CHAPTER 4

Transportation System Performance

Highlights

- The average annual delay per commuter rose from 26 hours in 1990 to 42 hours in 2014—a 62 percent increase. The total number of hours of delay experienced by all commuters across the Nation reached 6.9 billion hours in 2014—more than twice the 1990 total.
- Urban highway congestion cost the economy $160 billion in 2014, of which 17.5 percent, or $28 billion, was due to the effects of congestion on truck movements. Highway traffic congestion levels have increased over the past 30 years in all urban areas, from the largest to the smallest.
- On average in 2014, drivers had to allow 241 percent more travel time to arrive on time 95 percent of the time.
- Amtrak's on-time performance increased from 70 percent in 2005 to a record high 83 percent in 2012. On-time improvement was more prominent on long distance routes.
- Barge tows on the inland waterways experienced an average delay of 2 hours navigating a lock in 2014, the largest delay on record and nearly double the delay in 2000.
- At inland waterway locks in 2014, scheduled maintenance and unexpected stoppages due to weather and operational issues resulted in more than 135,000 hours of lock shutdowns to traffic, almost 80 percent higher than the level in 2000.
- Over 21 percent of domestic scheduled airline flights (or 1.2 million flights) arrived at the gate at least 15 minutes late in 2014. Almost 10 percent (or 576 thousand) arrived at the gate more than 2 hours late.

As used here, system performance refers to how efficiently and reliably people and freight carriers can travel to destinations on the transportation network. This chapter focuses on measures that can be used to determine whether certain aspects of system performance are improving or declining over time.[1] The performance measures discussed are accessibility, congestion, reliability, resiliency, and security. Other aspects of system performance, such as safety, energy usage, and environmental impacts, are discussed separately in other chapters.

System performance measures often are viewed from the perspectives of both the user and the operator. Users are interested in characteristics, such as travel cost, travel time, and the reliability of successfully completing a trip within a certain time, each of which directly affects their ability to accomplish a trip purpose. Owners and operators are concerned with the level of service provided to users and the ability to respond to service disruptions so as to promote reliable and safe mobility and accessibility.

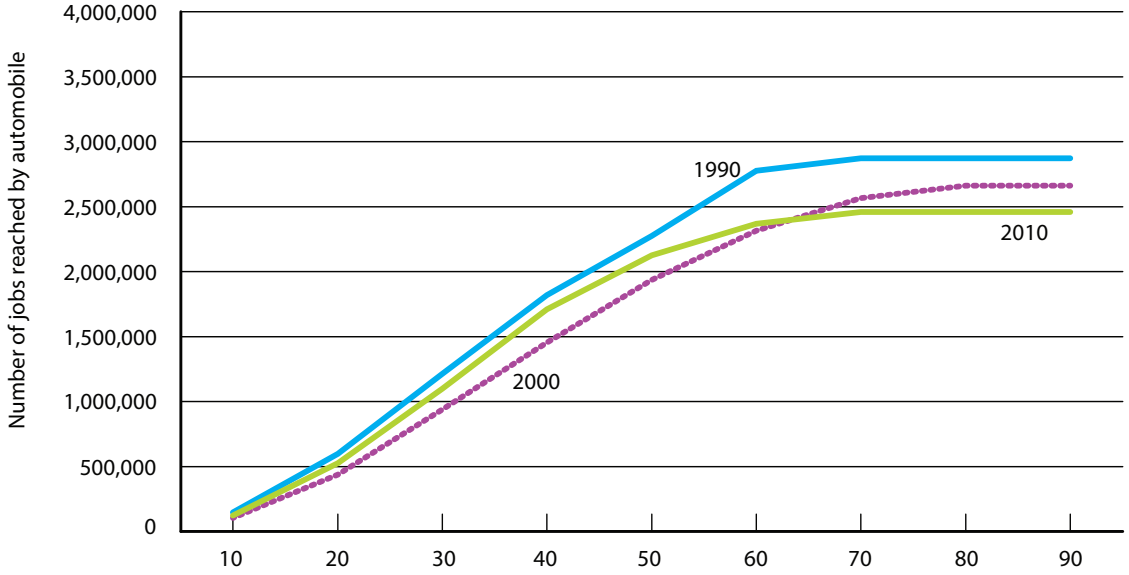
System Accessibility

System accessibility is defined as the ability of travelers and freight shippers and carriers to reach key destinations, such as hospitals, job sites, schools, factories, airports, ports, and community centers. The use of accessibility as a performance measure may need to be modified to take into account the impact of modern telecommunication systems. In today's world one can accomplish many objectives without ever traveling, such as electronic banking, shopping, and communications. This substitution effect for trip-making has in some cases reduced the number of trips made, but it might increase the number of trips in other categories, such as the number of truck deliveries resulting from internet shopping.

In evaluating system performance, it is important to know how accessibility has changed over time. The measure most often used is the number of destinations reachable within a given travel time, in particular transportation system accessibility to jobs. The Center for Transportation Studies, at the University of Minnesota, has developed a method for comparing morning peak-period accessibility to jobs by automobile across 51 U.S. metropolitan areas for 1990, 2000, and 2010 [UMN CTS 2013]. Figure 4-1 shows how accessibility to jobs has changed from 1990 to 2010. In 1990, for example, 2 million jobs across 51 metropolitan areas were accessible in an average travel time of 44 minutes by automobile. A decade later, in 2000, the average travel time increased to 52 minutes. But by 2010 that average travel time dropped to 47 minutes as travel speeds increased (to about where they were in 1990) [UMN CTS 2013]. The crossing of the 2000 and 2010 lines in figure 4-1 most likely reflects the impact of the December 2007 through June 2009 recession and the subsequent slow recovery, that is, not as many jobs were available for access.

[1] The *Moving Ahead for Progress in the 21st Century Act* (MAP-21) requires the U.S. Department of Transportation to establish performance measures and standards for several program/policy areas. MAP-21 also requires statewide and metropolitan transportation planning agencies to establish and use performance-based approaches for transportation decision-making.

FIGURE 4-1 Number of Jobs Accessible by Commute Time: 1990, 2000, and 2010



SOURCES: Levinson, D. 2013. *Access Across America*, Center for Transportation Studies, University of Minnesota, *Access Across America*. CTS 13-20. Figure 3.1. Available at http://www.cts.umn.edu/Research/featured/access/ as of June 2015.

A second University of Minnesota study [UMN CTS 2014] extends the analysis to consider transit accessibility to jobs. This more limited effort considers only morning peak-period transit schedules in 46 of the 50 largest (by population) U.S. metropolitan areas in January 2014. The 10 metro areas with the greatest accessibility to jobs by transit were (in rank order) New York, San Francisco, Los Angeles, Washington, Chicago, Boston, Philadelphia, Seattle, Denver, and San Jose. New York dominates this list by a wide margin. Due to its development density and extensive transit resources, it has 210,000 jobs accessible by transit within 30 minutes of total travel time, and 1.2 million jobs within 60 minutes. In contrast, for the ninth ranked city, Denver, where the jobs and population are more dispersed and transit service includes a rapidly expanding light rail system and an extensive bus network, the comparable accessibility figures are, respectively, 20,000 and 176,000 jobs. A more robust analysis would include other time periods, including tracking how transit accessibility changes over time, and other travel modes.

Congestion

The ability of travelers to reach a destination in a cost-effective, safe, and reliable manner is an important aspect of the Nation's transportation system. The characteristics of making such trips, including travel time, costs, and access to facilities/services, are used to indicate the level of mobility afforded to users. Box 4-A describes how system performance measures, such as travel time and congestion, are viewed from two different perspectives—the user's versus the operator's.

BOX 4-A System Performance User's v. Operator's Perspectives

From the user's standpoint, system performance is based on an individual trip. Travel time to work refers to the total number of minutes it normally takes a person to get from home to work each day, including time spent waiting for public transportation, picking up passengers in carpools, and on other activities related to getting to work [USDOC CENSUS 2015b]. In 2000 average travel time as measured by the decennial census was 25.5 minutes, which was an increase of 3.8 minutes (17.5 percent) from 21.7 minutes in 1980, and an increase of 3.1 minutes (13.8 percent) from 22.4 minutes in 1990 [USDOC CENSUS 2015b]. In 2014, based on the American Communities Survey, the average travel time stood at 26.0 minutes [USDOC CENSUS 2015a].

From the operator's perspective, congestion can also be measured by the yearly hours of delay. Table 4-1 shows that annual delay per commuter has increased by 16 hours (61.5 percent) from 26 hours in 1990 to 42 hours in 2014). This is extra time spent traveling at congested speeds rather than free-flow speeds by private vehicle drivers and passengers who typically travel in the peak periods [TAMU TTI 2015]. The Travel Time Index (TTI) is another important indicator for system operators and is discussed in detail in this chapter.

Road congestion in urban areas is one of the major causes for travel time delay. The Texas Transportation Institute has monitored congestion levels on the U.S. road network for decades and has reported in a biannual *Urban Mobility Report*[2] on the number of hours of congestion experienced by network users and the associated economic costs [TAMU TTI 2015]. Recent editions of the report provide data for 498 urban areas in the United States.

Table 4-1 shows the estimates for annual hours of delay, the number of gallons of wasted fuel due to delay, the dollar value of delay and wasted fuel, and a measure called the Travel Time Index (TTI).[3] For example, a TTI value of 1.21 indicates that a trip taking 30 minutes without congestion will take an average of 21.0 percent longer, or just over 36 minutes (1.21 × 30), during the peak travel period.

Road congestion, in terms of amount and cost, has steadily increased since 1990. The exception was the economic recession from the end of 2007 to the middle of 2009, which had a dampening effect. Congestion in the Nation's urban areas in 2014 had an economic cost of $160 billion compared to $65 billion in 1990 (2014 dollars). The average yearly delay per commuter rose from 26 hours in 1990 to 42 hours in 2014, a 62 percent increase, and the total national hours of delay in 2014 reached 6.9 billion hours—more than twice the 1990 total. The effects of congestion on truck movements accounted for $28 billion (17.5 percent) of the total congestion cost [TAMU TTI 2015]. In addition, the average commuter:

- wasted 19 gallons of fuel in 2014 (a week's worth of fuel for the average U.S. driver), up from 8 gallons in 1982;

[2] In 2015 the report title was changed to *Urban Mobility Scorecard*.

[3] The ratio of the travel time during the peak period to the time required to make the same trip at free-flow speeds.

TABLE 4-1 Annual Congestion Delay and Costs: 1990, 1995, 2000, & 2005–2014
498 urban areas

Year	Travel Time Index	Delay per commuter (hours)	Total delay (billion hours)	Fuel wasted (billion gallons)	Total cost (billions of 2014 U.S. dollars)
1990	1.13	26	3.0	1.3	$65
1995	1.16	31	4.0	1.5	$87
2000	1.19	37	5.2	2.1	$114
2005	1.21	41	6.3	2.7	$143
2006	1.21	42	6.4	2.8	$149
2007	1.21	42	6.6	2.8	$154
2008	1.21	42	6.6	2.4	$152
2009	1.20	40	6.3	2.4	$147
2010	1.20	40	6.4	2.5	$149
2011	1.21	41	6.6	2.5	$152
2012	1.21	41	6.7	3.0	$154
2013	1.21	42	6.8	3.1	$156
2014	1.22	42	6.9	3.1	$160

NOTES: Includes 15 very large urban areas (population over 3 million), 32 large urban areas (population over 1 million but less than 3 million), 33 medium urban areas (population over 500,000 but less than 1 million), 21 small urban areas (population less than 500,000), and 397 other urban areas.
SOURCE: Texas A&M University, Texas Transportation Institute, *2015 Urban Mobility Scorecard*. Available at http://tti.tamu.edu/ as of August 2015.

- experienced an average yearly delay of 42 hours in 2014; and
- planned for approximately 2.41 times (freeway only) as much travel time as would be needed in noncongested conditions to arrive at their destination ontime 9 times out of 10 [TAMU TTI 2015].

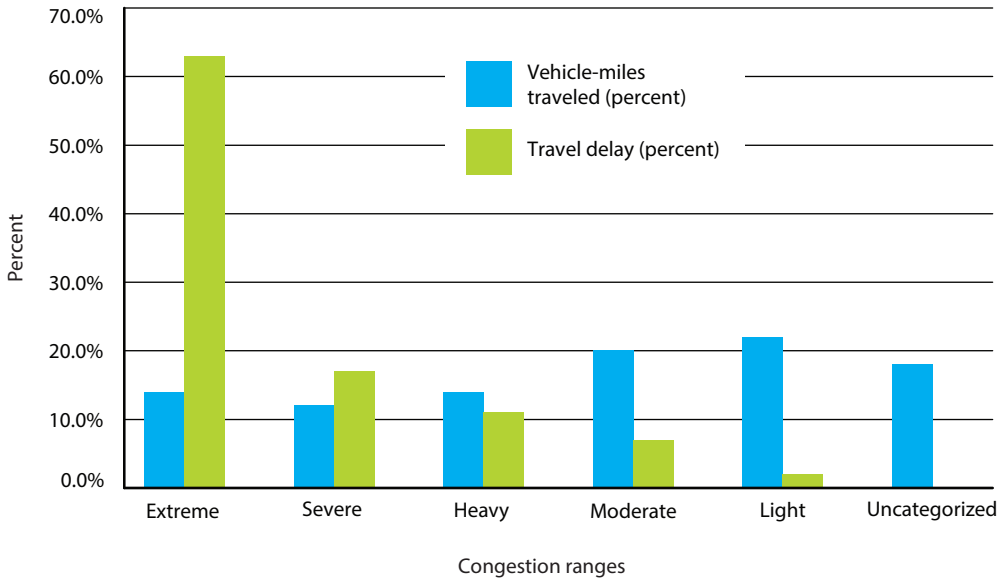
The worst congestion levels (defined as "extreme," "severe," or "heavy") affected only one in nine trips in 1982, whereas this proportion increased to more than one in three trips in 2014. In addition, the most congested sections of road (labeled extreme and severe) handled only 26.0 percent of all urban road travel, but accounted for 80 percent of peak period delays as shown in figure 4-2. It is important to note that congestion levels have increased over the past 30 years in all urban areas, from the largest to the smallest. Congestion is worse in the afternoon, but it can occur at any time throughout the day (figure 4-3).

The Federal Highway Administration (FHWA) uses vehicle probe data[4] to compile the *Urban Congestion Trends* report, which tracks 3 congestion measures in the 52 largest urban areas in the United States. While not as comprehensive as the *Urban Mobility Report*, which covers 498 urban areas and all of the congestion indicators reported above, the smaller scope of *Urban Congestion Trends* allows for more frequent updates. The latest edition of this report shows that congestion has continued to increase through 2014 [USDOT FHWA 2015]. The average duration of daily congestion[5] increased from 4 hours and 30 minutes in 2013 to 5 hours and 16 minutes in 2014, and the Travel Time Index (TTI) increased from 1.32 to 1.36.

[4] Vehicle probe data are based on real-time vehicle positions, typically obtained from the vehicle's GPS receiver or the operator's mobile phone.

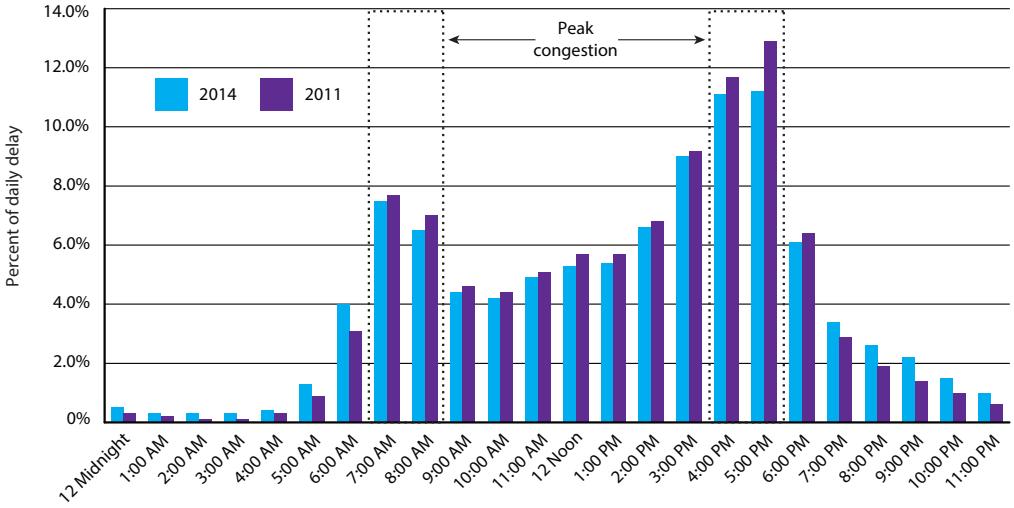
[5] Hours of congestion is defined as the amount of time when highways operate at less than 90 percent of free-flow speeds.

FIGURE 4-2 Vehicle Travel and Travel Delays in Congestion Ranges: 2014



SOURCES: Texas A&M University, Texas Transportation Institute, 2015 *Urban Mobility Scorecard*. Available at http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/mobilicorecard-2015-wappx.pdf as of August 2015.

FIGURE 4-3 Percent of Congestion by Time of Day: 2011 and 2014



SOURCES: Texas A&M University, Texas Transportation Institute, 2015 *Urban Mobility Report* (August 2015: full report with exhibits), Exhibit 5. Available at http://tti.tamu.edu/ as of October 2015.

Congestion and delay are not limited to roadways. The average length of flight delays has been over 50 minutes in every year since 2004 and reached 57 minutes in 2014, even though the number of arriving domestic flights operated by the large U.S. airlines decreased by 22.5 percent over that period (table 4-2). Mainline carrier's domestic aircraft size increased in 2014 by 1.2 seats—from 153.9 to 155.1 seats. This trend is forecasted to continue through 2035, especially with the retirement of older, smaller narrow-body aircraft (i.e. MD-80's, 737-300/400/500, and 757's). Airlines are retiring these inefficient aircraft and shifting to wide-body and larger narrow-body aircraft [USDOT FAA 2015], which often require more separation in the air and on the ground. Larger aircraft (a.k.a. "heavy") typically require a safety margin or separation of 4 to 8 nautical miles from the following aircraft. This is because of wake turbulence, which is a violent or unsteady movement of air that forms behind an aircraft especially during takeoff and landing. Operational factors and weather conditions may require additional separation, which may contribute to congestion and delays. For instance, if the separation between aircraft using the runway is increased to 5 nautical miles, then capacity would be cut by a third [NASA 2003].

Flight delays are caused by a variety of reasons, ranging from extreme weather to disruptions in airline carrier operations (figure 4-4). The combined effects of nonextreme weather conditions, airport operations, heavy traffic volume, and air traffic control

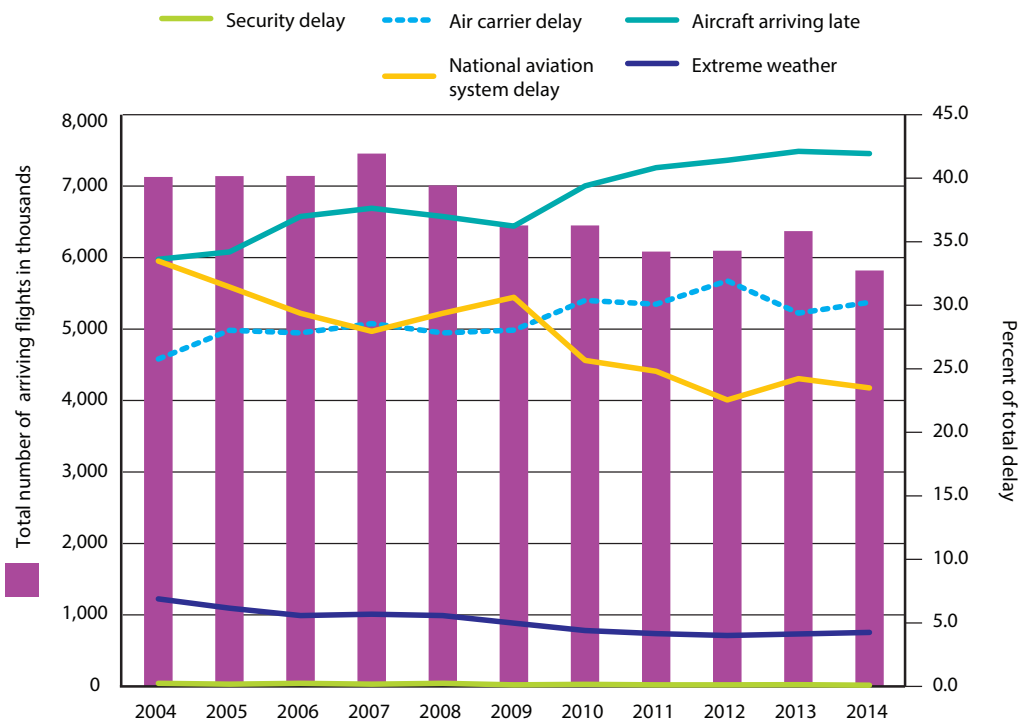
TABLE 4-2 Percentage of All Delayed Flights by Length of Time Delayed: 2004–2014

	Total number of arriving flights	Percentage of arriving flights, delayed	Average length of delay (minutes)	15-29 minutes	30-59 minutes	60-89 minutes	90-119 minutes	More than 120 minutes
2004	7,129,270	19.9	51	42.3	31.3	12.3	6.1	7.8
2005	7,140,596	20.5	52	41.8	31.1	12.4	6.2	8.1
2006	7,141,922	22.6	54	40.3	31.2	12.8	6.5	8.9
2007	7,455,458	24.1	56	39.1	31.0	13.1	6.9	9.7
2008	7,009,726	21.7	57	39.1	30.5	13.0	6.9	10.2
2009	6,450,285	18.8	54	40.7	30.7	12.7	6.6	9.0
2010	6,450,117	18.2	54	41.2	30.7	12.5	6.5	8.9
2011	6,085,281	18.2	56	40.4	30.1	12.8	6.8	9.7
2012	6,096,762	16.6	56	40.6	30.1	12.6	6.7	9.8
2013	6,369,482	19.9	56	39.7	30.4	12.7	6.8	10.1
2014	5,819,811	21.3	57	39.2	31.3	12.8	6.6	9.9

NOTES: For the monthly number of carriers reporting, please refer to the *Air Travel Consumer Reports* available at http://airconsumer.dot.gov/reports/index.htm. A flight is considered delayed when it arrived *at the gate* 15 or more minutes later than scheduled. Arriving flights consists of scheduled operations less canceled and diverted flights. Average *length of delay* is calculated for delayed flights only. Percents may not add to 100 due to rounding. The average length of flight delays has been over 50 minutes in every year since 2004 and reached 57 minutes in 2014, even though the number of arriving domestic flights operstedoperated by the large U.S. airlines flights decreased by 22.5 percent over that period.

SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, Transtats Database, *Airline On-Time Performance*. Available at http://www.transtats.bts.gov/ as of June 2015.

FIGURE 4-4 National Flight Delays by Cause, Percent of Total Delay Minutes: 2004–2014



NOTES: *Air Carrier Delay*-the cause of the cancellation or delay was due to circumstances within the airline's control (e.g. maintenance or crew problems, etc.). *Extreme Weather Delays*-significant meteorological conditions (actual or forecasted) that, in the judgment of the carrier, delays or prevents the operation of a flight. *National Aviation System Delay*-delays and cancellations attributable to the national aviation system refer to a broad set of conditions non-extreme weather conditions, airport operations, heavy traffic volume, air traffic control, etc. *Security Delay*-delays caused by evacuation of terminal or concourse, reboarding of aircraft because of security breech, inoperative screening equipment and long lines in excess of 29 minutes at screening areas. *Late Arriving Aircraft Delay*-previous flight with same aircraft arrived late which caused the present flight to depart late.

SOURCES: U.S. Department of Transportation, Bureau of Transportation Statistics, Transtats Database, *Airline On-Time Performance*, available at http://www.transtats.bts.gov/ as of June 2015.

contributed to 23.5 percent of delays in 2014, a 10 percentage point improvement from 2004. Flight delays can ripple through the U.S. aviation system as late arriving flights, for whatever reason, delay subsequent flights—the cause of 41.9 percent of delays for scheduled flights in 2014.

Congestion is especially a problem for time-sensitive freight shipments. Various performance indicators are used to monitor time-related system performance. The USDOT's FHWA, in cooperation with the American Transportation Research Institute (ATRI), is working to quantify the impact of traffic congestion on truck-based freight at 250 specific locations across the United States. Similar to the TTI, the primary measure is the ratio of uncongested speed to congested speed at key freight locations (often interstate-to-interstate interchanges). For example, a 23.1 mph peak period average speed and a 42.6 mph nonpeak period average speed in Austin, TX, yields a ratio of 1.84. Some of the most congested truck bottlenecks on freight-heavy highways in 2012 could be found in Austin,

TX (1.84); Chicago, IL (1.81); Houston, TX (1.46); and Atlanta, GA (1.46) [USDOT FHWA and BTS 2013].

On the inland water network, the U.S. Army Corps of Engineers (Corps) is responsible for 239 lock chambers and monitoring the movements of barges and other commercial vessels. In 2014 barge tows experienced an average delay of 2 hours navigating a lock (table 4-3), the largest delay on record and nearly double the delay in 2000 [USACE 2015]. Furthermore, the percent of vessels that experienced any delays increased from 35 to 49 percent. The increase in delay is most likely due to the aging of the locks in the inland water system. On older systems, the majority of tows must be split into two parts and locked through their smaller (e.g., 600-foot) lock chambers, which were not designed to handle today's longer (e.g., 1,200-foot) tows. The average age of locks under jurisdiction of the Corps is 62 years,[6] and it is expected that delays will likely increase without the needed rehabilitation and reconstruction of key locks.

System Reliability

Reliability is defined as the level to which one can make trips with some certainty that the actual trip will occur within an expected range of travel times. More reliability means less uncertainty associated with trips due to events

[6] A recent study [TRB 2015] shows that, when adjusted for the dates of major rehabilitation projects, the effective average age of locks is about 10 years less, but that still puts the average age at over 50 years.

TABLE 4-3 Lock Characteristics and Delays on Rivers with 5,000 or More Lockages: 2000, 2010, and 2014

				Average delay in minutes			Percent of vessels delayed		
	Total lock-ages (2014)	Average age of locks (2014)	Percent commercial vessels (2014)	2000	2010	2014	2000	2010	2014
All Waterways	**611,125**	**59**	**61**	**64**	**80**	**121**	**35**	**36**	**49**
Ohio River	111,734	52	88	52	97	95	31	34	43
Mississippi River	91,622	73	52	90	81	163	20	19	45
Gulf Intracoastal Waterway	39,015	52	99	58	65	110	78	84	90
Illinois Waterway	25,854	80	88	127	53	166	41	29	62
Monongahela River	23,079	70	78	12	11	24	16	18	27
Arkansas River	22,830	46	81	11	13	13	35	23	23
Tennessee River	20,719	68	67	209	122	277	24	24	43
Tennessee Tombigbee Waterway	18,636	32	46	9	3	11	38	10	14
Chicago River	10,959	77	34	5	5	13	1	1	83
Allegheny River	8,380	84	24	8	4	47	7	3	11
Columbia River	8,075	47	92	32	30	22	85	90	84
Red River	6,570	25	36	8	1	18	49	23	24
St. Mary's River	6,051	79	88	27	16	31	26	19	41
Cumberland River	5,536	54	59	16	18	113	13	12	30

NOTES: A lockage is the movement through the lock by a vessel or other matter. Commercial vessels include all vessels operated for purposes of profit and include freight and passenger vessels.

SOURCE: United States Army Corps of Engineers, Navigation Data Center, *Lock Use, Performance, and Characteristics*, (Alexandria, VA: annual issues). Available at www.navigationdatacenter.us/ as of October 2015.

such as crashes, vehicle breakdowns, and similar incidents; work zones; unannounced road work; weather; and special events that can often lead to widely varying travel times from one day to the next for the same trip.

The Planning Time Index (PTI)[7] is used to estimate the extra time that one should plan for a trip to assure on-time arrival with 95 percent confidence. For example, a PTI of 1.5 means that for a traveler to arrive on time 19 out of 20 times, the traveler should allow 50 percent more time. This means 30 extra minutes should be budgeted for a trip that in free flow conditions would typically take 60 minutes to arrive on-time. The extra time allowed, in this example 30 minutes, is called the buffer index, which is often used to assess system reliability. Figure 4-5a shows that the Travel Time Index (TTI) has been trending upward with 2015 levels mostly above 2013 and 2014. Based on PTI data collected from 52 cities between 2013 and 2015, travelers would have to plan a minimum of about 150 percent more travel time to arrive "on-time" for 19 out of 20 trips (figure 4-5b). Figure 4-5c shows the potential impact of weather on travel as the congested hours were generally higher in winter than in summer months. Also average congested hours per day in 2015 likely fell below their 2014 levels.

For nonhighway modes, different measures can be used to assess system reliability. For passenger transportation, for example, on-time performance is often an indicator of service reliability. Amtrak experienced a significant improvement in on-time performance with a record 83.0 percent on-time performance in

[7] The ratio of travel time on the worst day of the month compared to the time required to make the same trip at free-flow speeds.

FIGURE 4-5a Travel Time Index (TTI): July 2013 to June 2015

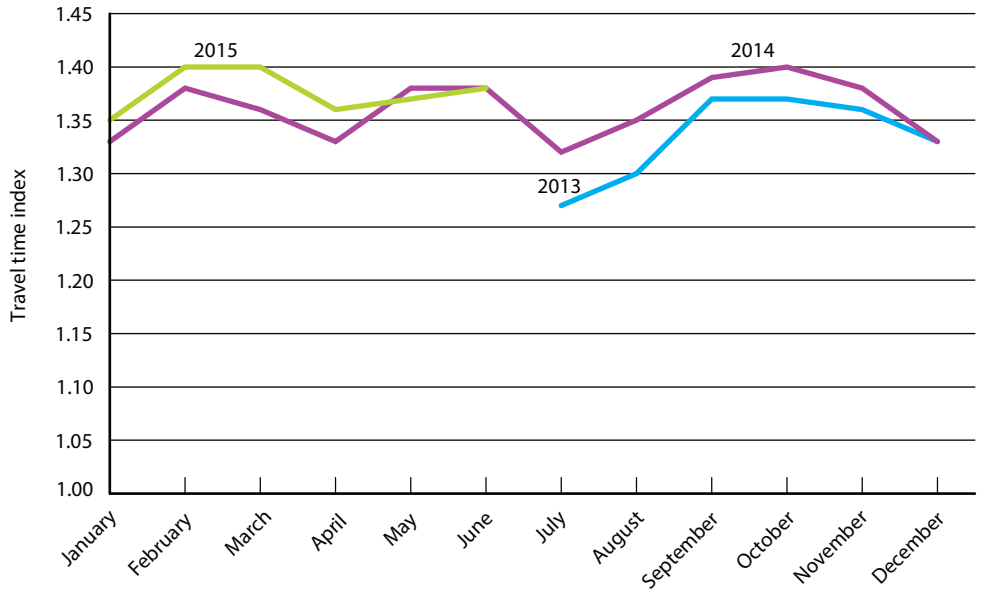


FIGURE 4-5b Planning Time Index (PTI): July 2013–June 2015

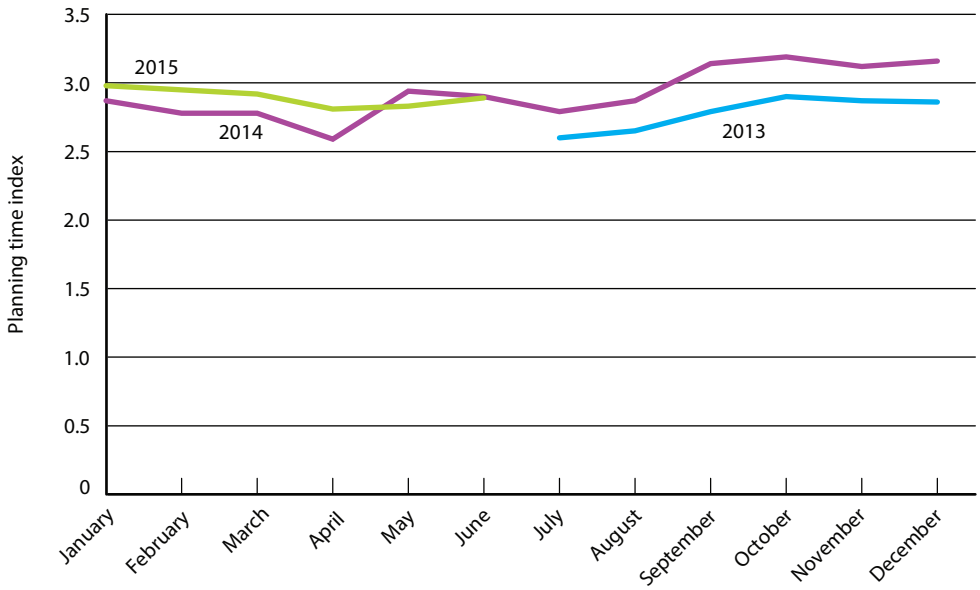
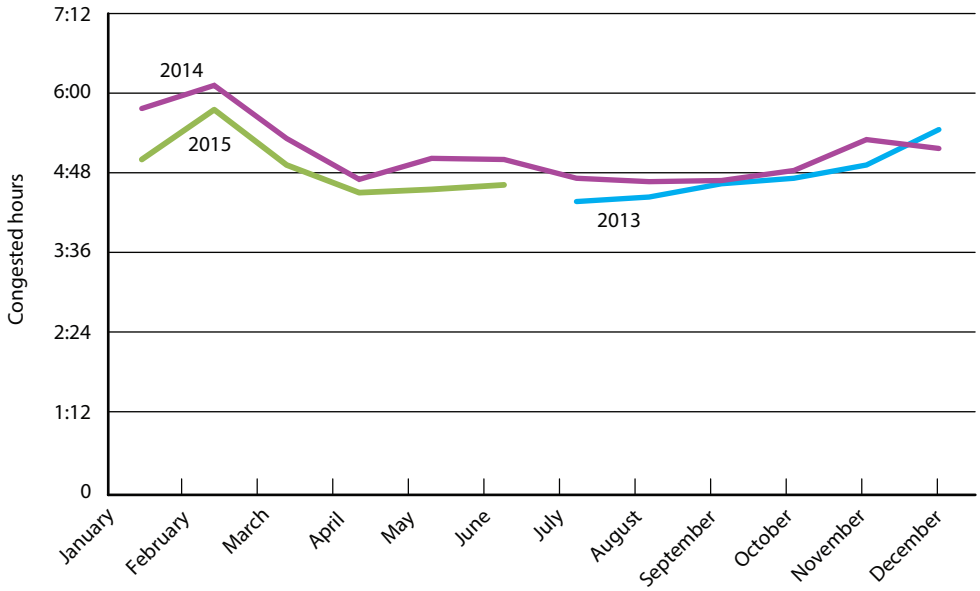


FIGURE 4-5c Congested Hours: July 2013–June 2015



NOTES: The reports utilize vehicle probe-based travel time data from FHWA's National Performance Management Research Data Set (NPMRDS). The reports are currently using data from 52 urban areas in the U.S. Congested Hours are computed as the average number of hours during specified time periods in which road sections are congested — speeds less than 90 percent of free-flow speed (e.g., 54 mph if free-flow speed is 60 mph). This measure is reported for weekdays (6:00 a.m. to 10:00 p.m.). Averages are weighted across road sections and urban areas by VMT using volumes from FHWA's HPMS. *Travel Time Index* is the ratio of the peak-period travel time as compared to the free-flow travel time. This measure is computed for the AM peak period (6:00 a.m. to 9:00 a.m.) and PM peak period (4:00 p.m. to 7:00 p.m.) on weekdays. Averages across urban areas, road sections, and time periods are weighted by VMT using volume estimates derived from FHWA's HPMS. *Planning Time Index* is the ratio of the 95th percentile travel time as compared to the free-flow travel time. The measure is computed during the AM and PM peak periods as defined in the TTI, and averages across urban areas, road sections, and time periods are weighted by VMT using volume estimates derived from FHWA's HPMS.

SOURCES: U.S. Department of Transportation, Federal Highway Administration, National Performance Management Research Data Set. Available at http://www.ops.fhwa.dot.gov/ as of November 2015.

TABLE 4-4 Amtrak On-Time Performance Trends and Hours of Delay by Cause: 2000, 2005, and 2010–2012

	2000	2005	2010	2011	2012
On-time performance, total percent (weighted)	78.2	69.8	79.7	78.1	83.0
Short distance (<400 miles), percent	82.0	73.6	80.3	79.8	84.5
Long distance (>=400 miles), percent	55.0	42.1	74.7	63.6	70.7
Hours of delay by cause, total[a]	**70,396**	**95,259**	**79,976**	**86,021**	**79,235**
Amtrak[b]	23,337	25,549	23,404	26,121	21,384
Host railroad[c]	43,881	64,097	44,090	48,707	46,564
Other[d]	3,176	5,613	12,482	11,192	11,286

[a] Amtrak changed its method for reporting delays in 2000. Therefore, the data for 2000 and following years are not comparable with prior years. [b] Includes all delays that occur when operating on Amtrak owned tracks and all delays for equipment or engine failure, passenger handling, holding for connections, train servicing, and mail/baggage handling when on tracks of a host railroad. [c] Includes all operating delays not attributable to Amtrak when operating on tracks of a host railroad, such as track and signal related delays, power failures, freight and commuter train interference, routing delays, etc. [d] Includes delays not attributable to Amtrak or other host railroads, such as customs and immigration, law enforcement action, weather, or waiting for scheduled departure time.

NOTES: Host railroad is a freight or commuter railroad over which Amtrak trains operate for all or part of their trip. Numbers may not add to totals due to rounding. All percentages are based on Amtrak's fiscal year (October 1–September 30). Amtrak trains are considered on time if arrival at the endpoint is within the minutes of scheduled arrival time as shown on the following chart. Trip length is based on the total distance traveled by that train from origin to destination:

Trip length (miles):
- 0–250
- 251–350
- 351–450
- 451–550
- > 551

SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics. *National Transportation Statistics*, Table 1-73. Available at http://www.bts.gov/ as of June 2015.

2012, up from 69.8 percent in 2005 (table 4-4). Greater improvement in on-time performance is seen for trips over 400 miles in length, where on-time performance jumped from 42.1 percent in 2005 to 70.7 percent in 2012. The vast majority of passenger train services outside the Northeast Corridor are provided over tracks owned by and shared with the Class I freight railroads. As a result, Amtrak's on-time performance is largely dependent on the condition and performance of the host railroads, with the important exception of Amtrak-owned tracks in the Northeast Corridor.

U.S. airlines reported that over 21 percent of domestic scheduled flights, or more than 1.2 million flights, arrived at the gate at least 15 minutes late in 2014. The average length of delay for late arriving flights was almost an hour. Almost 10 percent, or nearly 580,000 flights, arrived at the gate more than 2 hours late (table 4-2). Between 2005 and 2014, late arrivals increased from 20.5 to 21.3 percent.

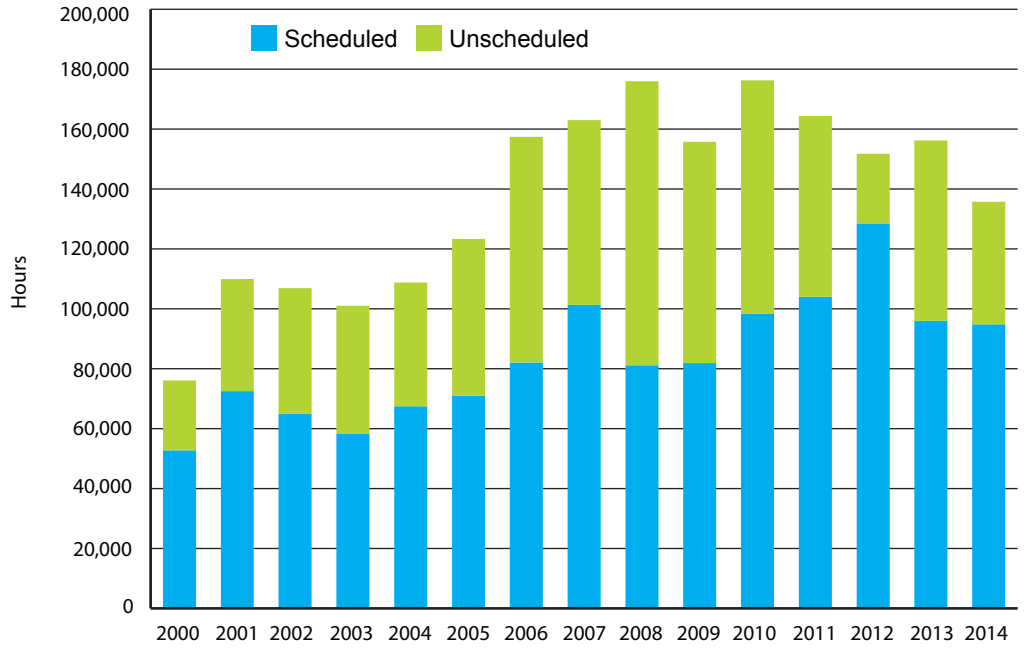
For the U.S. Army Corps of Engineers inland waterway locks, system reliability can be measured as the percent of time a lock is unavailable for use (defined as the cumulative periods over a year during which a lock facility was unable to pass traffic). Locks could be unavailable for a number of reasons, ranging from scheduled maintenance, unexpected stoppages due to operational issues, and weather conditions such as flooding and ice. For example, high water levels and flows shut down 22 locks and stopped cargo movements along the Upper Mississippi River and its

confluences in late April 2013 [USACE 2013]. As shown in figure 4-6, the total number of hours of unavailability in 2014 was almost 136,000, nearly 80 percent higher than the level in 2000. Lock unavailability due to scheduled operations, such as maintenance, ranged from 46 to 85 percent over the period shown and averaged 61 percent. Scheduled downtime was 70 percent of total down time in 2014, which was exceeded only by the 85 percent recorded for 2012. Unscheduled lock chamber downtime peaked during the 2006 to 2010 timeframe, over which it averaged about 77,000 hours per year. Over the past 4 years unscheduled lost time dropped to more typical levels, averaging about 46,000 hours per year. A recent study by the Transportation Research Board (TRB) examined data on lost transportation time, due to both delay and unavailability, at all locks over the period 2000 to 2013, and found no overall correlation between lock age (adjusted for the date of the most recent rehabilitation) and lost time [TRB 2015], although there are notable exceptions as discussed in Chapter 1.

System Resiliency

Many parts of the Nation's transportation system are vulnerable to both natural and man-made disruptions. Because of this vulnerability, transportation firms and agencies have become interested in providing a system that is resilient to disruptive impacts. A resilient transportation system has design-level robustness so that it can withstand severe blows, respond appropriately to threats, and mitigate the

FIGURE 4-6 Total Number of Hours of Lock Closures: 2000–2014



SOURCE: U.S. Army Corps of Engineers, *Navigation Data Center, Lock Performance Monitoring System. Locks by Waterway, Locks Unavailability, Calendar Years 1993-2014* (May 22, 2015). Available at http://www.navigationdatacenter.us/ as of June 2015.

consequences of threats through response and recovery operations [USDOT VOLPE 2013]. A resilient transportation system is one that can "take a punch" and recover in a timely way to provide the mobility and accessibility that are critical to the economy and to the quality of life of the Nation's citizens.

The United States has experienced extreme weather events throughout its history. However, with the heavy concentration of the Nation's population in urban areas (many along the coasts) and with a strong reliance on the efficient movement of people and goods, recent weather events have resulted in extensive economic and community costs. For example, the U.S. Department of Commerce (USDOC), National Oceanic and Atmospheric Administration (NOAA) estimated that the United States has experienced 178 weather/climate disasters (or about 5 per year on average) since 1980, including such events as hurricanes, tornadoes, floods, and droughts/wildfires. The overall damage from each of these events exceeded $1 billion, resulting in more than a $1 trillion cumulative cost to the Nation [USDOC NOAA]. Part of the physical recovery costs and overall economic impact were due to the damage and disruption to the transportation system. The year 2005 was the most costly since 1980, with over $200 billion in damages and 2,002 deaths due to extreme weather. In 2014 there were 8 such events (figure 4-7), causing 53 deaths and damages of $17 billion.

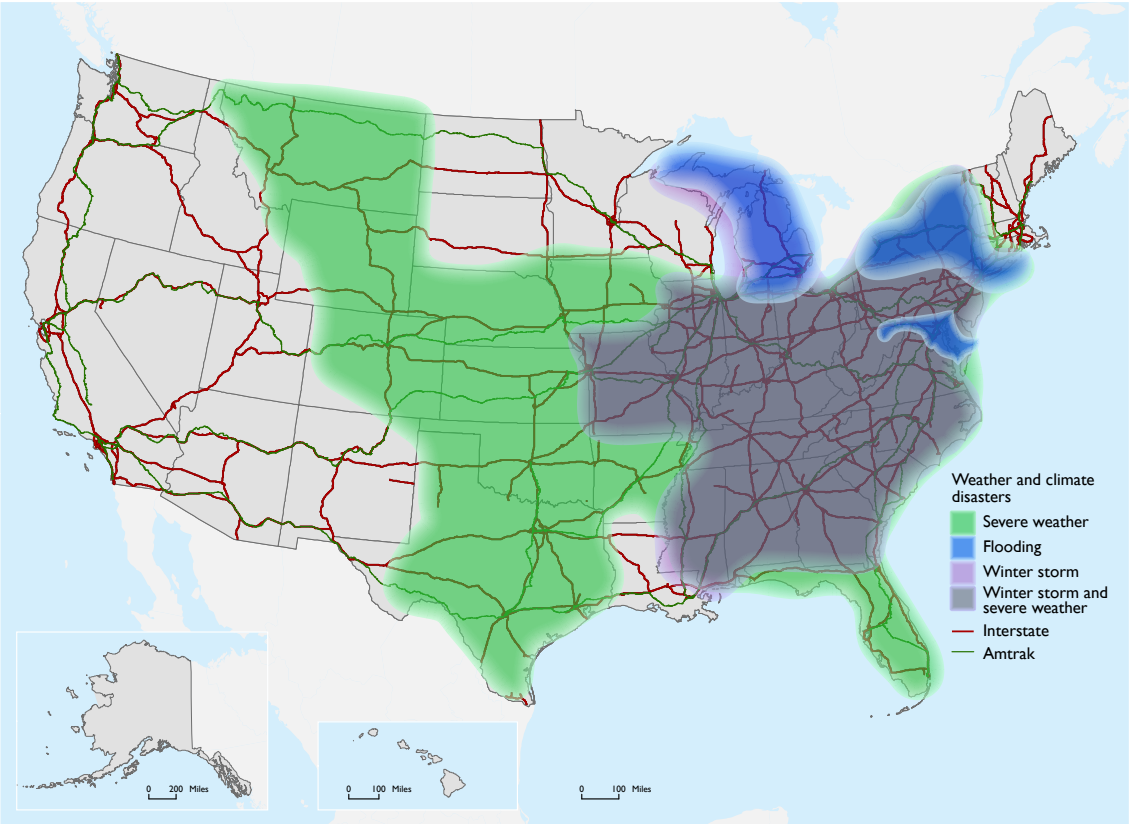
System Disruptions from Extreme Weather

Hurricane Sandy and the January–February 2015 New England blizzards are two recent examples of extreme weather events that disrupted the transportation system. Hurricane Sandy caused extensive damage in October 2012 along the New Jersey, New York, and Connecticut coasts and record flooding in lower Manhattan. Roads and bridges were damaged throughout the region, and road and rail tunnels were flooded. The region's major airports were closed, and transit service was not restored in many areas until several months after the storm [KAUFMAN, QING, LEVENSON and HANSON 2012].

Between January 24th and February 25th, 2015, severe winter weather produced blizzard-like conditions and record setting snowfalls throughout the New England region. Boston and Worcester, MA, were hit particularly hard, each recording over 94 inches of snow over the 30-day period. This extreme snow accumulation was accompanied by sustained subfreezing temperatures.[8] The transportation system in the region was severely disrupted. Over those 30 days the Massachusetts Bay Transportation Authority (MBTA), which is the country's fifth largest public transportation system, was forced to completely shut down revenue service on three separate occasions. MBTA commuter rail, heavy rail, and light rail services ran between 50 and 80 percent of normal levels over much of the period, and ferry service was similarly reduced. Boston Logan International Airport experienced 4,576 flight cancellations, impacting approximately 230,000 passengers. AMTRAK canceled all Northeast corridor service between New York

[8] The mean temperature for Boston over this period was 19.0 degrees Fahrenheit, which was the second-coldest on record.

FIGURE 4-7 Billion-Dollar Weather and Climate Disasters: 2014



SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics based upon U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Climatic Data Center (NCDC), *2014 Billion-Dollar Weather and Climate Disasters*, available at https://www.ncdc.noaa.gov/billions/ as of November 2015.

and Boston on January 27th, and canceled two or more trains on 10 additional days. The Massachusetts Department of Transportation implemented 171 lane or road closures of significant duration. The extreme snow accumulation produced dangerously high snowbanks along roadways and pedestrian routes, creating significant safety hazards for motorists and pedestrians attempting to traverse the narrowed streets and nonexistent sidewalks. [MEMA 2015]

Although the New Jersey/New York/Connecticut and New England regions suffered huge losses during their respective storms, one of the key lessons from each event was the importance of transportation system resilience. Major transportation facilities—roads, bridges, transit systems, ports, and airports—were in operation within weeks of the severe weather. In most cases advanced preparations by state and local government agencies (e.g., moving transit vehicles out of vulnerable areas and establishing emergency management centers) can mitigate disruption to transportation systems [MTA 2012]. The existence of redundant paths in the New Jersey/New York/

Connecticut and New England transportation network provided travel options for both person and freight trips seeking to avoid travel blockages. In both cases the transportation agencies were able to quickly put the transportation system back into operation, thus minimizing the economic impact to state and regional economies.

There are economic and other costs associated with such major disruptions, including those resulting from extreme weather events, infrastructure repair, and loss in productivity. For example, the economic impact to New Jersey and New York resulting from Hurricane Sandy was estimated at $67 billion [USDOC NOAA], although some studies have suggested that the impact was less given the economic rebound associated with the recovery from the hurricane [RUTGERS UNIVERSITY 2013]. This cost included the estimated expenditures to replace the roads, bridges, and transit facilities damaged by the storm. IHS Global Insight estimates that each day of snow-related shut down in Massachusetts results in direct and indirect economic impacts exceeding $250 million[9] [IHS 2015].

Security Concerns

The Transportation Security Administration (TSA), of the U.S. Department of Homeland Security, screens people as they pass through security checkpoints at 450 airports with Federal screening, and at other passenger checkpoints. In 2014 alone, the TSA prevented more than 2,200 firearms from being brought onto passenger aircraft [USDHS TSA 2015].

International piracy incidents and armed robberies at sea are another security concern affecting U.S. citizens traveling overseas, particularly in the waters surrounding the horn of Africa. This area has been monitored closely, especially after the hijacking of the U.S.-flagged *Maersk Alabama* on April 8, 2009. While, reported piracy activity at the horn of Africa was at a low in 2014, with no hijackings or boardings and only two attempted boardings, piracy activity was more prevalent in other waters in 2014, with 99 total events in West Africa (Gulf of Guinea) and 200 events in Southeast Asia [USN ONI 2015].

Economic Benefits of Improved System Performance

The following discussion focuses on the economic costs associated with poor transportation system performance, costs associated with system disruptions, and expected benefits from strategies that will improve system performance.

The *Urban Mobility Scorecard* [TAMU TTI 2015] includes an estimate of the cost to system users of about $160 billion in delay and fuel wasted in congestion costs in 2014. The 2012 *Urban Mobility Report* [TAMU TTI 2013] also estimated the beneficial effects of public transportation and roadway operational improvements to reduce these costs. For public transportation, the analysis examined what would happen if transit services were eliminated in the 498 urban areas that were part of the study. The additional system cost (or the cost foregone given transit service) is thus

[9] IHS estimates for other, more populous states are: New York, $700 million; Illinois, $400 million; Pennsylvania, $370 million; Ohio, $300 million; and New Jersey, $290 million.

considered the benefit of transit investment. For 2011 the benefit includes 865 million hours of delay eliminated and 450 million gallons of fuel saved, resulting in an estimated $20.8 billion (2011 dollars) in cost savings. For road operational improvements, the report estimated 364 million hours of delay eliminated and 194 million gallons of fuel saved, resulting in an estimated $8.5 billion in cost savings.

With respect to businesses, three critical aspects of operations can be affected directly by congestion:

- direct travel (user) cost, comprising vehicle operating costs and value of time (including reliability-related buffer time[10]) for drivers and passengers, for all business-related travel;
- logistics and scheduling costs, including costs of stocking, perishability, and just-in-time processing, and buffer times included in all of these; and
- market accessibility and scale, including loss of market-scale economies and reduced access to specialized labor and materials because of congestion.

Eliminating or reducing these costs through improved system performance would produce large economic benefits, but comprehensive estimates beyond those given in this chapter are not available.

With a new emphasis on performance-based decision making in the Federal *Moving Ahead for Progress in the 21st Century Act* (MAP-21) legislation, it is likely that state transportation planning agencies throughout the Nation will be collecting more data on system performance. This data, and the information it produces, could be useful to decision makers in identifying targeted opportunities for improving transportation system performance, with its attendant economic and quality of life benefits.

[10] Buffer time is the amount of time built into a trip to reduce the risk of being late.

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