shipping, including under what jurisdiction the passage would fall. The United States and Canada are contesting whether the passage falls within Canadian territorial waters or should be considered an international strait. Other uncertainties are whether and to what extent the Arctic will be ice-free, whether navigational aids of the largely uncharted Arctic will be sufficient for safe passage, and whether use of the Northwest Passage will prove economical (Griffiths 2004; Birchall 2006; Somanathan, Flynn, and Szymanski 2007).

A key uncertainty to any assessment of potential vulnerabilities is the demand for the movement of goods within the United States and internationally. Historically, domestic vehicle miles travelled (by both passengers and goods), has tracked very closely with GDP. While this has changed somewhat in the last decade, the two are still highly correlated. Growth in world trade volume has outpaced world gross domestic production over the last decade. Global and domestic economic activity is a key driver of the demand for the movement of goods, as evidenced by the drop in demand after the 2008 economic collapse. The pattern of production and consumption is also uncertain, but determines the demand for goods movement both around the globe, within the United States, and within metropolitan regions. Of course local and regional effects depend on many things, including land-use policies, property values, and government incentives both in the United States and around the globe. Finally, given the volume of CO_2 produced in the distribution of freight, another key uncertainty is the price shippers and carriers will be expected to pay for CO_2 emissions. Any pricing of emissions (not just those from mobile sources) will directly affect global and local trade and the cost of transportation.

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Endnotes

i States adopting the California standards can be found at: http://www.c2es.org/what_s_being_done/in_the_states/vehicle_ghg_standard.cfm.

ii The Southwest states contain major land ports between the two countries such as San Ysidro/Tijuana and Calexico/Mexicali (CEC 2011).