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IMPACTS OF CLIMATE CHANGE AND WEATHER ON COMMERCIAL MOTOR VEHICLES

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1. BACKGROUND

Observed climatic patterns represent the averages and variability of long term weather conditions. These patterns result from the interactions of oceanic, geologic, and solar influences, the atmospheric concentrations of various gases and aerosols, and other factors. Various studies now indicate that the planet is getting warmer and that this global warming is beginning to impact regional weather patterns and thus weather-sensitive sectors of the economy (AMS 2007). As part of these impacts, climate change can produce both economic gains and losses (IPCC 2007 and Changnon 2005).

Commercial motor vehicles (CMVs) include trucks with a gross vehicle weight rating of >10,001 lbs, as well as most types of buses. The study period for which CMV data are available is 1975 to the present. Exposure to adverse weather may occur at any point in distribution supply chain and cause ripple effects in the intermodal transportation system. This paper looks at a specific problem area from the transportation sector, the role of different types of weather events as risk factors in CMV crashes and performance. This includes the possible role of climate change in increasing the distribution, frequency or severity of those weather events and their impacts on measures such as safety and delay.

The Federal Motor Carrier Administration (FMCSA) sponsored this work as part of its responsibilities to reduce the number and severity of CMV crashes and enhance the efficiency of CMV operations. Through an understanding of the how weather and climate forces affect CMV safety, the FMCSA hopes to address future risks posed by climate variability and climate change. Since FMCSA's primary mission is to reduce large truck and bus crashes and fatalities, FMCSA has been analyzing how crashes occur, but has never heavily investigated the role of weather in these crashes. The

FMCSA needs to know the trends and factors in weather-related CMV crashes, and also if actions within its jurisdictional realm (e.g., driver training, truck technologies, highway alerts) can be taken to reduce weather-related crashes. These are in addition to external programs such as improved observation and detection systems, more accurate and precise models, and better weather forecasts.

2. PROFILE OF CMV ACTIVITY IN THE U.S.

There are now over 9 million CMVs registered in the U.S., most of which are large trucks. From 1975 to 2005, CMV registrations increased by 60 percent, while vehicle miles traveled (VMT) grew by 163 percent (Figure 1). Combined with similar increases in automobile VMT, and virtually no growth in highway capacity, congestion has become a serious problem on the nation's road system. From a weather perspective, CMVs and their operators face a variety of weather-related exposure risks.

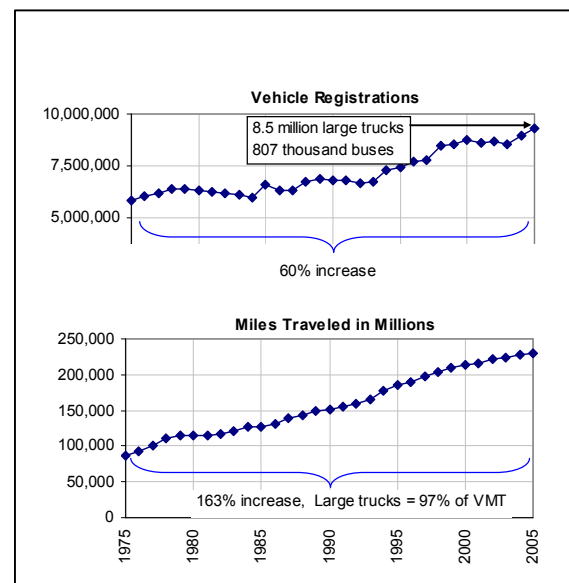


Figure 1 - Commercial Motor Vehicle Registrations and VMT, 1975-2005

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The impacts on safety from the combination of congestion and weather exposure is of concern to the FMCSA as it pertains to how climate change could amplify some of those effects in its long-term planning horizon by increasing the frequency or intensity of severe weather. Commodities carried by CMVs are of great economic importance. Recent data indicate that trucking as a single mode, or as part of intermodal combinations, accounts for about 80 percent of the total value of \$13 trillion for all commodity shipments in the U.S, and 42 percent of all ton-miles. CMVs share an infrastructure that includes 47,000 miles of Interstates, 115,000 miles of NHS roads, and 3.8 million miles of other roads (DOT/RITA 2006). The Federal Highway Administration (FHWA) estimates that about 25 percent of non-recurrent delays on freeways are due to weather, and that weather-related delay adds \$3.4 billion to freight costs annually (Maccubbin 2002).

3. WEATHER AND CLIMATE FACTORS IN CMV OPERATIONS

Weather is one of many determinants of truck crashes, along with socioeconomic and demographic factors, speed, alcohol, driver error, vehicle characteristics, etc. In addition, average temperatures have been found to show a positive association with vehicle deaths, and precipitation a negative association (Loeb 2007). Although only about 16 percent of all fatal CMV crashes are associated with adverse weather or wet pavement, that share can still have significant effects on vehicle performance and safety as well systemic effects that may impact other modes and economic sectors. In addition, FMCSA may have less influence in reducing weather-related crashes.

Specific types of short term weather conditions affect CMVs crash conditions, driver decision making, dispatchers, and state highway officials. Climate impacts include the longer term effects on safety, infrastructure and vehicles of larger, more frequent or more intense storms, precipitation and winds, extremes of temperature, and other factors.

Weather conditions affect CMVs by degrading safety, performance and capacity and can change shipping patterns and methods. Over a long period of time, climate patterns could affect CVM operations by impacting intermodal infrastructure and operations, vehicle components, drivers, and the underlying production patterns of agricultural and other industrial shipments. The U.S. Department of Transportation will soon publish a report indicating significant threats to the Gulf Coast of the U.S. from increased sea-level rise, subsidence and storm surges (U.S. DOT 2007). Although climate change may adversely affect transportation and CMVs, certain types of regimes may produce benefits. For example, by producing tranquil weather over the northern U.S., and as a stimulus to

consumer spending, the major El Nino event of 1997-1998 may have increased profits by up to 8 percent in the trucking and airline industries (Changnon 1999).

The transportation infrastructure relevant to CMVs includes all modes associated with the intermodal supply chain: highways, rail, air and water. This includes all activities related to the transportation of goods, and reflects a weather-sensitive supply chain that extends from raw materials, to suppliers, manufacturers, wholesalers, retailers, and consumers (Figure 2).

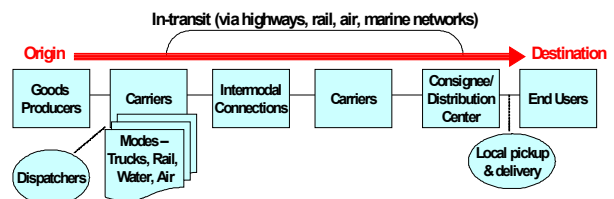


Figure 2 – Typical Supply Chain

These effects may occur en route or at specific nodes. In addition, because of growing modal interdependence, weather events may produce ripple effects and disrupt supply chains. Manufacturers and producers may have production delays due to employees unable to reach their jobs during bad weather, or because of delays in the shipment of intermediate goods needed for production. Carriers may lose speed, routing efficiency, and the ability to meet schedules for intermodal transfers. Consignees experience delays, or do not receive finished goods and supplies. Tight synchronization between production and delivery schedules to handle just-in-time (JIT) delivery practices may create an environment increasingly vulnerable to the effects of weather and climate.

Weather events hazardous to CMVs can range from wet pavement, rain, winter storms, icing, temperature extremes, floods, hurricanes, high winds and severe thunderstorms to more routine events such as solar glare, poor visibility and light rainfall. Some specific types of impacts are as follows:

Rainfall, Wet Pavements, and Flooding – Rainfall and wet pavements are the most common type of adverse weather that affects CMVs; over 60 percent of all weather-related fatalities occur in rainy conditions. Rainfall causes delays and increased risks of collisions with other vehicles and highway structures. It induces loss of control due to acceleration from wheel spinning and hydroplaning. The initial onset of rain may mix with preexisting road oils to produce slippery

conditions. Rain reduces braking performance, resulting in increased stopping distances and more frequent skidding; wet roads can double stopping distances.

Rainfall also reduces visibility and can make it harder to see clearly, especially at night. Wet surfaces produce similar effects on vehicles and their drivers even if skies are not currently causing rainfall. Even after rain stops, it may take 30 minutes or more before pavement begins to dry. Wet conditions may persist for a longer time under certain types of atmospheric and soil moisture conditions, from melting snow banks, from previous snow falling from other vehicles, and flooding episodes.

Widespread flooding in major rivers may result in wholesale rerouting of shipments. Problems posed by high waters from flash floods, river floods, persistent heavy rains, and hurricanes are sometimes a significant concern for CMVs. Wet brakes may weaken or apply unevenly. Floods also can make roads and bridges impassable or produce complete washouts that require closures and rerouting. Re-routing around flooded areas increases VMT and the likelihood of additional CMV crashes. Coastal flooding accompanied by wave battering caused by large storms is a threat to road infrastructure. Effects like these may gradually become more amplified if sea levels rise as projected by climate models. The Gulf Coast study (DOT 2007) tentatively projects that relative sea-level in the Gulf Coast area may increase at least one foot during the next 50-100 years.

Snow and Icing - Heavy snow causes delays, road closures, loss of traction, loss of visibility, and other driver control problems. Surface temperatures on bridges and ramps cool more rapidly than the surrounding roadbeds, producing hazardous local icing conditions and resultant property damage. Freezing rain, black ice and light frozen precipitation glaze roads as temperatures fall over a short period. Winter conditions also place additional stress on CMV components such as the cooling system, defrosting and heating equipment, wipers and washers, tires and chains, windows and mirrors, hand holds and deck plates, radiator shutters and exhaust systems. Many states require large trucks to carry and use tire chains as snow conditions warrant.

Fog and Visibility - CMVs have significant vulnerability to fog and poor visibility. Impaired visibility may result from intense storms, coastal and ground fog, smog, dust, precipitation-induced road spray and solar glare. Dense fog may form overnight in low-lying areas on highways resulting in reduced speeds, sudden losses of control and increased risks of collisions between vehicles and roadside structures. Lowered visibility poses a safety risk to truckers and increases the risk of damage in the event of collision. Fog events have the

potential for large, multi vehicle accidents. Signs and signals may become more difficult to see, thus leading to human error. Reduced visibility also increases the potential for schedule delays.

Strong Winds - Strong winds and cross winds can disrupt CMV operations. High profile trucks are susceptible to potential vehicle instability, loss of control and blowovers from crosswinds in exposed areas such as bridges, interstate highways and mountain passes. Expected peak wind gusts may also play a role in determining the maximum wind speed in which a heavy truck can safely drive.

Temperature Extremes - Prolonged episodes of heat and cold can impact both the safety and performance characteristics of CMVs. Extremely cold temperatures can affect the operation of vehicle engines, tires, mechanical and hydraulic systems. Hot weather can cause tar in the road pavement to rise and result in slippery surface conditions. Certain types of livestock carried by trucks are very sensitive to excessive heat and cold. Other types of commodities are perishable and temperature-sensitive, requiring protection from the external conditions.

Drought - Droughts affect transportation directly and indirectly. They promote conditions that result in forest fires that may produce smoke dense enough to cause delays and road closures. Dry conditions combined with strong winds can lower visibility from airborne dust and sand. Very dry conditions may lower yields on agricultural commodities and thus impact the demand for trucking.

Drought conditions may also impact CMVs through their effects on intermodal connections. Low water causes barges to run aground, resulting in delayed shipments of coal, chemicals, agricultural goods produced by manufacturing plants in that region. Shipments may be diverted from one mode to another. The summer of 2005, for example, produced such conditions over part of the Midwestern U.S., lowering water levels on the Mississippi, Missouri and Ohio rivers.

4. CMV WEATHER-RELATED CRASHES

The National Highway Traffic Safety Administration (NHTSA 2007) maintains a complete census of fatal crash data called the Fatal Accident Reporting System (FARS). FARS includes crash data CMVs and other vehicles that are collected from reports filed by police investigators at the scene. FARS data can be queried for "atmospheric conditions." Codes include:

- 1 No Adverse Atmospheric Conditions
- 2 Rain
- 3 Sleet (Hail)
- 4 Snow
- 5 Fog
- 6 Rain and Fog
- 7 Sleet and Fog
- 8 Other (Smog, Smoke, Blowing Sand, Dust)
- 9 Unknown

FARS does not include any weather-related crashes associated with high winds. FARS also reports road surface conditions with the following codes:

- 1 Dry
- 2 Wet
- 3 Snow or Slush
- 4 Ice
- 5 Sand, Dirt, Oil
- 8 Other
- 9 Unknown

In this study, "weather-related crashes" refer to all crashes coded with all combinations of atmospheric and road surface conditions that indicated either adverse weather or road surfaces that were wet, snowy, or icy.

Large trucks account for 3.4% of all vehicle registrations, 7.5% of VMT and 11.1% of fatal crashes. CMVs are over-represented in fatal crash data. Other studies show similar results (Braver et al 2002). The series of six charts displayed in Figure 3 shows the trend of specific types of weather elements associated with fatal CMV crashes. Rain, snow, fog and wet pavement are the four main associations. The raw data indicate a slight decreasing trend over the period for rain, snow and fog, as well as for total weather-related crashes. The series for snow and fog show slightly more volatility. This may reflect short term climate variability, such as exceptionally snowy winters in the eastern U.S.; 1996 is such an example.

Wet pavement crashes have shown little trend for many years. A 1980 study by the National Transportation Safety Board (NTSB) found that 13.5 percent of all fatal accidents occurred on wet pavement, while precipitation occurred only about 3.0 to 3.5 percent of the time nationwide. This indicates that fatal accidents on wet pavement occur 3.9 to 4.5 times more often than might be expected, and that the wet-pavement accident problem should be of concern to all States (NTSB 1980). Other studies have noted the persistent problem of wet pavement exposure to drivers and the seeming lack of appreciation for its risks (cite).

Normalized by VMT, the trend of fatal, weather-related CMV crashes shows a distinct downtrend, falling by about half from 1975-2006. The long-term trend may be indicative of the effects of many forces, such as benefits stemming from the National Weather Service's modernization program, advances in weather forecasts,

vehicular improvements and technology, the introduction of intelligent transportation system (ITS) features, changes in CMV traffic patterns, or possibly changes in the frequency or distribution of weather events. Additionally, because this study included only fatal crashes, the same trend may or may not apply to non-fatal, weather-related crashes.

Since about 2002, the decline in fatal crashes has leveled off (Figure 4). This may indicate that there could be a minimum number of weather-related crashes that will occur over which the FMCSA and other agencies have little control or that weather events that contribute to CMV crashes are becoming more frequent or severe, or are affecting a larger number of CMVs.

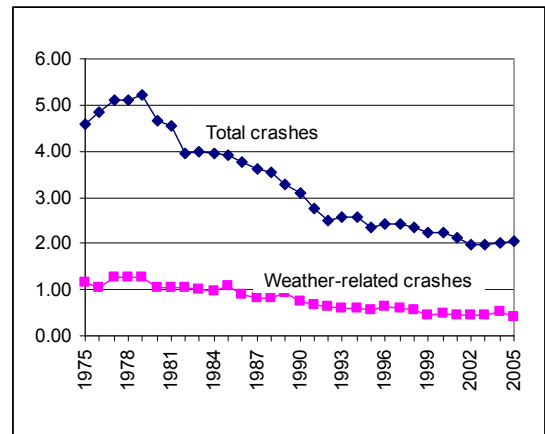


Figure 4 – Fatal Large Truck Crashes vs. Fatal, Weather-related Large Truck Crashes, per 100 million VMT, 1975-2005

Figure 5 shows the distribution of CMV fatal crash sites by latitude/longitude for the period 2004-2006. Icons show the type of weather reported by the police report. (FARS data have included lat/lon information since 2001). The map shows the expected higher frequencies of snow and sleet-related crashes in the northern and mountain states, fog in the Appalachian region, and rain in the southern tier of states.

Wet pavement crashes (with fair weather reported) are more evenly distributed throughout the county. Overall, the map shows a high concentration of fatal CMV crashes in the major interstate corridors of the East and Midwest, and in California. The segment of Interstate 80 that runs from New Jersey to Iowa shows a particularly high number of weather-related crashes, a likely combination of traffic volume and its exposure to adverse weather conditions throughout the year.

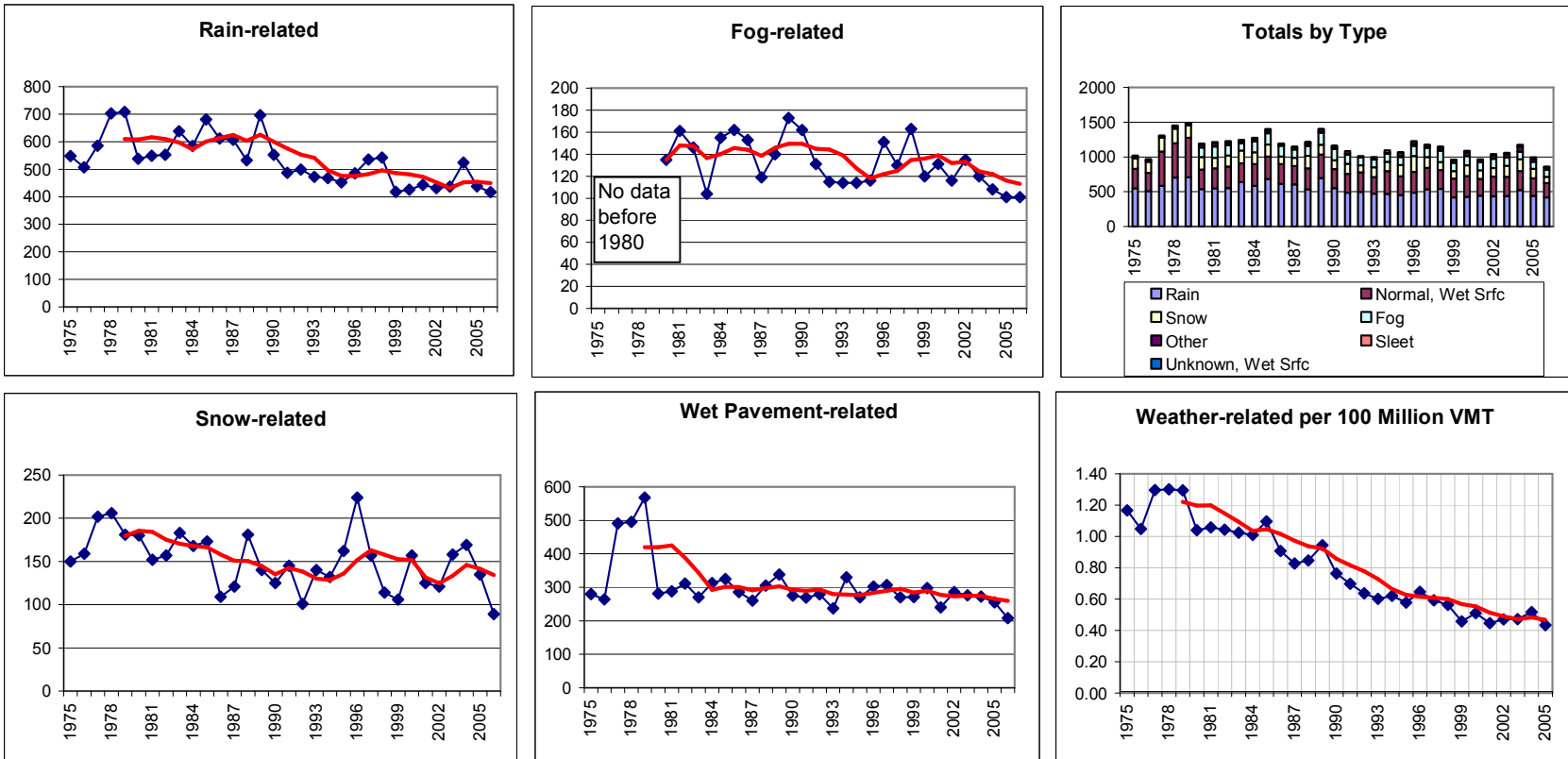


Figure 3 – Fatal, Weather-related CMV Crashes by Type of Weather Event, 1975-2006, with 5-year Moving Averages

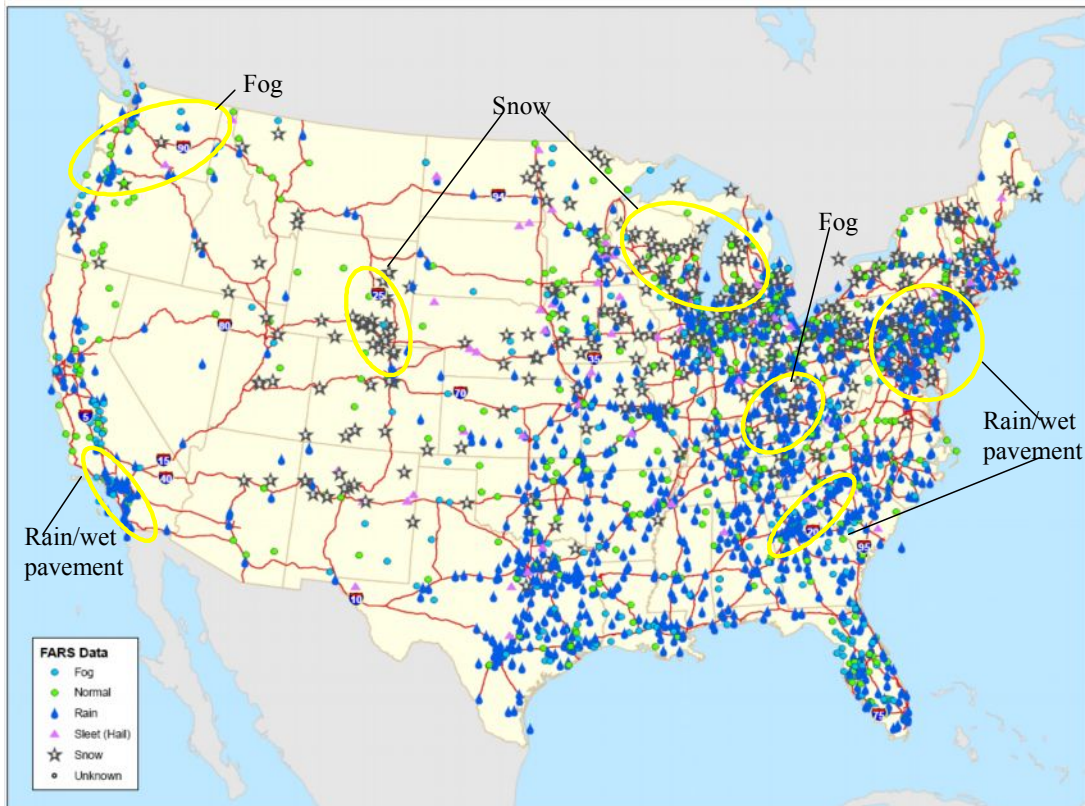
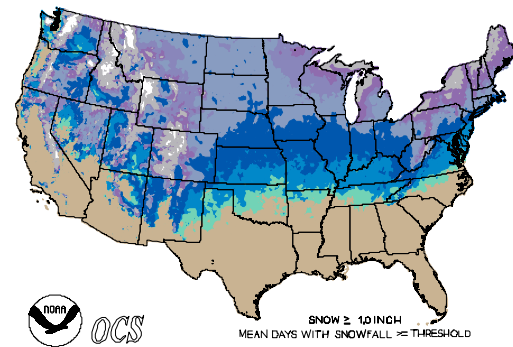
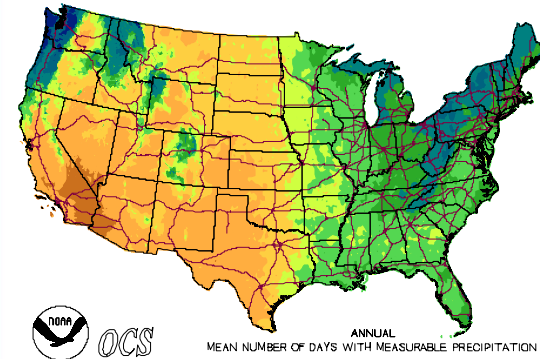
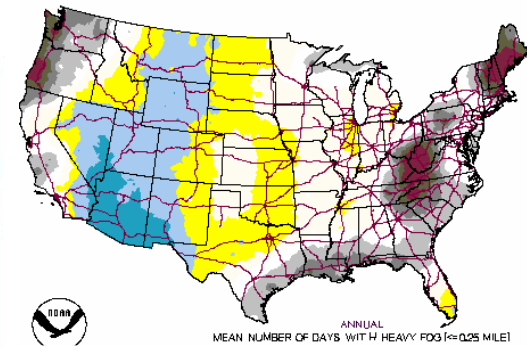


Figure 5 - Locations of Fatal Crashes involving Commercial Motor Vehicles, by type of Weather Event, 2004-2006



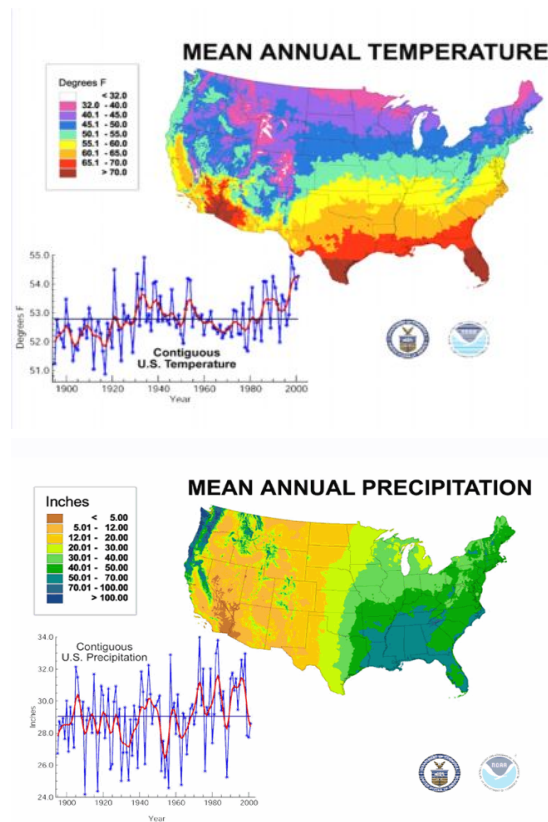


Figure 6 - Trends in Mean Annual Temperature and Precipitation, 1900-2002

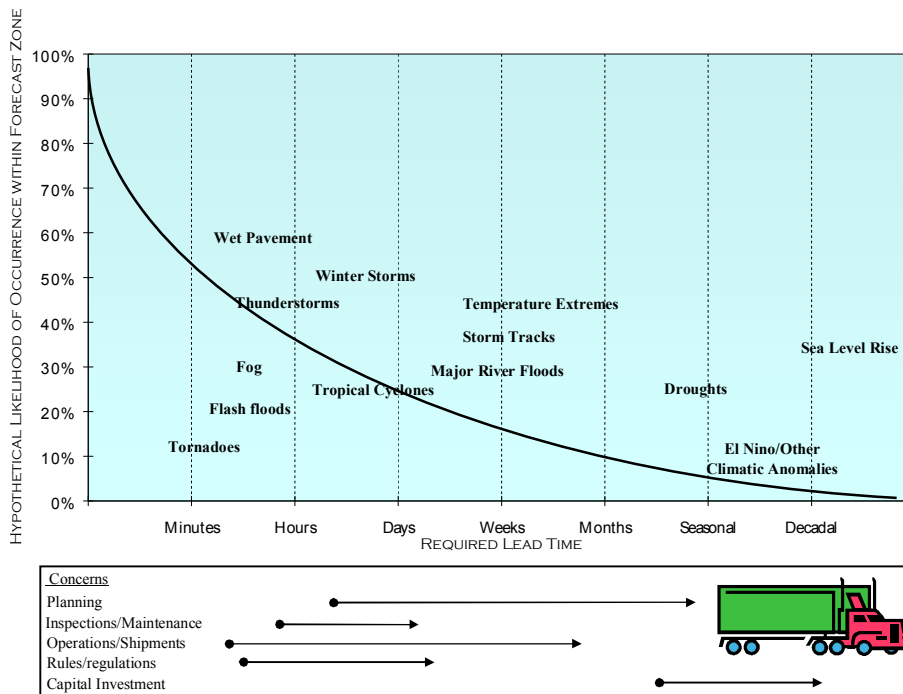


Figure 7 - Weather and Climate Events, Hypothetical Forecast Likelihood and Lead Times Required by Commercial Motor Vehicles

5. REGIONAL PROJECTIONS OF CLIMATE CHANGE AND POTENTIAL IMPLICATIONS

Although the reliability of regional scale climate and weather predictions is still low, and the degree to which climate variability may increase remains uncertain, potentially serious changes have been identified. These changes have the potential to affect the frequency and intensity of extreme weather events, regional distributions of temperature and precipitation, storm tracks, and sea levels). Results from the U.S. Climate Change Science Program (CCSP 2007) report on Weather and Climate Extremes under Climate Change will soon provide a better understanding about the potential and actual increases in storm events.

Trends in mean annual temperature and indicate a steady rise since the late 1970s (Figure 6). A similar uptrend seems evident for mean annual precipitation. Vulnerability of the national highway system CMVs to climate change arises from potential exposure to both unforeseen and secular changes in weather or climate patterns and from potential increases in the intensity and frequency of extreme weather events.

Relevant to transportation and CMV impacts, the National Assessment Report (USGCRP 2000) outlined various climate change scenarios for different U.S. regions. Table 1 summarizes these scenarios and lists the potential impact on CMV operations. The IPCC, in its recently issued Fourth Assessment Report (IPCC 2007), makes similar but more broadly based projections for the 21st century based on the Special Report on Emission Scenarios (SRES).

Under those scenarios, there should be a mixed bag of benefits and losses for CMVs. Warmer winters should simulate greater consumer spending and provide a boost to the manufacture of both producer and consumer goods. Those same conditions will favor more business and generally provide fewer weather impediments and improved safety margins to the shipment and delivery of those commodities throughout the transportation system.

On the other hand, various studies also project an increase in extreme or large events, such as higher incidences of flooding, larger and more intense snowstorms, and increased levels of severe thunderstorms (Trapp et al 2007). Although these may occur relatively less frequently, such high-impact storms could decrease CMV safety and performance under some scenarios.

The types of weather events that currently impact CMV safety and operations will require continued vigilance by the FMCSA, the industry, traffic managers, and other interested parties. It is important to advance efforts to reduce the lead time needed to avoid or

mitigate the impacts of those events on relevant time scales, ranging from the very short term to the possible time scales of climate change, to (Figure 7). Climate change scenarios could possibly enhance or diminish the impacts of some of the events illustrated. Accordingly, concerns such as safety, inspections, maintenance, operations, and capital investment depend on the ability of the FMCSA and CMV fleet operators to acquire and act appropriately upon this information.

6. FMCSA STRATEGIES FOR A CHANGING CLIMATE

The FMCSA is examining the trends and factors in weather-related CMV crashes, and also if actions within its jurisdictional realm can be taken to reduce weather-related crashes. One strategy might include driver training and education programs aimed at operating CMVs in inclement and occasionally extreme weather conditions. The agency could also consider expanded research into the role of human factors in responding to adverse weather conditions, and in the delivery to and use of weather information by vehicle drivers

Another part of this approach could include modifications or waivers to existing CMV rules FMCSA rules currently limit the number of hours of service permitted for CMV drivers. There are exceptions based on extenuating weather conditions. In addition, individual states sometimes grant temporary waivers, for example when drivers are hauling relief supplies into a flood-stricken area.

Other contributions to the solution include advanced truck technologies and telematics equipment. The FMCSA could also look at improved information programs aimed at CMV manufacturers to build in processes and equipment to respond to changes in climate regimes and weather conditions. Strategic opportunities exist for the FMCSA to improve the capability of CMVs and drivers to adapt to the type of weather conditions and climate regimes now projected by the CCSP, IPCC and others

7. CONCLUSIONS

This paper examined different types of weather events as risk factors in commercial motor vehicle (CMV) crashes and performance, including the possible role of climate change in increasing the distribution, frequency, or severity of those weather events. To the extent that CMVs are an integral part of an intermodal transportation system, these findings may also extend to other modes of transportation such as railroads, and marine.

Region	Possible Climate Scenarios	Potential CMV Impacts
Northeast	<ul style="list-style-type: none"> • Higher winter temperatures, especially in coastal areas • Shorter snow season/less extended cold in winter • Modest increases in summer temperatures • More variable precipitation for coastal areas • Sea level rise and elevated storm surges • Storms more intense • More flood episodes 	<ul style="list-style-type: none"> • Stresses on road and port infrastructures from thaw-freeze cycles, and coastal flooding • Extreme event storms, more situational delay • Less vehicle stress from extreme cold and snow • Less winter-related disruption • Increased exposure safety risks from severe events
Southeast	<ul style="list-style-type: none"> • Higher temperatures • Reduced soil moisture • Increased risk of fires • Agricultural dislocations • Sea level rise and coastal flooding • More frequent/intense hurricanes • Less extended cold in winter 	<ul style="list-style-type: none"> • Heat stresses on vehicles and cargo • More episodes of reduced visibility/road closures from smoke • Crop-specific changes in freight distribution patterns • Stresses on roads and transportation infrastructure from coastal flooding/wave battering • Increased exposure and safety risks from severe events
Midwest	<ul style="list-style-type: none"> • Warmer temperatures • Shorter snow season • Increases in heavy precipitation events/flash flooding • Reduced soil moisture • Increased risk of fires • More risk of both high and low water levels on rivers • Lower water levels and less ice on Great Lakes • Agricultural shifts 	<ul style="list-style-type: none"> • Intermodal disruptions and mode diversion from low water levels • Heat stresses on vehicles and cargo • Increased safety risks from extreme events • Crop-specific changes in freight distribution patterns • More episodes of reduced visibility/road closures from smoke and dust • Less vehicle stress from extreme cold • Increased exposure from severe events • Intermodal disruptions from intermittent impacts on barge traffic
Great Plains	<ul style="list-style-type: none"> • Higher temperatures throughout region, with largest increases in northern and western areas • Shorter snow season • Precipitation increases, except in less of Rockies • Reduced soil moisture • Increased risk of drought conditions 	<ul style="list-style-type: none"> • Increased exposure and safety risk from severe events • Less vehicle stress from extreme cold and snow • More episodes of reduced visibility/road closures from smoke and dust • Heat stresses on vehicles and cargo • Crop-specific changes in freight distribution patterns
West	<ul style="list-style-type: none"> • Warmer summer temperatures • Increases in extreme precipitation events • More extreme wet and dry years • Increased winter precipitation in California • Greater potential for flooding due to runoffs • Increases in average precipitation • Higher risk of fires 	<ul style="list-style-type: none"> • Increased exposure and safety risks from extreme events • Stresses on road infrastructure flash flooding/erosion • Extreme event storms, more situational delay • More episodes of reduced visibility/road closures from smoke and dust • Heat stresses on vehicles and cargo • Crop-specific changes in freight distribution patterns
Pacific Northwest	<ul style="list-style-type: none"> • Shorter snow season/earlier snowmelt • Sea level rise/coastal erosion • Wetter winters/drier summers • Increased risk of fires • Increases in extreme precipitation events 	<ul style="list-style-type: none"> • Stresses on road and port infrastructures from coastal flooding/wave battering/erosion • Less vehicle stress from extreme cold and snow • Increased exposure/safety risks from severe events • More episodes of reduced visibility/road closures from smoke • Intermodal disruptions in winter from high water levels on rivers

Table 1 - USGRP Climate Scenarios and Potential Impacts on Commercial Motor Vehicles

Overall fatal weather-related crash data from the FARS system shows a declining trend from 1975 to the present, with a recent leveling off. This trend provides encouragement to efforts to make highway travel less sensitive to adverse weather, although GIS data show pocket of persistent clusters of weather-related crashes along certain corridors or within specific regions of the country. The concern is that under scenarios of climate change, the conditions that give rise to these weather events may cause less safe driving conditions.

The FMCSA can address these concerns and promote safety through a combination of education and training programs, the introduction of vehicle telematics equipment, and working with the carrier industry and manufacturers to build in processes and equipment for responding to changes in climate patterns and weather conditions.

Benefits of CMV weather and climate information include improved safety, improved decision making for routing and scheduling, and better performance for the vehicle, driver and infrastructure, better information for forensic investigation and crash event reconstruction, enhanced research, training, and education, more accurate economic impact analysis, and more insightful research into the role human factors.

The FARS database has only recently included geospatial data as part of the police reports. As this cache of information continues to grow, there will be excellent opportunities to coordinate with NCDC climate and storms databases. The NCDC, for example, now has under development a Severe Weather Data Inventory (SWDI).

Climate variability and climate change, changes in transportation management and vehicle technology, and changes in infrastructure, may bring about future operating environments different than those of the past. CMV carriers, dispatchers and drivers will have access to enhanced information on weather conditions, and how such conditions may impact their vehicles, general traffic conditions, road surfaces, and driver responses to various weather phenomena. This accessibility can be fully realized through better dissemination technology, better training, and protocols that improve the skill of drivers in adverse weather and wet pavement.

If climate change results in more frequent or intense storms affecting commercial motor vehicles, the historic decline in weather-related crashes may level off (as may be currently occurring) or start to increase which would pose significant challenges to FMCSA's primary mission in reducing CMV fatalities and crashes. Because weather-related crashes may be difficult for FMCSA to influence, this could indicate that FMCSA may need to explore more aggressive or creative strategies for reducing weather-related crashes.

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