Weather Delay Costs to Trucking

www.its.dot.gov/index.htm
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FHWA-JPO-13-023

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16. Abstract

Estimates of the nation's freight sector of transportation range to upwards of $600 billion of total gross domestic product with 70 percent of total value and 60 percent of total weight moving by truck. Weather-related delays can add significantly to shipping costs, resulting in negative impacts on the overall economy. FHWA funded this project in order to estimate the impact of adverse weather on U.S. roadway freight operations.

The findings of the study were that weather phenomena impact freight traffic between 3 percent and 6 percent of the time, depending location, with a national average of 4.6 percent. The cost of weather-related delay to the freight industry was estimated at $8.659 billion or 1.6 percent of the total estimated freight market of $574 billion. While this appears on the surface to be a small percentage the dollar value is significant and it is important to note that improvements to road weather management programs, which are generally relatively inexpensive, can have major payoffs from a benefit/cost standpoint. Specific research required to refine this estimate is recommended in the report.

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1.0 Introduction

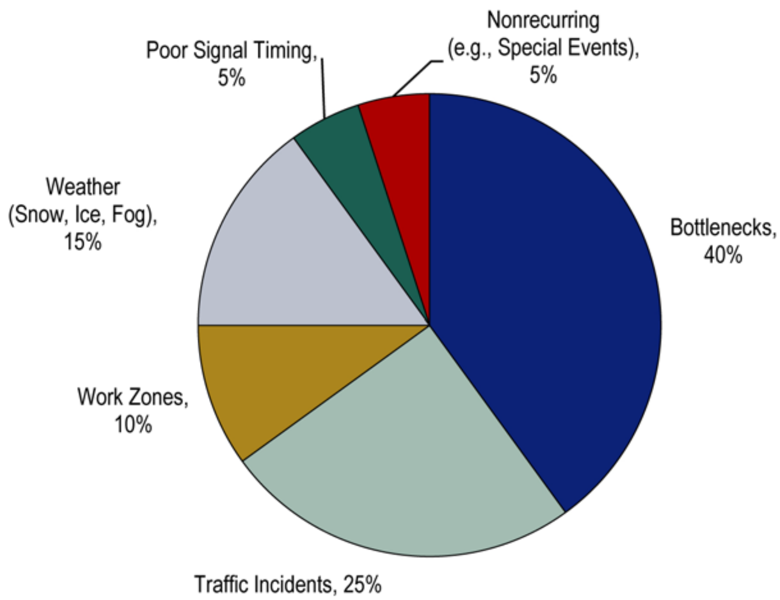
Commercial motor vehicles are the nation's dominant mode of freight transportation. Estimates of the nation's freight sector of transportation range to upwards of $600 billion of total gross domestic product with 70 percent of total value and 60 percent of total weight moving by truck. Weather-related delays can add significantly to shipping costs, resulting in negative impacts on the overall economy. Adverse weather is one of the major causes of delay on the roadway system. The FHWA's Road Weather Management Program web site estimates that delays as much as 23 percent of the nation's roadway delays may be the result of adverse weather. Other studies, as discussed below, show a lower, but still very significant percentage. A number of studies have indicated a wide variation in adverse weather impact on speed, volume, and delay. (http://ops.fhwa.dot.gov/weather/q1_roadimpact.htm).

A review of past work in this area suggests a wide range of potential approaches to estimating the impact of weather-related delay on roadways. Most studies that break down the components of delay have concentrated on urbanized areas, where detailed travel time data is more likely to be collected and available for analysis. A recent literature search conducted by Cambridge Systematics, Inc. (CS) for Strategic Highway Research Program (SHRP) 2 Project L08 identified several urban freeway studies which estimated the components of delay. Two of these studies did not assess the impact of weather on delay and the other two were conducted on freeways in the Seattle and San Francisco regions, neither of which tends to have severe winter weather. The work found that 9 percent of delay on three freeways in Seattle could be attributed to adverse weather and only 2 percent in San Francisco. A more recent CS study for SHRP 2, Project L03, analyzed the Seattle freeway system in more detail and estimated that 13 percent of delay was due to rainy conditions.

A study conducted by Oak Ridge National Laboratory did use modeling methods for the country as a whole as of 1999. As part of this effort, urban and rural, freeway and nonfreeway conditions were combined[1] to estimate causes of delay across all types of roadways and geographic area as shown in Figures 1.1 and 1.2.

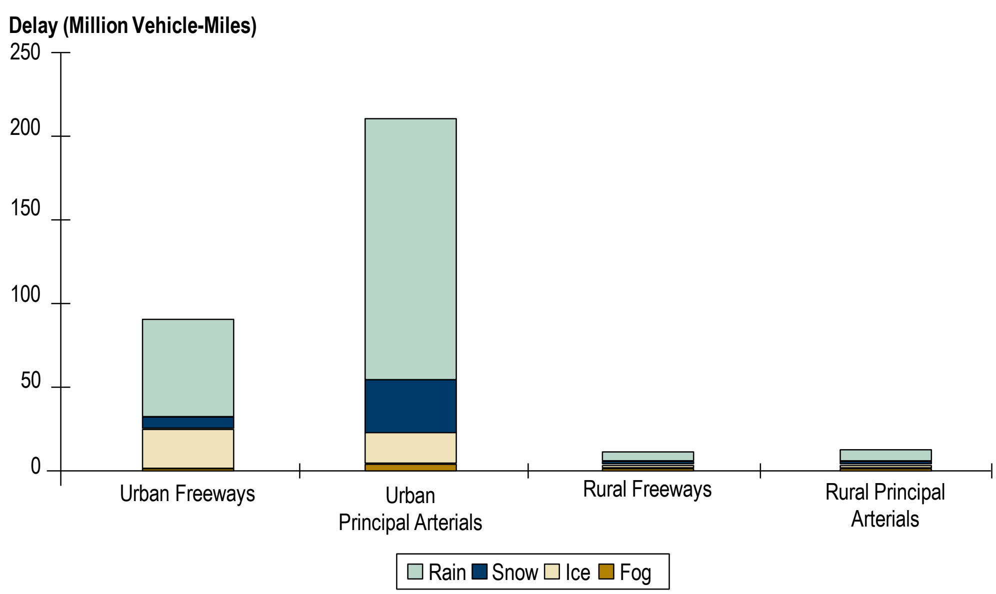
[1] Chin, et al., *Temporary Losses of Highway Capacity and Impacts on Performance,* prepared for FHWA, 2004, http://www-cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2004_209.pdf.

Figure 1.1 Estimate of Delay Components
1999



Source: Chin, et al., Temporary Losses of Highway Capacity and Impacts on Performance, prepared for FHWA, 2004, http://www-cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2004_209.pdf.

Figure 1.2 Estimate of Delay Components
1999



Source: Chin, et al., Temporary Losses of Highway Capacity and Impacts on Performance, prepared for FHWA, 2004, http://www-cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2004_209.pdf.

The 15 percent estimate in the Oak Ridge study reflects inclusion of cities with more weather events, as well as inclusion of rural Interstates. In making these estimates, it is important to note that adverse weather also increases the risk of incidents, which in turn results in further delay. It is, therefore, difficult to separate the impact of weather and incidents.

FHWA funded this project in order to estimate the impact of adverse weather on U.S. roadway freight operations. Through this study, the FHWA would like to expand the base of knowledge to understand the delay impact of adverse weather on the roadway freight industry and the cost of that delay. Our original approach identified four key questions to be addressed in identifying the required sources of data and refining the technical approach to quantifying the impact of weather delays on the freight transportation system. The key questions included:

- What is the overall level of delay in the roadway system?
- What portion of this delay is incurred by commercial vehicles?
- What portion of delay is caused by adverse weather? and
- What is the value of commercial vehicle shipments?

During the course of the project, a comprehensive database of truck speeds, developed through a partnership of FHWA and the American Transportation Research Institute, was made available to the project team. Because truck delays could be calculated directly, this eliminated the need to address the first two questions above; and substitute the question, "what is the delay caused to truck traffic during adverse weather?" The portion of delay caused by adverse weather remained a question since it is important to distinguish between normal peak delays and additional delays caused by adverse weather. The more general challenge was to design a work plan that used compatible databases and provided a level of analytical detail that can be achieved within the budget and schedule allocated to this effort.

1.1 Summary of Work Scope

The scope of work for this project included three key deliverables:

1. **Project Management Plan –** This document included the management strategy for the project, including key personnel, schedule, communications protocols, and key milestones. The document also included an assessment of project risks, which in this project revolved primarily around data quality, availability, and processing time.
2. **Work Plan –** This memorandum was the product of an evaluation of existing literature and data sources and described the two alternative approaches to the work plan requested by FHWA. This memorandum is incorporated into this final report as Section 2.0 through 6.0.
3. **Technical Report –** This report is the final product of the study, documenting the results of the analysis conducted and including an estimate of the economic impact of adverse weather on freight trucking delays. The methodology is documented in Sections 6.0 and 7.0 and a summary and recommendations for existing research are included in Section 8.0.

1.2 Summary of Technical Memorandum

This memorandum summarizes the following information:

- Section 2.0 includes the results of a literature review conducted on the impact of adverse weather on traffic flow and freight operations. The literature review documents studies on these topics and the summary presented includes specific estimates of delay derived from these studies. Results of the literature review are summarized by type of weather and by type of roadway facility. A tabular summary is provided.
- Section 3.0 provides a discussion of the types of weather data than could be utilized in the analytical work for this project. There are many very detailed sources of weather data, and this detail can in itself be a significant challenge. The National Climate Data Center, the *Clarus* system, and the Places Rated Almanac include databases that range greatly in the level of detail in terms of geography, observation type, and aggregation level. The major challenge in this effort was to identify a dataset that is compatible with the freight dataset but of adequate detail to distinguish between different regions.
- Section 4.0 includes a summary of freight data available for this analysis. Freight movement is generally a private sector function, with a very competitive market. As a result, detailed data are difficult to obtain and detailed estimates of freight movements needed to be developed from generalized data. This section documents various sources available and how they can be used to estimate the impact of adverse weather on freight delay costs.
- Section 5.0 includes a summary of different sources of traffic and congestion data that may be considered for use in this analysis. Data from FHWA's Urban Mobility program and Traffic Management Center databases will be considered, along with data from the Highway Performance Management System (HPMS), which is the most complete national database on traffic volume and speeds. Following the original research documented in this chapter, the consultant team received a dataset on truck speeds that was developed through a joint partnership of FHWA and the American Transportation Research Institute. This data source was clearly well-suited to the analysis and was used to calculate delay.
- Section 6.0 summarizes the two alternative approaches for conducting the project analysis and provides a recommendation on next steps to be conducted in Task 3.
- Section 7.0 includes the results of the analysis and a summary of the data sources and methodology used to derive the estimate of weather-related freight delay.
- Section 8.0 includes a summary of the findings and recommendations for additional work to enhance the estimate and the tools that were used.

2.0 Literature Review

2.1 Summary of Findings on Delay Impacts

Thirty-three studies concerning weather-related delay impacts on traffic were reviewed and the relevant findings summarized in this section. The impacts of weather events such as snow, rain, ice, visibility, and wind, on traffic operations result in reductions in traffic speed, capacity, and volume, and increases in travel time and delay. The studies reviewed, both international and local, took place mostly on freeways and highways in cold and temperate climates. The international locations include Spain, Germany, France, Canada, Japan, South Korea, Sweden, and the Netherlands; and domestic locations include Iowa, Minnesota, Illinois, New York, New Hampshire, Utah, Washington, among others. The sources are listed in Table 2.1, including the author, organization, document title, publication date, and brief description of the contents. The following sections will provide an overview of the delay impacts by weather event and transportation facility. The detailed findings of these articles are summarized in Appendix A.

2.2 Types of Weather

Snow

Twenty-six studies were reviewed with snowfall data from cold climates in international and domestic locations such as Spain, Canada, South Korea, Japan, the Netherlands, Sweden, and within the United States in cities or rural areas in States such as Minnesota, Illinois, Idaho, Iowa, Utah, New Hampshire, Washington, New York, Wisconsin, and Maryland.

The studies found that snow reduces traffic speed, traffic volume, and network capacity depending on the intensity of the snowfall. On average light snow, reduces speed 3 percent to 12 percent or 3 km/h to 10 km/h. Heavy snow, usually greater than 0.12 in/h, reduces speed 10 percent to 40 percent or 10 km/h to 50 km/h depending on snowfall intensity, wind speed, and pavement condition, e.g., wet and slushy, compacted snow, and ice and snow. Capacity is reduced 3 percent to 20 percent with light snow and 20 percent to 30 percent with heavy snow; and traffic volume decreases 7 percent to 80 percent depending on the category of the weather event as well as visibility and wind speed.

Travel time on, the other hand, is expected to increase with snowfall. Tu, et al. (2007) estimated that there is an increase of 20 percent in travel time and Chin, et al. (2004) found that on average there is a delay of 0.2 h/driver when it snows.

Rain

Eight studies had information on the effects of heavy rain on traffic speed and capacity. Heavy rain, usually precipitation greater than 0.25 in/h, was found to reduce traffic speed 5 percent to 15 percent or on average 7 km/h. Capacity was found to be reduced in a range of 10 percent to 30 percent.

Hranac, et al. (2006) and Smith, et al. (2004) found that capacity and speed, respectively, are reduced at the same ratio regardless of rain intensity. However, most studies found that rain intensity does influence the magnitude of the impacts on capacity and speed.

Light and medium rain reduce traffic speed 2 percent to 10 percent or 2 km/h to 10 km/h. Capacity was found to decrease from 5 percent to 10 percent with light rain and about 20 percent with medium rain; and traffic volume was reduced 2 percent to 5 percent. According to Billot's (2009) study in a French interurban freeway, time headway is expected to increase 39 percent. Chin, et al. (2004) estimated an average delay of 1.3 h/driver because of rain on freeways and principal arterials. Tu, et al. (2007) reported a 19 percent growth in travel time when it rains. With additional low visibility and high wind speed, Stern, et al. (2003) found a 25 percent increase in travel time during peak hour and a 13 percent increase during off-peak.

Ice

Five studies, mostly international, had findings on the impacts of ice on traffic. Ice on the pavement is expected to reduce speed 6 percent to 17 percent or 4 km/h to 9 km/h ranging from lightly icy to very icy. Travel time was found to increase by 54 percent and delay was estimated to be on average 0.2 h/driver.

Visibility

Six studies presented findings on the impacts of low visibility on speed, capacity, and travel time. Low visibility, usually less than 0.25 miles, in cold weather affects traffic by reducing speed 6 percent to 14 percent and capacity 9 percent to 11 percent. Travel time is estimated to increase 27 percent. Delay was estimated at 0.03 h/driver.

Wind

In their study on a rural freeway section in Idaho, Kyte, et al. (2000) and (2001) found that for wind speeds greater than 20 km/h, traffic speed was reduced 5 km/h to 12 km/h. Camacho, et al.'s (2010) study on a freeway in Spain, found that above freezing temperatures there is a 0.6 km/h speed reduction per each m/s wind speed increase. Below freezing temperatures, without precipitation there is a 0.2 km/h speed decrease and with snow a 1 km/h speed decrease, per each m/s wind speed increase. Capacity was found to decrease one percent to two percent with wind gusts greater than 32 km/h [Agarwal, et al. (2005)].

2.3 Types of Roadway/Transportation Facility

The studies took place in most cases in rural and urban sections of freeways and major highways, including a mountainous highway in Hokkaido, Japan. Five studies presented findings on speed reduction due to snow and rain on urban arterials and intersections. In general, there are no major differences in speed reduction between the different transportation facilities. However, in some cases, the percentage reduced is higher although the actual speed reduction (km/h) is about the same as for other types of roadways, e.g., in an urban arterial in Sapporo, Japan, the speed reduction due to snow is between 10 km/h and 20 km/h which represents a 40 percent to 44 percent speed decrease.

2.4 Table of Sources

Table 2.1 below summarizes the sources the weather delay studies documented above.

Table 2.1 Literature Review Sources

Author/Organization	Document	Date	Description
F. Camacho, A. García and E. Belda. Polytechnic University of Valencia, Spain	Analysis of the Impact of Adverse Weather on Freeway Free-Flow Speed in Spain	2010	It investigates the effect of different weather conditions on the traffic speed and flow for different freeways in Spain. It provides direct measurement of traffic conditions at 15-minute intervals under a variety of weather conditions.
S. Datla and S. Sharma. Transportation Planning, Evaluation and Monitoring Section, City of Edmonton, Canada, and University of Regina, Canada	Variation of the Impact of Cold Temperature, Snowfall and their Interaction on Traffic Volumes	2010	This paper investigates the effect of snow and cold on traffic flow variation using empirical weather and traffic flow data in Alberta, Canada.
C. Strong, X. Shi and Z. Ye. City of Oshkosh, and Montana State University	Safety Effects of Winter Weather: The State of Knowledge and Remaining Challenges	2009	This study is a compendium of various research findings on the impact of weather on traffic flow and concludes with recommendations for further research.
R. Billot. Institut National de Recherche sur les Transports et leur Securite (INRETS), École Centrale de Paris, France	Integrating the Effects of Adverse Weather Conditions on Traffic: Methodology, Empirical Analysis and Bayesian Modeling	2009	This project included the development of a theoretical framework, as well as an empirical analysis of weather impact on traffic flow, using a Bayesian modeling technique. Data were obtained from a motorway in France.
H.A. Rakha, M. Farzaneh, Arafeh and E. Sterzin. Virginia Polytechnic Institute and State University, Texas Transportation Institute, and Cambridge Systematics, Inc.	Inclement Weather Impacts on Freeway Traffic Stream Behavior	2008	This paper quantifies the impact of inclement weather (precipitation and visibility) on traffic stream behavior and key traffic stream parameters, including free-flow speed, speed at capacity, capacity, and jam density. The analysis is conducted using weather data and loop detector data obtained from Baltimore, Twin Cities, and Seattle.
M.G. Wellman, S. Miller, S. Gray and J. Zabransky. Hometown Forecast Services, Plymouth State University, and New Hampshire DOT	Long-Term Analysis of Reductions in Traffic Volume Across New Hampshire During Winter Storms	2008	This study compared weather observations from the National Climatic Data Center and Plymouth State University to traffic counts at 15 locations across the State. Fifty-one storm events were evaluated over a two-year period, and reductions in traffic volume correlated with snowfall and visibility reductions.
H. Tu, J.W.C. van Lint, and H.J. van Zuylen. Delft University of Technology, The Netherlands	The Impact of Adverse Weather on Travel Time Variability of Freeway Corridors	2007	This study used a large database of travel time information on various freeways and a year's worth of weather data to estimate the impact of weather on both travel time and travel time reliability. The research findings indicated that adverse weather did have a significant impact of travel time variability, but only at higher levels of traffic flow.

Author/Organization	Document	Date	Description
K. Munehiro, N. Takahashi and M. Asano. Civil Engineering Research Institute of Hokkaido, Japan Society of Traffic Engineers	Using Probe-Car Data to Analyze Winter Road Traffic Performance in the Urban Sapporo Area	2006	The authors analyze winter road traffic performance in terms of average travel speeds using the taxi probe-car data, and discuss the quality of service required by road users in Sapporo City.
R. Hranac, E. Sterzin, D. Krechmer, H. Rakha and M. Farzaneh. Federal Highway Administration	Empirical Studies on Traffic Flow in Inclement Weather	2006	This study used speed data collected from inductive loops, in combination with airport weather observations, to examine the effects of weather on vehicle speeds in the Twin Cities, Baltimore, and Seattle. The study looked at snow intensity and visibility as variables which could depress speed.
M. Agarwal, T.H. Maze and R. Souleyrette. Iowa State University	Impact of Weather on Urban Freeway Traffic Flow Characteristics and Facility Capacity	2005	This research utilized traffic speed and volume data and a mix of ASOS and RWIS weather station data to estimate capacity and speed reductions due to adverse weather. Snow, rain, and pavement condition were all evaluated in the Twin Cities region of Minnesota.
T.H. Maze, M. Agarwal and G. Burchett. Iowa State University	Whether Weather Matters to Traffic Demand, Traffic Safety, and Traffic Flow	2005	This paper includes a literature search that compiles and summarizes research on the impact of adverse weather on crash rates and traffic flow.
B.L Smith, K. Byrne, R. Copperman, S.M. Hennessy and N.J. Goodall. University of Virginia	An Investigation into the Impact of Rain on Freeway Traffic Flow	2004	This paper investigates the impact of rainfall, at varying levels of intensity, on freeway capacity and operating speeds. The findings indicate that the impact of rain is more significant than currently reported in the Highway Capacity Manual.
S.M. Chin, O. Franzese, D.L. Greene, H.L. Hwang and R.C. Gibson. Oak Ridge National Laboratory, and University of Tennessee	Temporary Losses of Highway Capacity and Impacts on Performance: Phase 2	2004	This report was part of a research effort to estimate TLC on a national basis. Weather was only one of a wide range of factors examined. Others include breakdowns, construction activity crashes, and poor signal timing.
A.D. Stern, V. Shah, L. Goodwin and P. Pisano. Federal Highway Administration, and Mitretek Systems, Inc.	Analysis of Weather Impacts on Traffic Flow in Metropolitan Washington, D.C.	2003	This study estimates the amount of delay due to inclement weather using three years of data from the Washington, D.C. area.
J.S. Oh, Y.U. Shim, and Y.H. Cho. Korea Institute of Construction Technology, New Airport Highway Company, and Chung-Ang University	Effect of Weather Conditions to Traffic Flow on Freeway	2002	In this paper, the effect of weather conditions both the speed-flow and flow-occupancy relationships was studied. The data used in the analysis were obtained from traffic management system installed in the Incheon International Airport Expressway. Regression analyses were performed to select proper models representing the speed-flow and flow-occupancy relationship for uncongested operation.

Author/Organization	Document	Date	Description
Y. Masuya, K. Urata, N. Ito, T. Tamura and K. Saito. World Road Association – PIARC	Analysis of Winter Travel Speed in Pass Sections in Hokkaido	2002	This paper presents various analyses carried out with data from winter travel speed investigations conducted in mountainous highway sections in Hokkaido, Japan, where travel conditions are especially severe. Weather observations were based on visual observations of atmospheric and pavement conditions. Atmospheric and pavement effects were treated separately.
J. Perrin, P.T. Martin and B.G. Hansen. University of Utah	Modifying Signal Timing During Inclement Weather	2001	This paper examines traffic parameters for developing signal timings during inclement weather conditions. Traffic flow data is collected over a range of seven inclement weather severity conditions at two intersections for the 1999/2000 winter season.
M. Kyte, Z. Khatib, P. Shannon and F. Kitchener. University of Idaho, Boise State University, and Meyer Mohaddes and Associates	The Effect of Weather on Free-Flow Speed	2001	The effects of poor weather conditions on free-flow speed on a rural Interstate freeway are considered. These models used a different combination of variables as Kyte, et al. (2000). It was found that free-flow speed is affected by pavement conditions, visibility, and wind speeds.
C.-G. Wallman. Transportation Research Board	Vehicle Speed and Flow at Various Winter Road Conditions	2000	This study used RWIS data, supplemented by visual observations, to define various weather and surface conditions. The product of the analysis was data on the average speed and flow for any particular state of the road compared to the averages for bare road conditions.
K. Knapp, D. Kroeger and K. Giese. Iowa State University	Mobility and Safety Impacts of Winter Storm Events in a Freeway Environment: Final Report	2000	This report estimates the safety-related effects of winter weather on Interstate highways. The report also looks at the effects of winter weather on vehicle speeds. It examines speed data on Iowa Interstate highways based on pavement condition, using recorded video images to establish visibility as well as how much of the pavement was snow-covered.
K.K. Knapp and L.D. Smithson. Iowa State University, and Iowa Department of Transportation	Winter Storm Event Volume Impact Analysis Using Multiple Source Archived Monitoring Data	2000	Data from information management systems in Iowa were used to analyze the traffic volume impacts of winter storm events. Roadway and weather condition data were acquired from a roadway weather information system, and hourly traffic volumes were obtained from automatic traffic recorders. The study found relations between intensity and duration of snowfall and reductions in traffic volume.
M. Kyte, Z. Khatib, P. Shannon and F. Kitchener. University of Idaho, Boise State University, and Meyer Mohaddes and Associates	Effect of Environmental Factors on Free-Flow Speed	2000	Developed regression models of vehicle speed as a function of road weather conditions, using the same data source as Liang, et al. (1998) from a rural section of Interstate 84 in southeast Idaho. This study refined the variables, considering precipitation rate as well.

Author/Organization	Document	Date	Description
Transportation Research Board	Highway Capacity Manual	2000	The manual provides a collection of state-of-the-art techniques for estimating the capacity and determining the level of service for transportation facilities, including weather-related capacity reductions.
A. De Palma and D. Rochat. University of Cergy-Pontoise, France	Understanding Individual Travel Decisions: Results from a Commuters Survey in Geneva	1999	This paper presents the results of an extended traveler behavior survey conducted in Geneva, Switzerland in 1994. In this survey, issues of mode, route, and departure time choice were investigated, together with the diversion from normal patterns in response to adverse weather conditions.
P.J. Maki. Short Elliott Hendrickson, Inc. (SEH) for the Minnesota Department of Transportation	Adverse Weather Traffic Signal Timing	1999	The paper evaluates the feasibility of implementing a traffic signal timing plan for a coordinated signal system that will accommodate traffic in adverse weather conditions. As part of the analyses, the author examined traffic speeds on an urban arterial in Minnesota during snow storms.
W.L. Liang, M. Kyte, F. Kitchener and P. Shannon. University of Idaho, CH2M-Hill, and Boise State University	Effect of Environmental Factors on Driver Speed: A Case Study	1998	A case study on the effects of visibility, wind speed, temperature, the presence of snow on the pavement, and whether it was in the daytime, on driver speed was conducted as part of an intelligent transportation system field operational test to reduce accidents caused by sudden changes in visibility levels. The models were developed using RWIS and automatic traffic recorder data from a rural section of Interstate 84 in southeast Idaho.
W. Brilon and M. Ponzlet. Ruhr University Bochum, Germany	Variability of Speed-Flow Relationships on German Autobahns	1996	The objective of this research project was to determine typical fluctuations of average speeds on autobahns that are not the result of different volumes. The investigations show that two types of time-dependent influences exist: the changing environmental factors such as weather conditions, and the varying driver behavior and traffic mix.
V. Shankar, F. Mannering, and W. Barfield. University of Washington	Effect of Roadway Geometrics and Environmental Factors on Rural Freeway Accident Frequencies	1995	This paper explores the frequency of occurrence of highway accidents on the basis of a multivariate analysis of roadway geometrics, weather, and other seasonal effects.
A.T. Ibrahim and F.L. Hall. Transportation Research Board	Effect of Adverse Weather Conditions on Speed-Flow-Occupancy Relationships	1994	The data used in the analysis were obtained from the Queen Elizabeth Way Mississauga freeway traffic management system. Dummy variable multiple regression analysis techniques were used to test for significant differences in traffic operations between different weather conditions.
R.M. Hanbali and D.A. Kuemmel. Transportation Research Board	Traffic Volume Reductions Due to Winter Storm Conditions	1993	This paper investigates volume reductions due to winter storms across varied intensity of snow fall, time of the day, day of the week, and roadway type.

Author/Organization	Document	Date	Description
S.T. Doherty, J.C. Andrey and J.C. Marquis. University of Waterloo, Canada	Driver Adjustments to Wet Weather Hazards	1993	The study provides self-reported data of what drivers do in response to various weather scenarios. The study found that speed adjustments during wet weather were minimal, but that the level of change increased as weather severity increased.
G.L. Ries. Minnesota Department of Transportation	Impact of Weather on Freeway Capacity	1981	A study on I-35W in Minneapolis that estimated and compared capacities for rain and snow.
J. McBride, W. Kennedy, J. Thuet, M. Belangie, R. Stewart, C. Sy and F. McConkie. Federal Highway Administration	Economic Impact of Highway Snow and Ice Control	1977	Seminal work in quantifying the challenges and benefits of winter maintenance. One aspect of this report included examinations of vehicle speeds on various test sections exposed to various winter weather conditions.

3.0 Weather Data Sources

The major factors that determine the impact of adverse weather on freight costs can be described simply as:

- The value of freight shipments; and
- The frequency and severity of weather events that cause delay in freight shipments.

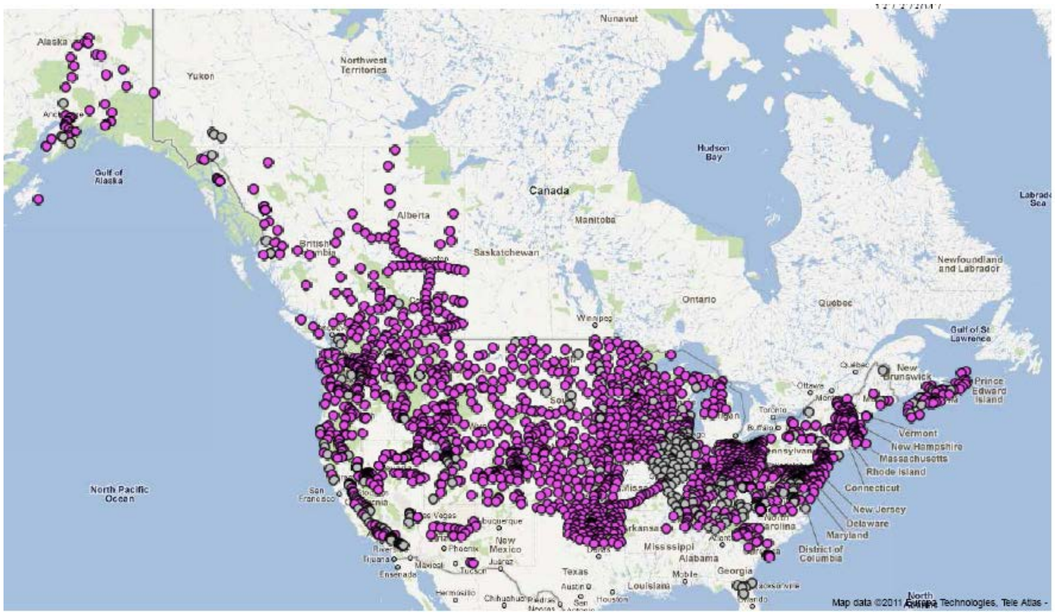
This section discusses data sources that can be used to quantify weather conditions that impact freight shipments.

3.1 Observational Systems and Archives

There are numerous detailed weather event data sources available, generally collected through a series of observation networks, many of which are operated or coordinated by National Oceanic and Atmospheric Administration (NOAA). Key networks include:

- Automated Surface Observing System (ASOS)/Automated Weather Observing System AWOS, which are primary sources of aviation data. ASOS installations, which provide data on surface conditions, have been expanded in recent years from larger airports to many midsized and small airports.
- The *Clarus* system, developed and operated by FHWA through its contractor, Mixon Hill, collects near real-time atmospheric and pavement observations from various State DOTs' road weather information systems. Over 30 States and several Canadian province currently feed data to *Clarus*. Most of the stations report at 20-minute intervals, while some report at 10-minute intervals. Figure 3.1 shows the current network of *Clarus* observations.

Figure 3.1 *Clarus* Observations



Source: http://www.clarus-system.com/.

- NOAA/NWS Cooperative Observer Program has approximately 10,000 participating cooperative observers located throughout the United States. As part of this, program observers routinely collects 15-minute observations of precipitation rain gauges operated by over 2,700 cooperative observers located throughout the United States.
- Remote Automated Weather Station (RAWS) Network – The United States Forest Service oversees this network of stations owned and operated by State and local wildland fire agencies.
- Hydrometeorological Automated Data System (HADS) – The NOAA Office of Hydrologic Development operates the HADS real-time data acquisition and data distribution system.
- NOAA/National Centers for Environmental Prediction (NCEP) Hourly Precipitation Data – NOAA/NCEP routinely develops a National Multisensor Hourly Precipitation Analysis (Stage II) data set from hourly radar precipitation estimates and from hourly gauge reports.
- Snowpack Telemetry (SNOTEL) Network – The United States Department of Agriculture Natural Resources Conservation Service (NRCS) operates this network of approximately 750 stations with locations throughout the mountainous areas of the western United States.
- USDA/NRCS Snow Survey Program – The USDA/NRCS Snow Survey Program provides mountain snow course data at approximately 800 locations throughout the western United States.

The NWS ASOS/AWOS system and *Clarus* are the two networks that focus primarily on comprehensive surface weather conditions. Table 3.1 shows data available from these sources, although it should be noted that not all data items are available from all stations. Those items likely to be most useful to this analysis highlighted.

Table 3.1 Observational Data from *Clarus* and ASOS/AWOS Stations

Clarus Data	ASOS/AWOS Data
Air Temperature	Cloud Height 30 seconds
Atmospheric Pressure	**Visibility 1 minute**
Dew Point Temperature	Photometer 1 minute
Maximum Temperature	Present Weather 1 minute
Minimum Temperature	**Freezing Rain 1 minute**
24-hour precipitation	Temperature/Dew Point 1 minute
1-hour precipitation	**Wind 2-minute average**
6-hour precipitation	Pressure 1 minute
3-hour precipitation	**Precipitation Accumulation 15 minutes**
12-hour precipitation	Lightning 1 minute
Relative Humidity	
Subsurface Temperature	
Surface Temperature	
Total Radiation	
Wet Bulb Temperature	
Average Wind Direction	
Average Wind Speed	
Wind Gust Speed	

3.2 Weather Archival Systems

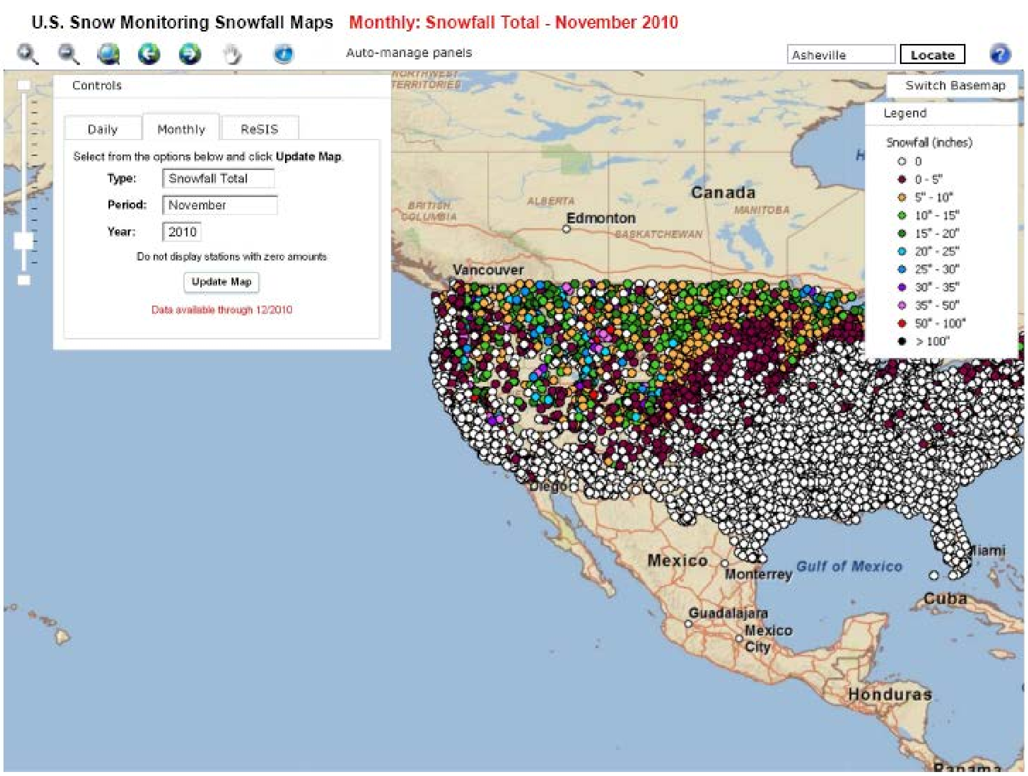
The data sources described above provide very detailed data from individual stations. Use of these detailed datasets requires significant resources to aggregate the information to a level that will be compatible with freight data and thus useful to this project. Both the National Climatic Data Center (NCDC) and the National Weather Service, through the Meteorological Assimilation Data Ingest System (MADIS) combine many of these observation sources to support climatic modeling efforts, provide quality control and allow users to access data from a single source, or at least smaller number of sources.

The stated purpose of MADIS is "to collect, integrate, quality control (QC), and distribute observations from NOAA and non-NOAA organizations." MADIS leverages partnerships with international agencies; Federal, State, and local agencies (e.g., state departments of transportation); universities; volunteer networks; and the private sector (e.g., airlines, railroads) to integrate observations from their stations with those of NOAA "to provide a finer density, higher frequency observational database for use by the greater meteorological community."

The National Climatic Data Center, located in Asheville, North Carolina has the world's largest active archive of weather data. NCDC produces numerous climate publications and responds to data requests from all over the world. NCDC operates the World Data Center for Meteorology which is colocated at NCDC in Asheville, North Carolina, and the World Data Center for Paleoclimatology which is located in Boulder, Colorado.

The NCDC provides a number of indices and summaries that track weather events over longer periods of time, including over decades. An example shown below is a relatively new index called ReSIS (Regional Snowfall Index Scale) that accounts for both snowfall levels and population impacted. Figure 3.2 shows snowfall totals from November 2010 represented on a map. These totals can be combined with population data to calculate the ReSIS index.

Figure 3.2 Map of Snowfall Amounts
November 2010



Source: National Climatic Data Center 2010 Snowfall map http://gis.ncdc.noaa.gov/maps/snowfall.map?view=monthly.

The Places Rated Almanac is another source that summarizes weather data for metropolitan areas. A report prepared by Cambridge Systematics, Inc. for FHWA ("Weather in the Infostructure" prepared by Cambridge Systematics, Inc. for FHWA, January 2003) to estimate needs for Environmental Sensor Stations (ESS), used an index for metropolitan areas based on a variety of inputs and then developed a map for use in estimating ESS density requirements. Winter and summer composite indices were developed based on the variables included in Table 3.2.

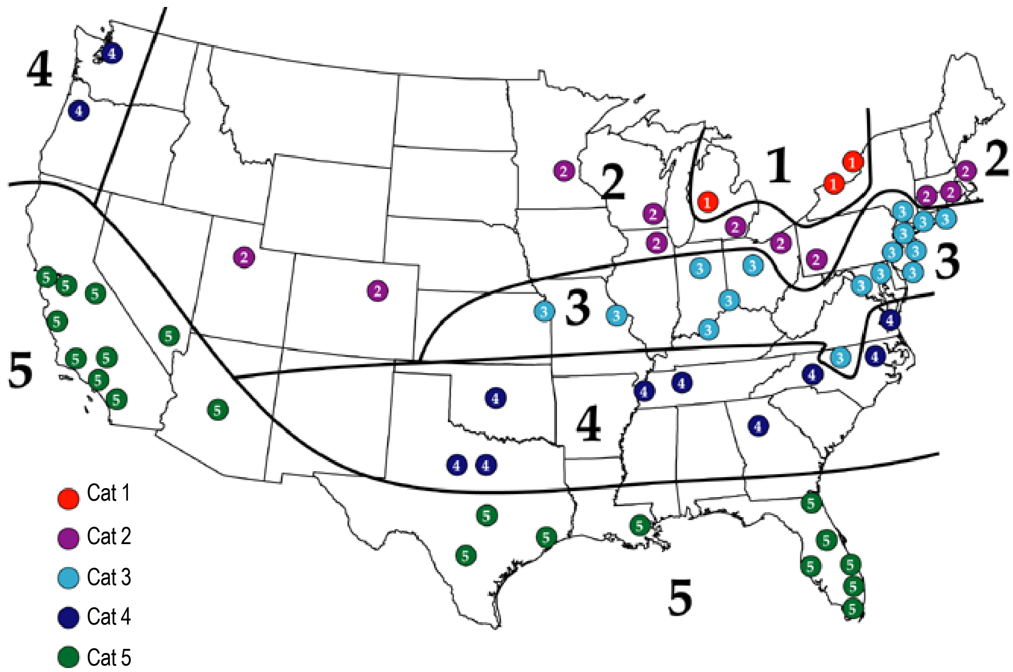
Table 3.2 Indices Used in Weather in the Infostructure Report

Variable	Description
Freezing Temperatures (Winter)	The average number of days per year (based on 30 years of record) that the daily temperature falls to or below freezing.
Snow (Winter)	The average amount of snow (in inches) per year (based on 30 years of record). The greatest amounts were found to be in the lee of the Great Lakes.
Ice (Winter)	The average number of hours that ice (in the form of freezing rain) occurred per year (based on 30 years of record). Freezing rain can occur anywhere from the northern tier to the deep south. However, the mid-Atlantic region to the east of the Appalachians from North Carolina to Pennsylvania is most susceptible.
Precipitation Days (Winter)	The average number of days where measurable precipitation (accumulations of >= 0.01 inches) occur during the winter half of the year from October through March (based on 30 years of data). These values were biased toward the Pacific Northwest and the northern tier in the lee of the Lakes.
Precipitation Days (Summer)	The average number of days where measurable precipitation (accumulations of >= 0.01 inches) occur during the summer half of the year from April through September (based on 30 years of data). These values displayed the convective nature of storms over the Gulf Coast and Central Plains.
Thunder (Summer)	The average number of days per year that thunder is heard (based on 30 years of data). These values showed maximums over the Gulf Coast/Florida and the Central Plains.
Heavy Rain (Summer)	The average number of days per year where rainfall of two inches or more occurred (based on 30 years of record). While heavy rain can occur at any time of the year, tropical summer storms produced the greatest frequency of events.
Hail (Summer)	The average number of days per year with large hail (diameter > ¾ inch) (based on 30 years of data). The greatest frequency of large hail extended from the Central Plains, northeast toward the Ohio River Valley.
Tropical Storms (Summer)	The probability (in percent) of any named tropical cyclone (hurricane or tropical storm) striking a location within a tropical season (June to November). This value was highest along the coastal region from the Outer Banks of North Carolina to south Texas.
Precipitation Amount (Annual)	The average amount of liquid precipitation (rain and melted snow/ice) per year (based on 30 years of record).
Wind (Annual)	The average number of times per year that peak wind speeds were greater than 50 mph. These events can occur during the summer with severe storms or during winter during blizzards.

Source: Cambridge Systematics, Inc. for FHWA "Weather in the Infostructure," 2003.

The indices were then summarized for each of the 50 largest metropolitan areas, sorted into 5 regions and mapped as shown in Figure 3.3.

Figure 3.3 Metropolitan Areas by Winter Index



Source: Cambridge Systematics, Inc. for FHWA "Weather in the Infostructure," 2003.

There are several issues to be considered in selecting between the many available sources of weather data for use in this project is to find sources that can easily to be aggregated to larger regions that are used to estimate freight movements.

- Much of the available weather are collected and archived by individual weather station and by relatively small time increments. Aggregating these databases can be very resource intensive in terms of both computer storage and labor.
- The larger regional boundaries that may be useful for freight analysis, such as the Bureau of Economic Analysis regions, are relatively large and may contain a great variety of weather conditions. It is a challenge to determine how to represent weather conditions in those regions.
- As shown in Section 2.0, there are numerous studies on the impact of adverse weather on traffic delay. Studies specific to freight are far more limited, however, so that the selection and weighting of weather variables will have to be based primarily on general traffic impacts.

4.0 Freight Data Sources

There are several public and private sources for freight data in the United States. This section discusses the most commonly used ones: Global Insight's TRANSEARCH Data, the Federal Highway Administration's (FHWA) Freight Analysis Framework (FAF), and the U.S. Census Bureau's Bureau of Transportation Statistics' (BTS) Commodity Flow Survey (CFS) which is a joint effort by the Research and Innovative Technology Administration, the Bureau of Transportation Statistics and the U.S. Census Bureau. Also included is discussion of the FTR Model data. Table 4.1 presents a summary of all four databases and their limitations.

4.1 Global Insight TRANSEARCH

TRANSEARCH is a privately maintained comprehensive market research database for intercity freight traffic flows compiled by Global Insight, formerly Reebie Associates. The database includes information describing commodities by Standard Transportation Commodity Code (STCC), tonnage, value, county origin and destination, and mode of transport, and offers such additional geographic units as zip codes, Economic Areas, States, and the nation. Data are obtained from Federal, State, provincial agencies, trade and industry groups, and a sample of motor carriers. Forecasts of commodity flows also are available.[2]

TRANSEARCH data are generally accepted as the most detailed available commodity flow data and are commonly used by States, metropolitan planning organizations (MPO), and FHWA in conducing freight planning activities; as well as railroads, trucking companies, and port authorities for market and network assessment; and financial groups for public infrastructure investment analyses. However, it should be noted that there are some limitations to how this data should be used and interpreted:

- **Use of Multiple Data Sources –** TRANSEARCH consists of a national database built from company-specific data and other available databases. To customize the dataset for a given region and project, local and regional data sources are often incorporated. This incorporation requires the development of assumptions that sometimes compromise the accuracy of the resulting database. Different data sources use different classifications; most economic forecasts are based on Standard Industrial Classification (SIC) codes while commodity data are organized by STCC codes. These and other conversions can sometimes lead to some data being miscategorized or left unreported.
- **Private Shipment Sample –** Although the vendor attempts to attract a diversity of carrier types, TRANSEARCH's private shipment sample depends on voluntary participation and thus it is not a random sample.

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[2] Federal Highway Administration. *Quick Response Freight Manual II*. Publication No. FHWA-HOP-08-010. September 2007.

- **Data Collection and Reporting –** The various levels of detail provided by some specific companies when reporting their freight shipment activities limits the accuracy of TRANSEARCH.
- **Proprietary Database –** Another drawback is the proprietary nature of the database, and hence, its lack of transparency. Users can obtain a reasonably complete account of the construction of the database, and its elements are subject to a degree of market testing in that industry clients can and do provide feedback to the vendor. Nevertheless, users must accept on faith the validity of the results, particularly at the county level.[3]

4.2 FHWA Freight Analysis Framework (FAF)

In order to better understand freight transportation demand, assess implications for the surface transportation system, and develop policy and program initiatives to improve freight efficiency, FHWA embarked on the Freight Analysis Framework (FAF) program. The FAF estimates commodity flows at a national level, and flows through international gateways, as well as related freight transportation activity (such as truck traffic on the highway network) using data integrated from various freight data sources.

The original version of FAF (FAF1) provided flows of specific commodities by mode (truck, rail, air, and water) for the base year, 1998, and forecasts of freight movement by mode for 2010 and 2020. In 2006, the FHWA published the second generation of FAF (FAF2), which improved on the first version by providing more geographic regions that cover sub-State areas (FAF2 includes 114 zones, while FAF1 displayed only Interstate flows); providing international freight flows to Canada, Mexico, Latin, and South America, Asia, Europe, the Middle East, and the rest of the world through more than 75 international gateways in the country; providing seven mode classifications (truck, rail, water, air, pipeline, intermodal, and others); and providing commodity data using the two-digit Standard Classification of Transported Goods (SCTG) scheme in order to match the 2002 Commodity Flow Survey (CFS). The FAF2 forecasts extends to 2035.[4]

Version 3.0 of the FAF, released in July of 2010, includes 2007 multimodal freight flows using the recently released 2007 Commodity Flow Survey and other contemporaneous sources, and provides forecasts of those freight flows through 2040. FAF3 includes 123 domestic analysis regions, 8 international regions, 43 two-digit STCG classes, and eight mode classes (truck, rail water, air, multiple modes and mail, other and unknown, and no domestic mode). With this latest version of the FAF a number of improvements to the commodity flow matrix have been possible over previous versions. Which include among others, a roughly doubling of the number of U.S. shipping establishments sampled as part of the 2007 U.S. Commodity Flow Survey (from some 50,000 establishments in 2002, to approximately 100,000 establishments surveyed in 2007); and the use of Port Import Export Reporting Services (PIERS) data to support improved estimates of the internal to

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[3] National Research Council of the National Academies. *How We Travel: A Sustainable National Program for Travel Data*. Transportation Research Board Special Report 304. Washington, D.C., 2011.

[4] Federal Highway Administration. *Quick Response Freight Manual II*. Publication No. FHWA-HOP-08-010, September 2007.

the U.S. allocations of imports and exports to FAF domestic zones of freight origination (for U.S. exports) and destinations (for U.S. imports).[5]

The complete database and documentation are available on line for download on the FHWA's Office of Freight Management and Operations web site.

4.3 Census Bureau Commodity Flow Survey (CFS)

The CFS was reestablished after a decade's hiatus in 1993, and since 1997 has been conducted at five-year intervals. The survey is undertaken through a partnership between the BTS, U.S. Department of Transportation, and the U.S. Census Bureau, U.S. Department of Commerce, with the former providing 80 percent and the latter 20 percent of the total funding, which amounted to about $24.5 million for the most recent 2007 survey.

The CFS is the primary source of national- and State-level data on domestic freight shipments by U.S. establishments in manufacturing, mining, wholesale trade, selected retail trade industries, and warehouses and regional management offices for selected retailers. Establishments classified in services, transportation, construction, and most retail industries are excluded from the survey. Farms, fisheries, foreign establishments, and most government-owned establishments also are excluded.[6]

It provides information on commodities shipped, their value, weight, and mode of transportation, as well as the origin and destination. The data from the CFS are used by public policy analysts and for transportation planning and decision-making to assess the demand for transportation facilities and services, energy use, and safety risk and environmental concerns.

Limitations of the CFS include a small sample size, which is inadequate to support desired geographic detail; lack of timeliness; gaps in coverage; and lack of information on supply chains. The sample size was cut to 50,000 establishments in 2002 but restored to 100,000 in 2007, which allowed better representation of international gateways. The CFS depends on shippers' knowing of where and how shipments were sent, yet many supply chains often involve third-party logistics firms that manage the freight shipments. Thus, shippers often do not know what mode a shipments is made or through what intermediate facility, which results in inaccurate or incomplete responses to the CFS.

The 2007 CFS documentation and reports are available on the BTS site.

4.4 FTR Model

In the early 1980s, FTR departed from traditional regression-based transport modeling in favor of a simple-arithmetic approach designed to explicitly test the effect of broad trucking trends. At the same

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5 Oak Ridge National Laboratory. *The Freight Analysis Framework, Version 3: Overview of the FAF3 National Freight Flow Tables*. Office of Freight Management and Operations, Federal Highway Administration, October 2010.

6 Federal Highway Administration. *Quick Response Freight Manual II*. Publication No. FHWA-HOP-08-010, September 2007.

time, FTR also abandoned traditional American Trucking Associations (ATA)-based freight data in favor of production-based data based on the conclusion that the ATA survey-based data missed more than half of the trucks in the market. The result of this radical departure from traditional forecasting methods is an analytical tool that explicitly models the productivity of the entire trucking industry. It allows the changing of a large collection of productivity variables to test the effects of almost any change in the trucking environment. FTR has historical data readily available back to 1992 and can go back farther, if necessary. Currently, forecasts are made to 2016 but can be extended to meet the 10-year horizon requested for this project. The FTR Model uses Bureau of Economic Analysis (BEA) regions as the basis for a forecast.

FTR's database has four parts:

1. At its core is an estimation of total truck tons, loads and ton-miles by three-digit Standard Transportation Commodity Code and length of haul segment. The data goes back to 1992 and currently is forecast through 2016 but can be extended. This data set is one of two in existence that give comprehensive coverage of trucking, the other being the Reebie data set. The latter contains geographic data, while FTR does not. However, the FTR data set has superior aggregate accuracy and in addition, FTR has access to the 2004 Reebie data and can extract sufficient geographic detail from it for this task. We can explore several other options to obtain sufficient geographic detail if the 2004 data is insufficient.
2. FTR is unique in its possession of a productivity model that translates the freight volumes above into estimates of truck work. This is an essential step in understanding the effect of weather delays on trucking. FTR can segment this data by length of haul and truck type. This data also goes back to 1992 and currently is forecast out to 2016.
3. FTR also maintains models of truck cost with data back to 2003 and forecasts currently to 2012. We have the ability to go back to 1992 and can forecast as far forward as far as necessary.
4. Finally, FTR maintains models of national logistics costs that can be used to estimate the supply chain implications of weather-caused transportation delays.

4.5 Table of Sources

Table 4.1 summarizes the sources of freight data discussed above.

Table 4.1 Freight Databases

Organization/ Agency	Database	Description	Limitations
IHS Global Insight	TRANSEARCH	The private database includes information describing commodities, tonnage, value, county origin and destination, and mode of transport. Data are obtained from Federal, State, provincial agencies, trade and industry groups, and a sample of motor carriers. Forecasts of commodity flows also are available.	Private shipment sample is not random. International movements are not accurately reported.
Federal Highway Administration	Freight Analysis Framework (FAF)	This public database includes information describing commodities, tonnage, value, origin and destination at the FAF Zone level, mode of transport, imports and exports. FAF3 includes 2007 freight flows using the most recently released 2007 Commodity Flow Survey and other contemporaneous sources, and provides forecasts of those freight flows through 2040.	Geographic regions do not provide county-level detail. Commodity detail only available at two-digit SCTG code.
U.S. Census Bureau, and Bureau of Transportation Statistics	Commodity Flow Survey (CFS)	Public source of State-level data on domestic freight shipments by U.S. establishments. It includes information on commodities shipped, their value, weight, and mode of transportation, as well as the origin and destination.	Small sample size. Establishments classified in services, transportation, construction, most retail industries, farms, fisheries, foreign establishments, and most government-owned establishments are excluded from the survey.
FTR	FTR Model	The FTR model is an analytical tool that explicitly models the productivity of the entire trucking industry. This model allows the changing of a large collection of productivity variables to test the effects of almost any change in the trucking environment, including weather. It includes a database covering the period back to 1992 as well as forecast capability. It also can supply truck-cost data to estimate the supply chain impacts of weather events.	Does not contain geographic data, however FTR has access to 2004 Reebie data and can extract sufficient geographic detail from it.

5.0 Congestion Data Sources

There are several national sources on highway volumes and speeds that can be used to develop an estimate of freight delay on a national basis. Use of network-based techniques provide greater detail in terms of traffic conditions and speed but do not account for the origins and destinations of commercial vehicles or the value of their cargo. Several of the databases which can be used are discussed below.

5.1 Highway Performance Monitoring System (HPMS)

HPMS serves as the basis for many of the summary and congestion reports developed on the U.S. highway system. The HPMS was developed in 1978 as a national highway transportation system database. In its current configuration, it includes limited data on all public roads, more detailed data for a sample of the arterial and collector functional systems, and areawide summary information for urbanized, small urban, and rural areas. The HPMS replaced numerous uncoordinated annual State data reports as well as biennial special studies conducted by each State. In the 1970s, FHWA discovered that it had to respond to Congressional inquiries about the status of the nation's highways. HPMS provides a way to measure and track trends in highway characteristics, pavement conditions, and congestion at a national level. The major purpose of the HPMS is to provide data that reflects the extent, condition, performance, use, and operating characteristics of the nation's highways. To meet this primary objective, the HPMS has gone through an evolutionary process that has recognized over time the changing needs for data related to these purposes. HPMS is used by State and local government for a variety of purposes, including capital investment strategies, travel demand modeling, and air quality analysis and general performance measurement. These data also are the source of a large portion of information included in FHWA's annual Highway Statistics and other media and publications.

The HPMS contains a large number of data items related to the physical characteristics and condition of the roadway segment but also includes traffic-related data such as current and projected AADT, peak-hour factors, volumes, capacity, and directional factors. The advantage of this database is that is covers all public roadways and provides a relatively straightforward path to calculating delay.

5.2 National Performance Measure Reports

The FHWA Office of Freight Management and Operations and other stakeholders are developing performance measures for freight transportation. Freight-specific performance measures help to identify needed transportation improvements and monitor their effectiveness. They also serve as indicators of economic health and traffic congestion. Efforts include measurement of travel times in key freight corridors and development of a Freight Performance Measure web-based tool that is being developed using the ATRI truck travel time data used in this report. Freight performance initiatives underway at FHWA and through other channels are documented at http://ops.fhwa.dot.gov/freight/freight_analysis/perform_meas/index.htm.

A key source of information is the Urban Mobility and Congestion Reporting Program, which has been funded by FHWA over the past decade to document trends in urban congestion. Reports currently are prepared by Texas Transportation Institute with support from Inrix Corporation. A combination of HPMS and archived data from Traffic Management Centers has been used to estimate various measures of urban delay. The reports use both aggregate data (total hours of delay) and various indices such as the travel time and buffer indices, which provide an estimate of how much extra time system users must allow to compensate for congested conditions. Recent incorporation of privately collected data has allowed the report to be expanded from only the largest metropolitan areas to a number of medium and small urban areas. A sample of the 2010 report for Washington, D.C. is shown in Figure 5.1. This figure shows various congestion measures for the past six years; however this particular report goes back to 1982.

Figure 5.1 Sample of Urban Mobility Report Data

The Mobility Data for Washington DC-VA-MD

Inventory Measures	2009	2008	2007	2006	2005	2004
Urban Area Information						
Population (1000s)	4,454	4,375	4,330	4,300	4,280	4,275
Rank	7	7	7	7	7	7
Peak Travelers (1000s)	2,249	2,201	2,174	2,154	2,131	2,120
Freeway						
Daily Vehicle-Miles of Travel (1000s)	37,450	38,175	39,045	38,400	38,580	38,200
Lane-Miles	2,075	2,075	2,075	2,060	2,050	2,050
Arterial Streets						
Daily Vehicle-Miles of Travel (1000s)	41,884	42,695	41,575	40,850	41,195	40,960
Lane-Miles	6,200	6,200	6,175	6,130	6,100	5,945
Public Transportation						
Annual Psgr-Miles of Travel (millions)	2,410.7	2,506.2	2,380.2	2,371.6	2,194.8	2,266.7
Annual Unlinked Psgr Trips (millions)	463.4	481.8	465.1	461.0	461.5	442.9
Cost Components						
Value of Time ($/hour)	16.01	16.10	15.47	15.06	14.58	14.10
Commercial Cost ($/hour)	105.67	106.06	102.12	98.77	94.06	86.24
Fuel Cost ($/gallon)	2.60	3.50	3.15	2.79	2.40	2.04
System Performance	**2009**	**2008**	**2007**	**2006**	**2005**	**2004**
Congested Travel (% of peak VMT)	78	78	81	81	81	81
Congested System (% of lane-miles)	63	63	63	63	63	63
Congested Time (number of "Rush Hours")	6.50	6.50	7.75	--	--	--
Annual Excess Fuel Consumed						
Total Fuel (1000 gallons)	148,212	141,783	168,522	161,144	163,232	162,705
Rank	4	4	4	4	4	4
Fuel per Peak Auto Commuter (gallons)	57	56	68	65	67	66
Rank	1	1	1	1	1	1
Annual Delay						
Total Delay (1000s of person-hours)	180,976	175,964	211,755	201,748	204,733	203,098
Rank	4	4	4	4	4	4
Delay per Peak Auto Commuter (pers-hrs)	70	70	85	82	83	83
Rank	1	1	1	2	1	1
Travel Time Index	1.30	1.29	1.36	1.35	1.35	1.35
Rank	2	2	3	4	4	3
Commuter Stress Index	1.43	1.43	1.54	--	--	--
Rank	2	2	3	--	--	--
Truck Congestion Cost ($ millions)	945	915	1,083	--	--	--
Truck Commodity Value ($ millions)	99,477	97,555	95,670	--	--	--
Congestion Cost						
Total Cost ($ millions)	4,066	4,081	4,699	4,269	4,139	3,896
Rank	4	4	4	4	4	4
Cost per Peak Auto Commuter ($)	1,555	1,615	2,552	2,335	2,274	2,143
Rank	2	2	1	3	3	3

Note: Zeroes in the table reflect values less than 0.5.

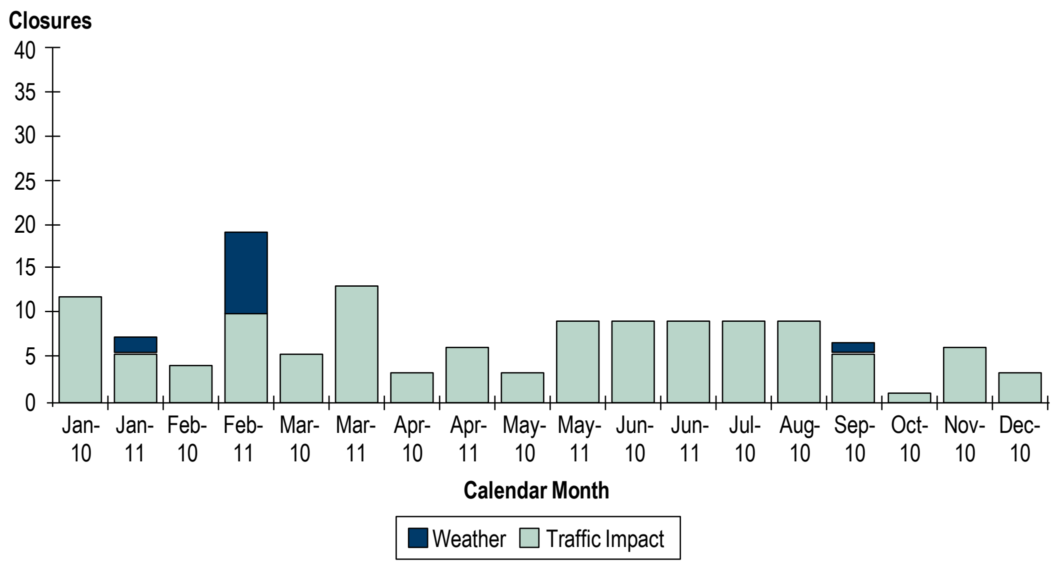
Source: http://mobility.tamu.edu/ums/congestion_data/tables/washi.pdf.

The major drawback in using this source of congestion data is that is covers urban areas only. While most congestion occurs in these areas, adverse weather can cause delays in any portion of the system and some events may have greater impact on rural travel due to lack of roadway infrastructure and services, as well as alternate routes.

5.3 Other Sources

Many State DOTs and regional agencies are developing their own performance measures for either summary "dashboard" reports as well as for internal analysis and evaluation purposes. Congestion measures are increasingly included in these reports as well as summaries of information related to incidents and closures. Figure 5.2 from the Missouri DOT's "Tracker" system shows the number of weather-related closures on I-70 in 2010.

Figure 5.2 Closures on Missouri I-70 in 2010



Source: Missouri DOT Tracker Report 2010, Uninterrupted Traffic Flow Report.

While more States are adopting dashboard programs, the data are collected, summarized, and reported differently in almost every State.

A number of States have expanded their roadway monitoring coverage by contracting with private firms, who collect and process probe data to estimate speeds on major highways. This has enabled State DOTs to obtain speed data from outlying and rural areas where installation of detection systems is not cost-effective. Several firms, including Inrix, Navteq, and Google currently provide speed maps on their own web sites and subscription services are being offered by a wide variety of vendors. These detailed reports focus primarily on more congested urban areas.

6.0 Proposed Work Plan Options

Based on the analysis of available data, both alternative analysis plans should follow several basic principles:

- The aggregation level of different sources of data used should be similar. There is limited benefit in using datasets with highly varying levels of geographic and/or temporal detail. The implication for this project is that surface weather event data will have to be aggregated in order to make it compatible with freight data.
- As weather varies significantly from year to year, data from multiple years should be averaged to provide a more realistic picture of weather conditions.
- As the desired outcome of the project is cost of weather-related freight delay, the methodology chosen should account if possible for economic differences in the goods shipped into, out of, and within different regions.
- To the extent possible the methodology should allow for sensitivity analysis. Of particular importance is the ability to test different assumptions regarding the impact of adverse weather on delay since parameters found in the literature vary widely.

Two methodologies are presented here, with some variations included within each. One methodology uses a network-based model with HPMS as the basis while the other uses direct estimates of freight movement from the FTR based on BEA regions. Both methods are described below.

6.1 Network-Based Methodology

The steps to develop an aggregate national estimate of the costs of adverse weather on freight trucking are:

1. Based on the literature search and review of available weather data, identify categories of weather events that result in freight delay. An initial list includes:
    a. Snow (heavy and light);
    b. Rain (heavy and light);
    c. Ice;
    d. Visibility reduction;
    e. High winds;
    f. Combinations of the above events; and
    g. Major disruptive events (blizzards, hurricanes).
2. Review delay parameters from research and select parameters for use in analysis.
3. Identify other variables that are feasible to incorporate into the analysis:
    a. Type of facility (freeway, major arterial, etc.);

   b. Weather regions; and
   c. Urban/rural.

4. Develop consolidated table of delay parameters. A sample table is shown below. The variables and categories used in the actual analysis may vary depending on further review of the research conducted. Different tables may be developed by geographic region.

Table 6.1 Sample Delay Parameter Table

Area Type	Urban			Rural		
Facility Type	Limited Access	Major Arterial	Other	Limited Access	Major Arterial	Other
Heavy Snow	-20% mph					
Light Snow	-8% mph					
Heavy Rain						
Light Rain						

5. Weather summaries will be compiled, most likely from the National Climatic Data Center (NCDC) archives. Regions used for the freight analysis will be based on Bureau of Economic Analysis regions (map shown in Appendix A). As a result, weather data will be assigned to BEA regions as well, using one of two methods:

   a. Representative weather stations will be selected for each BEA region and summaries of average weather event occurrence over a 10-year period will be compiled. These summaries will then be averaged over the region to obtain a weather event occurrence factor. The weight given to different stations may vary depending on the distribution of population and employment within the region. A sample table is shown below. The station observations would be averaged across the columns to arrive at an occurrence factor for each region.

Table 6.2 Sample Weather Event Occurrence Table

Station Event (Average Days of Occurrence/ Pct of Total Days)	1	2	3
Heavy Snow	5 (1.3%)		
Light Snow	12 (3.2%)		
Heavy Rain	45 (12.3%)		

   b. Similar factors could be developed through GIS/mapping techniques using data similar to that shown in Figure 3.2 in Section 3.0.

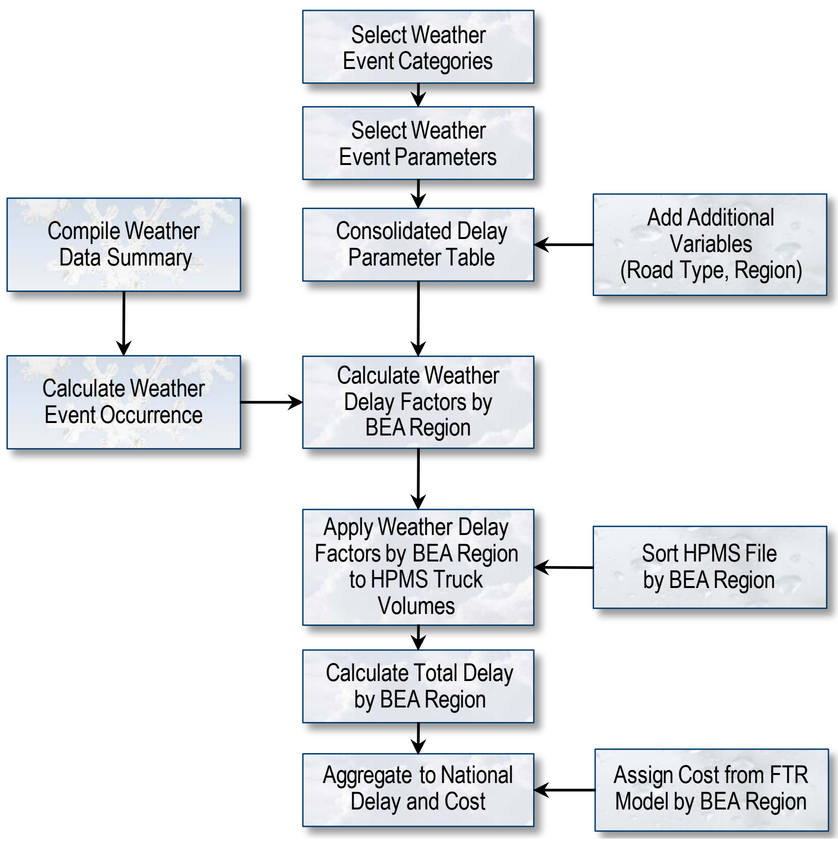
6. Delay parameters and occurrence rates will be combined so they can used as an factor on annual freight traffic using:

   [Annual weather delay factor=Delay factor*Occurrence]

7. The Highway Performance Monitoring System (HPMS) files will be sorted by Bureau of Economic Analysis (BEA) region. The factor developed in Step 6 will be applied to the HPMS files for either 2009 or 2010 (depending on availability) using the following formula:
   Total delay=[annual snow delay factor*volume*commercial vehicle percentage* segment travel time]+[annual rain delay factor*volume*commercial vehicle percentage*segment travel time]+…
8. Delay will be aggregated by BEA region and cost data from the FTR model will be applied to delay data to estimate total delay cost.
9. The process will be replicated for the future year forecast using growth factors in HPMS.

The overall flow of work is shown in Figure 6.1.

Figure 6.1 Methodology #1 Flow Chart



Source: Cambridge Systematics, Inc.

6.2 Direct Forecasting of Freight Delay

This method does not use the network data provided by HPMS but estimates total freight movement directly within BEA regions using the FTR model. The weather delay factors are calculated in a similar manner but aggregated to a composite index which can be used to forecast delay.

1. Based on the literature search and review of available weather data, identify categories of weather events that result in freight delay. An initial list includes:
    a. Snow (heavy and light);
    b. Rain (heavy and light);
    c. Ice;
    d. Visibility reduction;
    e. High winds; and
    f. Major disruptive events (blizzards, hurricanes).
2. Review delay parameters from research and select parameters for use in analysis.
3. Identify other variables that are feasible to incorporate into the analysis:
    a. Type of facility (freeway, major arterial, etc.);
    b. Weather regions; and
    c. Urban/rural.
4. Develop consolidated table of delay parameters. A sample table is shown below. The variables and categories used in the actual analysis may vary depending on further review of the research conducted. Different tables may be developed by geographic region.

Table 6.3 Sample Delay Parameter Table

Area Type	Urban			Rural		
Facility Type	Limited Access	Major Arterial	Other	Limited Access	Major Arterial	Other
Heavy Snow	-20% mph					
Light Snow	-8% mph					
Heavy Rain						
Light Rain						

5. Weather summaries will be compiled, most likely from the National Climatic Data Center (NCDC) archives. Regions used for the freight analysis will be based on Bureau of Economic Analysis regions (map shown in Appendix A). As a result, weather data will be assigned to BEA regions as well, using one of two methods:
    a. Representative weather stations will be selected for each BEA region and summaries of average weather event occurrence over a 10-year period will be compiled. These summaries will then be averaged over the region to obtain a weather event occurrence factor. The weight given to different stations may vary depending on the distribution of population and employment within the region. A sample table is shown below. The station observations would be averaged across the columns to arrive at an occurrence factor for each region.

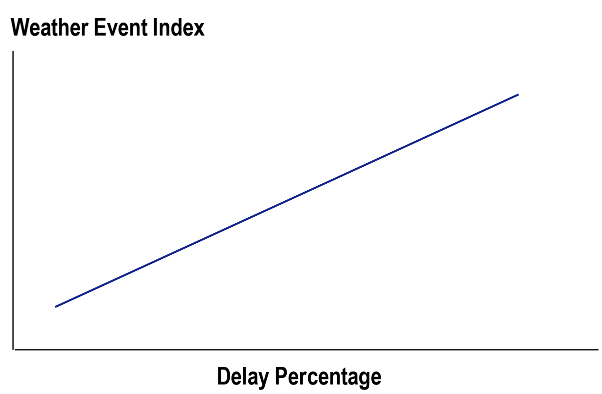
Table 6.4 Sample Weather Event Occurrence Table

Station Event (Average Days of Occurrence/ Pct of Total Days)	1	2	3
Heavy Snow	5 (1.3%)		
Light Snow	12 (3.2%)		
Heavy Rain	45 (12.3%)		

b. Similar factors could be developed through GIS/mapping techniques using data similar to that shown in Figure 3.2 in Section 3.0.

6. Weather event data will be combined into a composite index that combines the occurrence of weather events with delay factors. Summer and winter indices may be developed separately and combined to better distinguish between different regions. A representation is shown in the graph below.

Figure 6.2 Weather Event Index

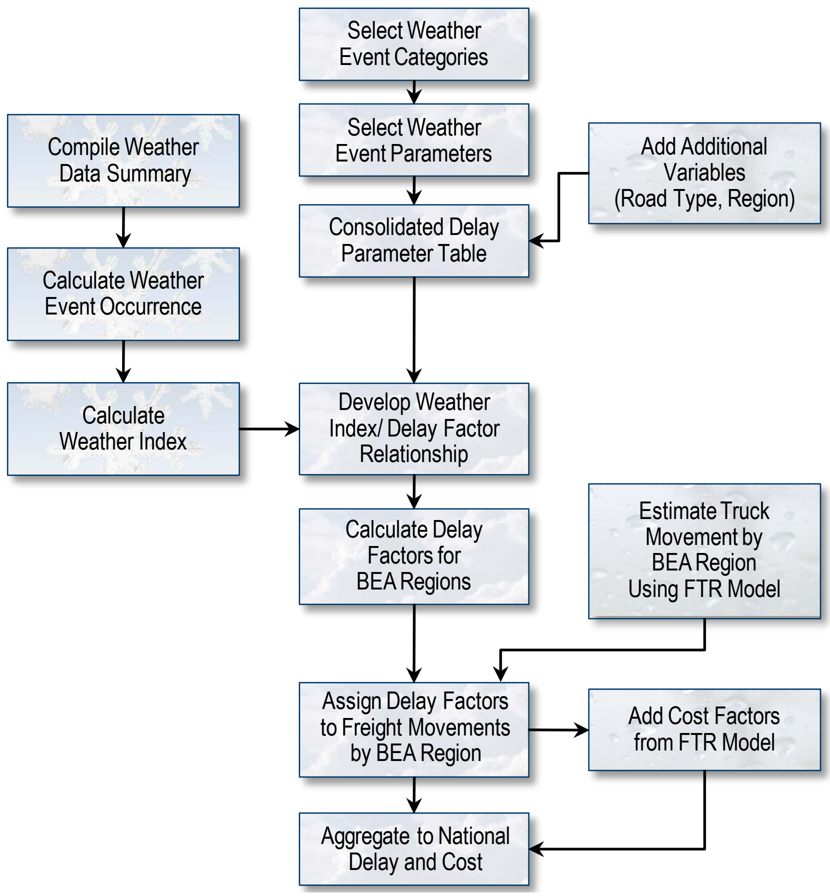


Source: Cambridge Systematics, Inc.

7. A weather event index would be developed for each BEA region and the delay percentage calculated from the graph.
8. The FTR model will be run providing an aggregate estimate of freight movements in each BEA region. The delay factor would be applied as a percentage to the freight movement data. The FTR model will incorporate differential-cost impacts of weather delay depending on the nature of the supply chain.
9. Delay costs will be summed over all BEA regions and an aggregate cost of weather-related delay estimated.
10. The FTR model will be rerun to obtain the future year estimates. Future year freight movements are incorporated into the model.

The overall flow of work is shown in Figure 6.3.

Figure 6.3 Methodology #2 Flow Chart

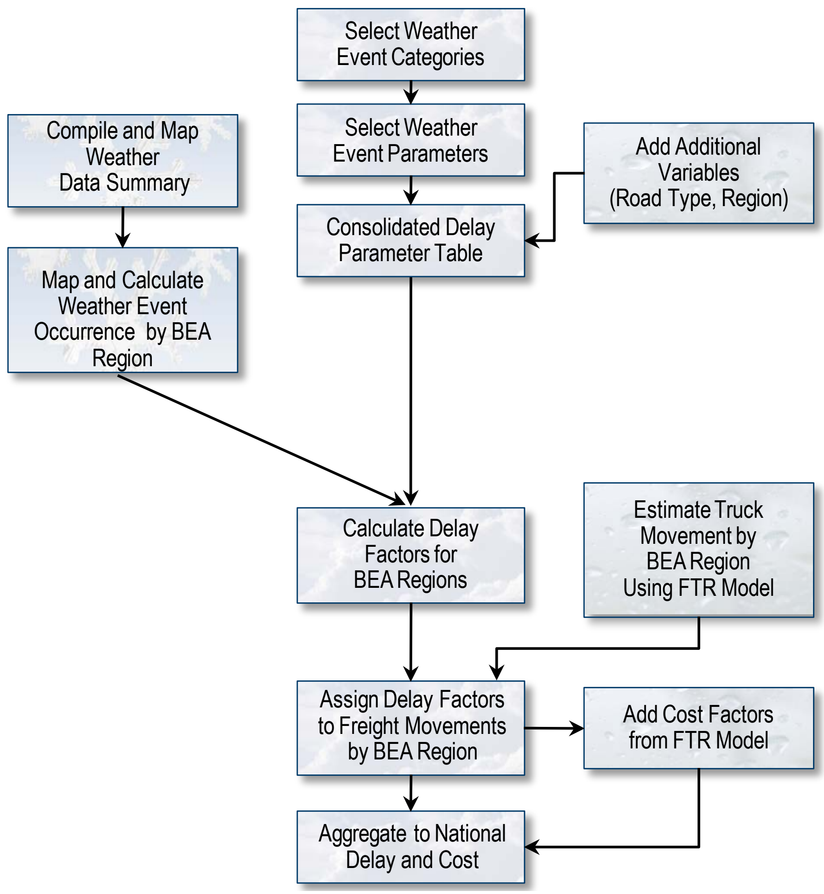


Source: Cambridge Systematics, Inc.

6.3 Summary and Recommendation

It should be noted that the methods can be modularized. For example, the weather delay calculation proposed in the first method could be combined with the use of the FTR model in the second methodology. Following review by FHWA and other members of the technical team, it was decided to combine the approach to calculating weather delay in methodology #1 with the freight modeling approach proposed in methodology #2. NCDC has 30-year climatic data that can be used to map the various weather events that cause most freight delay. These events can then be related to specific BEA regions, and delay factors assigned as indicated in Steps 6 and 7 in Section 6.1. Factors will then be applied to the freight movements calculated through the FTR model as recommended in Section 6.2. The hybrid method proposed is shown graphically in Figure 6.4.

Figure 6.4 Preferred Methodology #3 Flow Chart



Source: Cambridge Systematics, Inc.

The primary reason recommending use of the FTR model to develop estimates of freight movement and cost is that it generates freight movements directly from STCC data and thus can distinguish the difference in shipment costs, which varies widely. This is a more effective method of obtaining a cost of delay estimate than bringing in an average cost at the end of the process, as proposed in the first methodology. A commodity-based methodology also should provide a more accurate forecast of truck movements than using commercial vehicle percentages from HPMS, many of which are estimated.

One potential use of the HPMS methodology is to use it as a second method in several regions to see the range between the two methods.

7.0 Application of Methodology

The methodology actually applied to develop the delay estimate varied slightly from the preferred alternative #3 in Figure 6.4 due to two factors:

1. A very extensive data source on truck speeds was obtained through a partnership of the FHWA Office of Freight Management and Operations and the American Transportation Research Institute (ATRI). This source provided much greater detail on truck speeds that could be matched with weather station data. Since the data were only available for 3 years, the weather analysis was limited to 3 years, rather than the 10 originally envisioned.
2. The team considered using freight data based on the 167 U.S. regions of the Bureau of Economic Analysis (BEA). However, the freight data available did not support an analysis at the Bureau BEA region level originally proposed, especially given that the data processing requirements involved in using BEA regions was far more demanding. Instead the analysis was developed at the State level instead with five of the larger, more heavily traveled States, divided into two parts.

This section describes the datasets that were used to conduct the analysis and process applied and provides a summary of results at the end.

7.1 Key Steps and Basic Assumptions

The methodology documented in this section relies on a number of assumptions. These are summarized in this section, which includes a summary of the sequence of steps used and the basic assumptions behind these steps. Specific tables and figures from this section are referenced in the list below to help guide the reader through the methodology. There are a number of opportunities to improve upon some of these assumptions with additional analysis. These are highlighted in bold and noted in the list below.

1. Truck Trips:
   a. The number of trips were based on update of 2004 Reebie data of freight movements origins and destinations from State to State and within States (six States were divided in two).
   b. Truck movements were updated based on truck counts/economic data.
   c. **A routing guide was developed by hand, which identified the most likely routes for travel between each pair of States. This network could be expanded and additional detail added in a subsequent phase.**
   d. **Trips were estimated for each of three categories based on level of economic activity in State and routing guide (Figure 7.5). This could be refined in a subsequent phase of the project but would require origin-destination data that would probably have to be purchased. The three trip categories are:**
      i. **Local trips made entirely within the State;**
      ii. **Trips with either an origin or destination within the State; and**
      iii. **Trips passing through without an origin or a destination in the State.**

2. Truck Speed Data:
   a. Baseline speeds were developed from truck speed data for each of four roadway categories (Figure 7.6):
      i. Rural Interstate;
      ii. Urban Interstate;
      iii. Rural Non-Interstate; and
      iv. Urban Non-Interstate.
   b. Congestion sensitivity factors were developed to adjust the baseline speed for adverse weather. These factors assume there is a greater degradation in speed during adverse weather on a road that already is congested (Figure 7.7). These assumptions could be refined using simulation work based on field studies. The extent of improvement from such an effort is unclear however when applied on a national basis. Use of HPMS files could help to refine the estimate of the percentage of roadway in each category.
      i. Sensitivity factors ranged from 1 for least sensitive to congestion (rural Interstate in Wyoming) to 6 for most sensitive (urban freeway in Chicago).
      ii. Assumptions were made regarding the percentage of roadway in each State that fell into the six categories. (Could be enhanced with additional analysis of HPMS data.)
3. Weather Event Data:
   a. One hundred forty-two stations located near Interstate corridors were selected to represent weather conditions.
   b. The total number of weather events in various categories was calculated from GSOD (Figure 7.8).
   c. Assumed duration for each type of weather event (range from 2 to 12 hours). This is a key assumption that could be improved by using hourly data to estimate duration of most frequent events for a sample of stations.
4. Weather Impact Calculation:
   a. The number of weather events for each of the 142 stations used was calculated.
   b. Multiple events were given their own category (e.g., rain and high wind was a category).
   c. The number of weather events was multiplied by the assumed duration to obtain total hours event occurred.
   d. Durations were converted the total hours into a percentage of total time (438 hours of event/8,760 hours annually = 5%).
   e. Weather conditions were averaged over all stations in a State (or sub-State region) to match the level of detail in the economic data.
   f. Degradation curves were developed that estimates the percentage reduction in baseline speed as a function of weather event and volume/capacity ratio (Tables 7.1 and 7.2). The congestion "buckets" were defined by FHWA. The actual speed by weather event and V/C ratio is then estimated for each roadway type (Table 7.3). This research could be enhanced using research results but still requires extensive extrapolation.

g. **The percent of each roadway category (Urban Interstate, etc.) in each State is then assigned to a Congestion bucket (Table 7.4 – buckets were defined in Item 4f). This assumption could be refined using HPMS data but it is not clear there would significant payoff in improving the accuracy of the results.**

h. The next step was to calculate the percentage of delay that occurs in each congestion bucket and for each roadway type. This is a calculation of the percentage increase in travel time for each weather event weighted by the percentage of roadway in each congestion bucket (Table 7.5).

i. The next step is to combine the weather and roadway datasets by taking the percentage of time that various weather events occur (Item 3b) and combining it with the threshold index in Table 7.4. The resulting table shows the percent of time that specific events occur on each type of roadway in each State (Table 7.6).

5. Application of Delay Parameters to Truck Travel:

   a. **The length of truck trips for different trip categories (local, pass-through, OD) is estimated for each State (Table 7.7). This could be refined using models or freight data from individual States. However, updating truck trip length on a national basis would take significant effort.**

   b. Average length is multiplied by number of trips (from 1d) to get vehicle-miles traveled (Table 7.8).

   c. Daily truck trips are then assigned to specific roadway types for each State based on FHWA truck count stations (Table 7.9).

   d. **Truck volumes are then assigned to different types of roadway (Table 7.10 where horizontal percentages add up to 100 percent) with percentages estimated for each State. This step could be refined using HPMS and truck count data from individual States.**

   e. The final calculation of VMT (Table 7.11) is then made based on the average trip lengths (Item 5a) and the number of truck trips for each type of roadway (Items 5c and 5d).

   f. **The next step is to calculate the truck/weather interactions by State and roadway type. The percentage of trips that use the different roadway types (Urban Interstate, etc.) are developed for each State (Tables 7.12 and 7.13). Note that the percentages exceed 100 percent since a single trip may use more than one type of roadway. Similar to Step 5d, this step could be refined using HPMS and truck count data from individual States.**

   g. The percentages calculated in Step 5f are then used to allocate the number of truck passings on each type or road (Table 7.14).

   h. Miles per trip and hours per move by State and roadway type are then calculated (Tables 7.15 and 7.16).

   i. The percentage of time that weather events occur are then brought back from Step 4i and used to calculate the percentage increase in travel time due to weather events by State and roadway type (Tables 7.17 and 7.18).

   j. **Trucking costs are divided into six categories and a weight assigned to each since weather has different impacts on different cost components. (Table 7.19). Additional geographic and temporal detail in the weather data would help improve the accuracy of this estimate.**

k. **Trucking costs are based on national estimate of value and apportioned to States based on VMT. This step could be refined using purchased freight economic data but the cost could be significant.**

6. Delay Calculations:
    a. The actual number of hours impacted by adverse weather is calculated (Table 7.20).
    b. Delay costs are calculated based on calculation of hours of delay by State and roadway type (Table 7.21).

7.2 Truck Speed Data

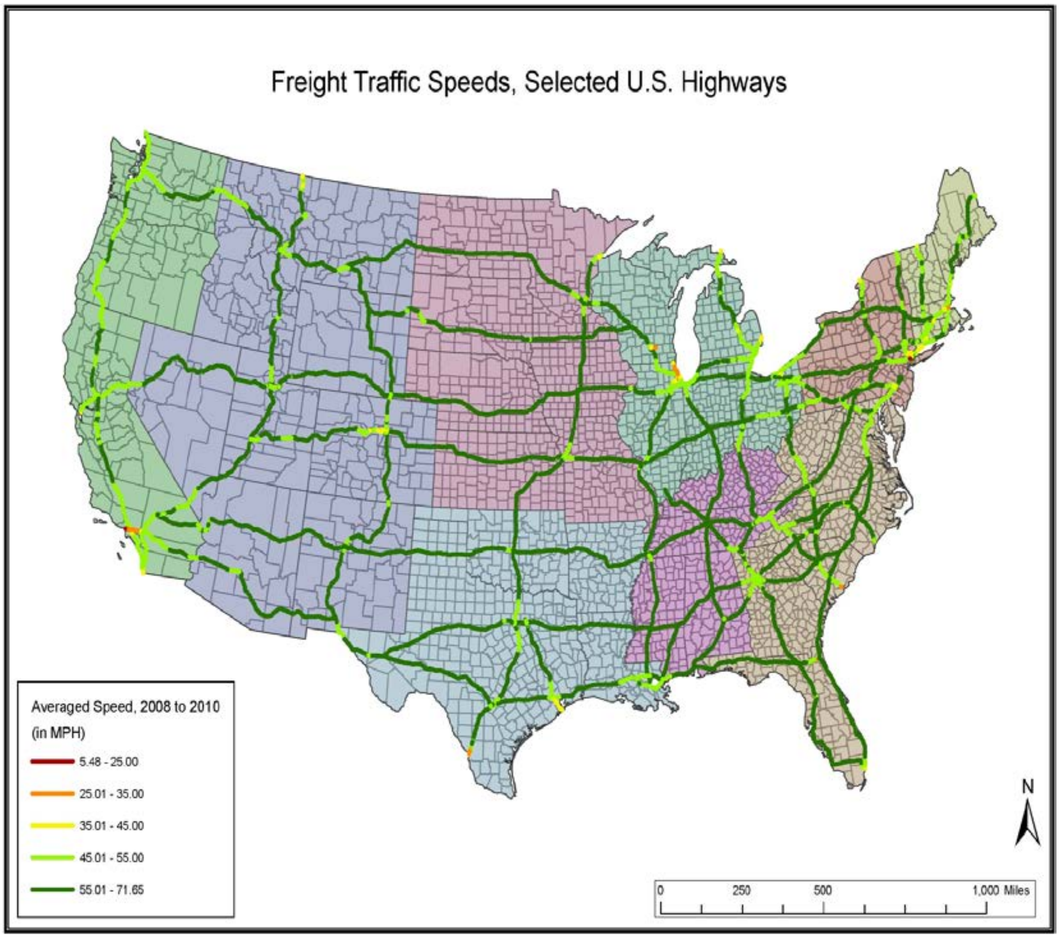
Data on truck speeds were obtained through an initiative of the FHWA Office of Freight Management and Operations, in partnership with the American Transportation Research Institute (ATRI), a nonprofit organization whose "primary mission is to conduct research in the field of transportation, with an emphasis on the trucking industry's essential role in a safe, efficient, and viable transportation system." http://atri-online.org/.

The ATRI data include a complete set of truck speeds on U.S. Interstate highways at 15-minute intervals. Probe data are collected from GPS units in several thousand trucks and the overall data sample includes billions of truck data position points.

The study used the last three years for which a full dataset was available which were 2008-2010. Data were downloaded for all 48 contiguous States and the District of Columbia. All Interstate highways were included as well as some other National Highway System roads. Files were downloaded using the FPM WebTool and the shapefile was mapped using the data from ESRI ArcMap 9.3.

Layers were intersected, road segments were aggregated, and average speeds developed for the segments. Aggregation was necessary due to the relatively short length of the segments. However, care needed to be taken during this effort to make sure that the averaging process did not wash out variation in the data. Since the BEA Regions used for the freight analysis were county-based, county boundaries were attached to the shapefile. Figure 7.1 shows a sample of the speed map developed with counties and Census subregions shown.

Figure 7.1 Freight Traffic Speeds, Selected U.S. Highways



Source: Federal Highway Administration, American Transportation Research Institute.

7.3 Weather Condition Data

Unlike truck speed data sources, which are very limited, there are numerous sources of weather data that could be applied to this effort, as described in Section 3.0. The weather source selected for this analysis is the Global Summary of the Day (GSOD), a joint effort using data from the National Oceanic and Atmospheric Administration (NOAA) and two of its subagencies, the National Environmental Satellite, Data, and Information Service (NESDIS), and the National Climatic Data Center (NCDC). The GSOD contains data for a wide range of weather phenomena, including:

- Mean temperature (.1 Fahrenheit);
- Mean dew point (.1 Fahrenheit);
- Mean sea-level pressure (.1 mb);
- Mean station pressure (.1 mb);

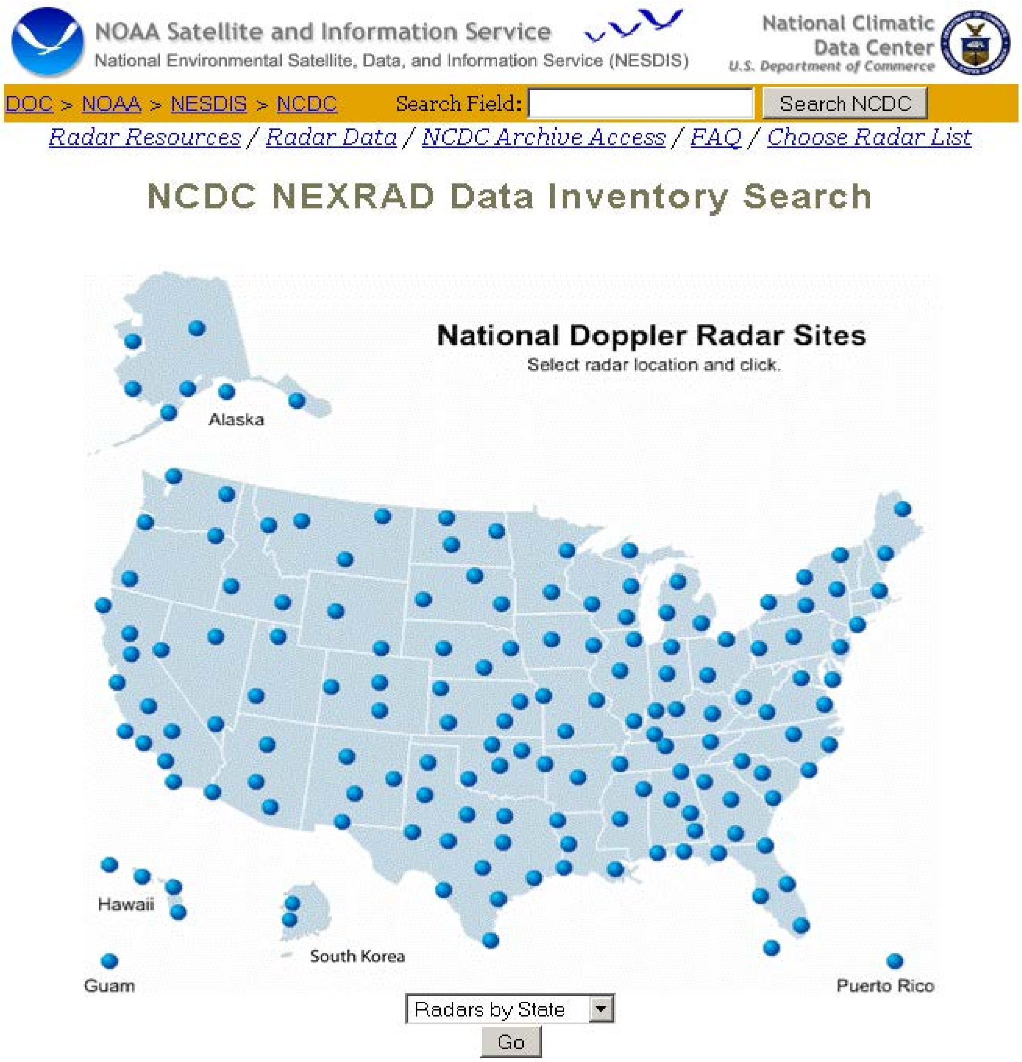
- Mean visibility (.1 miles);
- Mean wind speed (.1 knots);
- Max sustained wind speed (.1 knots);
- Maximum wind gust (.1 knots);
- Max temperature (.1 Fahrenheit);
- Minimum temperature (.1 Fahrenheit);
- Precipitation amount (.01 inches); and
- Snow depth (.1 inches).

There also are presence indicators, including:

- Fog;
- Rain or Drizzle;
- Snow or Ice Pellets;
- Hail;
- Thunder; and
- Tornado/Funnel Cloud.

The GSOD data are available at no cost on NOAA's FTP site. Data were available to match the three years of information collected for truck speeds. The advantage of the GSOD data is that the information is tied to specific stations. For purposes of analysis, 142 stations along the Interstate system from the National Doppler Radar Site Map (see Figure 7.2) to match with the truck speed data. It is important to recognize that many of the stations are located at airports and thus not directly located on the Interstate highways. However, the located stations the best representation of the weather conditions faced by truck drivers on Interstate highways that could be obtained within the project scope and budget.

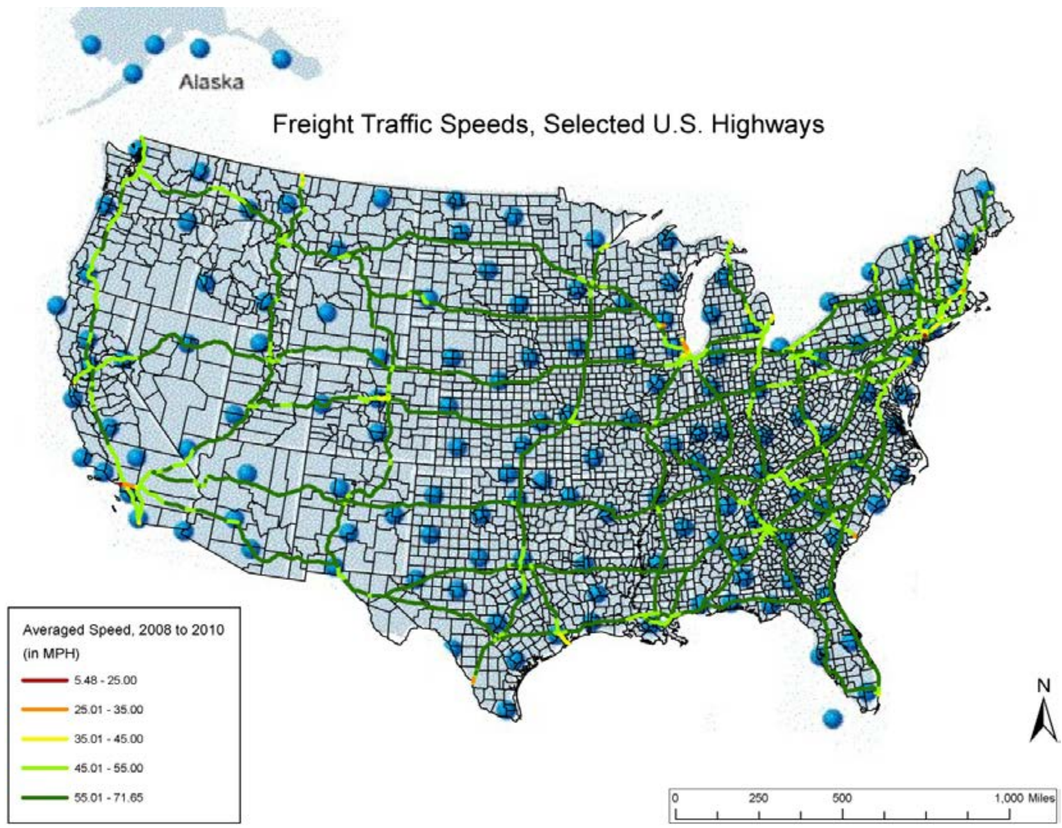
Figure 7.2 National Doppler Radar Sites



Source: National Climatic Data Center, http://www.ncdc.noaa.gov/nexradinv/.

Care also was taken in the selection process to account for changes in climate that may be found within States. For example, there are several stations located close together in the Rocky Mountain States to account for the large changes in elevation that occur along the front range of the mountains. Figure 7.3 shows the location of the selected stations in relation to the truck speed map that includes the Interstate system.

Figure 7.3 Overlay of Weather Stations on Freight Traffic Network

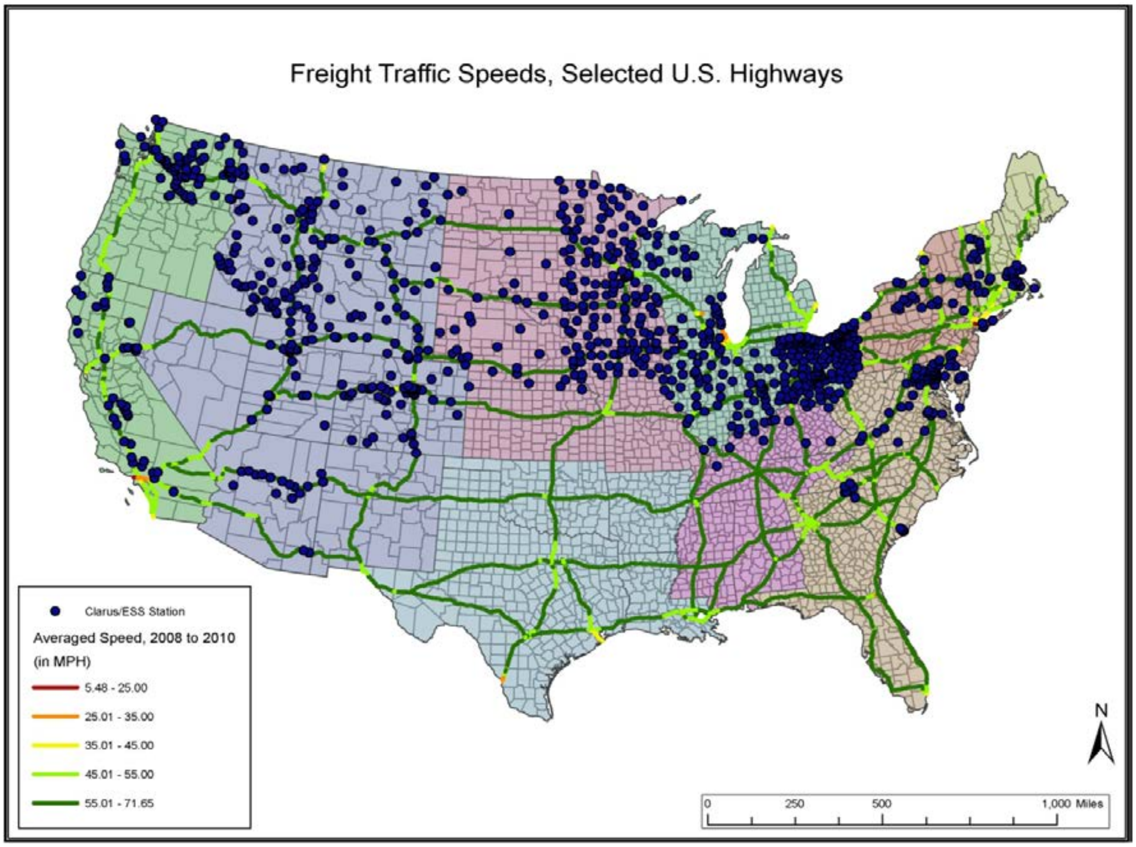


Source: National Climatic Data Center.

Two other sources were considered for use in the analysis but were not used. These include:

1. DSI 3505 – Integrated Surface Data – This dataset is developed by NCDC and is available at no cost from the FTP site. It includes hourly surface data on a global basis. However, data must be accessed by station and the information was provided in a variable-width text format that resulted in excessive download time and, once downloaded, the format was not easily usable for analysis.
2. *Clarus* – *Clarus* is a FHWA-developed database that was originally implemented to provide a national warehouse for State DOT-owned Environmental Sensor Station (ESS) data. Since its implementation, additional data have been added from other sources. *Clarus* was a focus for this project since stations are generally located on roadways and include information on surface conditions. However, the geographic coverage of *Clarus* is not complete since many States, particularly in the South, do not have ESS networks. Figure 7.4 shows the coverage limitations of *Clarus.* While this map represents a point in time and, thus, is missing observations that may not have been active at that time, it clearly shows the limited number of observations available from the southern States. In addition, the format of the archived data source made it difficult to utilize the information in this analysis.

Figure 7.4 *Clarus* Coverage



Source: Federal Highway Administration *Clarus* System.

7.4 Weather and Transport Modeling Work

The work conducted covered 48 contiguous States with 5 of the larger States broken into two segments. The three key initial inputs on the are:

1. Trucking trips by State;
2. Weather events by State; and
3. Base highway performance by State.

A number of interim outputs were required before estimating the overall cost of delay, including:

- The impact of weather on highway performance – What impacts do individual weather events have on highway speeds? The literature search described in Section 2.0 provided a starting point for evaluation of these impacts, but due to the large number of weather events considered and limited number of empirical studies available, additional assumptions regarding weather/speed relationships were to conduct the analysis.

- Delays and other operating effects on trucking – The ability to match the ATRI speed data with weather station data provided a unique opportunity to assess the impact of weather on truck speeds with empirical data.
- Cost, service, and other economic effects on supply chains – There are unique aspects to the trucking industry that must be considered in the analysis. Goods shipment is part of an overall logistics chain, in which delays can impact costs of other activities. The FTR model includes factors that account for these additional costs.

Base speeds vary significantly between urban and rural areas and between Interstates and other National Highway System roadways. In order to establish base congestion levels, the highway network was broken into four segments:

1. Rural Interstate;
2. Urban Interstate;
3. Rural off-Interstate; and
4. Urban off-Interstate.

For organizational purposes three main categories were established for the data collection and analysis:

1. Trucking trips by State, including:
   a. Trips with origin in State;
   b. Trips with destination in State; and
   c. Trips traveling through the State.
2. Weather events by State:
   a. Frequency of occurrence; and
   b. Duration of event.
3. Base highway performance:
   a. Free-flow speed.

Truck Trip Calculations

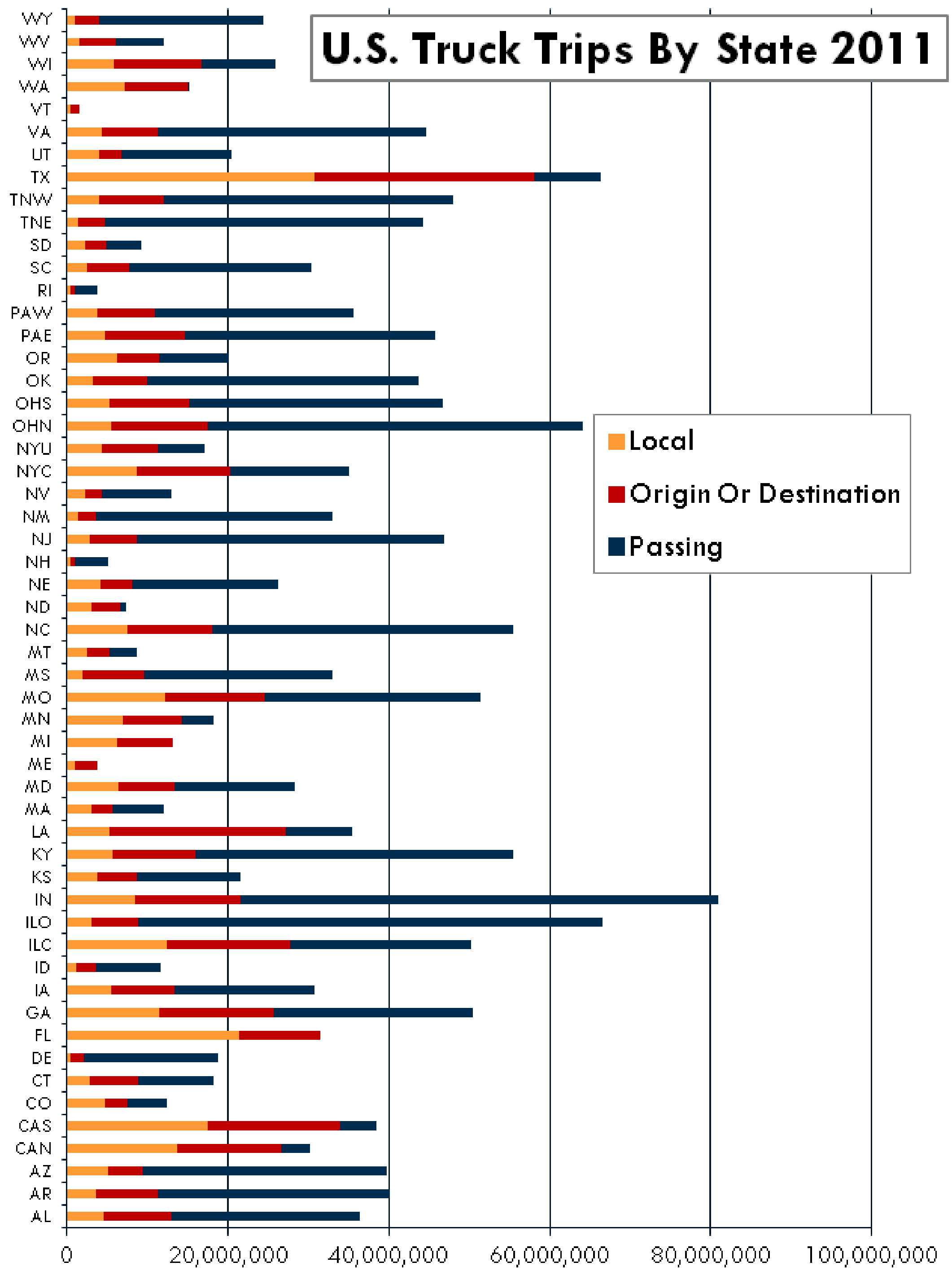
Annual truck trips for the three analysis years were estimated based by FTR Associates based on an update of Reebie data from 2004 and data collected by FTR. The Reebie data was used as a starting point for the origin/destination data. These data were then enhanced through the FTR model. Three categories of truck trips were estimated for each State:

1. Local trips made entirely within the State;
2. Trips with either an origin or destination in the State; and
3. Trips passing through the State.

The first two categories were estimated for each State based on economic data and through trips assigned based on a State-to-State routing guide that was developed specifically for this project. The size and distribution of economic activity within the State also was considered. The analysis indicated that nearly half (47 percent) of all truck traffic in the lower 48 States is transient. The incorporation of transient travel is an advance over many previous freight analysis efforts, which have focused primarily on origin and destination data. The breakdown of truck trips by the three categories and by State are shown in the graph in Figure 7.5. Note the following States, all of which experience large volumes of freight traffic, were divided into two parts:

- California (north/south);
- Illinois (Chicago area/downstate);
- New York (upstate/New York City area);
- Ohio (north/south);
- Pennsylvania (east/west); and
- Tennessee (east/west).

Figure 7.5 U.S. Truck Trips by State and Category 2011



Source: FTR Associates Freight Model.

The routing model is unlikely to change over time, thus providing a stable base for use in developing future forecasts.

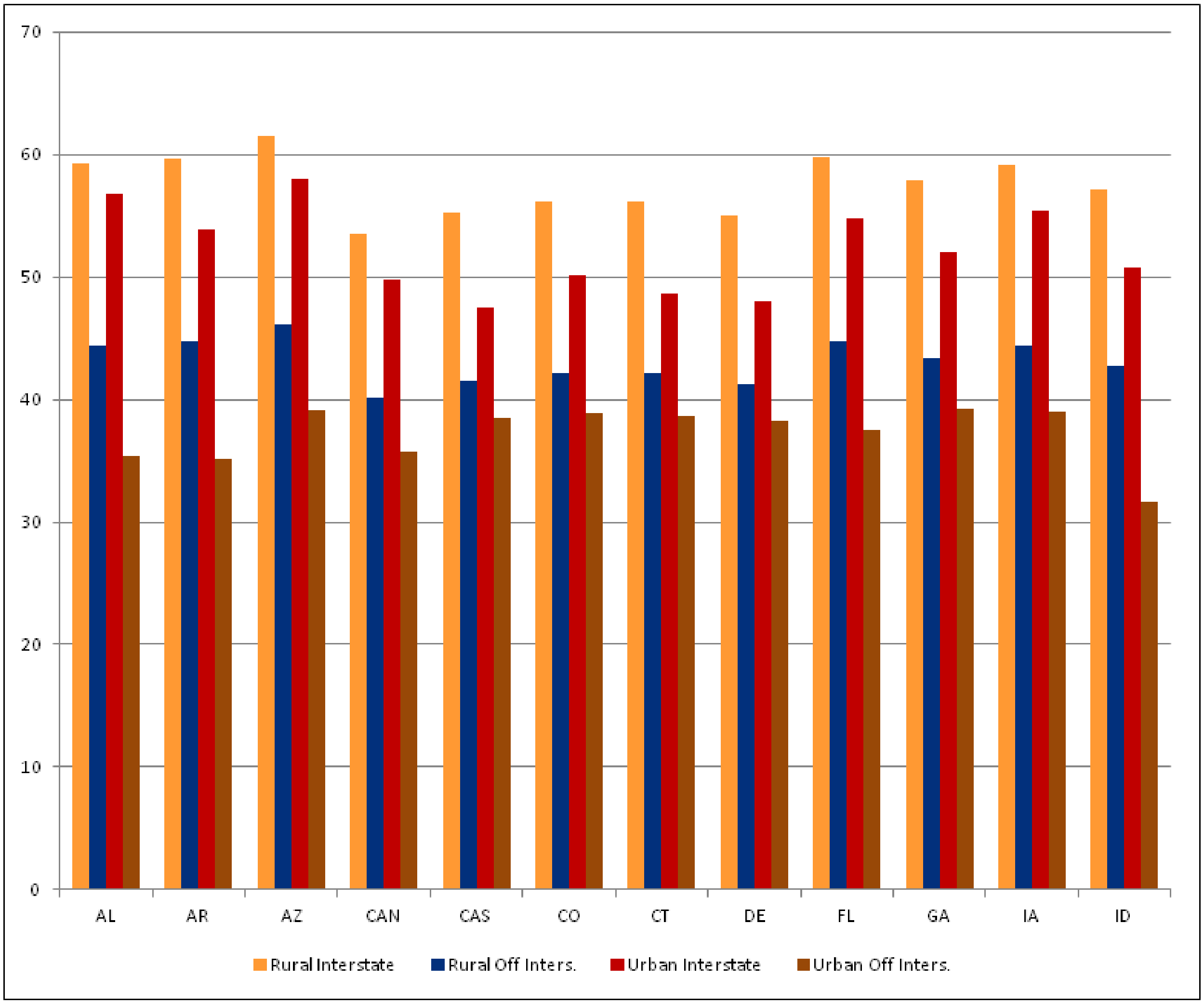
Highway Performance Data

As mentioned different performance characteristics were assumed for the four categories of highways included in the study:

1. Rural Interstate;
2. Urban Interstate;
3. Rural Non-Interstate; and
4. Urban Non-Interstate.

Sensitivity indicators were developed for off-peak and peak conditions based on the type of roadway included. Baseline speeds developed from the truck speed data were used as the starting point with which to calculate weather degradation. Figure 7.6 shows a sample of baseline speeds from which weather degradations are calculated. While the chart shows a sample of States, it shows the expected differential in baseline speeds between dense urban States such as Connecticut and Delaware and States such as Arizona and Iowa.

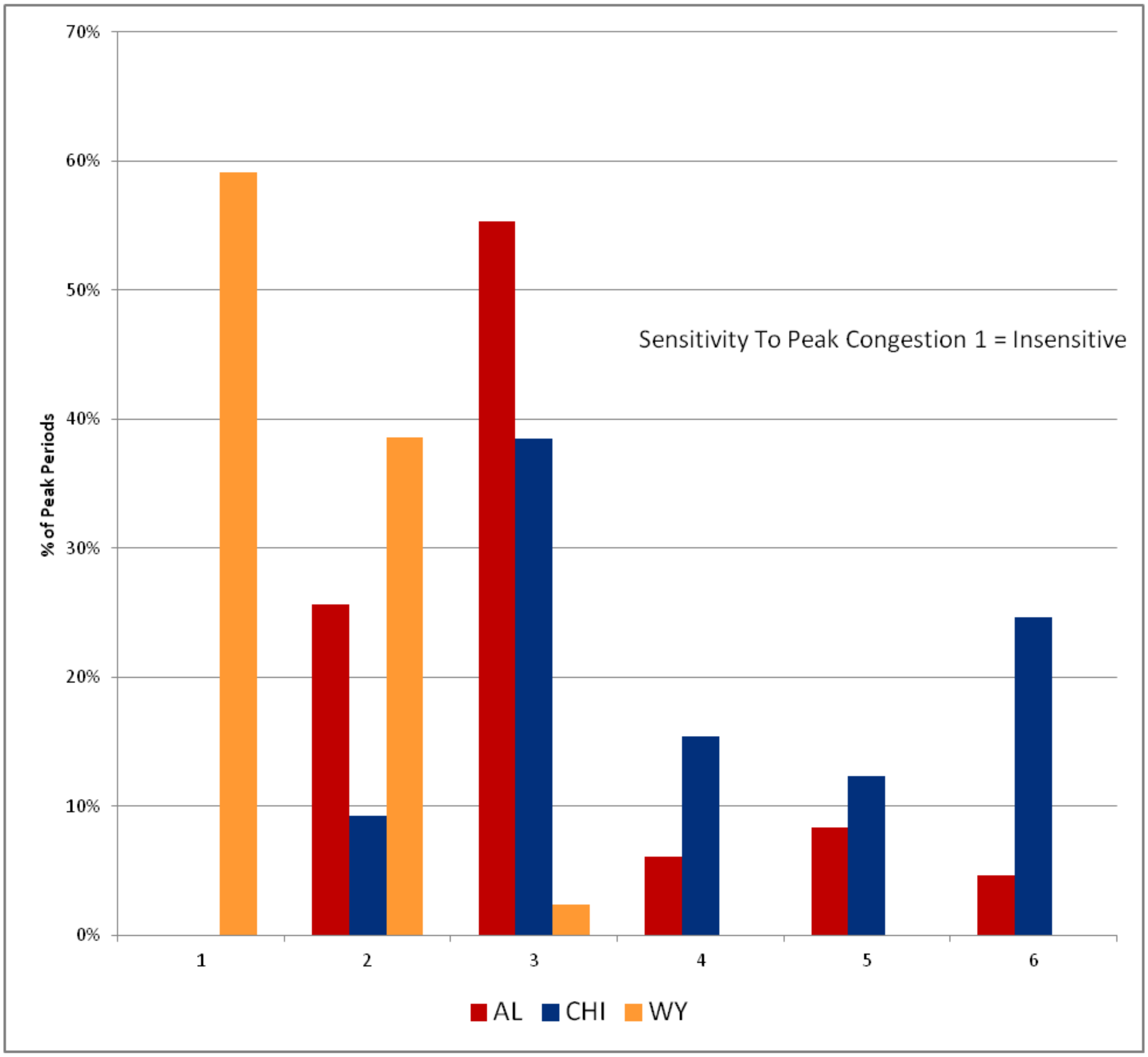
Figure 7.6 Baseline Speeds by State and Roadway Category



Source: FTR Associates Freight Model.

Adjustments factors were developed based sensitivity to peak congestion which were then used to vary the level of degradation resulting from weather events. These adjustments were based on the fact that adverse weather will have a greater delay impact on roadways that were. A gradation of six levels was used to adjust baseline speeds with more urban, congested areas having a larger adjustment factor and more rural, less congested areas having a lower factor. As shown in Figure 7.7, Category 1 represented areas least sensitive to congestion while Category 6 represented areas most sensitive. For each State or sub-State area, peak traffic adjustments were distributed across the six factors. Wyoming, for example, shows minimal sensitivity to congestion, with almost all traffic in Categories 1 and 2, while the Chicago/Northern Illinois region factors are mostly in Categories 4 through 6.

Figure 7.7 Sample of Congestion Sensitivity Factors
U.S. Average Highway Speeds 2008-2010



Source: FTR Associates Freight Model.

Weather Event Data

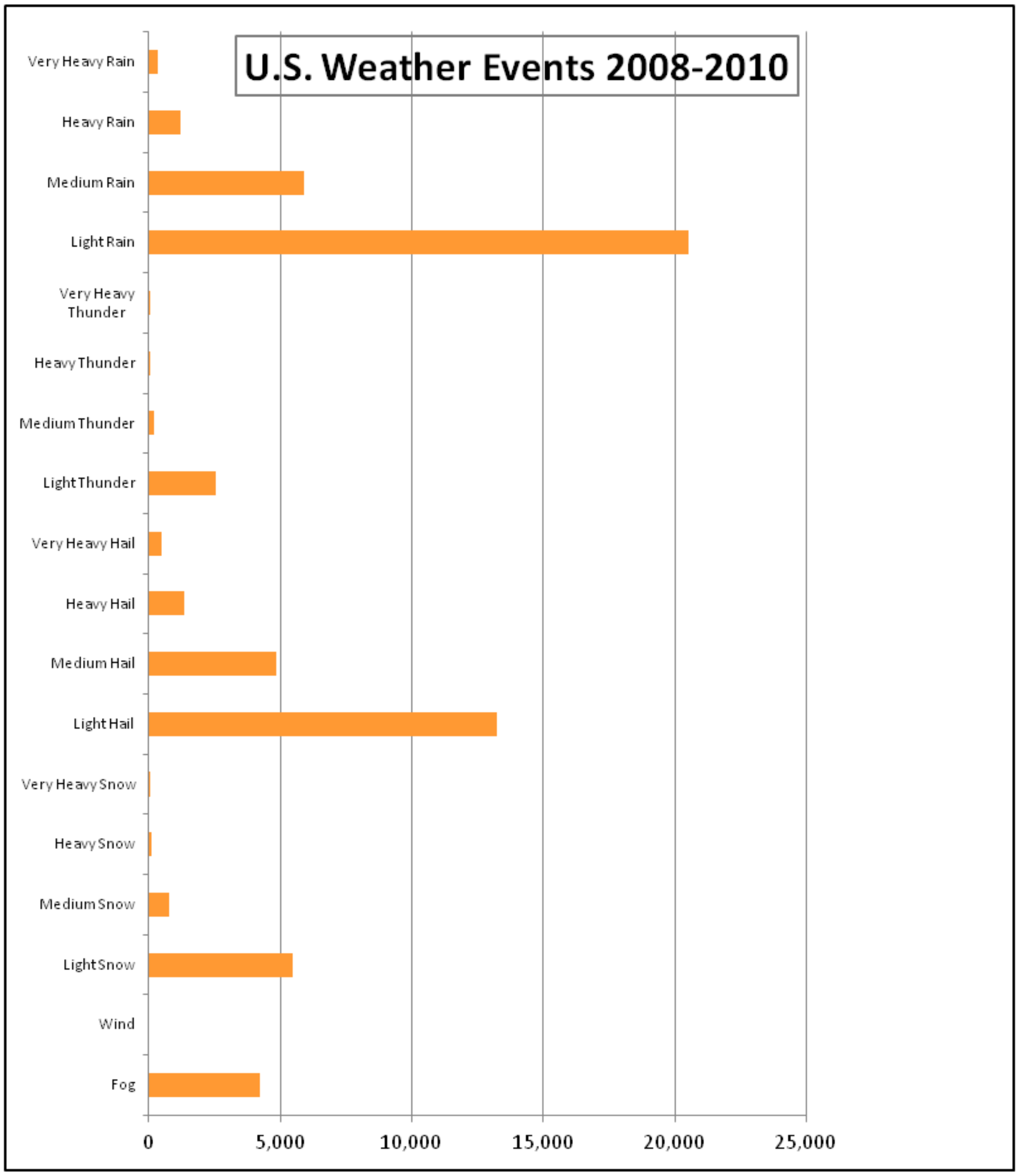
Detailed weather event data were obtained from the NCDC NEXRAD Data Inventory Search, Global Summary of the Day data. The total number of weather events in the various categories was calculated, including:

- Rain;
- Snow;
- Thunderstorm;
- Hail;
- Wind; and
- Fog.

The frequency of specific weather events was then estimate and are shown for the three-year analysis period in Figure 7.8. The estimated breakout highlights the fact that most events are relatively minor, and while the impact of these individual events may be limited, they occur with adequate frequency to account for a specific proportion of delay. The congestion sensitivity index helps to account for the fact that even minor weather events can have significant impacts when they occur at peak hours in a highly congested environment.

The total number of weather events are multiplied by an average duration factor that was developed for this study and assigned based on weather station location to each State or sub-State region. The percentage of time each event occurs forms the basis for calculation of weather impacts on truck delay.

Figure 7.8 Distribution of Weather Events
U.S. Weather Events 2008-2010



Source: FTR Associates Freight Model.

Another important consideration is event duration, which is not covered in the GSOD data. The consultant team conducted an analysis of hourly data for several stations located in Pennsylvania but a correlation between weather and travel speeds could not be established. This correlation is more difficult to establish using hourly data if the weather station is not located right on the roadway. Reasonable event durations were estimated for specific events and various combinations of events. Durations ranged from a low of 2 hours for events such as fog, high wind, and light rain up to 12 hours for events involving heavy snow.

During events such heavy snow or high winds combined with heavy rain, the impacts on roadway speed are likely to extend well beyond the actual weather event.

7.5 Calculation of impacts

The calculation phase of the model brought together the truck volume and speed estimates with the weather delay parameters to calculate overall delay due to weather. Key calculation steps included:

- The number of weather events by category for each of the 142 stations. As described in Section 7.3, when multiple events occurred at once they were combined into categories.
- The number of weather events for each station was multiplied by the estimated duration of the event to calculate total hours that weather events occurred.
- Total hours were then converted into a percentage of time that could be applied on annual basis to estimate how much freight traffic was impacted by the weather events.
- Since most States had multiple weather stations, the frequency of weather events were averaged across the State or the sub-State regions.
- Using the speed data from the ATRI data as a starting point, degradation curves were estimated for each type of weather event, each of the four types of roadway and the Volume/Capacity of the roadway. First, the reduction in speed under each event and traffic condition (V/C ratio) was calculated as shown in Table 7.1. The congestion "buckets" were developed from FHWA.

Table 7.1 Speed as Pct of Standard by Weather Event and V/C Ratio
Rural Interstate

Percentage of Capacity In Use	< 0.21	0.21-0.40	0.41-0.70	0.71-0.79	0.80-0.95	> 0.95
Standard	100%	100%	100%	100%	100%	100%
Fog	73%	70%	67%	63%	60%	56%
High Wind	93%	92%	91%	89%	88%	87%
Very High Wind	87%	86%	85%	83%	82%	80%
High Wind and Light Snow	84%	81%	78%	76%	72%	69%
High Wind and Moderate Snow	75%	70%	65%	59%	53%	47%
Very High Wind and Moderate Snow	69%	64%	59%	53%	47%	40%

This was then converted to percent increase in travel time as shown in Table 7.2 below.

Table 7.2 Percent Decrease in Speed by Weather Event and V/C Ratio
Rural Interstate

Percentage of Capacity In Use	< 0.21	0.21-0.40	0.41-0.70	0.71-0.79	0.80-0.95	> 0.95
Standard	100%	100%	100%	100%	100%	100%
Fog	38%	43%	50%	58%	68%	80%
High Wind	8%	9%	10%	12%	14%	15%
Very High Wind	15%	16%	18%	20%	22%	25%
High Wind and Light Snow	20%	23%	28%	32%	38%	45%
Very High Wind and Light Snow	28%	33%	38%	44%	52%	61%
High Wind and Moderate Snow	34%	43%	55%	69%	88%	114%
Very High Wind and Moderate Snow	45%	56%	70%	88%	114%	150%
High Wind and Heavy Snow	77%	96%	122%	158%	213%	309%

Table 7.3 shows the final conversion made, which is actually speed by weather event and V/C ratio.

Table 7.3 Sample of Speed Curves by Weather Event and V/C Ratio

Percentage of Capacity In Use	< 0.21	0.21-0.40	0.41-0.70	0.71-0.79	0.80-0.95	> 0.95
Standard	55	53	51	49	47	45
Fog	40	37	34	31	28	25
Gusty	53	50.6	48.2	45.8	43.4	41
Very Gusty	50	47.6	45.2	42.8	40.4	38
High Wind	51	48.6	46.2	43.8	41.4	39
Very High Wind	48	45.6	43.2	40.8	38.4	36
High Wind and Light Snow	46	43	40	37	34	31
Very High Wind and Light Snow	43	40	37	34	31	28
High Wind and Moderate Snow	41	37	33	29	25	21
Very High Wind and Moderate Snow	38	34	30	26	22	18
High Wind and Heavy Snow	31	27	23	19	15	11
Very High Wind and Heavy Snow	28	24	20	16	12	8

The congestion buckets shown in Figure 7.7 were then applied to adjust speeds based on sensitivity to congestion. The percentage of roadway category in each "bucket" were drawn from the FHWA Annual Highway Statistics Report from 2008. A sample of the data are shown in Table 7.4 which shows the distribution for several States. As expected, Urban Interstates in large metropolitan areas have more of their roadway in the high congestion "buckets." An average score was calculated to simplify the delay estimate.

Table 7.4 Percent of Urban Interstate in each Congestion "Bucket"

State	Urban Interstate Congestion Threshold						Average Score
	1	2	3	4	5	6	
Indiana	2%	41%	33%	7%	11%	5%	2.0
Kansas	19%	21%	37%	7%	5%	11%	3.0
Kentucky	0%	2%	35%	2%	33%	27%	3.0
Louisiana	1%	10%	45%	13%	16%	16%	3.0
Massachusetts	0%	11%	47%	7%	12%	22%	3.0
Maryland	2%	4%	25%	17%	35%	17%	3.0
Maine	18%	46%	34%	1%	1%	0%	2.0
Michigan	1%	5%	31%	11%	24%	27%	3.0
Minnesota	2%	2%	18%	7%	28%	43%	4.0
Missouri	6%	14%	37%	13%	14%	17%	3.0
Mississippi	0%	30%	40%	2%	19%	9%	2.0
Montana	42%	58%	0%	0%	0%	0%	2.0
North Carolina	1%	4%	34%	18%	20%	23%	3.0
North Dakota	37%	42%	21%	0%	0%	0%	2.0
Nebraska	3%	23%	33%	16%	13%	11%	3.0
New Hampshire	4%	17%	43%	12%	24%	0%	2.0
New Jersey	0%	4%	33%	11%	14%	39%	4.0

The next adjustment made was to calculate the percentage of delay in each congestion bucket for each weather event and each type of roadway. This was done by calculating the percentage increase in travel time weighted by the share of time in each congestion bucket. Table 7.5 shows a sample distribution for high wind conditions by State and congestion bucket for Urban Interstate roads. Note that these distributions were made by State, even in cases like Pennsylvania and Tennessee where sub-State regions were created. These regions were used primarily for calculating freight flows.

Table 7.5 Percent of Delay in Each Congestion Category by State for High Wind

High Wind	Congestion Threshold					
	1	2	3	4	5	6
PAE	0.60%	3.55%	25%	10%	25%	36%
PAW	0.60%	3.55%	25%	10%	25%	36%
RI	0.00%	2.91%	33%	5%	27%	32%
SC	0.64%	8.60%	33%	11%	12%	34%
SD	39.18%	60.82%	0%	0%	0%	0%
TNE	0.64%	8.60%	33%	11%	12%	34%
TNW	0.64%	8.60%	33%	11%	12%	34%
TX	2.72%	9.54%	31%	11%	24%	22%
UT	3.02%	13.17%	35%	5%	27%	18%
VA	3.11%	9.74%	43%	13%	23%	9%
VT	8.47%	38.00%	51%	3%	0%	0%

The final calculation linking weather and roadway data is to combine the above datasets in order to calculate the actual percent delay for each type of roadway by State and weather event. This is done by retrieving the percentage of time that various events occur and the average congestion threshold index shown in Table 7.4. Table 7.6 shows a sample summary for high wind/light snow conditions. For example, high wind and light snow conditions are found to influence 0.12 percent of the traffic on Urban Interstate and secondary roads in Idaho.

Table 7.6 Percent of Traffic Impacted by Weather Event by State and Roadway Type

High Wind and Light Snow	Rural		Urban	
	Interstate	Secondary	Interstate	Secondary
AL	0.00%	0.00%	0.00%	0.00%
AR	0.00%	0.00%	0.00%	0.00%
AZ	0.01%	0.02%	0.03%	0.03%
CAN	0.00%	0.00%	0.00%	0.00%
CAS	0.00%	0.00%	0.00%	0.00%
CO	0.05%	0.06%	0.08%	0.08%
CT	0.01%	0.02%	0.02%	0.02%
DE	0.06%	0.07%	0.08%	0.09%
FL	0.00%	0.00%	0.00%	0.00%
GA	0.00%	0.00%	0.00%	0.00%
IA	0.08%	0.09%	0.13%	0.11%
ID	0.07%	0.09%	0.12%	0.12%
ILC	0.03%	0.04%	0.05%	0.05%
ILO	0.07%	0.08%	0.13%	0.12%
IN	0.07%	0.09%	0.11%	0.12%

The next series of steps involves application of the delay parameters to the estimated level of truck travel. VMT was calculated by estimating the length of truck trips on different types of roadways. As mentioned earlier, truck trips are divided into categories of:

- Local (wholly within the State);
- Origin/destination (one end of trip either originates or ends in State); and
- Pass through (origin and destination are both out of State).

A sample of truck length estimates is included below in Table 7.7 for selected States.

Table 7.7 Average Trip Length of Truck Trips by Type of Trip and State

State	Average Trip Mileage			Weighted Average
	Local	O&D	Passing	
KS	126	190	380	256
KY	80	75	150	117
LA	92	105	210	103
MA	68	72	90	45
MD	72	55	110	57
ME	110	100	50	78
MI	80	200	100	80
MN	94	110	220	92
MO	104	135	270	165
MS	102	91	130	108
MT	188	220	440	248
NC	88	114	190	135

The next step is to estimate vehicle miles of travel by type of trip as shown in Table 7.8. This involves simple multiplication of average trip mileage by number of trips (see Figure 7.5).

Table 7.8 Truck VMT by State and Type of Trip

	Local	Origin/Destination	Passing	Total
KS	468,680,382	1,530,363,659	4,906,405,936	6,905,449,978
KY	449,537,861	1,207,923,830	5,928,030,379	7,585,492,069
LA	489,412,801	3,176,297,869	1,747,170,776	5,412,881,445
MA	205,392,390	856,018,845	569,366,169	1,630,777,403
MD	462,965,558	1,212,258,525	1,649,910,474	3,325,134,558
ME	112,714,456	401,818,556	–	514,533,012
MI	491,793,207	3,466,380,201	–	3,958,173,408
MN	657,921,916	1,561,612,912	872,801,733	3,092,336,561
MO	1,274,653,583	3,052,110,133	7,234,967,995	11,561,731,711
MS	197,437,162	1,014,754,287	3,028,506,526	4,240,697,975
MT	464,228,931	986,912,289	1,431,365,242	2,882,506,462
NC	668,727,397	2,443,648,437	7,125,812,812	10,238,188,647

In the next step, daily truck trips are assigned to specific roadway types. A sample of data is shown in Table 7.9. The source of these estimates is FHWA summaries derived from truck count stations.

Table 7.9 Daily Truck Trips by State and Type of Roadway

	Rural		Urban		
State	Freeway	Secondary	Freeway	Secondary	Total
FL	7,745	1,040	9,332	2,165	20,282
GA	8,337	594	13,965	1,436	24,332
IA	5,192	364	6,186	626	12,368
ID	3,099	393	5,746	879	10,117
ILC	6,935	1,047	14,001	1,976	23,959
ILO	5,676	568	7,646	898	14,788
IN	8,153	1,030	13,317	2,127	24,627
KS	3,386	413	5,473	1,067	10,339
KY	9,301	859	11,526	1,528	23,214
LA	6,662	869	11,502	2,208	21,241
MA	3,450	527	7,219	995	12,191

Truck volumes per day are then reallocated to roadway types based on factors developed for this project. A set of sample data is shown in Table 7.10.

Table 7.10 Distribution of Truck Volume by State and Type of Roadway

	Rural		Urban	
State	Freeway	Secondary	Freeway	Secondary
TNE	43.9%	2.3%	48.5%	5.3%
TNW	39.3%	2.2%	52.4%	6.0%
TX	32.1%	3.9%	54.1%	9.8%
UT	20.1%	3.5%	61.5%	14.9%
VA	45.3%	4.0%	43.5%	7.1%
VT	78.9%	21.1%	0.0%	0.0%
WA	30.1%	3.9%	57.5%	8.5%
WI	28.4%	3.9%	55.9%	11.8%
WV	89.9%	10.1%	0.0%	0.0%
WY	92.9%	7.1%	0.0%	0.0%

Factors are then applied to roadway types to allocate the average trip per State to the various roadway types. Trips may use both Rural and Urban freeway segments, for example, which have different exposures to congestion. Pass through trips in northern California for example were estimated to average 300 miles with the following breakdown of roadway types:

- Two hundred fifty-one miles on rural freeway;
- Five miles on rural secondary;
- Thirty-seven miles on urban freeway; and
- Six miles on urban secondary.

These adjustments were made for all States or sub-State regions.

The final VMT calculation is now made based on the average trip lengths calculated above and the number of truck trips. A sample of VMT calculations is shown in Table 7.11.

Table 7.11 Truck VMT by Roadway Category

	Rural		Urban		
State	**Freeway**	**Secondary**	**Freeway**	**Secondary**	**Total**
NE	9,010,808,273	262,394,518	1,314,386,244	208,287,133	10,795,876,167.8
NH	138,240,764	15,554,357	34,306,300	19,107,210	207,208,630.0
NJ	2,937,485,877	139,252,324	454,286,176	124,596,681	3,655,621,058.2
NM	7,406,658,565	227,723,470	1,044,292,414	200,893,665	8,879,568,114.0
NV	2,922,644,833	155,080,621	560,517,619	199,619,427	3,837,862,499.8
NYC	–	–	1,348,437,136	237,959,495	1,586,396,630.9
NYU	3,810,410,241	297,821,274	737,452,348	257,942,072	5,103,625,935.5
OHN	11,747,891,422	390,273,257	1,387,571,372	231,539,853	13,757,275,903.9
OHS	7,990,431,736	216,819,695	1,116,699,516	155,741,081	9,479,692,027.4
OK	9,194,037,082	298,988,358	1,431,749,271	289,822,798	11,214,597,509.0
OR	3,998,024,766	164,290,573	878,414,879	188,499,288	5,229,229,505.6

The next interim calculation is to combine trip segments, VMT shares on different roadway types and adjustment factors. These percentages are used to calculate the number of truck/weather event interactions. The percentages exceed 100 percent because a single truck trip on different roadways may experience different weather impact interactions. Table 7.12 shows a sample of the data for local roadways. These trips greater use of secondary roads than pass through trips, for example, which are shown in Table 7.13 and are concentrated more heavily on Interstates.

Table 7.12 Percent of Truck/Weather Interactions by State and Roadway Type
Local Trips

	Rural		Urban	
State	Freeway	Secondary	Freeway	Secondary
GA	81.1%	50.3%	66.3%	50.4%
IA	84.4%	50.2%	65.2%	50.0%
ID	81.4%	50.5%	65.8%	50.7%
ILC	0.0%	0.0%	94.0%	100.0%
ILO	85.9%	50.0%	64.8%	49.9%
IN	82.9%	50.4%	65.4%	50.4%
KS	80.9%	50.8%	65.6%	50.9%
KY	84.7%	50.3%	64.9%	50.1%
LA	75.0%	51.9%	66.4%	52.1%
MA	75.3%	51.4%	66.9%	51.8%

Table 7.13 Percent of Truck/Weather Interactions by State and Roadway Type
Passing Trips

	Rural		Urban	
State	Freeway	Secondary	Freeway	Secondary
GA	98.9%	12.4%	57.8%	2.7%
IA	99.1%	12.2%	56.5%	1.9%
ID	99.0%	12.7%	57.2%	3.3%
ILC	0.0%	0.0%	92.5%	15.0%
ILO	99.2%	11.8%	56.0%	1.7%
IN	99.0%	12.5%	56.7%	2.8%
KS	98.9%	13.2%	57.0%	3.7%
KY	99.2%	12.3%	56.2%	2.1%
LA	98.6%	15.1%	58.0%	6.1%
MA	98.6%	14.2%	58.6%	5.5%

The output of these distributions is total truck passings by roadway type, with a sample shown in Table 7.14.

Table 7.14 Truck Passings
By State and Roadway Type

	Rural		Urban	
State	Freeway	Secondary	Freeway	Secondary
PAE	53,179,152	12,063,336	32,731,007	8,779,129
PAW	39,386,803	8,486,081	23,492,416	5,734,920
RI	4,830,425	1,124,335	2,979,644	841,351
SC	32,830,905	6,810,676	19,777,995	4,463,436
SD	10,244,774	2,926,559	5,483,285	2,084,287
TNE	46,609,765	6,938,829	26,668,387	2,888,329
TNW	52,591,378	10,312,796	31,651,351	6,669,966
TX	65,446,680	31,352,250	52,851,640	30,758,953
UT	21,038,316	5,353,554	13,835,567	4,428,529
VA	49,026,024	10,539,897	29,426,669	6,806,727

Miles per trip and hours per each truck move are then calculated as shown in Tables 7.15 and 7.16. These calculations are required to establish the baseline against which to calculate the weather impact delay.

Table 7.15 Miles per Trip by State and Roadway Type

	Rural		Urban	
State	Freeway	Secondary	Freeway	Secondary
AL	193	6	29	5
AR	182	3	27	3
AZ	226	7	44	11
CAN	64	7	17	8
CAS	67	7	17	8
CO	110	7	30	10
CT	37	1	7	1
DE	11	1	3	2
FL	76	13	21	11

Table 7.16 Hours per Move by State and Roadway Type

	Rural		Urban	
State	Freeway	Secondary	Freeway	Secondary
AL	3.63	0.13	0.61	0.17
AR	3.44	0.07	0.57	0.09
AZ	4.27	0.17	0.92	0.35
CAN	1.21	0.16	0.35	0.25
CAS	1.26	0.17	0.36	0.26
CO	2.07	0.15	0.62	0.35
CT	0.69	0.03	0.15	0.04
DE	0.20	0.02	0.06	0.07
FL	1.43	0.29	0.43	0.36

At this point in the process, the weather impact information was compiled in a vertical database that included both State and roadway type by weather event. Calculations were made of the percent increase in travel time due to weather (Table 7.17) and the percent of total truck travel time taken by weather delay Table 7.18). When applied to total trucking costs, these databases allowed the cost of delay to be estimated.

Table 7.17 Percent Increase in Travel Time
By Weather Event, Roadway Type, and State

Roadway Type	State	Fog	Gusty	Very Gusty	High Wind
Rural Freeway	AL	0.211%	0.0160%	0.0000%	0.0039%
Rural Freeway	AR	0.205%	0.0162%	0.0000%	0.0071%
Rural Freeway	AZ	0.034%	0.0469%	0.0003%	0.0396%
Rural Freeway	CAN	0.005%	0.0368%	0.0013%	0.0502%
Rural Freeway	CAS	0.006%	0.0575%	0.0006%	0.0642%
Rural Freeway	CO	0.053%	0.0672%	0.0016%	0.1097%
Rural Freeway	CT	0.159%	0.0429%	0.0000%	0.0230%
Rural Freeway	DE	0.050%	0.0201%	0.0003%	0.0014%

Table 7.18 Percent of Travel Time Accounted Resulting from Weather Event
By Roadway Type and State

Roadway Type	State	Light Rain	Moderate Rain	Heavy Rain	Very Heavy Rain
Rural Freeway	AL	0.04859%	0.17155%	0.33194%	0.19442%
Rural Freeway	AR	0.02527%	0.08679%	0.05702%	0.09309%
Rural Freeway	AZ	0.01420%	0.01965%	0.01523%	0.00514%
Rural Freeway	CAN	0.04721%	0.12667%	0.12754%	0.09650%
Rural Freeway	CAS	0.02415%	0.03047%	0.01318%	0.00000%
Rural Freeway	CO	0.01426%	0.02047%	0.00465%	0.00000%
Rural Freeway	CT	0.03065%	0.09311%	0.06702%	0.05410%
Rural Freeway	DE	0.06768%	0.18518%	0.15105%	0.03135%

The percent travel time delay is then used in the truck cost calculation to determine the percentage of truck cost accounted for by delay. The truck cost model is shown in Table 7.19 below. Trucking costs are divided into the six categories shown in the left column and a percentage share of cost is assigned to each. Some categories of cost are more susceptible to weather delays than others; however, and this is accounted for in the effect of time delay column. Fuel and overhead are disproportionately impacted by weather delay for example while equipment, a fixed cost, is less impacted. The weighted proportions add up to slightly more than 100 percent. The total base revenue estimated of the industry estimated through the FTR freight model is $574 billion annually and this cost was proportioned to different States and roadway types based on the proportion of VMT estimated for that category. The weighted impacts below were then applied to the added cost of delay.

Table 7.19 Truck Cost Component Model

	Shares	Effect of Time Delay	Weighted Effect
Labor	0.38	1	0.38
Equipment	0.14	0.66	0.0924
Fuel	0.25	1.2	0.3
Overhead	0.17	1.05	0.1785
Margin	0.06	1	0.06
Multiplier			1.0109
Total Revenue (Millions)			**574,169**

7.6 Calculations of Delay

Aggregate cost of delay calculations were developed for each State, type of roadway based on the aggregate delay experienced from all weather impacts. The study showed that adverse weather causes delays for trucking roughly 4.5 percent of the time across the United States although this varies by State. Table 7.20 shows the list average hours impacted by weather by State in terms of total annual hours and percentage of annual hours.

Table 7.20 Annual Hours Impacted by Weather Events

State	Hours Impacted by Weather Events	Percent of Hours Impacted by Weather Events
AL	400.8	4.6%
AR	338.0	3.9%
AZ	211.2	2.4%
CAN	314.1	3.6%
CAS	254.5	2.9%
CO	357.0	4.1%
CT	384.0	4.4%
DE	436.4	5.0%
FL	388.3	4.4%
GA	273.7	3.1%
IA	461.8	5.3%
ID	374.0	4.3%
ILC	305.7	3.5%
ILO	431.6	4.9%
IN	431.6	4.9%
KS	459.2	5.2%
KY	346.7	4.0%
LA	388.3	4.4%
MA	487.3	5.6%
MD	377.3	4.3%
ME	390.0	4.5%
MI	447.3	5.1%
MN	403.3	4.6%
MO	444.7	5.1%
MS	399.0	4.6%
MT	429.1	4.9%
NC	408.4	4.7%
ND	407.8	4.7%
NE	412.3	4.7%
NH	344.2	3.9%
NJ	466.3	5.3%
NM	379.6	4.3%
NV	497.3	5.7%
NYC	495.6	5.7%
NYU	446.6	5.1%
OHN	526.7	6.0%
OHS	354.7	4.0%
OK	413.0	4.7%
OR	452.2	5.2%
PAE	456.7	5.2%
PAW	345.7	3.9%
RI	406.9	4.6%
SC	351.8	4.0%
SD	480.4	5.5%
TNE	411.3	4.7%
TNW	432.7	4.9%
TX	354.4	4.0%
UT	326.5	3.7%
VA	361.6	4.1%
VT	546.7	6.2%
WA	473.6	5.4%
WI	388.4	4.4%

State	Hours Impacted by Weather Events	Percent of Hours Impacted by Weather Events
WV	514.7	5.9%
WY	425.7	4.9%
Average for U.S.	404.0	4.6%

The total cost annual cost of this delay is $8.659 billion or 1.5 percent of all trucking revenue. Table 7.21 summarizes the cost of delay by State and by type of roadway. An interesting finding is that delay costs are not disproportionately found in cold weather States but are largely proportional to truck VMT. Relatively minor weather events, such as rain and fog, have a major impact because they are more frequent.

Table 7.21 Cost of Truck Delay in Millions by State and Type of Roadway

	Rural		Urban		
State	Freeway	Secondary	Interstate	Secondary	Grand Total
AL	$317.955	$10.648	$78.813	$11.982	$419.398
AR	$287.626	$5.530	$70.654	$6.478	$370.287
AZ	$67.036	$3.237	$28.482	$7.358	$106.112
CAN	$73.060	$10.505	$37.785	$18.526	$139.876
CAS	$62.949	$9.908	$33.167	$16.600	$122.624
CO	$27.009	$2.694	$15.792	$5.463	$50.958
CT	$37.158	$1.476	$12.514	$2.110	$53.258
DE	$6.637	$0.702	$2.546	$2.092	$11.977
FL	$140.136	$27.576	$66.115	$38.120	$271.947
GA	$144.121	$5.010	$49.064	$6.596	$204.790
IA	$175.494	$5.992	$47.614	$5.583	$234.683
ID	$17.825	$1.039	$6.948	$1.480	$27.291
ILC	$0.000	$0.000	$78.627	$14.976	$93.603
ILO	$188.667	$5.390	$56.442	$7.696	$258.195
IN	$276.157	$12.103	$76.924	$16.884	$382.067
KS	$105.265	$6.781	$36.073	$9.669	$157.787
KY	$140.807	$5.403	$43.228	$6.238	$195.675
LA	$104.214	$9.699	$41.450	$17.219	$172.581
MA	$45.844	$3.393	$17.201	$5.731	$72.168
MD	$49.019	$4.032	$15.923	$4.375	$73.349
ME	$7.201	$2.892	$0.000	$0.000	$10.093
MI	$59.266	$8.058	$27.478	$10.410	$105.213
MN	$42.518	$5.399	$27.856	$12.300	$88.072
MO	$271.934	$17.808	$97.572	$27.625	$414.939
MS	$87.039	$7.062	$26.900	$13.397	$134.398
MT	$26.585	$4.428	$0.000	$0.000	$31.013
NC	$245.082	$14.728	$69.696	$20.200	$349.707
ND	$23.631	$3.772	$0.000	$0.000	$27.403
NE	$152.567	$5.764	$43.994	$6.460	$208.785
NH	$1.680	$0.305	$0.759	$0.470	$3.215
NJ	$104.444	$5.747	$24.484	$7.239	$141.914
NM	$59.168	$3.066	$17.322	$3.007	$82.564
NV	$71.010	$5.173	$31.535	$13.163	$120.881
NYC	$0.000	$0.000	$59.400	$11.463	$70.863
NYU	$85.920	$8.809	$32.448	$12.426	$139.603
OHN	$361.558	$12.482	$79.479	$10.216	$463.735
OHS	$143.946	$4.597	$38.021	$4.239	$190.803
OK	$193.431	$7.650	$54.766	$10.018	$265.866
OR	$48.307	$2.895	$21.099	$4.977	$77.278
PAE	$123.817	$4.349	$35.968	$4.943	$169.077
PAW	$301.568	$8.558	$71.631	$8.254	$390.010

State	Rural		Urban		Grand Total
	Freeway	Secondary	Interstate	Secondary	
RI	$2.442	$0.080	$0.547	$0.094	$3.163
SC	$85.002	$3.614	$22.847	$5.117	$116.579
SD	$44.936	$3.614	$0.000	$0.000	$48.551
TNE	$193.729	$3.439	$44.751	$4.350	$246.270
TNW	$264.394	$6.352	$71.665	$9.322	$351.733
TX	$320.326	$37.994	$159.707	$70.058	$588.085
UT	$33.377	$2.546	$15.597	$6.257	$57.776
VA	$42.371	$1.967	$10.082	$2.141	$56.561
VT	$4.210	$1.954	$0.000	$0.000	$6.164
WA	$2.555	$3.217	$7.960	$5.193	$18.926
WI	$53.237	$4.254	$22.892	$9.250	$89.633
WV	$59.512	$4.616	$0.000	$0.000	$64.128
WY	$103.217	$4.168	$0.000	$0.000	$107.385
Grand Total	**$5,886.959**	**$342.474**	**$1,931.816**	**$497.765**	**$8,659.014**

Note that the steps required to obtain the final result included in this table are summarized at the beginning of this chapter in Section 7.1.

8.0 Summary and Recommendations

The objective of this project was to provide a high-level estimate of the cost of weather-related delays to the U.S. trucking industry. The analysis required the melding of multiple sources of weather and traffic data, and the processing of significant amounts of economic and weather-related data. Primary sources of information used to conduct the analysis were NOAA's Global Summary of the Day (GSOD), which provides detailed measurements of various weather phenomena from stations across the United States and a detailed database of truck speeds developed through a partnership of FHWA and the American Transportation Research Institute (ATRI). A freight movement model developed by team member FTR Associates also was a critical input to the process.

The key outputs of the study are estimated hours of delay by weather phenomena and by State, with several key States subdivided, and an estimate of the cost of that delay to the freight industry. The findings of the study were that weather phenomena impact freight traffic between 3 percent and 6 percent of the time, depending location, with a national average of 4.6 percent. The cost of weather-related delay to the freight industry was estimated at $8.659 billion or 1.6 percent of the total estimated freight market of $574 billion. While this appears on the surface to be a small percentage, the dollar value is significant and it is important to note that improvements to road weather management programs, which are generally relatively inexpensive, can have major payoffs from a benefit/cost standpoint. It also is important to note that the analysis did not address crash reduction benefits. Commercial vehicle crashes can have significant economic costs; thus programs that eliminate even a small number of crashes can have a major impact in terms of dollars saved and life safety.

The model used for this analysis greatly advanced the state of the practice for analyzing weather impacts on freight delays, and the framework and techniques developed also can be applied to analysis of weather impacts on general traffic. Time and budget constraints limited the scope of this analysis and there are a number of recommended improvements that would be helpful in refining and improving the methodology and, ultimately, the accuracy of the estimate:

- Daily weather data were used in this analysis. Adjustments were made to account for peak and off-peak speeds but ultimately the analysis would benefit from use of peak period or even hourly data, rather than daily. As described in Section 7.0, a limited analysis of hourly data was conducted, using the weather stations and speed data from Pennsylvania. However, this analysis did not establish a relationship between weather events and travel speeds. This may have been due to the limited number of weather stations involved and the fact they were not located directly on the highway segments analyzed. It is recommended that more detailed study be conducted on several States or subregions with additional weather stations and greater granularity of geographic detail. This effort would not only be helpful in improving estimates of weather event duration, but also would help to refine the assumptions regarding the impact of those weather events on truck speeds. Another benefit would be to obtain better measurement of regional variations in driver response to weather phenomena.

- In order to estimate delays, assumptions were required about the duration of various weather phenomena. The estimate is relatively sensitive to these assumptions. The study did not allow for a detailed analysis of weather event durations, which should be broken down not only by type of weather event, but by geographic region as well. Additional research should be conducted on available weather datasets to better refine duration estimates and distinguish in more detail between different States and regions.
- Assumptions were necessary regarding the distribution of freight traffic between different roadway categories. While data available to accomplish this are still limited, there are a number of detailed freight models in use at the State and regional level that could be used to better refine these assumptions. Development of a more granular model in several metropolitan areas which have good freight movement data would be useful and provide factors that could be used on a national basis. A first step would be to refine the model to use BEA regions, as originally envisioned.
- This analysis was limited in its ability to distinguish between the value of freight shipments in different regions and on different roadways. Data available to refine these estimates are scarce and often not highly detailed but the State and local freight models mentioned above would provide a good starting point for refinement of these parameters. Other sources of economic data could be used as well. This effort also should incorporate additional review and refinement of the freight model factors in this study, which incorporated the impact of delay on different parts of the supply chain.

This study has provided an important benchmark in estimating the impact of adverse weather on the freight industry. The recommendations above focus on improving the accuracy of the assumptions in the model and providing more granularity to reflect the differences in regional weather, driver response, and freight shipments. This, in turn, will help to establish which road weather management investments can be most effective in mitigating the impacts of weather-related freight delay.

U.S. Department of Transportation
ITS Joint Program Office-HOIT
1200 New Jersey Avenue, SE
Washington, DC 20590

Toll-Free “Help Line” 866-367-7487
www.its.dot.gov

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