CHAPTER 4

Transportation System Performance

Highlights

- The average annual delay per commuter rose from 37 hours in 2000 to 42 hours in 2014, a 13.5 percent increase, and the combined hours of delay experienced by all communities across the Nation in 2014 reached 6.9 billion hours—about a third higher than the 2000 total.
- Highway traffic congestion levels have increased over the past 30 years in all urban areas, from the largest to the smallest. Urban highway congestion cost the economy $160 billion in 2014, of which 17.5 percent, or $28 billion, was largely due to congestion that affected truck movements.
- Nearly one million flights, arrived at the gate at least 15 minutes late in 2016, and of those flights nearly 116,000 flights arrived at least 2 hours behind schedule, impacting more than 9 million passengers.
- Amtrak experienced a significant improvement in on-time performance in 2016, with four out of five trains arriving on schedule. On-time improvement was more prominent on long-distance routes.
- Barge tows on the inland waterways experienced an average delay of 2.4 hours navigating a lock in 2016, the largest delay on record and more than double the delay in 2000. Scheduled maintenance and unexpected stoppages due to weather and operational issues resulted in almost 144,000 hours of lock shutdowns, almost 90 percent higher than the 2000 level.

As used here, system performance refers to how efficiently, reliably, and safely people and freight carriers can travel to destinations on the transportation network. This chapter focuses on measures that can be used to assess 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 are often 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 to reach key destinations, such as hospitals, job sites, schools, factories, airports, ports, and community centers. The measure most often used is the number of jobs that are accessible within a given travel time. The Center for Transportation Studies, at the University of Minnesota, estimated the accessibility to jobs by private automobile for each of the 11 million U.S. census blocks and analyzed these data in detail for the 50 largest (by population) metropolitan areas [UMN CTS 2016a]. Highway travel times were calculated using a detailed road network and speed data that reflect typical conditions for an 8:00 a.m. Wednesday morning departure.[2] Figure 4-1 shows the national level results for the number of jobs accessible within a 30 minute drive. As might be expected from this study, the map tends to resemble a map of U.S. population density because the calculations weight driving time by the number of jobs. High levels of employment accessibility are seen for the Boston to Washington Northeast Corridor and for the Chicago, Los Angeles, and San Francisco metropolitan areas.

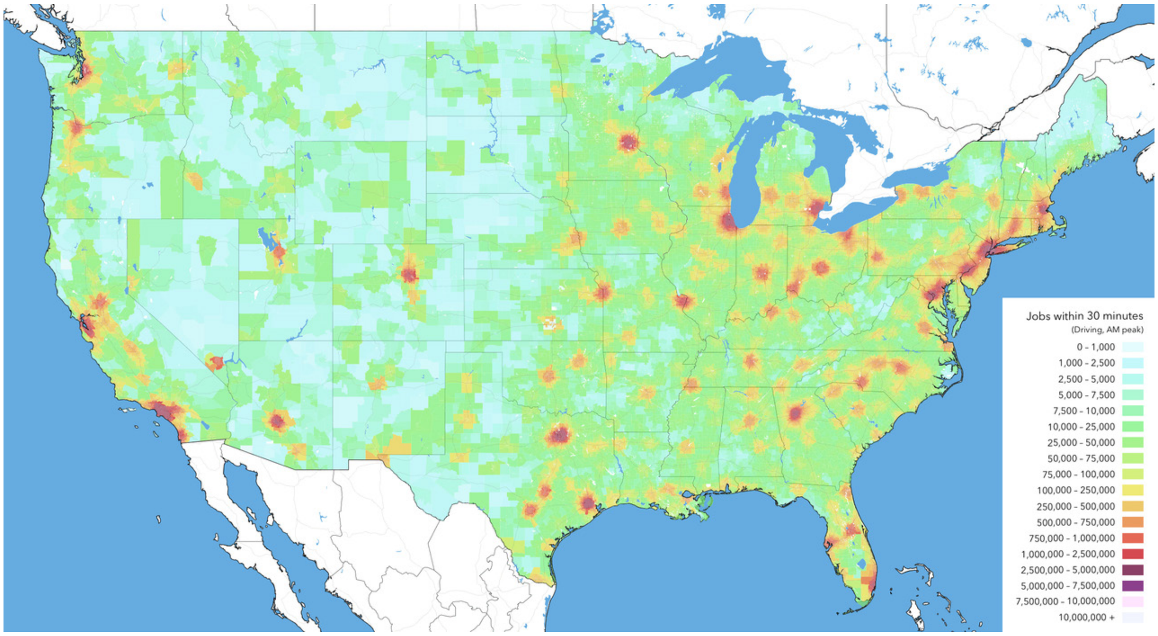
University of Minnesota studies extend the analysis to consider accessibility to jobs by transit and by walking. The transit analysis [UMN CTS 2016a] estimated the accessibility to jobs by transit (and walking to and from transit stops) for each of the 11 million U.S. census blocks, and analyzed these data in detail for 49 of the 50 largest metropolitan areas[3] using transit schedules from 2015. The university also estimated the accessibility to

[1] The *Moving Ahead for Progress in the 21st Century Act* (MAP-21) required the U.S. Department of Transportation to establish performance measures and standards for several program/policy areas. MAP-21 also required statewide and metropolitan transportation planning agencies to establish and use performance-based approaches for transportation decision-making. The *Fixing America's Surface Transportation* (FAST) *Act*, enacted in December 2015, continues these initiatives.

[2] In an earlier study, the Center used a similar methodology to examine changes in job accessibility by auto over the period 1990 to 2010 [UMN CTS 2013]. Those results are summarized in chapter 4 of the 2016 TSAR.

[3] The 41st largest city, Memphis, TN was excluded due to the non-availability of digitized transit schedules.

FIGURE 4-1 Accessibility to Jobs by Auto in 30 minutes: 2015



SOURCES: Center for Transportation Studies, University of Minnesota. 2016. Access Across America: Auto 2015, Report CTS 16-07. Figure 1. Available at http://www.cts.umn.edu/Publications/ResearchReports/, as of May 2017.

jobs by walking in the 50 largest metropolitan areas [UMN CTS 2015]. Table 4-1 shows the total number of jobs reachable within 30 minutes of travel time by auto, transit, and walking for the top 10 metro areas based on total employment. The most jobs reachable within 30 minutes across all the areas are by auto, followed by transit, and then walking.

New York City (NYC) dominates this listing by a wide margin, especially for jobs accessible by transit and walking. Due to its development density and extensive transit resources, NYC has 205,000 jobs accessible by transit within 30 minutes of total travel time and 47,000 jobs accessible within 30 minutes by walking. In contrast, for the city of Atlanta, where the jobs are more dispersed, the comparable accessibility figures for jobs reachable within 30 minutes are about 805,000 by auto, 7,000 by transit, and 3,000 by walking.

Figure 4-2 highlights the job accessibility results for three very different types of urban areas—New York, Atlanta, and San Antonio. The figure depicts the cumulative number of jobs available at increasing values of travel time. (Note that the vertical scales are different for the various graphs.) The New York metropolitan area, with a total of 8.3 million jobs, is densely developed and provides a rich array of intensively used transit and walking options as well as the traditional private automobile. More than three-quarters of the jobs in the New York metro area can be reached by transit within 60 minutes (figure 4-2). Atlanta (2.2 million total

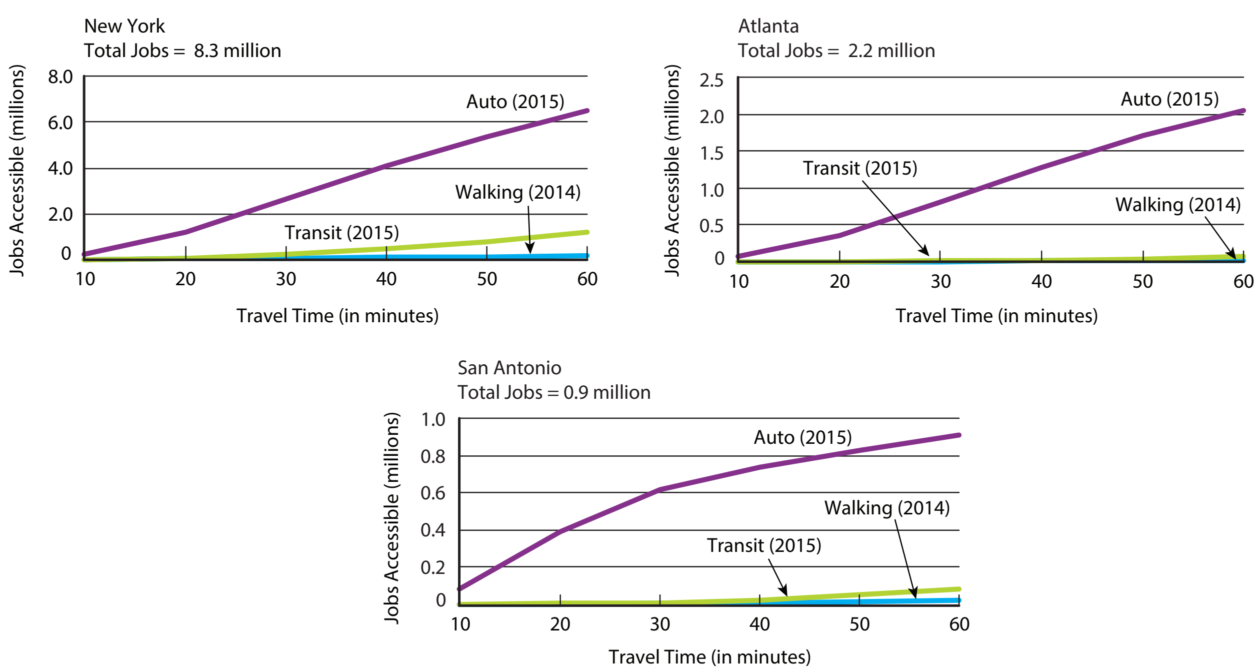
TABLE 4-1 Jobs Reachable by Auto, Transit, or Walking in the Top 10 U.S. Metropolitan Areas

Metropolitan area	Total jobs (2015)	Auto (2015)	Walking (2014)	Transit (2015)	60-minutes transit (2015)
New York	8,271,797	2,630,585	47,338	204,745	1,221,944
Los Angeles	5,364,930	2,323,105	14,490	39,564	358,984
Chicago	4,242,819	1,277,622	13,965	50,586	328,034
Dallas	2,987,734	1,346,253	5,118	9,825	95,130
Philadelphia	2,703,026	992,362	9,929	34,234	193,921
Washington, DC	2,689,299	1,157,426	12,310	46,416	328,133
Houston	2,674,987	1,150,184	6,008	12,666	106,955
Miami	2,256,047	991,891	6,872	14,462	122,624
Boston	2,247,058	938,582	9,988	43,778	271,810
Atlanta	2,245,086	804,812	3,102	6,869	63,956

NOTE: Top 10 status is based on total employment.

SOURCES: **Auto**—Center for Transportation Studies, University of Minnesota. 2016. *Access Across America: Auto 2015*, Report CTS 16-07. Table 2. **Transit**—Center for Transportation Studies, University of Minnesota. 2016. *Access Across America: Transit 2015*, Report CTS 16-09. Table 2. **Walking**—Center for Transportation Studies, University of Minnesota. 2015. *Access Across America: Walking 2014*, Report CTS 15-03. Table 2. All available at http://www.cts.umn.edu/Publications/ResearchReports/ as of May 2017.

FIGURE 4-2 Job Accessibility by Auto, Transit, or Walking in Three Selected Metropolitan Areas



SOURCES: University of Minnesota (UMN), Center for Transportation Studies (CTS).
—2016a. Access Across America: Auto 2015. Report CTS 16-07. Available at http://www.cts.umn.edu/ as of May 2017
—2016b. Access Across America: Transit 2015. Report CTS 16-09. Available at http://www.cts.umn.edu/ as of May 2017.
—2015. Access Across America: Walking 2014. Report CTS 15-03. Available at http://www.cts.umn.edu/ as of May 2017.

jobs), on the other hand, has a fast but smaller heavy rail system, a large bus system, a more decentralized job and population distribution, and lower accessibility. On average, about half of the jobs in Atlanta and New York can be reached by car in less than 40 minutes. San Antonio (910,000 total jobs in the metro area) is decentralized and automobile-dependent and has no rail transit, but has more jobs accessible by car or transit within 20 minutes than Atlanta.

Congestion

Travelers want to reach a destination in a cost-effective, safe, and reliable manner. 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.

Highways

Road congestion in urban areas is one of the major causes for travel time delay. The Texas A&M Transportation Institute (TTI) has monitored congestion levels on the U.S. road network since 1982. TTI reports findings in an annual *Urban Mobility Scorecard*[4] 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 4-2 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

[4] Prior to 2015 the report was titled the *Urban Mobility Report.*

TABLE 4-2 Annual Congestion Delay and Costs: 2000 and 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)
2000	1.19	37.0	5.20	2.1	$114
2005	1.21	41.0	6.3	2.7	$143
2006	1.21	42.0	6.4	2.80	$149
2007	1.21	42.0	6.6	2.8	$154
2008	1.21	42.0	6.60	2.4	$152
2009	1.2	40.0	6.30	2.4	$147
2010	1.2	40.0	6.40	2.5	$149
2011	1.21	41.0	6.60	2.5	$152
2012	1.21	41.0	6.70	3	$154
2013	1.21	42.0	6.80	3.1	$156
2014	1.22	42.0	6.90	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. 2014 is the most recent year available.

SOURCE: Texas A&M University, Texas Transportation Institute, *2015 Urban Mobility Scorecard*, available at http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/mobility-scorecard-2015-wappx.pdf as of May 2017.

Time Index (TTI).[5] For example, a TTI value of 1.21 indicates that a trip taking 30 minutes without congestion will take an average of 21 percent longer, or just over 36 minutes (1.21 × 30), during the peak congestion period.

Road congestion, in terms of amount and cost, has steadily increased since 2000. The exception was the economic recession from the end of 2007 to the middle of 2009, which had a dampening effect on congestion. Congestion in the Nation's urban areas in 2014 cost $160 billion compared to $114 billion in 2000 (2014 dollars).[6] The average yearly delay per commuter rose from 37 hours in 2000 to 42 hours in 2014, a 13.5 percent increase, and the total national hours of delay in 2014 equates to nearly 788 thousand years—about a third higher than the 2000 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;
- 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 non-congested conditions to arrive at their destination on time 9 out of 10 times [TAMU TTI 2015].

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

[6] 2014 is the most recent year available.

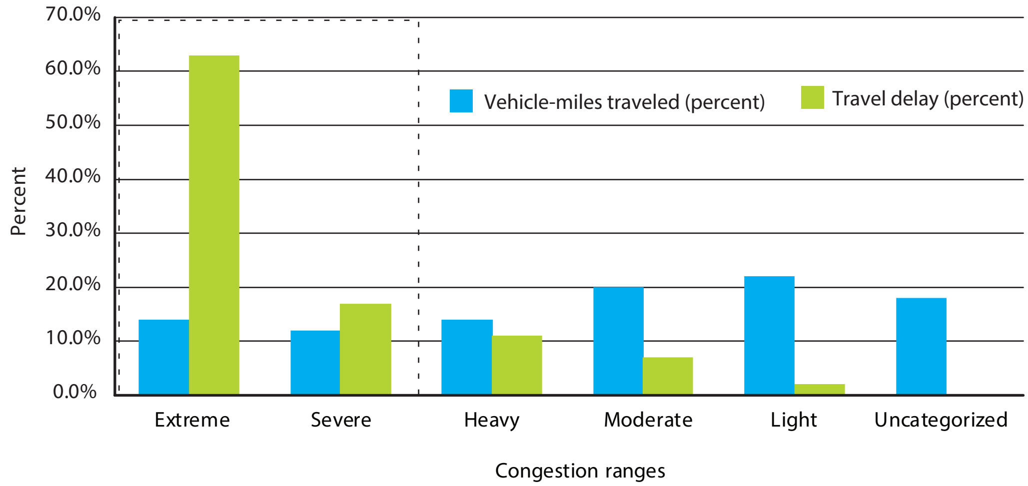
The worst congestion levels (defined as "extreme, severe, or heavy") affected only one in nine trips in 1982, whereas this proportion increased to more than one in three trips in 2014. In addition, the most congested sections of road (labeled extreme and severe) handled only 26.0 percent of all urban road travel, but accounted for 80 percent of peak period delays, as shown in figure 4-3. 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 of the day (figure 4-4). Between 2011 and 2014, the percent of congestion during peak commuting hours declined somewhat, possibly as workers shifted their work schedules to avoid the worst traffic—reducing the severity of the peaks as congestion spread over more hours.

The Federal Highway Administration (FHWA) uses vehicle probe data[7] to compile the *Urban Congestion Trends* report, which tracks congestion measures in the 52 largest urban areas in the United States. While not as comprehensive as the *Urban Mobility Scorecard*, which covers 498 urban areas and all 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 between 2015 and 2016 congestion remained unchanged or marginally improved [USDOT FHWA 2017]. The average duration of daily congestion[8]

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

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

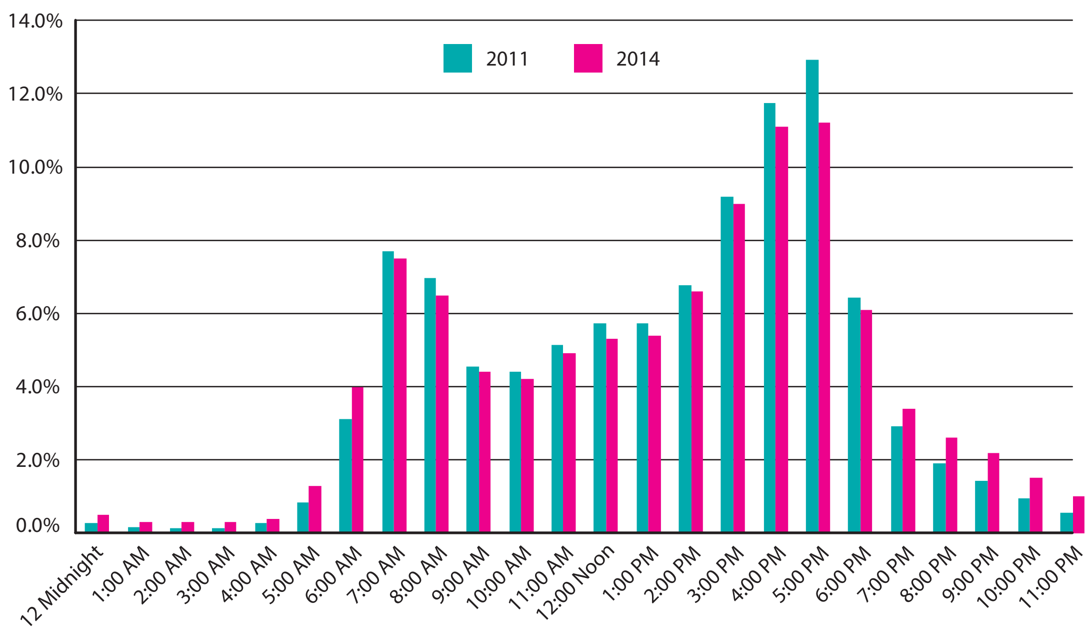
FIGURE 4-3 Vehicle and Travel Delays in Congestion Ranges: 2014



NOTE: 2014 is the most recent year available.

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 November 2017.

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



NOTE: 2014 is the most recent year available.

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 March 2017.

remained almost constant from 4 hours and 40 minutes in 2015 to 4 hours and 43 minutes in 2016, but is 20 minutes lower than the 5 hours and 3 minutes of average duration in 2014.

Countering the overall trend, congestion in 11 urban areas (21 percent) worsened, while that in 10 areas (19 percent) improved. Most (but not all) of the areas with more congestion in 2016 than in 2015 were in the South and on the West coast, while most of the areas with less congestion were in the Northeast [USDOT FHWA 2017]. This is likely related to population changes that are occurring in these regions. Increases in the number of drivers and vehicles in the Sun Belt and Pacific coast areas are outpacing the ability of those areas to implement traffic improvements

Congestion is especially a problem for time-sensitive freight shipments, such as perishable agricultural products, just-in-time manufacturing parts and components, and high-value consumer goods. Various performance indicators are used to monitor time-related system performance. The Federal Highway Administration (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 17.59 mph peak period average speed and a 39.51 mph non-peak period average speed in Chicago yields a ratio of 2.25, suggesting that it takes more than twice as long to travel the same route during the peak travel hours. Some of the most congested truck bottlenecks on freight-heavy highways in 2014 were in Chicago, IL (2.25), Austin, TX (1.90), and Atlanta, GA (1.68) [USDOT BTS 2017].

Another impact of peak-period highway congestion is its effect on access to jobs. The University of Minnesota study of job accessibility by private automobile, discussed earlier [UMN CTS 2016a], included an analysis for the top 50 U.S. metropolitan areas. Accessibility was calculated assuming departure times of 4:00 a.m., representing free-flow conditions, and compared with the results using a start time of 8:00 a.m., representing peak period conditions. The congestion effect is defined as the percentage decrease in the number of jobs that can be reached within specified time thresholds at congested times of day relative to free-flow times. For the top 10 cities as ranked by job accessibility, the number of jobs reachable within a given driving time is typically 10 to 25 percent lower during the congested times of the day.

Aviation

Congestion and delays are not limited to roadways. The average length of commercial airline flight delays has been over 50 minutes every year since 2004 and reached an all-time high of 62 minutes in 2016. During this period the number of arriving domestic flights operated by large U.S. airlines decreased by 21.2 percent, but the enplanements increased by 80.2 percent (table 4-3). Late arrivals peaked at 24.1 percent in 2007, and since then have been in the range of about 17 to 20 percent.

TABLE 4-3 Percentage of All Delayed Flights by Length of Time Delayed: 2004–2016

Year	Total number of arriving flights	Delayed flights	Minutes late					Passengers impacted by > 120 minute delay
			15-29	30-59	60-89	90-119	> 120	
2004	7,129,270	1,421,391	42.3%	31.3%	12.4%	6.1%	7.8%	4,063,357
2005	7,140,596	1,466,065	41.9%	31.2%	12.5%	6.3%	8.2%	4,704,777
2006	7,141,922	1,615,537	40.4%	31.3%	12.9%	6.5%	8.9%	5,347,226
2007	7,455,458	1,804,028	39.1%	31.0%	13.2%	6.9%	9.7%	6,538,474
2008	7,009,726	1,524,735	39.2%	30.6%	13.1%	6.9%	10.2%	6,215,888
2009	6,450,285	1,218,288	40.8%	30.8%	12.8%	6.6%	9.0%	4,356,447
2010	6,450,117	1,174,884	41.2%	30.7%	12.5%	6.6%	9.0%	4,776,924
2011	6,085,281	1,109,872	40.4%	30.1%	12.8%	6.8%	9.8%	5,057,873
2012	6,096,762	1,015,158	40.6%	30.2%	12.7%	6.7%	9.8%	5,691,358
2013	6,369,482	1,269,277	39.8%	30.5%	12.8%	6.9%	10.1%	6,538,060
2014	5,819,811	1,240,528	39.2%	31.3%	12.8%	6.6%	10.0%	7,420,175
2015	5,819,079	1,063,439	38.8%	30.6%	12.8%	6.9%	10.9%	8,236,337
2016	5,617,658	964,239	38.1%	30.0%	13.0%	7.0%	12.0%	9,381,444

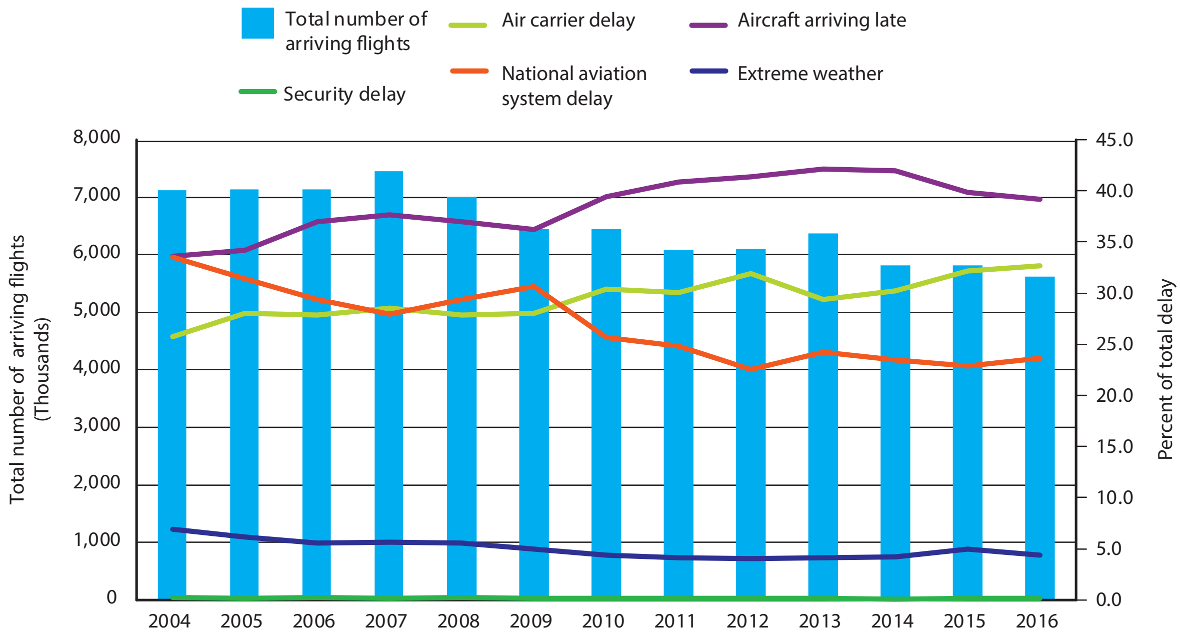
NOTES: For the monthly number of carriers reporting, please refer to the Air Travel Consumer Reports available at http://airconsumer.dot.gov/reports/index.htm. A flight is considered delayed when it arrived at the gate 15 or more minutes later than scheduled. Arriving flights consists of scheduled operations less canceled and diverted flights. Average length of delay is calculated for delayed flights only. Percents may not add to 100 due to rounding.

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 November 2017.

The average aircraft size (seats per aircraft mile) of major U.S. commercial air carriers increased in 2016 by 2.3 seats, from 149.1 in 2015 to 151.3, which is the highest level since 1994. This trend is forecast to continue through 2037, especially with the retirement of older, smaller narrow-body aircraft (i.e., MD-80s, 737-300/400/500, and 757s). Airlines are retiring these less efficient aircraft and shifting to wide-body and larger narrow-body aircraft [USDOT FAA 2017], 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.

Flight delays are caused by various reasons, ranging from extreme weather to disruptions in airline carrier operations (figure 4-5). The combined effects of non-extreme weather conditions, airport operations, heavy traffic volume, and air traffic control contributed to 23.7 percent of delays in 2016, a 9.8 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

FIGURE 4-5 National Flight Delays by Cause, Percent of Total Delay Minutes: 2004–2016



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.). Aircraft Arriving Late-previous flight with same aircraft arrived late which caused the present flight to depart late. 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. National Aviation System Delay-delays and cancellations attributable to the national aviation system refer to a broad set of conditions, including non-extreme weather conditions, airport operations, heavy traffic volume, air traffic control, etc. Extreme Weather-significant meteorological conditions (actual or forecasted) that, in the judgment of the carrier, delays or prevents the operation of a flight.

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 March 2017.

cause of 39.2 percent of delays for scheduled flights in 2016. Despite the often-heard passenger complaints about long lines and other delays due to TSA check-point screening procedures, that has been the source of only 0.1 percent of flight delays every year from 2011 to 2016.

Waterways

On the inland water network, the U.S. Army Corps of Engineers (USACE) is responsible for 239 lock chambers and monitoring the movements of barges and other commercial vessels. In 2016 barge tows experienced an average delay of 2.4 hours navigating a lock (table 4-4), the largest delay on record and more than double the delay in 2000 [USACE 2017]. Furthermore, the percent of vessels that experienced any delays increased from 35 to 48 percent, impacting more than 360,000 vessels. On average, 9 of every 10 vessels on the Gulf Intracoastal Waterway experienced more than 1 hour of delay in 2016, and more than half of the vessels navigating a lock in the Tennessee River experienced close to 4 hours of delay (table 4-4). The increase in delay is likely due to the aging of the locks in the inland water system.

TABLE 4-4 Lock Characteristics and Delays on Rivers with 5,000 or More Lockages: 2000, 2010, and 2016

	Average Age of Locks (2016)	Total Lockages (2016)	Percent Commercial Lockages (2016)	Average Tow Delay in Minutes			Percent of All Vessels Delayed		
				2000	2010	2016	2000	2010	2016
All Waterways	61	590,218	78	64	80	146	35	36	48
Mississippi River	75	115,769	80	90	81	133	20	19	52
Ohio River	54	95,778	91	52	97	83	31	34	44
Gulf Intracoastal Waterway	54	35,916	98	58	65	76	78	84	91
Illinois Waterway	82	26,020	93	127	53	107	41	29	61
Arkansas River	48	22,307	92	11	13	11	35	23	15
Tennessee River	70	21,058	66	209	122	235	24	24	46
Monongahela River	72	20,781	83	12	11	33	16	18	18
Tennessee Tombigbee Waterway	34	19,845	71	9	3	10	38	10	23
Chicago River	79	11,218	68	5	5	19	1	1	76
Allegheny River	86	9,371	30	8	4	137	7	3	8
Caloosahatchee River	57	9,298	13	5	2	4	26	16	7
Columbia River	49	7,440	96	32	30	38	85	90	77
Cumberland River	56	6,728	73	16	18	139	13	12	31
St. Mary's River	81	5,848	91	27	16	29	26	19	42

NOTES: A lockage is the movement through the lock by a vessel or other matter. Commercial lockages are all those that service 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 March 2017.

On older systems, the majority of tows must be split into two parts and locked through 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 USACE is over 64 years,[9] and it is expected that delays will likely increase in the absence of needed rehabilitation and reconstruction of key locks.

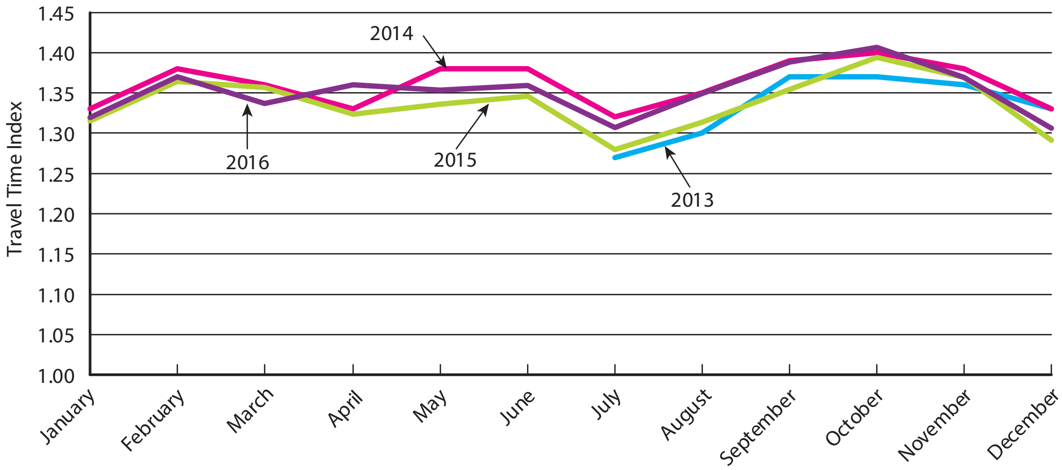
[9] A recent study [TRB 2015] shows that, when adjusted for the dates of major rehabilitation projects, the effective average age of locks is about 10 years less, but that still puts the average age at over 50 years.

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 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.

Figure 4-6 shows that the Travel Time Index has been trending upward with 2016 levels

FIGURE 4-6 Travel Time Index: July 2013–December 2016



SOURCE: U.S. Department of Transportation, Federal Highway Administration, National Performance Management Research Data Set (NPMRDS), available at https://ops.fhwa.dot.gov/perf_measurement/ as of October 2017.

mostly above 2013 and 2015, indicating that urban traffic congestion has been increasing. The figure also illustrates the effects of seasonality as travel time during the summer months shows a marked decline.

For non-highway 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 2012, which declined to 71 percent in 2015 but increased to 79 percent in 2016 (table 4-5). Greater improvement is seen for trips over 400 miles in length, where on-time performance jumped from 42.1 percent in 2005 to 63 percent in 2016. The vast majority of passenger train services outside the Northeast Corridor (NEC) 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 NEC (see figure 1-7a and b). Amtrak's recent improvements are likely due to a combination of greater host railroad investments in track and signaling improvements, and Amtrak's investments in newer rolling stock (see chapter 1). Aviation on-time performance was discussed earlier in this chapter.

For USACE inland waterway locks, system unreliability 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

TABLE 4-5 Amtrak On-Time Performance Trends and Hours of Delay by Cause: 2010–2016

	2010	2011	2012	2013	2014	2015	2016
On-time performance, total percent (weighted)	79.7	78.1	83.0	82.3	72.4	71.2	79.1
Short distance (<400 miles), percent	80.3	79.8	84.5	83.6	75.1	73.3	81.1
Long distance (>=400 miles), percent	74.7	63.6	70.7	71.9	50.6	53.7	63.0
Hours of delay by cause, total	**79,976**	**86,021**	**79,235**	**78,604**	**100,018**	**102,058**	**89,983**
Amtrak[a]	23,404	26,121	21,384	22,379	31,787	31,582	26,339
Host railroad[b]	44,090	48,707	46,564	44,632	57,413	57,701	48,555
Other[c]	12,482	11,192	11,286	11,592	10,816	12,774	15,087

[a] 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.

[b] 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.

[c] 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:

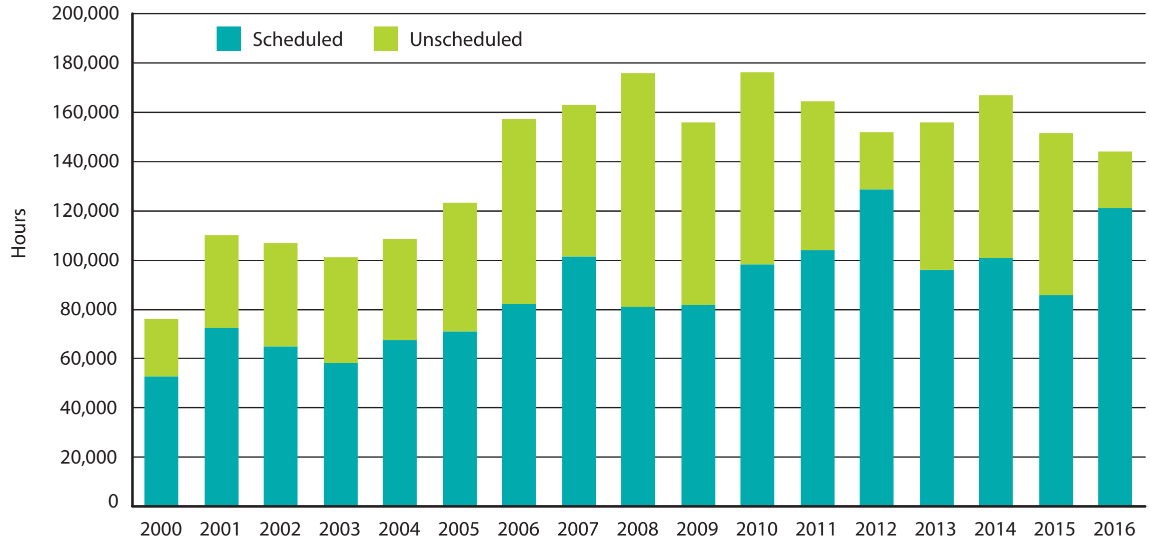
Trip length (miles)	Minutes late at endpoint
0–250	10 or less
251–350	15 or less
351–450	20 or less
451–550	25 or less
> 551	30 or less

SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics. National Transportation Statistics, Table 1-73. Available at http://www.bts.gov/ as of November 2017.

Mississippi River and its confluences in late April 2013 [USACE 2013]. As shown in figure 4-7, the total number of hours of unavailability in 2016 was almost 144,000, nearly 90 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 84 percent of total down time in 2016. Unscheduled lock chamber downtime peaked from 2006 to 2010, over which it averaged about 77,000 hours per year. Over the prior 4 years, unscheduled lost time dropped, averaging about 52,000 hours per year. There were 23,000 hours of unscheduled closures in 2016, which is down 65.4 percent from 2015 and about half the 5-year average.

The U.S. locks of the St. Lawrence Seaway have posted a remarkable record of reliability in recent years. The number of ocean vessel incidents due to mechanical, electrical or structural failures, human factors, or groundings dropped steadily from 29 in 1999 to only 3 in 2016 [SLSDC 2017]. Seaway officials attribute the improvement to the

FIGURE 4-7 Total Number of Hours of Lock Closures: 2000–2016



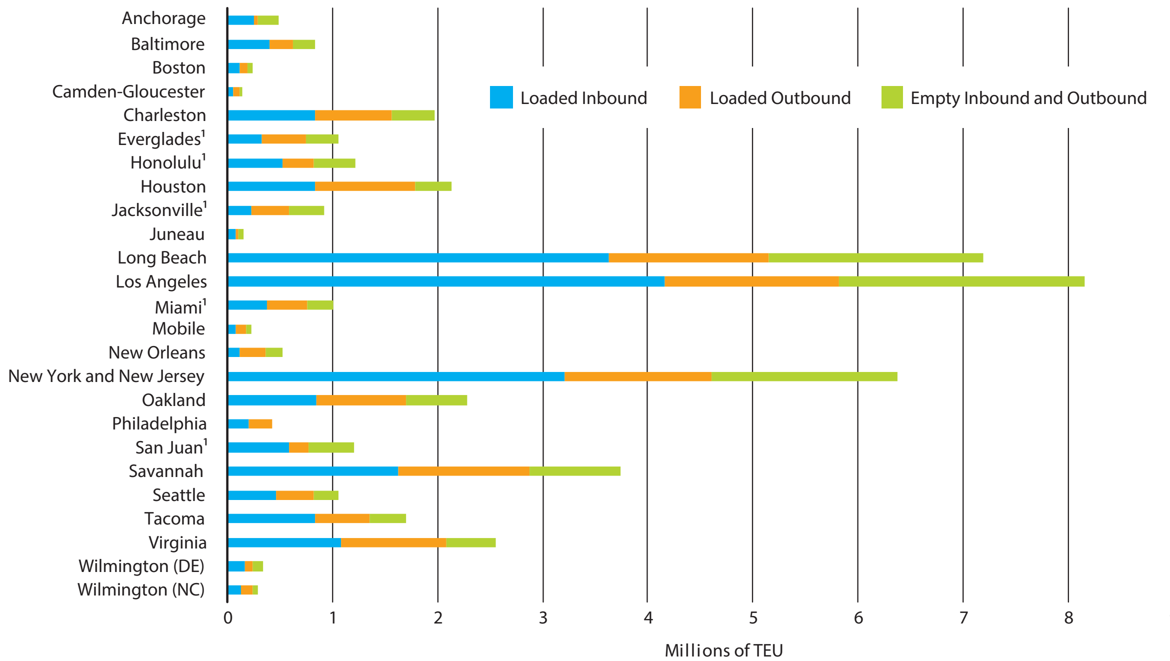
SOURCE: U.S. Army Corps of Engineers, Navigation Data Center, Lock Performance Monitoring System. Locks by Waterway, Locks Unavailability, Calendar Years 1993-2016 (February 2, 2017). Available at http://www.navigationdatacenter.us/ as of March 2017.

Enhanced Seaway Inspection Program that went into effect in 1997, in which inspection activities were concentrated at Montreal at the Seaway's point of entry. Over the past 10 years, lock availability has averaged 99.85 percent and has consistently exceeded the operational goal of at least 99 percent. To maintain this level of safety, efficiency, and reliability, the Saint Lawrence Seaway Development Corp. is investing in new technologies, such as an automated draft information system implemented 5 years ago, and a new hands-free mooring system that will shave as much as 10 minutes from average lockage time at each lock.

In 2015 Congress took action to develop more data and analysis pertaining to the performance of maritime ports. *The Fixing America's Surface Transportation* (FAST) *Act* directs BTS to establish a port performance freight statistics program, and submit an annual report to Congress that includes statistics on capacity and throughput for at least the top 25 ports, as measured by total cargo tonnage, dry bulk tonnage, or twenty-foot equivalent units (TEU) of containers handled [USDOT BTS 2016]. Figure 4-8 displays the 2015 TEU volumes for the top 25 U.S. container ports. Containers tend to carry high value, just-in-time cargo.

Port capacity could be measured by the maximum throughput in tons, TEU, or other units (e.g., number of vehicles) that a port and its terminals can handle over a given period. Precise estimates of port capacity generally require extensive terminal-by-terminal engineering studies, and at the present time are neither nationally available nor nationally consistent. Hence, four indicators of port capacity are reported at this time:

FIGURE 4-8 Annual TEU of the Top 25 Ports by TEU: 2015



[1] Data based on fiscal year not calendar year.

SOURCE: U.S. Department of Transportation. Bureau of Transportation Statistics. 2016. *Port Performance Freight Statistics Program: Annual Report to Congress 2016*. Figure 3. Available at https://www.bts.gov as of May 2017.

1. channel depth,
2. berth length for container ships,
3. number and type of container cranes, and
4. number of on-dock rail transfer facilities.

These four measures indicate the size of a port, which is used as a proxy for its capacity. BTS continues to improve port performance statistics for future annual port performance reports.

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 that can withstand severe blows, respond appropriately to threats, and mitigate the consequences of threats through response and recovery operations [USDOT VOLPE 2013].

System Disruptions from Extreme Weather

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. The U.S.

Department of Commerce (USDOC), National Oceanic and Atmospheric Administration (NOAA) estimated that from 1980 to 2016 the United States experienced 203 weather disasters (or about 5.5 per year on average), 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 $1.1 trillion cumulative cost to the Nation [USDOC NOAA NCEI 2017]. Part of the physical recovery costs and overall economic impact were due to the damage and disruption to the transportation system.

These extreme events are increasing in frequency, as the annual average for the most recent 5 years (2012–2016) is 10.6 events. In 2016 there were 15 such events, causing 138 deaths and estimated damages of $46.8 billion.

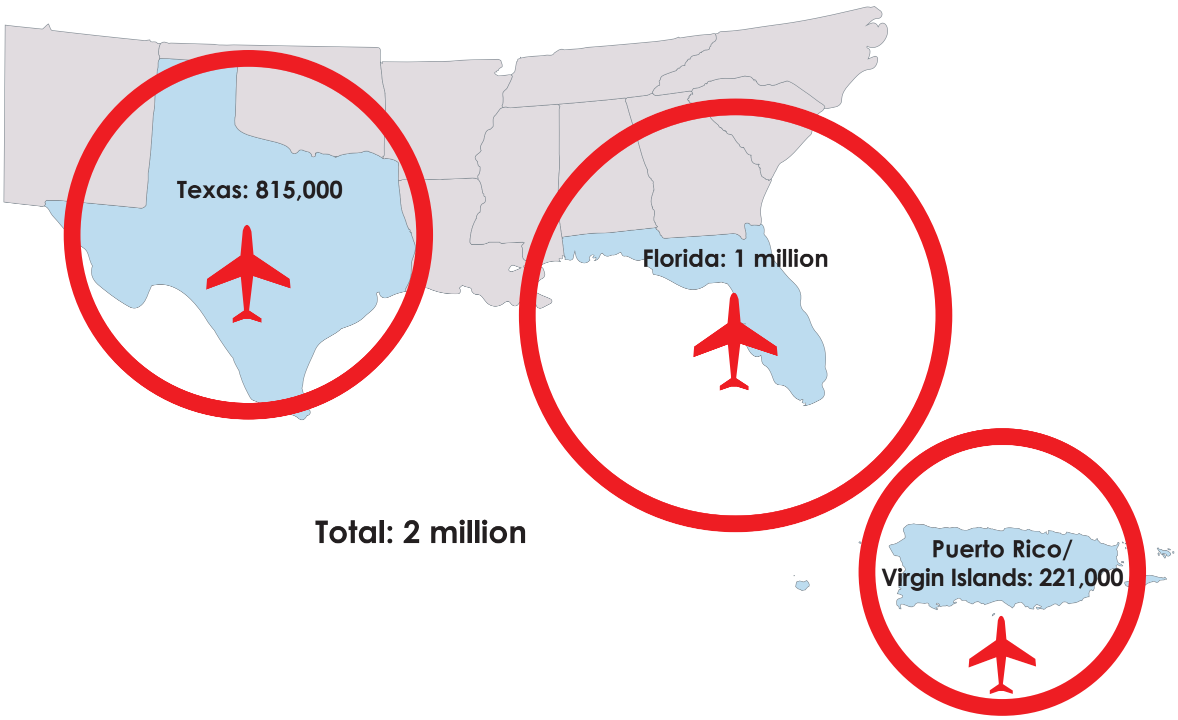
Hurricane Katrina, which hit New Orleans in 2005 and severely impacted the Gulf Coast; and Hurricane Sandy, which devastated the New Jersey, New York, and Connecticut coasts in 2012 and caused record flooding in lower Manhattan; caused severe disruptions of the transportation system. Highways, railroads, and bridges were damaged throughout the regions, and many bridges had to remain closed until their structural safety could be evaluated. In both cases, the regions' major airports were closed for several days, and transit service was severely curtailed for many weeks. Maritime ports had to close for several days, but many had difficulty reopening due to shortages of workers, who were busy dealing with their own losses.

Hurricanes Harvey, Irma, and Maria left a trail of destruction that included the widespread disruption of the aviation system. Even though the system was resilient and bounced back quickly, the Bureau of Transportation Statistics (BTS) estimates that numerous flight cancellations in hurricane-ravaged areas left 2 million would-be passengers without the flights they had booked – 815,000 passengers in Texas, 1 million in Florida, and 221,000 in Puerto Rico and the Virgin Islands (figure 4-9).

Figure 4-10 shows some of the critical U.S. transportation infrastructure, including airports, seaports, and highways near the path of Hurricane/Tropical Storm Harvey. Airport and port operations ceased as the storm passed through the region, placing significant pressure on the numerous petroleum facilities along the Gulf coast, which is home to 45 percent of total U.S. petroleum refining capacity and 51 percent of total U.S. natural gas processing plant capacity [USDOE EIA 2017]. The full impact of the 2017 hurricane season, including the major hurricanes Harvey, Irma, and Maria, are still being assessed.

Other types of extreme weather events also have large impacts. In 2016 widespread flooding in West Virginia, tornados in the Ohio River Valley at the same time, and flooding in Louisiana later in the summer together caused 36 deaths and $11.1 billion in damages. Wildfires in the west and southeast in the second half of 2016 destroyed hundreds of square miles of forestland, closed roads in national parks, and caused 21 deaths and $2.4 billion in estimated damages. A devastating blizzard struck the eastern United States in January of 2016. It is estimated that each day of snow-related shut down in the Northeast results in direct and indirect economic impacts

FIGURE 4-9 Estimated Number of Passengers on Flights Canceled During Hurricanes Harvey, Irma, and Maria: 2016



SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information, available at www.bts.gov as of November 2017.

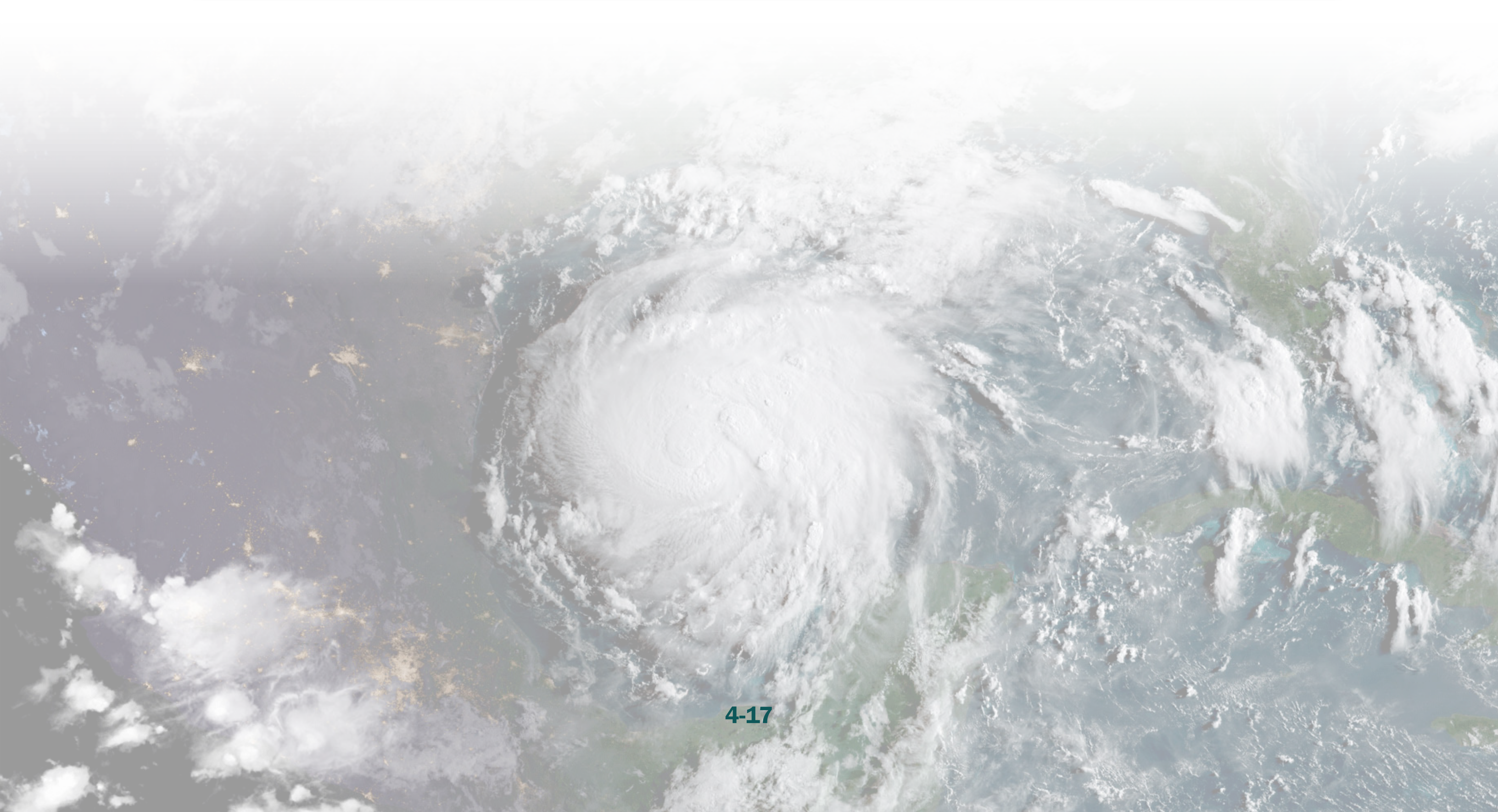
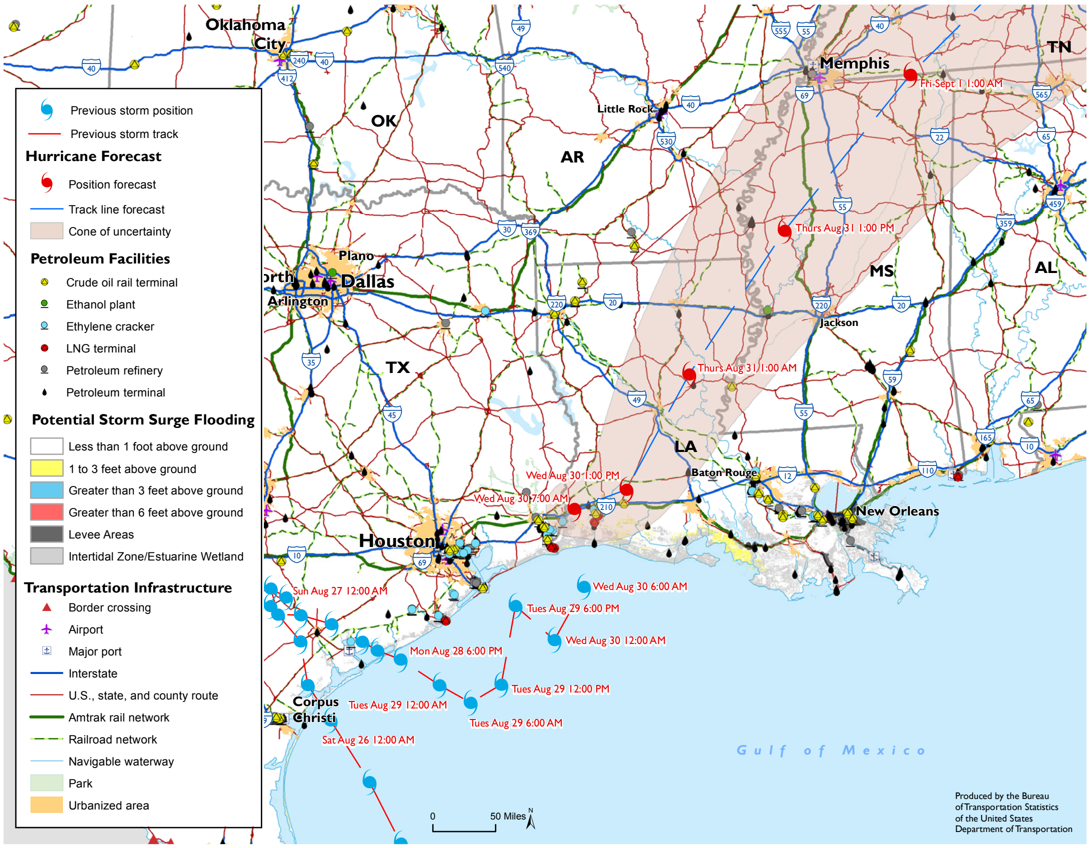


FIGURE 4-10 Selected U.S. Transportation Infrastructure and Hurricane/Tropical Storm Harvey (As of Wednesday Morning, August 30th)



SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, Office of Spatial Analysis and Visualization, available at www.bts.gov as of November 2017.

ranging from $250 to $700 million, much of which is due to transportation disruptions [IHS 2015].

Human-Caused Disruptions

Transportation disruptions can also have human causes. For example, a fire under an elevated section of I-85 in Atlanta caused it to collapse, closing the highway for 6 weeks as detailed in box 4-A. Similar impacts were observed in the I-35W bridge collapse in Minneapolis in 2007, which has also been attributed to human causes.

Although the regions impacted by Hurricanes Katrina and Sandy suffered huge losses, as did the other areas affected by the disasters discussed above, one of the key lessons learned from each event was the importance of transportation system resilience. Major transportation facilities—roads, bridges, transit systems, ports, and airports—were in operation within days or weeks of the severe event. In

Box 4-A Atlanta Bridge Collapse

On Thursday, March 30, 2017, a fire that started in some construction materials stored under a bridge on I-85 in Atlanta, between I-75 and GA-400, burned hot enough to cause a section of the northbound lanes to collapse. Although there were no deaths or injuries, both the northbound and southbound lanes had to be closed, which produced massive impacts on travel through downtown Atlanta and throughout the area's transportation system.

The I-85 bridge is close to downtown, providing a major thoroughfare for hundreds of thousands of travelers. Transportation officials advised Atlanta-area travelers that alternative routes would be carrying traffic far exceeding normal levels, and urged them to use public transportation, carpooling, and alternative work schedules and telecommuting during the extended period when that segment of I-85 would be closed. As drivers sought alternate routes, traffic in the morning peak period increased 30 to 50 percent on area roads, and peak-spreading occurred (traffic congestion started earlier and lasted longer than before the I-85 closure). The Georgia Department of Transportation (GDOT) altered signal timing to better handle the increased flows on arterial streets, and local jurisdictions provided officers to keep traffic moving at critical intersections.

The Metropolitan Atlanta Rapid Transit Authority (MARTA) scheduled extra rail and bus service, and area express bus companies added runs from suburban and exurban locations to outlying MARTA rail transit stations. Local media sources quickly sprang into action to provide print and internet maps and guides to assist travelers in using the transit options. The MARTA system experienced a 25 percent increase in ridership and a 45 percent increase in revenue on the first Monday after the bridge collapse. Over the ensuing weeks, the system-wide ridership increase stabilized at 11.5 percent. MARTA made aggressive use of social media to inform commuters of parking availability at its rail stations because all parking spaces were filling early in the day at several stations.

GDOT used the overhead changeable message signs on the highway system to warn through traffic of the closure and provide information on alternative routes. Highway freight carriers and package delivery services used their contingency planners to develop updated routes and schedules. The airlines at Hartsfield-Jackson Atlanta International Airport worked directly with passengers who were being delayed by the collapse effects, and also urged them to use the MARTA system to reach the airport.

GDOT move aggressively to have the damaged structure replaced. As a result, the I-85 lanes (and others that were closed on nearby streets) were all reopened in mid-May 2017, at a cost of more than $16 million. The reopening was 6 weeks after the collapse, 1 month ahead of the anticipated schedule.

SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, research using sources cited in the references section 2017 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 transportation network provided travel options for both person and freight trips seeking to avoid travel blockages. In all cases, the transportation agencies were able to quickly put critical links in the transportation system back into operation, thus minimizing the economic impact to state and regional economies.

Cybersecurity

Position, navigation, and timing (PNT) services are widely used in all modes of transportation. Global Positioning Systems (GPS) help prevent transportation accidents, aid search and rescue efforts, and speed the dispatch of emergency services [NCO 2014]. The Next Generation Air Transportation System (NextGen) integrates GPS to help increase operational safety and situational awareness for aviation system users, especially during approaches and departures, and while taxiing on the ground [NCO 2014]. Positive Train Control (PTC) works in conjunction with GPS technologies to track train location and speed—data that can be used to prevent train-to-train collisions, overspeed derailments, and the unauthorized movement of trains into work zones [NTSB 2016]. On waterways and especially in ports, GPS helps vessels maneuver around navigational hazards and traffic [NCO 2014]. GPS technologies can help track freight vehicles and their valuable cargo, which may help to reduce the loss of $15 to $30 billion annually in cargo theft and pilferage from commercial motor vehicles [FMCSA 2011].

As with other types of electronic communications, cybersecurity is a serious concern for PNT systems. In particular, GPS spoofing and jamming devices can cause PNT system malfunctions, with potentially severe safety consequences. Spoofing devices deliberately cause GPS transmitters to report erroneous identification or location information. GPS, cellphone, or radar jammers disrupt receipt of radio frequency signals [NOVATEL 2013]. Signal jamming devices can prevent completion of 911 and other emergency calls, and can also interfere with communications networks utilized by police, fire, and emergency medical services. Because signal jamming devices pose such significant risks, Federal law prohibits consumers from operating these devices within the United States, and violations are punishable by fines of up to $112,500 per violation [FCC 2014].

A recent study conducted by the United Kingdom government estimated that the economic impact of a 5-day GPS disruption on the UK transportation system to be at $2.5B, or $500M a day. Given the amount of roadway traffic in the United States is 10 times of that in UK, a simple interpolation of the economic impact of a 5-day GPS disruption on U.S. transportation could be about $25 billion, or $5 billion per day [LONDON ECONOMICS 2017].

In October 2016 NHTSA released proposed guidance for improving motor vehicle cybersecurity, especially since hackers may attempt to gain unauthorized access to vehicle systems for manipulating functionality or retrieving private driver data. The guidance focuses on layered solutions to ensure vehicle systems are designed to protect critical vehicle controls, and to take appropriate and safe actions, even when an attack is successful [USDOT NHTSA 2017].

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 and at other passenger checkpoints. In 2016 TSA officers screened more than 738 million passengers (more than 2 million per day), 466 million checked bags, and 24.2 million airport employees [USDHS TSA 2017]. Despite news headlines that report long lines when they do occur, nationwide less than 2 percent of passengers (14.1 million) waited in line for more than 20 minutes in 2015 [USDHS TSA 2016].

These TSA inspections prevented a wide array of prohibited items from being brought onto passenger aircraft, notably 3,391 firearms, 83 percent of which were loaded (see box 4-B). Other prohibited items discovered in checked and carry-on bags included many thousands of knives, swords, and other sharp blades; ammunition; gunpowder, black powder, flashbang grenades, and fireworks; and inert and replica explosive devices. Federal air marshals flew more than a billion miles to help keep the skies secure for travel [USDHS TSA 2016].

International piracy incidents at sea, including attacks, boardings, hijackings, and kidnappings, are another security concern affecting U.S. citizens traveling overseas. Piracy activity has been monitored closely by the Office of Naval Intelligence (ONI), especially after the hijacking of the U.S.-flagged *Maersk Alabama* on April 8, 2009. In 2016 the waters of Southeast Asia experienced 117 piracy events, less than half the abnormally high number of 254 reported for 2015 and 62 percent of the average for 2013–2014. The Gulf of Guinea, in West Africa, had 171 events in 2016, which appears to be about 70 percent above the recent average of about 100 per year. However, most of the increase is due to the inclusion of incidents in the Niger Delta, which were not reported in prior years. The Horn of Africa waters, which have been of major concern since 2009, had only 1 event in 2016 and none in 2015 [USN ONI 2017].

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