MULTI-STATE EMERGENCY ROUTE SCENARIO STUDY OF VEHICLE DELAYS

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16. Abstract

Commercial motor vehicle regulations and permitting procedures that work well during times of normal commercial operations can increase the time for emergency responders to move equipment and personnel rapidly across State lines to support response and recovery operations during emergencies. The Federal Highway Administration (FHWA) conducted this study to estimate the impacts of delays that emergency vehicles responding to natural disasters in other States may encounter.

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LIST OF ACRONYMS

AHC	All Hazards Consortium
APPA	American Public Power Association
AASHTO	American Association of State Highway and Transportation Officials
EEI	Edison Electric Institute
ERWG	Emergency Routing Working Group
FAST	Fixing America's Surface Transportation Act
FEMA	Federal Emergency Management Agency
GCWR	Gross Combined Weight Rating
GVWR	Gross Vehicle Weight Rating
HVAC	Heating, Ventilation, and Air Conditioning
IFTA	International Fuel Tax Agreement
IRP	International Registration Plan
MAP-21	Moving Ahead for Progress in the 21st Century Act
OS/OW	Oversize/Overweight
RMAG	Regional Mutual Aid Group
SC&RA	Specialized Carriers and Rigging Association
USDOT	U.S. Department of Transportation
VMT	Vehicle Miles Traveled

EXECUTIVE SUMMARY

This study was conducted in response to one of the recommendations of the Emergency Route Working Group (ERWG) established by the U.S. Department of Transportation (USDOT). The goal of this study is to estimate the delays that emergency response vehicles and equipment responding to natural disasters in other States may encounter in transit to their destination, and to estimate the costs and impacts of those delays on emergency response activities. By realistically describing problems associated with the routing of emergency response and recovery vehicles, this study aims to help educate stakeholders on the nature of the problem and its impacts. A detailed description of the emergency routing problem and its costs and impacts will help to make policymakers aware of the importance of this issue.

To accomplish the study's goal, FHWA created the following five natural disaster scenarios based on actual natural disasters that have occurred in the U.S.: a tropical storm along the East Coast, based on Hurricane Sandy (2012); a hurricane in Florida, based on Hurricane Michael (2018); a tornado in the Midwest, based on an EF-5 tornado in Joplin, Missouri (2011); a wildfire on the West Coast, based on the Tubbs Fire in Northern California (2017); and a flood in Colorado, based on a 1,000-year rainfall event in Colorado (2013).

The emergency response vehicles and equipment included in this study are those involved in power restoration, including bucket trucks, digger derricks, pole trucks, and transformers, as well as temporary housing units, fuel trucks, and mobile cranes. For each natural disaster scenario, each vehicle type was subject to a number of potential delays, including delays from receiving International Registration Plan (IRP), International Fuel Tax Agreement (IFTA), and/or oversize/overweight (OS/OW) permits, undergoing weight inspections, and getting stopped at a toll booth due to a lack of sufficient funds to pay the necessary toll. These delays were assigned to vehicles based on their dimensions, as well as the route from their origin to their destination. The resulting delay time was then used to quantify the impact of those delays based on the role that each vehicle plays in emergency response activities.

Each scenario looked at a different number of each vehicle type and different origins, destinations, and pass-through States, yet revealed commonalities regarding the largest source of delays. A key finding from this study is that while, overall, a fewer number of vehicles were subject to delays from receiving OS/OW permits then other delays, OS/OW permit delays were the largest contributors of delays, both in terms of the additional transit time added to each vehicle and the resulting cumulative delay time across all vehicles. Therefore, reducing the delay from receiving OS/OW permits could contribute to the largest reduction in costs and impacts associated with routing emergency response vehicles across State lines. The following can reduce these impacts:

1. Encourage and assist States in implementing automated permitting systems for OS/OW permits.
2. Encourage State DOTs to include information on how to obtain IRP, IFTA, and OS/OW permits during off hours on their websites.
3. Encourage State DOTs to expedite weight and roadside safety inspections for emergency response vehicles.

4. Encourage State DOTs to implement cashless tolling or waive tolls for emergency response vehicles.
5. Extend strategies used by ambulances and fire trucks for bypassing traffic congestion, such as shoulder use, to utility and other vehicles responding to disasters.

The continued certainty of future natural disasters requires continued advancement of strategies for emergency response and recovery.

CHAPTER I. INTRODUCTION

BACKGROUND

In accordance with Section 5502 of the Fixing America's Surface Transportation (FAST) Act (Public Law 114-94), the U.S. Department of Transportation (USDOT) established the Emergency Route Working Group (ERWG) in 2016 to determine best practices for expeditious State approval of special permits for vehicles involved in emergency response and recovery. The ERWG was comprised of representatives from State highway transportation agencies or departments, relevant modal agencies within the USDOT, emergency response or recovery experts, relevant safety groups, and entities affected by special permit restrictions during emergency response and recovery efforts. The ERWG organized a series of public meetings and outreach efforts to identify recommendations to improve the permitting process for vehicles providing response and recovery efforts for emergencies. The recommendations included, but were not limited to, the following:

- Incentivizing State departments of transportation (DOTs) to modernize State DOT permitting systems.
- Conducting a multi-State emergency route scenario analysis for vehicles involved in emergency response and recovery.
- Studying pre-clearance processes for moving equipment.
- Researching a nationwide alert system for movement of emergency response convoys.
- Developing an online resource for relevant permitting and regulatory compliance information to reduce impediments to the movement of utility and other vehicles.
- Expanding the coverage of the Moving Ahead for Progress in the 21st Century Act (MAP-21) (Public Law 112-141), Section 1511 provision to emergencies declared by a Governor of a State.

The ERWG Report of Recommendations to the Secretary of Transportation can be found at: https://ops.fhwa.dot.gov/fastact/erwg/reports/erwgreport/index.htm.

STUDY GOALS

This study was conducted in response to the recommendations of the ERWG to conducting a multi-State emergency route scenario analysis for vehicles involved in emergency response and recovery. The goal of the multi-State routing study is to estimate the impacts of delays that emergency vehicles responding to natural disasters in other States may encounter. While natural disasters are complex and unpredictable, this study aims to provide examples of emergency routing scenarios that could occur based on real-life natural disasters and the emergency responses that followed.

This study develops a set of scenarios and a methodology to estimate the length and impact of delays associated with permitting and enforcement activity for these vehicles. The scenario analysis estimates what types of delays could occur, how many vehicles could be affected by each type of delay, how the delays could impact transit time, and what types of impacts these delays could have on emergency response and recovery efforts. This study is limited to quantifying the costs associated with equipment delays and did not attempt to quantify the impacts of delays on deaths or injuries resulting from the disasters. By realistically describing problems associated with the routing of emergency response and recovery vehicles, this study aims to help educate stakeholders on the nature of the problem and its impacts. A detailed description of the emergency routing problem and its costs and impacts will help to make policymakers aware of the importance of this issue.

CHAPTER II. METHODOLOGY

Below is a description of each step in the methodology used to develop the estimated impacts.

DEVELOP NATURAL DISASTER SCENARIOS

Disaster scenarios were chosen that represent different geographic areas in the U.S., different types of natural disasters, and disaster events of varying scale to ensure this analysis covered a wide range of emergency routing scenarios. The five natural disasters chosen are as follows: a tropical storm along the East Coast, based on Hurricane Sandy (2012); a hurricane in Florida, based on Hurricane Michael (2018); a tornado in the Midwest, based on an EF-5 tornado in Joplin, MO (2011); a wildfire on the West Coast, based on the Tubbs Fire in Northern California (2017); and a flood in Colorado, based on a 1,000-year rainfall event in Colorado (2013). The development of these scenarios was based on information from after-action reports created by Federal, State, county, and local governments.

The following information was collected for each natural disaster scenario, to the extent that it was available. This information was then used to describe the event and its impacts, as well as to determine the number of out-of-State emergency response vehicles that would be required:

- Event details:
  - The date of occurrence
  - The primary location of the event and its damage
  - Other nearby areas that were significantly impacted
  - Emergency declarations (e.g., local, State, and Federal)
- Major impacts and emergency response efforts:
  - Number of people impacted (e.g., how many people lost power, how many people were displaced, how many people needed emergency services)
  - Major impacts and response needs (e.g., power outages, emergency supplies, property damage)
  - Number and type of equipment and vehicles that responded
  - Number and type of personnel that responded
  - Length of the response effort
- Emergency response vehicle inventory:
  - Vehicle type and total number required
  - Types of supplies/services required

IDENTIFY VEHICLES AND ESTIMATE THEIR ORIGINS

Vehicle Types and Numbers

Six types of vehicles and equipment were used in this study, based on the emergency response equipment identified in the "Emergency Route Working Group (ERWG) Report of

Recommendations to the Secretary of Transportation."[1] A brief description of each is included in table 1.

Table 1. Vehicle/Equipment Types

Vehicle/Equipment Type	Description
Bucket truck	A utility service vehicle with an extendable boom that is used to repair electrical infrastructure.
Digger derrick	A utility service vehicle that is used to dig holes and set utility poles.
Pole truck	A tractor semi-trailer with a flatbed that is used to transport utility poles.
Transformer	A large piece of electrical equipment that is used to convert alternating current from one voltage to another. This equipment is transported by a tractor semi-trailer with a flatbed.
Fuel truck	A hazmat tanker that is used for transporting fuel.
Temporary housing unit	A mobile home that is used for temporary housing. These units are transported by a tractor semi-trailer with a flatbed.
Mobile crane	A self-propelled, truck-mounted crane that is used to lift heavy objects.

The number of each type of equipment required in each scenario was based on actual amounts used in the natural disasters, to the extent the information was available from the scenario. For example, the Federal Emergency Management Agency (FEMA) after action reports provide information on the actual number of temporary housing units deployed in response to each natural disaster. Additionally, for some of the scenarios, data on the number of utility poles that were damaged and the number of gallons of fuel delivered was available from Federal after-action reports and news articles written following the natural disaster. The number of pole trucks and fuel trucks required was then determined based on the number of utility poles that one pole truck can transport and the number of gallons of fuel that one fuel truck can carry. The fuel truck configuration was based off a fuel tanker trailer with a capacity to transport 9,500 gallons of fuel, though it was assumed that the tankers were only filled to the point where the gross vehicle weight rating (GVWR) of the fuel truck was under 80,000 lbs., since fuel is a divisible load. It was assumed that 50 percent of the pole trucks required came from out-of-State, while 100 percent of the fuel trucks required came from out-of-State.

Information on the number of bucket trucks and digger derricks required in each real-life natural disaster was not readily available. Therefore, assumptions were made regarding how many of each vehicle type was required based on the number of people who lost power during the real-life natural disaster. Using an example provided by the American Public Power Association (APPA), it was determined that for every 428 customers without power, one mutual assistance utility crew was required from out-of-State. This ratio was then used to determine how many mutual assistance crews were required based on the total number of customers that lost power in

[1] U.S. Department of Transportation, Federal Highway Administration, *Emergency Route Working Group (ERWG) Report of Recommendations to the Secretary of Transportation*, (December 2018), https://ops.fhwa.dot.gov/fastact/erwg/reports/erwgreport/erwgreport.pdf.

each scenario, and it was assumed that one crew came with one vehicle. It was assumed that 75 percent of the utility vehicles were bucket trucks, and 25 percent of the utility vehicles were digger derricks.

The number of transformers required was based loosely on the total number of people who lost power in each scenario. For the East Coast Tropical Storm scenario, in which 2.5 million customers lost power in the State of New Jersey, it was estimated that five transformers would be transported from out-of-State. For the remaining four scenarios, in which power outages ranged from 10,000 customers to 400,000 customers, it was estimated that either one or two transformers would be transported from out-of-State.

Similarly, using power outages and the ensuing response as a proxy for the scale of a natural disaster, the number of mobile cranes was determined based on the number of bucket trucks and digger derricks required in each scenario. For every 100 bucket trucks and digger derricks, it was assumed that one mobile crane was required. Though this resulted in less than one mobile crane being required in the Midwest Tornado and the Colorado Flood scenarios, it was assumed that one mobile crane traveled across State lines in each of these scenarios.

The estimated number of each type of vehicle required in each scenario is listed in table 2.

Table 2. Vehicle/Equipment Numbers Required in Each Scenario

Vehicle/Equipment Type	Number Required in West Coast Wildfire	Number Required in Florida Hurricane	Number Required in East Coast Tropical Storm	Number Required in Midwest Tornado	Number Required in Colorado Flood
Bucket truck	88	701	4,384	31	18
Digger derrick	29	234	1,461	10	6
Pole truck	53	73	36	43	53
Transformer	1	2	5	1	1
Fuel truck	5	50	979	5	5
Temporary housing unit	301	871	114	348	54
Mobile cranes	1	9	58	1	1

Vehicle Origins and the Pass-Through States

While the destination State of each vehicle type is based on where the real-life natural disaster occurred, the origin and pass-through States for the bucket trucks, digger derricks, pole trucks, transformers, fuel trucks, and mobile cranes are based mainly on actual private sector utility equipment routing data compiled by the All Hazards Consortium (AHC).[2] The AHC has routing data available for equipment that traveled across State lines in response to Hurricane Michael and a 2018 wildfire in California. A subset of routes was used from each set of data for each of the respective natural disaster scenarios. Five routes were chosen from each set of data to create a diverse set of routes.

In addition to the AHC data, the Edison Electric Institute's (EEI) map of regional mutual assistance groups (RMAG) was used to determine the origins of equipment for the scenarios that do not have AHC data available.[3] Requests for mutual assistance are coordinated through the RMAG that a utility belongs to. A requesting utility contacts its RMAG point of contact, who then coordinates the request with other member utilities.[4] If the request cannot be fulfilled within the RMAG, typically due to the scale of the natural disaster, the RMAG point of contact will then work with other RMAGs to coordinate resources at a more national level. Based on this, it was assumed that most of the origin States for each scenario were either within the same RMAG as the destination State or in a neighboring RMAG, though some outliers were included based on actual data. For example, the East Coast Tropical Storm scenario includes California as an origin State, since emergency response vehicles in Hurricane Sandy came from as far away as California. Origin States that were also significantly impacted by the real-life natural disaster were excluded as an origin State.

The origin States for temporary housing units were determined differently. FEMA has two permanent storage sites for its inventory of manufactured housing units that are deployed in response to a natural disaster.[5] These two sites are in Cumberland, Maryland, and Selma, Alabama; therefore, all temporary housing units in this study originated from either Maryland or Alabama. Pass-through States were determined based on similar routes in the AHC data.

Finally, using the general understanding that a higher proportion of vehicles likely originates from States closer to where the natural disaster occurs, it was assumed that approximately 60 percent of vehicles coming from out-of-State originate from States that are within a 1-day drive of the destination State, approximately 30 percent come from within a 2-day drive, and approximately 10 percent come from within a 3-day drive. This method was used to determine how many vehicles came from each of the determined origin States.

DEVELOP A BASELINE ROUTING SCENARIO (NO DELAYS)

The baseline for each of the routing scenarios assumed free movement of equipment and no delays, meaning that all vehicles already had the necessary permits and all pass-through States

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[2] "Storm Central: Centralized Disaster Documentation," All Hazards Consortium, accessed June 9, 2020, https://www.ahcusa.org/storm-central.html.
[3] Edison Electric Institute, "2017 Historic Storms, Historic Responses," February 21, 2018, https://www.energy.gov/sites/prod/files/2018/02/f49/1_Mutual%20Assistance%20Agreements%20-%20David%20Bonenberger%2C%20EEI.pdf.
[4] Keogh, Miles, and Sharon Thomas, "Regional Mutual Assistance Groups: A Primer," The National Association of Regulatory Utility Commissioners, 2015, https://pubs.naruc.org/pub/536E475E-2354-D714-5130-C13478337428.
[5] U.S. Department of Homeland Security, Office of Inspector General, *FEMA Purchased More Manufactured Housing Units Than It Needed in Texas After Hurricane Harvey* (Washington, D.C.: February 26, 2020), https://www.oig.dhs.gov/sites/default/files/assets/2020-03/OIG-20-15-Feb20.pdf.

had issued weigh station and toll waivers. Using the origin, pass-through, and destination States identified in Step 2, baseline routing scenarios were developed for each route identified for each natural disaster scenario. The origin and destination States were input into PC Miler, a truck routing software, and the route was adjusted as necessary to ensure that the route went through the identified pass-through States. Additionally, the below route settings were used in PC Miler. The resulting distance and total hours of each route were then used as the baseline travel distance and transit time for each route. The scenarios compare baseline to delayed transit time and does not include hours of service breaks:

- Routing Preferences:
    - Route Type: Practical (as opposed to Shortest or Fastest)
    - Road Network: State and National Network (This is defined by PC Miler as routing that favors the U.S. Federally designated National Network (Interstates and State-designated extensions to the National Network). This option also incorporates roads that permit 53-foot trailers or 28-foot twin trailers.[6]
    - Roads: Highways and Streets
    - Toll Roads: Allowed
    - International Borders: Closed
    - Restrictions: Use
    - Ferries: Discouraged
    - Hub Routing: Disabled
    - Side of Street Adherence: Off
    - Governor Speed Limiting: Disabled
    - Elevation: Any
    - Site Routing: Disabled
- Vehicle Dimensions:
    - Vehicle Type: Truck
    - Height: Adjusted based on vehicle type
    - Length: Adjusted based on vehicle type
    - Width: Adjusted based on vehicle type
    - Weight: Adjusted based on vehicle type
    - Axles: Adjusted based on vehicle type

IDENTIFY DELAY SCENARIOS AND ESTIMATE THE IMPACT OF DELAYS ON TOTAL TRANSIT TIME

Five different delay scenarios were identified and incorporated into each baseline routing scenario, including delays due to International Registration Plan (IRP) and International Fuel Tax Agreement (IFTA) registration requirements; oversize/overweight (OW/OS) permit transactions; tolls; and weight and roadside safety inspections. A description of each delay

[6] "Routing Preferences," PC Miler Web, accessed August 28, 2020, https://pcmilerweb.com/app?center=8,31.304,-86.215.

scenario that a vehicle could encounter, as well as the assumptions used to determine the amount of transit time each scenario added to each vehicle, are detailed below.

IRP and IFTA Registration Delays

IRP and IFTA registration delays arise when there are delays in obtaining permits from a vehicle's base State. Additionally, vehicles that qualify for IRP (vehicles with a gross vehicle weight rating [GVWR] greater than 26,000 lbs. or have three or more axels), but are not registered, must obtain temporary trip and fuel permits before entering another State. Delays in obtaining IRP and IFTA permits as well as temporary trip and fuel permits can be caused by waiting for the permit to be processed and issued, and by the issuing office being closed for weekends or holidays. To determine the length of this type of delay for this study, it was assumed that all vehicles traveling were not already registered with IRP and IFTA, and therefore needed to obtain temporary trip and fuel permits from each pass-through State. It takes approximately 2 hours for these permits to be processed and issued,[7,8] and therefore the transaction had little impact on total transit time assuming that this could be completed in parallel with other departure preparation activities.

OS/OW Permit Transaction Delays

OS/OW permits transaction delays are delays in obtaining a permit from all States along the route to the destination State. Delays can be caused by waiting for the permit to be processed and issued for States without automated permitting, and by the office being closed for weekends or holidays. The length of time to receive an OS/OW permit was based on the Specialized Carriers and Rigging Association's (SC&RA) permitted weight configuration chart for eleven of the most common vehicle configurations used by the specialized transportation industry.[9] This chart indicates how long it takes to receive an OS/OW permit in each State based on the vehicle configuration, and whether the State has automated permitting. If a State does not have automated permitting, the chart indicates whether the manual permitting process will take less than 3 days or more than 3 days. The following delay assumptions were used based on this chart:

- Automated permitting: No delay
- Manual permitting with < 3 days to issue: 48-hour (2-day) delay
- Manual permitting with > 3 days to issue: 120-hour (5-day) delay

In States with automated permitting, there still may be a small delay to receive the permit based on the time it takes to file the permit online. However, similar to the temporary trip and fuel permit transactions, it was assumed that this could be completed in parallel with other departure preparation activities, and therefore did not impact a vehicle's total transit time. In States with

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[7] "Temporary Trip (IRP) Permits," Coast2Coast Trucking Permits, accessed August 28, 2020, https://coast2coasttruckingpermits.com/permit/temporary-trip-irp-permits/#:~:text=The%20average%20for%20Temporary%20Trip,a%20specific%20State%20turnaround%20time.
[8] "Temporary Trip Permits," J. J. Keller Permit Service, accessed August 28, 2020, https://www.kellerpermits.com/permits/trip-permits.
[9] Specialized Carriers and Rigging Association, "OS/OW Permit Harmonization Initiative: Weight Configurations," December 11, 2019, https://www.scranet.org/SCRADocs/2020_Documents/UPT2021-STS-12-11-19.pdf.

manual permitting that take more than 3 days to issue OS/OW permits, a 5-day delay was used as an intermediate estimate. While these States can issue a permit in as little as 4 days, it could also take longer than 5 days.

Based on the SC&RA's chart, certain vehicle configurations in each State were not considered for an OS/OW permit. In these cases, the average amount of time it takes to receive an OS/OW permit was used for that specific vehicle configuration across all States that do consider the configuration.

Finally, it was assumed that OS/OW permit applications for each pass-through State are submitted at the same time. Therefore, to determine how much total transit time was added to each route, the longest delay time resulting from a permit transaction in a pass-through State was used as the delay time from the OS/OW permit transaction, rather than summing the delays in each pass-through State.

Toll Delays

Toll delays are caused by a lack of information about tolls and drivers having insufficient cash funds to pay tolls. The number of tolls along each route was determined using PC Miler, and it was assumed that if a vehicle does not have sufficient funds to pay a toll, 6 hours is added to the vehicle's total transit time. This delay was based on an extreme example in which vehicles were stopped at a toll for 12 hours, so the delay time was cut in half. It was assumed that if there are multiple tolls along a route, a vehicle will only encounter this delay at the first toll it drives through. Furthermore, it was assumed that only utility vehicles (i.e., bucket trucks and digger derricks) are subject to this delay since they are less likely to regularly work across State lines than other vehicles in this study, and only half of these vehicles traveling along toll routes encounter the delay. The remaining vehicles are commercial vehicles, so it was assumed that the drivers of these vehicles are prepared to pay for tolls.

OS/OW and Roadside Safety Inspection Delays

Finally, OS/OW and roadside safety inspections delays are delays caused by the requirement to stop at a weigh station and undergo a size and weight inspection or a roadside safety inspection. States typically require commercial vehicles that weigh 10,000 lbs. or more to stop at all open weigh stations, unless they have a weigh station bypass transponder.[10] Once the vehicle has been weighed, it may be flagged for an inspection by a DOT or State inspection officer.[11] The inspection may take anywhere from 15 minutes to 1 hour, depending on the type of inspection.[12]

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[10] "3 Things for Drivers to Know About Weigh Station Requirements," Suddath, accessed December 31, 2019. https://suddath.com/about-us/blogs/november-2015/3-things-for-drivers-to-know-about-weigh-station-r/.
[11] "What is a Weigh Station?" Trucker Path, accessed December 31, 2019. https://truckerpath.com/blog/what-is-a-weigh-station/.
[12] "Do You Know the Six Levels of a DOT Inspection?" ATBS, April 2019. https://www.atbs.com/knowledge-hub/trucking-blog/the-six-levels-of-a-dot-inspection.

To determine delays due to weight inspections, the total number of fixed and portable scale weight inspections that occurred in 2019 was divided by the total vehicle miles traveled (VMT) by single-unit and combination trucks with a GVWR of 10,000 lbs. or more in 2018 to get the number of inspections per VMT. VMT data from 2018 was used as more recent data was not available at the time of this report. This was then multiplied by the baseline distance for each route to get the total number of weight inspections along each route and assumed that each weight inspection added 1hour to a vehicle's total transit time.

To determine delays due to safety inspections, the total number of Federal and State roadside inspections for trucks with a gross combined weight rating (GCWR) of 10,000 lbs. or more in 2018 was divided by total VMT by single-unit and combination trucks with a GVWR of 10,000 lbs. or more in 2018 to get the number of inspections per VMT. Data from 2018 was used as more recent VMT data was not available at the time of this report. This was then multiplied by the baseline distance for each route. The North American Standard Inspection (Level 1) is the most common type of inspection and takes approximately 1 hour. Therefore, it was assumed that each inspection added 1 hour to a vehicle's total transit time. However, given that the number of inspections per VMT was close to zero, this delay ended up having a negligible impact on transit time.

Weekend Delays

In addition to these delay scenarios, a weekend scenario was created to account for delays in obtaining IRP, IFTA, and OS/OW permits that vehicles may encounter due to issuing offices without automated permitted systems being closed on the weekend. Almost every State DOT has an on-call permitting staff person available in the case of an emergency, and the list of contact information for these staff is maintained by the American Association of State Highway and Transportation Officials (AASHTO) and shared with FHWA.[13] In the event that permits are required after hours or during the weekend, a driver may contact AASHTO or FHWA to obtain the relevant contact information. However, during emergency response efforts, vehicles that typically operate in one State often need to operate across State lines and may not be aware that this list exists nor how to access it. Therefore, an extra day was added to total transit time in the weekend scenario to account for situations like this, along with other delays that may be associated with offices being closed on the weekend.

The configuration of each vehicle type was modeled after actual examples of vehicles as well as the SC&RA's weight configuration chart. These configurations were used to determine which State permits were required by each vehicle type, as well as the delays that each vehicle type could encounter. The configurations, required permits, and applicable delays for each vehicle are detailed in table 3.

[13] Patrick Zelinski, American Association of State Highway and Transportation Officials, email to authors, November 6, 2020.

Table 3. Equipment Details

Types of Equipment	Vehicle Configuration	State Permits	State Requirements
Utility service vehicle: bucket truck	• Axles: 2 • Width: 8’ 5” • Height: 13’ 4” • Length: 39’ 9” • GVWR: 54,000 lbs	• IRP • IFTA	• IRP/IFTA Permit Transactions • Tolls • Weight Inspections • Safety Inspections
Utility service vehicle: digger derrick	• Axles: 2 • Width: 8’ 5” • Height: 11’ 2” • Length: 22’ 6.5” • GVWR: 28,000 lbs	• IRP • IFTA	• IRP/IFTA Permit Transactions • Tolls • Weight Inspections • Safety Inspections
Tractor semi-trailer: flatbed/specialized for delivering utility poles	• Axles: 5 • Width: 8’ 6” • Height: 13’ 7” • Length: 48’ • GVWR: 112,000 lbs	• IRP • IFTA • OS/OW	• IRP/IFTA Permit Transactions • OS/OW Permit Transactions • Weight Inspections • Safety Inspections
Tractor semi-trailer: flatbed for delivering transformers	• Axles: 7 • Width: 8’ 6” • Height: 15’ 7” • Length: 53’ • GVWR: 140,000 lbs	• IRP • IFTA • OS/OW	• IRP/IFTA Permit Transactions • OS/OW Permit Transactions • Weight Inspections • Safety Inspections
Tractor semi-trailer: flatbed for delivering temporary housing units	• Axles: 6 • Width: 14’ • Height: 13’ 7” • Length: 60’ • GVWR: 126,000 lbs	• IRP • IFTA • OS/OW	• IRP/IFTA Permit Transactions • OS/OW Permit Transactions • Weight Inspections • Safety Inspections
Tractor semi-trailer: hazmat tank truck for delivering fuel	• Axles: 5 • Width: 8’ 5” • Height: 13’ 6” • Length: 53’ • GVWR: 80,000 lbs	• IRP • IFTA	• IRP/IFTA Permit Transactions • Weight Inspections • Safety Inspections

Table 3. Equipment Details (continuation)

Types of Equipment	Vehicle Configuration	State Permits	State Requirements
Mobile crane	• Axles: 5 • Width: 10' • Height: 13' • Length: 50' • GVWR: 132,000 lbs	• IRP • IFTA • OS/OW	• IRP/IFTA Permit Transactions • OS/OW Permit Transactions • Weight Inspections • Safety Inspections

Finally, based on each vehicle's configuration and route, delays were incorporated into each baseline routing scenario to calculate the total added transit time and the total transit time for each vehicle traveling along each route in all five scenarios. It was assumed that vehicles began traveling once all the required permits had been received, and then applicable delays were added to each vehicle's baseline travel time. Additionally, it was assumed that no States issued permit, toll, or weigh station waivers for responding vehicles.

For example, in the Florida Hurricane scenario, a pole truck traveled from Massachusetts to Florida, and the baseline travel time (i.e., travel time with no delays) was 25 hours. The pole truck was subject to delays from OS/OW permit transactions, and passed through 11 States, and was required to receive an OS/OW permit from each State. Five pass-through States had automated permitting, three States took 13 hours to issue the permit, and two States took 48 hours to issue the permit. As previously discussed, only the maximum delay time to receive an OS/OW permit was added to a vehicle's total transit time, rather than summing the delay from each pass-through State. Therefore, 48 hours was added to the baseline travel time from this permit transaction. The pole truck was also subject to delays from weight inspections, and encountered four weight inspections, which added 4 hours to the vehicle's total transit time. To get the total added transit time from the delays encountered, the total number of hours of delay was summed to get 52 hours (48 hours from OS/OW permits + 4 hours from weight inspections = 52 hours of added transit time). To determine the vehicle's total transit time, the total number of hours of delay was added to the baseline travel time for a total of 77 hours (52 hours of delay + 25 hours of baseline travel = 77-hour trip).

As previously discussed, a weekend scenario was also created for each route to account for delays in receiving IRP, IFTA, and OS/OW permits when permit issuing offices are closed. In the weekend scenarios, an additional 24 hours is added to each route. In the context of the above pole truck example, the total added transit time for the pole truck was 76 hours (52 + 24 = 76), and the total transit time was 101 hours (76 + 25 = 101).

IDENTIFY THE IMPACTS OF DELAYS

Impacts of Delayed Bucket Trucks, Digger Derricks, Pole Trucks, and Transformers

The impacts of delayed power restoration vehicles and equipment—the bucket trucks, digger derricks, pole trucks, and transformers—included the costs to the utilities and the costs to customers. The delays in bucket trucks and digger derricks translated directly into costs for utilities and delays in power restoration. It was assumed that delays in pole trucks and transformers would result in delays in utility crews completing their work, which then would result in costs for utilities and delays in power restoration.

In the calculation of the costs to utilities, one vehicle represented one utility crew, and responding utilities paid each of their crews for a 16-hour workday (referred to as a crew-day moving forward) while they were responding to disasters in other States, including the days that crews spent traveling to their final destination.[14] To calculate the cost to utilities, a daily rate for one utility crew ($3,930.00)[15] was multiplied by the total number of days that each vehicle was delayed on each route.

To calculate the total costs to residential, commercial, and industrial customers, the number of each type of customer that could have had their power restored by each delayed vehicle was found using a power restoration example provided the APPA.[16] Using this example, the number of customers that one utility crew could restore power to on day one of restoration work, day two of restoration work, and so on was calculated. This method assumes that the power restoration rate (i.e., the number of customers that one crew can restore power to in one crew-day) decreases each day following the first day of restoration work, given that power infrastructure serving the greatest number of customers is prioritized following a major power outage. Based on the number of housing units, employer establishments, and manufacturing businesses in the U.S., it was estimated that 95 percent, 4.5 percent, and 0.5 percent of the total number of customers restored each day were residential, commercial, and industrial customers, respectively.[17,18,19] Based on the number of days that each vehicle type was delayed on each route and the power restoration rate for each day of delay, the number of each type of customer whose power would have been restored was calculated, and then multiplied by the total number of vehicles traveling on each route. The rates in table 4 were then used to calculate the economic cost to each type of customer that would have had their power restored had the responding vehicles not been delayed.

Table 4. Economic Cost of Sustained Power Interruption by Customer Type

Customer Type	Hourly Cost
Residential Customer	$2.99
Commercial Customer	$1,067.00
Industrial Customer	$4,227.00

Finally, based on after-action reports describing increased risks to elderly populations from extended power outages, a high-risk population was determined for each scenario. According to

[14] U.S. Department of Transportation, *ERWG Report of Recommendations*.
[15] U.S. Department of Transportation, *ERWG Report of Recommendations.*
[16] Alex Hoffman, American Public Power Association, email to authors, May 7, 2020.
[17] U.S. Census Bureau, *Housing Units, 2019,* accessed December 22, 2020, https://data.census.gov/cedsci/profile?q=United%20States&g=0100000US.
[18] U.S. Census Bureau, *Business Counts, 2016,* accessed December 22, 2020, https://data.census.gov/cedsci/profile?q=United%20States&g=0100000US.
[19] IBIS World, *Manufacturing in the U.S., 2020,* accessed December 22, 2020, https://www.ibisworld.com/industry-statistics/number-of-businesses/manufacturing-united-States/.

the U.S. Census Bureau, 3.8 percent of the national population is 80 years or older.[20] This proportion was applied to the total number of utility customers that lost power in each natural disaster scenario to estimate the high-risk population in each scenario.

Impacts of Delayed Fuel Trucks

The impacts of delayed fuel trucks were quantified in terms of the number of residential generators, ambulances, and fire trucks that could have been filled by the fuel being transported. It was assumed that each generator used 18 gallons of fuel, each ambulance had a 40-gallon fuel tank, and each fire truck had a 65-gallon fuel tank.

Impacts of Delayed Temporary Housing Units

The impacts of delayed temporary housing units were quantified based on the number of people that could have been housed in each unit. It was assumed that each unit could accommodate a maximum of four people that were displaced from their homes as a result of the natural disaster. The number of people impacted by delayed temporary housing units was therefore calculated by multiplying the number of temporary housing units required in a certain scenario by four.

Impacts of Delayed Mobile Cranes

The impacts of delayed mobile cranes were quantified based on the cost of renting a mobile crane and hiring a crane operator for 8 hours per day. Using an average hourly rate for 165-ton to 200-ton mobile crane rentals in three crane rental companies Colorado, Florida, and Texas, all origin States for mobile cranes in this study, it was estimated that the daily cost would equate to approximately $3,800.[21,22,23] Mobile cranes can be used for a variety of purposes in an emergency response, including removing debris blocking roadways or other critical infrastructure, and assisting in search and rescue operations where buildings have collapsed and people may be trapped. Therefore, it was assumed that delayed cranes disrupt other emergency response activities, and the value of that delay was at least three times the cost of the crane rental.

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[20] U.S. Census Bureau, *Age and Sex, 2018*, accessed August 28, 2020, https://data.census.gov/cedsci/table?q=age&tid=ACSST1Y2018.S0101&hidePreview=false.

[21] "Price List," Duffy Crane and Hauling, last modified May 5, 2014, https://duffycrane.com/wp-content/uploads/2014/07/Combined-Duffy-Price-List_7-16-2014.pdf.

[22] "Crane Rates," George's Crane Service, Inc., accessed April 9, 2021, https://georgescraneservice.com/crane-rates.html.

[23] "Mobile Crane Rental Service," North Texas Crane Service, accessed April 9, 2021, https://www.northtexascranerental.com/equipment.

CHAPTER III. NATURAL DISASTER SCENARIOS

EAST COAST TROPICAL STORM

Scenario Description

The East Coast Tropical Storm scenario is based on Hurricane Sandy, which made landfall in New Jersey on October 29, 2012, and had significant impacts on the New York metropolitan region and affected 24 other East Coast States.[24] An estimated 8.5-8.6 million customers lost power as a result of the storm, 2.5 million of which were in New Jersey alone.[25,26] Additionally, acute fuel shortages in New York and New Jersey required the delivery of 9.3 million gallons of fuel to both States.[27] Due to the number of States impacted by the storm, power restoration crews often needed to respond in their State before moving across State lines to areas that were more significantly impacted, such as New York and New Jersey. Approximately 67,000-70,000 mutual assistance personnel from 80 utilities across the country (as far as California) were deployed to restore power.[28,29]

This scenario represents a storm with heavy rainfall, storm surge, flooding, and hurricane-force winds that significantly affect multiple East Coast States, causing wide-spread power outages and infrastructure and property damage. Major response efforts include search and rescue, clearing fallen trees, debris, and snow, restoring power, delivering fuel, draining flooded areas, providing medical care, and providing temporary housing for those displaced. Debris clearance, power restoration, and fuel delivery are three critical efforts that require large numbers of personnel, equipment, and vehicles. The number of each type of vehicle traveling from each of the origin States in this scenario is detailed in table 5, along with the baseline travel time for the route. For this analysis, Newark, New Jersey, was used as the destination for these vehicles.

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[24] U.S. Department of Homeland Security, Federal Emergency Management Agency, *Hurricane Sandy FEMA After-Action Report* (2013), https://www.fema.gov/media-library-data/20130726-1923-25045-7442/sandy_fema_aar.pdf.
[25] U.S. Department of Homeland Security, Hurricane Sandy FEMA After-Action Report.
[26] "Electricity restored to many in the Northeast but outages persist," U.S. Energy Information Administration, November 9, 2012, https://www.eia.gov/todayinenergy/detail.php?id=8730.
[27] U.S. Department of Homeland Security, Hurricane Sandy FEMA After-Action Report.
[28] U.S. Department of Homeland Security, Hurricane Sandy FEMA After-Action Report.
[29] U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability, *Overview of Response to Hurricane Sandy-Nor'Easter and Recommendations for Improvement* (2013), https://www.energy.gov/sites/prod/files/2013/05/f0/DOE_Overview_Response-Sandy-Noreaster_Final.pdf.

Table 5. East Coast Tropical Storm Baseline Routing Scenario

Number of Vehicles Travelling	Origin State	Baseline Transit Time (Hours)
• Bucket trucks: 438 • Digger derricks: 146 • Pole trucks: 4 • Transformers: 1 • Fuel trucks: 98 • Mobile crane: 6	California	50
• Bucket trucks: 877 • Digger derricks: 292 • Pole trucks: 7 • Transformers: 1 • Fuel trucks: 196	Indiana	13
• Temporary housing units: 114 • Mobile Crane: 12	Maryland	5
• Bucket trucks: 877 • Digger derricks: 292 • Pole trucks: 7 • Transformers: 1 • Fuel trucks: 196 • Mobile crane: 12	Tennessee	17
• Bucket trucks: 877 • Digger derricks: 292 • Pole trucks: 7 • Transformers: 1 • Fuel trucks: 196 • Mobile crane: 18	Texas	33
• Bucket trucks: 877 • Digger derricks: 292 • Pole trucks: 7 • Transformers: 1 • Fuel trucks: 196 • Mobile crane: 12	Vermont	6

Delays

The delays encountered by each vehicle type along each route in this scenario are included in Appendix A. Figure 1 shows the cumulative days of delay experienced by each vehicle type travelling along all routes broken down by delay type. In the Tropical Storm scenario, weight inspections add the most transit time to each applicable vehicle, followed by toll delays (figure 1). Both of these types of delay account for a relatively higher proportion of delay time in this scenario compared to the other scenarios. This is because some vehicles in this scenario are traveling from as far as California and are therefore subject to a greater number of weight inspections. Additionally, more bucket trucks and digger derricks are required in this scenario compared with the others, and these are the only vehicle types that are subject to toll delays.

While the transformers in this scenario are subject to fewer cumulative delays relative to other vehicles, the one transformer being transported from Vermont, the closest State to New Jersey in this scenario, experiences a delay of 5 days due to waiting for an OS/OW permit to be issued from Massachusetts. This is the longest delay time by both delay type and vehicle type in this scenario.

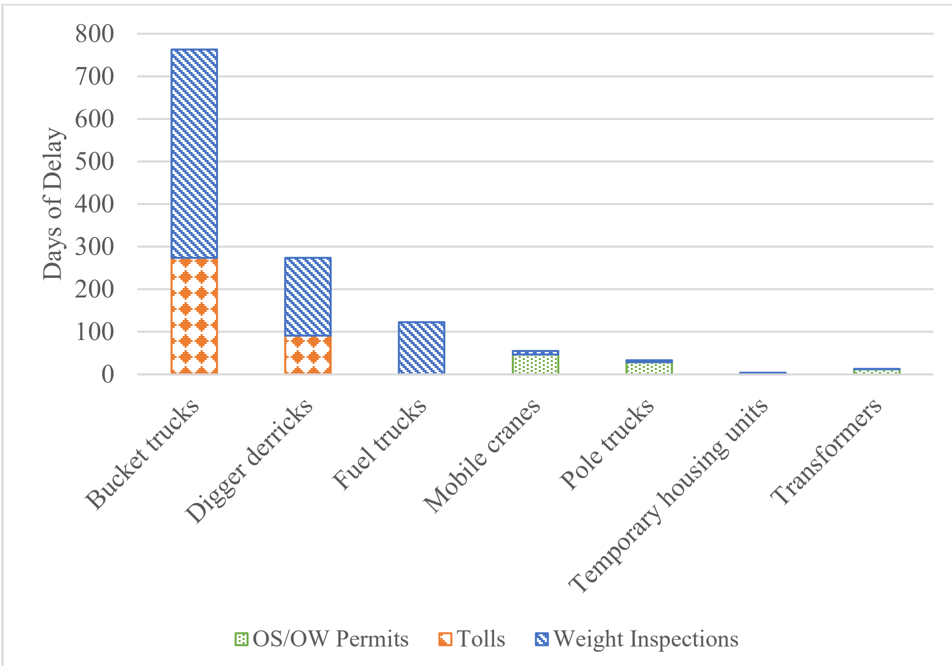

Figure 1. Cumulative Days of Delay Encountered by All Vehicles in the Weekday Tropical Storm Scenario.

Impacts of Delays

The East Coast Tropical Storm scenario is the largest of the scenarios in this study in terms of the number of States affected, the number of people impacted, and the size of the response effort. As a result, the impacts of delayed equipment are significant. Table 6 details the economic impacts from the delayed bucket trucks, digger derricks, pole trucks, and transformers. The additional labor costs incurred by out-of-State utilities is over $5 million. The economic costs to the approximately 175,000 residential and 8,000 commercial customers that would have had their power restored is over $4 million and $67.8 million, respectively. For industrial utility customers, the economic cost is almost $30 million for the approximately 922 industrial utility customers that would have had their power restored without delays.

When an additional day of delay is added to each vehicle to account for delays in receiving the necessary IRP, IFTA, and OS/OW permits due to permitting offices being closed on a weekend (i.e., the weekend scenario), the number of residential, commercial, and industrial customers that would have had their power restored during that time increases to over 551,000, 26,000, and 2,000, respectively. The resulting economic costs increase to $48.4 million for residential customers, $818.2 million for commercial customers, and $359.9 million for industrial customers. Additional costs to utilities increase to $28.1 million.

Table 6. Monetary Impacts of Delayed Power Restoration Vehicles in the Tropical Storm Scenario

Scenario	Weekday	Weekend
Total Cost to Utilities	$5,032,918	$28,143,881
Number of Residential Customers Impacted	175,117	551,280
Total Cost to Residential Customers	$4,015,467	$48,403,612
Number of Commercial Customers Impacted	8,295	26,113
Total Cost to Commercial Customers	$67,876,314	$818,200,813
Number of Industrial Customers Impacted	922	2,900
Total Cost to Industrial Customers	$29,877,453	$359,902,658

In addition to these costs, extended power outages result in increased public health and safety risks, especially for elderly populations. These populations may be reliant on at-home electrical medical equipment, such as oxygen tanks, or more susceptible to either heat stroke or hypothermia when heating, ventilation, and air conditioning (HVAC) systems are down.[30,31] An estimated 2,500,000 customers lost power in New Jersey as a result of Hurricane Sandy,[32] equating to a high-risk population of approximately 95,000 people in this scenario.

Fuel deliveries in emergency response situations are needed for a variety of reasons, including fueling emergency response vehicles, vehicles transporting people and supplies, and back-up generators when the power is out.[33] Service stations can deplete their fuel supplies in 2 days, and this time frame may be even shorter in an emergency, making it pertinent that fuel deliveries arrive promptly.[34] Delays in fuel deliveries can have ripple effects, including further increasing the costs in table 7 due to power restoration vehicles running out of fuel. The 979 fuel trucks in this scenario are delayed by a range of 1 to 8 hours in the weekday scenario and are transporting a total of 9.3 million gallons of fuel, which is enough to fuel 516,667 generators, 232,500 ambulances, or 143,077 fire trucks.

The 114 temporary housing units being transported from Maryland to New Jersey in this scenario experience a minimal delay of 1 hour per vehicle, and therefore do not have a significant impact on those waiting for a more permanent housing situation.

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[30] U.S. Department of Transportation, *ERWG Report of Recommendations.*
[31] Klinger Chaamala, Owen Landeg, and Virginia Murray, "Power Outages, Extreme Events and Health: A Systematic Review of the Literature from 2011-2012," *PLOS Currents Disasters* (2014): doi: 10.1371/currents.dis.04eb1dc5e73dd1377e05a10e9edde673.
[32] "Electricity restored," U.S. Energy Information Administration.
[33] American Trucking Association, "When Trucks Stop, America Stops," 2015, https://www.trucking.org/sites/default/files/2019-12/When%20Trucks%20Stop%20America%20Stops.pdf.
[34] American Trucking Association, "When Trucks Stop."

Finally, the 58 mobile cranes are delayed by a range of 1 hour to almost 2.5 days. The total additional rental costs incurred are over $210,000, and the costs of disruption to other emergency response activities is over $631,000.

FLORIDA HURRICANE

Scenario Description

The Florida Hurricane Scenario is based on Hurricane Michael, which hit the Florida Panhandle, particularly Panama City Beach to Mexico Beach, on October 10, 2018, and continued to southwest Georgia. Over 400,000 people lost power (100 percent of customers in portions of the Florida Panhandle and southwest Georgia), and 375,000 were evacuated from Florida.[35]

This scenario is similar to the East Coast Tropical Storm scenario, yet with significant impacts primarily occurring in Florida. Major response efforts include search and rescue, clearing fallen trees and debris, restoring power, providing medical care, and providing temporary housing for those displaced. Table 7 includes the total number of vehicles traveling to Panama City Beach, Florida, from each origin State, as well as the baseline transit time for each route.

Table 7. Florida Hurricane Baseline Routing Scenario

Number of Vehicles Travelling	Origin State	Baseline Transit Time (Hours)
• Temporary housing units: 871	Alabama	5
• Bucket trucks: 140 • Digger derricks: 47 • Pole trucks: 15 • Fuel trucks: 10 • Mobile crane: 2	Illinois	15
• Bucket trucks: 140 • Digger derricks: 47 • Pole trucks: 15 • Fuel trucks: 10 • Mobile crane: 1	Massachusetts	25
• Bucket trucks: 140 • Digger derricks: 47 • Pole trucks: 15 • Transformers: 2 • Fuel trucks: 10 • Mobile crane: 3	Mississippi	8

[35] Florida State Emergency Response Team, *Hurricane Michael: After Action Report and Improvement Plan* (2019), https://portal.floridadisaster.org/SERT/AfterActionReports/Real-World%20AARs/Hurricane%20Michael%20AAR-IP%201-7-19.pdf.

Table 8. Florida Hurricane Baseline Routing Scenario (continuation)

Number of Vehicles Travelling	Origin State	Baseline Transit Time (Hours)
• Bucket trucks: 140 • Digger derricks: 47 • Pole trucks: 15 • Fuel trucks: 10 • Mobile crane: 1	Nebraska	29
• Bucket trucks: 140 • Digger derricks: 47 • Pole trucks: 15 • Fuel trucks: 10 • Mobile crane: 2	Texas	18

Delays

Appendix B includes the amount of delay experienced by each vehicle type along each route in the Florida Hurricane scenario. As shown in figure 2, OS/OW permit transactions make up the majority of delays in this scenario. All vehicles are routed through Alabama, which does not have automated OS/OW permitting. Therefore, an additional 2 days of transit time is added for each vehicle that requires an OS/OW permit. Additionally, all vehicles in this scenario traveled from States that are just over a 1-day drive away or less, which results in a smaller cumulative delay from weigh station stops than the previous scenario.

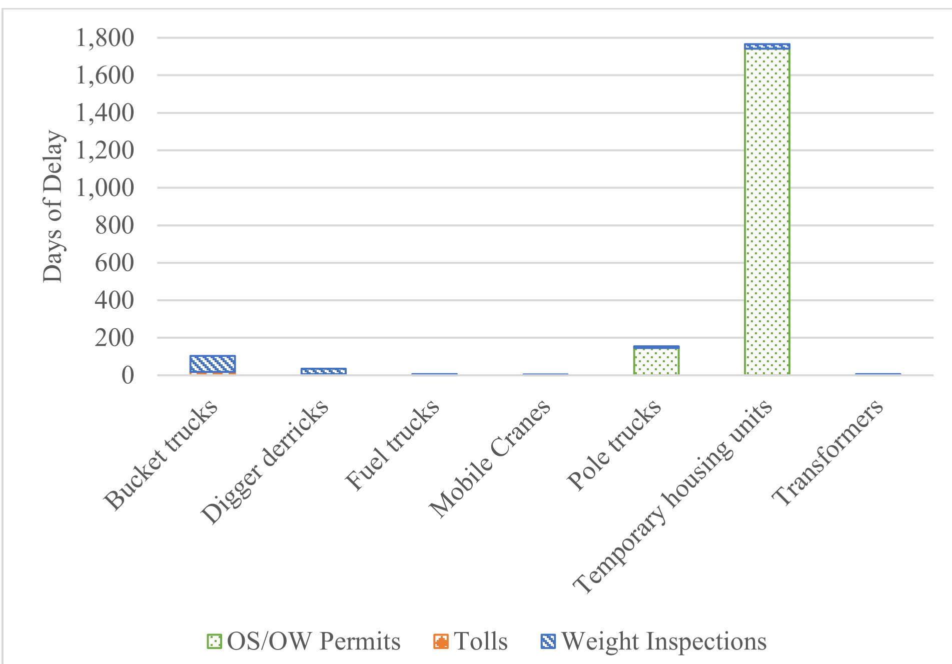

Figure 2. Cumulative Days of Delay Encountered by All Vehicles in the Weekday Hurricane Scenario

Impacts of Delays

The impacts resulting from the delayed power restoration vehicles in this scenario are shown in table 8. Responding utilities incur an additional $1.1 million in labor costs, while the extended power outage costs residential, commercial, and industrial utility customers over $1.6 million, $36.9 million, and $32.3 million, respectively. The weekend scenario increases utility costs to $5.1 million and results in delayed power restoration for over 99,000 residential customers, over 4,000 commercial customers, and over 500 for industrial customers. The resulting economic costs are $9.7 million for residential customers, $164 million for commercial customers, and $72.4 million for industrial customers.

Table 9. Impacts of Delayed Power Restoration Vehicles in the Hurricane Scenario

Scenario	Weekday	Weekend
Total Cost to Utilities	$1,166,016	$5,134,334
Number of Residential Customers Impacted	24,835	99,072
Total Cost to Residential Customers	$1,667,323	$9,735,480
Number of Commercial Customers Impacted	3,608	4,693
Total Cost to Commercial Customers	$36,925,198	$164,565,768
Number of Industrial Customers Impacted	1,534	521
Total Cost to Industrial Customers	$32,396,800	$72,437,728

An estimated 400,000 customers lost power in Florida as a result of Hurricane Michael,[36] resulting in a high-risk population of approximately 15,200 people in this scenario.

The 50 fuel trucks in this scenario are each delayed by 1 to 4 hours. The 475,000 gallons of fuel being transported by these vehicles is enough to fuel 26,389 generators, over 11,875 ambulances, or over 7,308 fire trucks.

The 871 temporary housing units traveling from Alabama are each delayed by just over two days, predominantly due to the OS/OW permit needed for Alabama. This results in a delay of 3,484 people being placed in more permanent housing by an additional 2 days.

Finally, the ten mobile cranes are delayed by a range of 1 hour to almost 2.5 days. The total additional rental costs incurred are just over $14,500, and the costs of disruption to other emergency response activities is over $43,000.

MIDWEST TORNADO

Scenario Description

The Midwest Tornado scenario is based on a tornado that landed in Joplin, Missouri, on May 22, 2011. Compared to the hurricane and tropical storm, the tornado had more localized impacts,

[36] Florida State Emergency Response Team, *Hurricane Michael.*

with a ¾-mile-wide and 6-mile long path of damage through the City of Joplin.[37] Due to the scale of destruction and the fact that a regional hospital was destroyed, the city's resources were overwhelmed and required assistance from nearby States. Approximately 18,000 people lost power, and 8,000 buildings were damaged or destroyed. There were 1,100 responders from out-of-State, and 14,000 police cars, ambulances, and fire trucks were sent to Joplin from Illinois, Kansas, and Oklahoma, among other States.

This scenario represents a tornado with impacts focused on a local community, yet requires assistance from other States. Major response efforts include search and rescue, providing medical care, providing shelter for those displaced, debris removal (including in search and rescue operations), and restoring power. All vehicles in this scenario travel to Joplin, Missouri, from the relatively nearby States listed in table 9.

Table 10. Midwest Tornado Baseline Routing Scenario

Number of Vehicles Traveling	Origin State	Baseline Transit Time (Hours)
• Temporary housing units: 348	Alabama	13
• Bucket trucks: 6 • Digger derricks: 2 • Pole trucks: 9 • Fuel trucks: 1	Colorado	13
• Bucket trucks: 6 • Digger derricks: 2 • Pole trucks: 9 • Fuel trucks: 1 • Mobile crane: 1	Illinois	7
• Bucket trucks: 6 • Digger derricks: 2 • Pole trucks: 9 • Transformer: 1 • Fuel trucks: 1	Kansas	6
• Bucket trucks: 6 • Digger derricks: 2 • Pole trucks: 9 • Fuel trucks: 1	Nebraska	10
• Bucket trucks: 6 • Digger derricks: 2 • Pole trucks: 9 • Fuel trucks: 1	Oklahoma	5

[37] U.S. Department of Homeland Security, Federal Emergency Management Agency, *The Response to the 2011 Joplin, Missouri, Tornado: Lessons Learned Study* (2011), https://kyem.ky.gov/Who%20We%20Are/Documents/Joplin%20Tornado%20Response,%20Lessons%20Learned%20Report,%20FEMA,%20December%2020,%202011.pdf.

Delays

Appendix C includes the delays experienced by each vehicle type in this scenario. The cumulative delays in the Midwest Tornado scenario are similar to the cumulative delays in the Florida Hurricane scenario. OS/OW permit transactions account for the majority of delays for applicable vehicles. Weight inspections contribute less to each vehicle's total transit time, given that all responding vehicles are traveling from States that are less than a one-day drive away (figure 3).

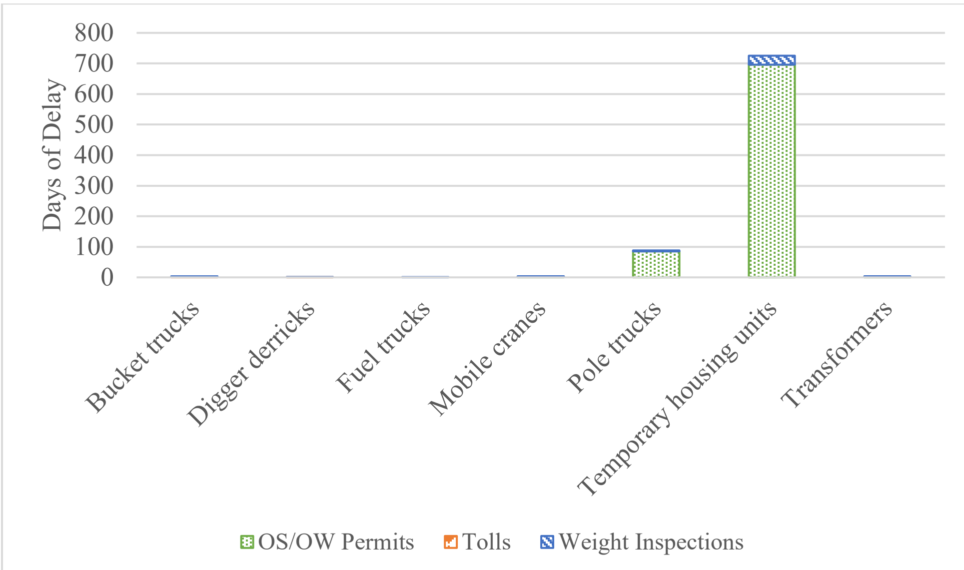

Figure 3. Cumulative Days of Delay Encountered by All Vehicles in the Weekday Tornado Scenario

Impacts of Delays

Delays in power restoration vehicles arriving in Missouri cost responding utilities an additional $370,116 (table 10). The economic cost to residential, commercial, and industrial customers is over $947,000, $16 million, and $838,000, respectively. The weekend scenario increases the additional costs to utilities to over $713,000, and the economic costs to residential, commercial, and industrial customers to over $1.7 million, $29.3 million, and $12.9 million, respectively.

Table 11. Impacts of Delayed Power Restoration Vehicles in the Tornado Scenario

Scenario	Weekday	Weekend
Total Cost to Utilities	$370,116	$713,478
Number of Residential Customers Impacted	6,135	10,383
Total Cost to Residential Customers	$947,355	$1,735,489
Number of Commercial Customers Impacted	291	491
Total Cost to Commercial Customers	$16,016,551	$29,336,217
Number of Industrial Customers Impacted	7	54
Total Cost to Industrial Customers	$838,499	$12,913,068

An estimated 18,000 customers lost power in Missouri as a result of the 2011 tornado,[38] resulting in a high-risk population of approximately 684 people in this scenario.

The five fuel trucks in this scenario are each delayed by 1 to 2 hours. The 50,000 gallons of fuel being transported by these vehicles is enough to fill 2,778 generators, 1,250 ambulances, or 769 fire trucks; however, given the minimal delay time, the impacts of delayed fuel trucks are minimal.

The 348 temporary housing units in this scenario are each delayed by just over 2 days, leaving up to 696 displaced people without a more permanent housing situation for an additional 2 days.

Finally, the one mobile crane is delayed by 2 days, resulting in an additional rental cost of approximately $7,700. The additional cost of disruption to other emergency response activities is over $23,000.

WEST COAST WILDFIRE

Scenario Description

The West Coast Wildfire scenario is based on the Tubbs Fire that burned for about three weeks in Sonoma and Napa Counties in Northern California in October 2017.[39] Approximately 110,000 acres were burned, 100,000 people were evacuated, and 6,686 buildings were destroyed in Sonoma County.[40]

This scenario represents a wildfire that affects a large area within a State. Major response efforts include containing the fire, providing temporary shelter for those displaced, providing medical care, debris removal, and power restoration. Table 11 details the total number of vehicles that travel from each origin State to Sonoma County, California, in this scenario, as well as the baseline transit time for each vehicle type along each route.

Table 12. West Coast Wildfire Baseline Routing Scenario

Number of Vehicles Travelling	Origin State	Baseline Transit Time (Hours)
• Temporary housing units: 151	Alabama	42
• Bucket trucks: 18 • Digger derricks: 6 • Pole trucks: 11 • Fuel trucks: 1	Kansas	29
• Temporary housing units: 151	Maryland	46

[38] U.S. Department of Homeland Security, The Response to the 2011 Joplin, Missouri, Tornado.
[39] County of Sonoma, *October 2019 Complex Fires: Emergency Operations Center After Action Report & Improvement Plan* (2018), https://sonomacounty.ca.gov/WorkArea/DownloadAsset.aspx?id=2147560486.
[40] County of Sonoma, October 2019 Complex Fires.

Table 11. West Coast Wildfire Baseline Routing Scenario (continuation)

Number of Vehicles Travelling	Origin State	Baseline Transit Time (Hours)
• Bucket trucks: 18 • Digger derricks: 6 • Pole trucks: 11 • Fuel trucks: 1	Minnesota	35
• Bucket trucks: 26 • Digger derricks: 9 • Pole trucks: 16 • Fuel trucks: 2 • Mobile crane: 1	New Mexico	24
• Bucket trucks: 26 • Digger derricks: 9 • Pole trucks: 16 • Transformer: 1 • Fuel trucks: 2	Oregon	12

Delays

The delays encountered by each vehicle type along each route are included in Appendix D. Similar to the Florida Hurricane and Midwest Tornado scenarios, delays from OS/OW permit transactions contribute the most to cumulative delay time (figure 4). OS/OW permitting is not automated in Oregon and California, so an additional 2 days is added to the transit time for pole trucks, fuel trucks, and transformers traveling from Oregon, which requires the crossing of only one State line.

While toll delays make up only a small fraction of cumulative delays, the 22 bucket trucks and digger derricks that are delayed from tolls in this scenario contribute a total of 7 days to cumulative delay time.

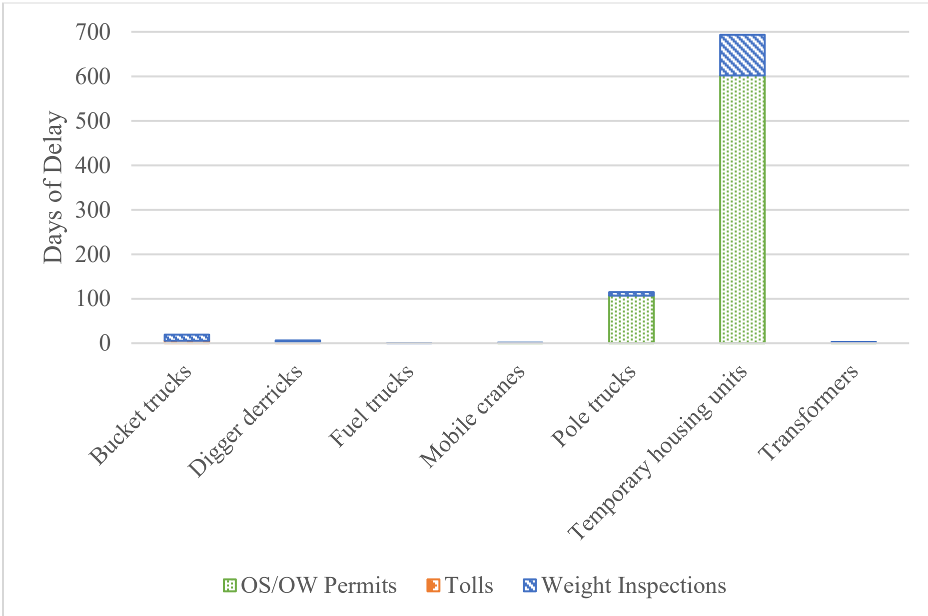

Figure 4. Cumulative Days of Delay Encountered by All Vehicles in the Weekday Wildfire Scenario

Impacts of Delays

As shown in table 13, utilities pay an additional $560,918 in labor costs in this scenario due to delayed power restoration vehicles. The cost to customers from the delays that otherwise would have been avoided is $1.1 million for residential customers, $18.8 million for commercial customers, and $8.2 million for industrial customers (table 12). The cost to utilities increases to over $1.2 million in the weekend scenario, and the costs to utilities increases to $2.8 million, $36.1 million, and $15.9 million for residential, commercial, and industrial customers, respectively.

Table 13. Impacts of Delayed Power Restoration Vehicles in the Wildfire Scenario

Scenario	Weekday	Weekend
Total Cost to Utilities	$560,918	$1,236,650
Number of Residential Customers Impacted	10,270	19,278
Total Cost to Residential Customers	$1,115,249	$2,800,725
Number of Commercial Customers Impacted	486	775
Total Cost to Commercial Customers	$18,851,863	$36,184,321.97
Number of Industrial Customers Impacted	54	86
Total Cost to Industrial Customers	$8,298,118	$15,927,431

An estimated 500,000 customers lost power in California due to the Tubbs Fire, resulting in a high-risk population of approximately 1,900 people in this scenario.

The five fuel trucks are delayed by a range of 2 to 6 hours, and the 50,000 gallons of fuel they are transporting is enough to fuel 2,778 generators, 1,250 ambulances, or 769 fire trucks.

The delays experienced by the 301 temporary housing units leave up to 1,204 people without a more permanent housing situation for an additional almost 2.5 days.

Finally, the one mobile crane is delayed by just under 1 day, resulting in an additional rental cost of almost $3,000, and an additional cost of disruption to other emergency response activities of approximately $8,700.

COLORADO FLOOD

Scenario Description

The Colorado Flood scenario is based on the 1,000-year rainfall event that resulted in flash floods and mudslides along Northern Colorado's Front Range in September 2013.[41,42] While Boulder County suffered the worst impacts, the State experienced 200 miles of flooding spanning 18 counties, with over 17 inches of rainfall in some areas.[43] The flooding resulted in power outages for 10,113 customers, and gas service was suspended for 4,977 customers. Additionally, 18,000 people were evacuated, 17,882 structures were either damaged or destroyed, 150 to 200 miles of roadway were damaged, and an estimated 26,000 gallons of oil were spilled.

This scenario represents flash floods that affect a large area within a State. Major response efforts include search and rescue, providing temporary shelter for those displaced, providing medical care, clearing wooded areas to allow for the passage of land-based rescue vehicles and the landing of air-based transports, and power restoration. Included in table 13 is the number of each vehicle type traveling from the determined origin States, as well as the baseline transit time for vehicles along each route.

Table 14. Colorado Flood Baseline Routing Scenario

Number of Vehicles Travelling	Origin State	Baseline Transit Time (Hours)
• Bucket trucks: 4 • Digger derricks: 1 • Pole trucks: 11 • Transformers: 1 • Fuel trucks: 1	Kansas	42
• Temporary housing units: 54	Maryland	27

[41] Colorado Division of Homeland Security & Emergency Management, *After Action Report: State of Colorado 2013 Floods and Black Forest Fire* (2015), https://www.colorado.gov/pacific/dhsem/atom/60701.
[42] U.S. Department of Homeland Security, Federal Emergency Management Agency, *Integrated Incident Command: Colorado Floods 2013* (2014), https://www.hsdl.org/?view&did=758185.
[43] Colorado Division of Homeland Security & Emergency Management, *After Action Report.*

Table 13. Colorado Flood Baseline Routing Scenario (continuation)

Number of Vehicles Travelling	Origin State	Baseline Transit Time (Hours)
• Bucket trucks: 4 • Digger derricks: 1 • Pole trucks: 11 • Fuel trucks: 1	Montana	11
• Bucket trucks: 4 • Digger derricks: 1 • Pole trucks: 11 • Fuel trucks: 1	South Dakota	11
• Bucket trucks: 4 • Digger derricks: 1 • Pole trucks: 11 • Fuel trucks: 1	Texas	15
• Bucket trucks: 4 • Digger derricks: 1 • Pole trucks: 11 • Fuel trucks: 1 • Mobile crane: 1	Utah	10

Delays

Appendix E includes the delays encountered by each vehicle type along each route in this scenario. Except for the temporary housing units coming from Maryland, all vehicles in this scenario travel from States that are less than a 1-day drive away from Colorado. While most vehicles traveling either do not need an OS/OW permit or travel through States with automated permitting, the majority of the cumulative delay time is still attributed to OS/OW permit transactions, and in particular, to the temporary housing units (figure 5). This is due to the large number of temporary housing units being transported to Colorado relative to other vehicle types.

Toll delays contribute a total of half a day of delay in this scenario since there is only one route with tolls and only two bucket trucks that experience the toll delay.

Figure 5. Cumulative Days of Delay Encountered by All Vehicles in the Weekday Flood Scenario

Impacts of Delays

The delays to power restoration vehicles in this scenario result in an additional $221,523 to responding utilities (table 14). The economic costs to residential customers, commercial customers, and industrial customers are over $451,000, $7.6 million, and $3.3 million, respectively. The weekend scenario increases the costs to utilities to over $527,000 and the economic costs to residential customers, commercial customers, and industrial customers to $1.1 million, $19.8 million, and $8.7 million, respectively.

Table 15. Impacts of Delayed Power Restoration Vehicles in the Flood Scenario

Scenario	Weekday	Weekend
Total Cost to Utilities	$221,523	$527,991
Number of Residential Customers Impacted	4,184	8,596
Total Cost to Residential Customers	$451,198	$1,176,275
Number of Commercial Customers Impacted	198	407
Total Cost to Commercial Customers	$7,626,938	$19,883,431
Number of Industrial Customers Impacted	22	45
Total Cost to Industrial Customers	$3,357,187	$8,752,188

An estimated 10,000 customers lost power in Colorado due to the 2013 floods,[44] resulting in a high-risk population of approximately 380 people in this scenario.

The five fuel trucks are each delayed by a range of 1 to 2 hours. The 50,000 gallons of fuel they are transporting is enough to fuel 2,778 generators, 1,250 ambulances, or 769 fire trucks, however, given the small delay time, the impacts of delayed fuel trucks are minimal.

The delay experienced by the 54 temporary housing units results in 216 people lacking a more permanent housing situation for an additional 2 days.

Finally, the one mobile crane is delayed by 2 hours, resulting in minimal additional rental and disruption costs totaling less than $1,000.

[44] Colorado Division of Homeland Security & Emergency Management, *After Action Report.*

CHAPTER IV. CONCLUSION

FINDINGS

The goal of this study is to quantify the cost of delays that emergency response vehicles and equipment responding to natural disasters in other States may encounter in transit to their destination, and to estimate the impacts of those delays on emergency response activities.

Though each of the five scenarios in this study are unique in terms of the numbers of out-of-State emergency response vehicles and origin and destination of the vehicles, using the same vehicle types in each scenario reveals commonalities among each scenario. OS/OW permit transaction delays are the largest contributors of delays, both in terms of the additional transit time added to each vehicle as well as the resulting cumulative delay time across all vehicles. While all vehicles traveling are subject to weight inspections, and the likelihood of encountering a weight inspection increases as vehicles travel farther distances, the large amount of delay time attributed to OS/OW permit transactions is particularly significant given that not all vehicles in this study are required to receive OS/OW permits. Furthermore, OS/OW permit transactions are not dependent on a vehicle's baseline transit distance, meaning that vehicles traveling across just one State line may experience a longer delay time than a vehicle traveling from farther away, depending on which pass-through States have automated permitting and which have manual permitting. Across each scenario, OS/OW permit transactions add more time to an individual vehicle's total transit time than do weight inspections.

While many vehicles in this study are delayed by 1 or 2 days, the cumulative impacts are significant. Monetary impacts to utilities and their customers range from hundreds of thousands of dollars to millions of dollars. Adding just 1 additional day of delay to each vehicle significantly increases the monetary impacts to utilities and their customers. Therefore, reducing the delay in obtaining OS/OW permits could contribute to the largest reduction in costs and impacts associated with routing emergency response vehicles across State lines.

The impacts of delayed emergency response vehicles go beyond the monetary impacts to utilities and their customers. Extended, wide-spread power outages also result in increased public health and safety risks in the affected community that are more difficult to quantify. Community risks could be lessened through rapid restoration of power. In addition to the previously discussed impacts, other public health and safety impacts include:

- An increased reliance on at-home generators, which may be improperly used and can lead to carbon monoxide poisoning
- Food and water safety issues due to lack of refrigeration, running water, and sewage services
- The inability to call for help due to downed communication services[45]

There are also a variety of equipment delays that cause problems in effective emergency response. Delays in fuel trucks can result in fuel shortages for generators, private vehicles, and

[45] Klinger et al., "Power Outages, Extreme Events and Health."

emergency response vehicles. Delays in temporary housing units can result in those who have lost their homes or have otherwise been displaced as a result of a natural disaster, to be without a permanent shelter for a longer period of time, causing additional stress for displaced families, as well as on temporary shelters and the resources required to sustain them. Delays in mobile cranes can result in further delays to emergency response activities if they are required to clear debris blocking critical roadways and infrastructure.

RECOMMENDATIONS

Reducing the delay from receiving OS/OW permits could contribute to the largest reduction in costs and impacts associated with routing emergency response vehicles across State lines. The following can reduce these impacts:

1. Encourage and assist States in implementing automated permitting systems for OS/OW permits
2. Encourage State DOTs to include information on how to obtain IRP, IFTA, and OS/OW permits during off hours on their websites
3. Encourage State DOTs to expedite weight and roadside safety inspections for emergency response vehicles or defer inspections until after emergency
4. Encourage State DOTs to implement cashless tolling or allow reimbursement of tolls for emergency response vehicles

Though not explored in this study, congestion delays will also inevitably contribute to delays in routing emergency response vehicles to their destination. FHWA's Transportation Systems Management and Operations strategies and Incident Management Strategies offer suggested methods for mitigating congestion delays that can be implemented for emergency response vehicles, including, but not limited to:

1. Allowing emergency response vehicles to travel on shoulders, and managed lanes and by-pass ramp meters
2. Utilizing dynamic lane assignment for the dedicated use of emergency response vehicles
3. Employing signal preemption, which interrupts normal traffic operations to give emergency response vehicles the right of way over non-emergency response vehicles
4. Working with law enforcement officials to escort emergency response vehicles through congested urban areas

While these strategies may already be in use for traditional emergency response vehicles, such as ambulances and fire trucks, these practices are not typically available for some vehicles in this study, such as bucket trucks and pole trucks. Therefore, extending these strategies to more vehicle types could further assist in reducing delays and their associated impacts.

The continued certainty of future natural disasters requires continued advancement of solutions for emergency response and recovery. Enhancing resilience supports the goals of the National Highway Freight Program to improve the safety, security, efficiency, and resiliency of the transportation system and the Nation.

APPENDIX A: EAST COAST TROPICAL STORM WEEKDAY DELAY TABLE

Vehicle Type	Origin State	Delay from OS/OW Permit Transactions (Hours)	Delay from Tolls (Hours)	Delay from Weight Inspections (Hours)	Total Transit Time Added Per Vehicle (Days)
Bucket truck	CA	0	6	8	0.3
Bucket truck	IN	0	6	2	0.1
Bucket truck	TN	0	0	3	0.1
Bucket truck	TX	0	0	5	0.2
Bucket truck	VT	0	6	1	0.0
Digger derrick	CA	0	6	8	0.3
Digger derrick	IN	0	6	2	0.1
Digger derrick	TN	0	0	3	0.1
Digger derrick	TX	0	0	5	0.2
Digger derrick	VT	0	6	1	0.0
Fuel truck	CA	0	0	8	0.3
Fuel truck	IN	0	0	2	0.1
Fuel truck	TN	0	0	3	0.1
Fuel truck	TX	0	0	5	0.2
Fuel truck	VT	0	0	1	0.0
Mobile crane	CA	48	0	8	2.3
Mobile crane	IN	0	0	2	0.1
Mobile crane	TN	0	0	3	0.1
Mobile crane	TX	48	0	5	2.2
Mobile crane	VT	0	0	1	0.0
Pole truck	CA	48	0	8	2.3
Pole truck	IN	0	0	2	0.1
Pole truck	TN	13	0	3	0.6
Pole truck	TX	13	0	5	0.7
Pole truck	VT	48	0	1	2.0
Temporary housing unit	MD	0	0	1	0.0
Transformer	CA	48	0	8	2.3
Transformer	IN	48	0	2	2.1
Transformer	TN	48	0	3	2.1
Transformer	TX	48	0	5	2.2
Transformer	VT	120	0	1	5.0

APPENDIX B: FLORIDA HURRICANE WEEKDAY DELAY TABLE

Vehicle Type	Origin State	Delay from OS/OW Permit Transactions (Hours)	Delay from Tolls (Hours)	Delay from Weigh Stations (Hours)	Total Transit Time Added Per Vehicle (Days)
Bucket truck	IL	0	0	2	0.1
Bucket truck	MA	0	6	4	0.2
Bucket truck	MS	0	0	1	0.0
Bucket truck	NE	0	0	4	0.2
Bucket truck	TX	0	0	3	0.1
Digger derrick	IL	0	0	2	0.1
Digger derrick	MA	0	6	4	0.2
Digger derrick	MS	0	0	1	0.0
Digger derrick	NE	0	0	4	0.2
Digger derrick	TX	0	0	3	0.1
Fuel truck	IL	0	0	2	0.1
Fuel truck	MA	0	0	4	0.2
Fuel truck	MS	0	0	1	0.0
Fuel truck	NE	0	0	4	0.2
Fuel truck	TX	0	0	3	0.1
Mobile crane	IL	0	0	2	0.1
Mobile crane	NE	0	0	4	0.2
Mobile crane	MA	48	0	4	2.2
Mobile crane	MS	0	0	1	0.0
Mobile crane	TX	0	0	3	0.1
Pole truck	IL	48	0	2	2.1
Pole truck	MA	48	0	4	2.2
Pole truck	MS	48	0	1	2.0
Pole truck	NE	48	0	4	2.2
Pole truck	TX	48	0	3	2.1
Temporary housing unit	AL	48	0	1	2.0
Transformer	MS	48	0	1	2.0

APPENDIX C: MIDWEST TORNADO WEEKDAY DELAY TABLE

Vehicle Type	Origin State	Delay from OS/OW Permit Transactions (Hours)	Delay from Tolls (Hours)	Delay from Weigh Stations (Hours)	Total Transit Time Added Per Vehicle (Days)
Bucket truck	CO	0	0	2	0.1
Bucket truck	IL	0	6	1	0.0
Bucket truck	KS	0	0	1	0.0
Bucket truck	NE	0	0	2	0.1
Bucket truck	OK	0	6	1	0.0
Digger derrick	CO	0	0	2	0.1
Digger derrick	IL	0	6	1	0.0
Digger derrick	KS	0	0	1	0.0
Digger derrick	NE	0	0	2	0.1
Digger derrick	OK	0	6	1	0.0
Fuel truck	CO	0	0	2	0.1
Fuel truck	IL	0	0	1	0.0
Fuel truck	KS	0	0	1	0.0
Fuel truck	NE	0	0	2	0.1
Fuel truck	OK	0	0	1	0.0
Mobile crane	IL	48	0	1	2.0
Pole truck	CO	48	0	2	2.1
Pole truck	IL	48	0	1	2.0
Pole truck	KS	48	0	1	2.0
Pole truck	NE	48	0	2	2.1
Pole truck	OK	48	0	1	2.0
Temporary housing unit	AL	48	0	2	2.1
Transformer	KS	48	0	1	2.0

APPENDIX D: WEST COAST WILDFIRE WEEKDAY DELAY TABLE

Vehicle Type	Origin State	Delay from OS/OW Permit Transactions (Hours)	Delay from Tolls (Hours)	Delay from Weigh Stations (Hours)	Total Transit Time Added Per Vehicle (Days)
Bucket truck	KS	0	6	5	0.2
Bucket truck	MN	0	0	6	0.2
Bucket truck	NM	0	6	4	0.2
Bucket truck	OR	0	0	2	0.1
Digger derrick	KS	0	6	5	0.2
Digger derrick	MN	0	0	6	0.2
Digger derrick	NM	0	6	4	0.2
Digger derrick	OR	0	0	2	0.1
Fuel truck	KS	0	0	5	0.2
Fuel truck	MN	0	0	6	0.2
Fuel truck	NM	0	0	4	0.2
Fuel truck	OR	0	0	2	0.1
Mobile crane	NM	15	0	4	0.8
Pole truck	KS	48	0	5	2.2
Pole truck	MN	48	0	6	2.2
Pole truck	NM	48	0	4	2.2
Pole truck	OR	48	0	2	2.1
Temporary housing unit	AL	48	0	7	2.3
Temporary housing unit	MD	48	0	8	2.3
Transformer	OR	48	0	2	2.1

APPENDIX E: COLORADO FLOOD WEEKDAY DELAY TABLE

Vehicle Type	Origin State	Delay from OS/OW Permit Transactions (Hours)	Delay from Tolls (Hours)	Delay from Weigh Stations (Hours)	Total Transit Time Added Per Vehicle (Days)
Bucket truck	KS	0	0	1	0.1
Bucket truck	MT	0	0	2	0.1
Bucket truck	SD	0	0	2	0.1
Bucket truck	TX	0	6	2	0.1
Bucket truck	UT	0	0	2	0.1
Digger derrick	KS	0	0	1	0.1
Digger derrick	MT	0	0	2	0.1
Digger derrick	SD	0	0	2	0.1
Digger derrick	TX	0	0	2	0.1
Digger derrick	UT	0	0	2	0.1
Fuel truck	KS	48	0	1	0.1
Fuel truck	MT	48	0	2	0.1
Fuel truck	SD	13	0	2	0.1
Fuel truck	TX	0	0	2	0.1
Fuel truck	UT	0	0	2	0.1
Mobile crane	UT	0	0	2	0.1
Pole truck	KS	48	0	1	2.1
Pole truck	MT	48	0	2	2.1
Pole truck	SD	13	0	2	0.6
Pole truck	TX	0	0	2	0.1
Pole truck	UT	0	0	2	0.1
Temporary housing unit	MD	48	0	4	2.2
Transformer	KS	48	0	1	2.1

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