ROAD WEATHER MANAGEMENT PROGRAM

How Do Weather Events Impact Roads?

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Weather acts through visibility impairments, precipitation, high winds, and temperature extremes to affect driver capabilities, vehicle performance (i.e., traction, stability and maneuverability), pavement friction, roadway infrastructure, crash risk, traffic flow, and agency productivity. The table below, summarizes the impacts of various weather events on roadways, traffic flow, and operational decisions.

Table: Weather Impacts on Roads, Traffic and Operational Decisions

Road Weather Variables	Roadway Impacts	Traffic Flow Impacts	Operational Impacts
Air temperature and humidity	N/A	N/A	• Road treatment strategy (e.g., snow and ice control) • Construction planning (e.g., paving and striping)
Wind speed	• Visibility distance (due to blowing snow, dust) • Lane obstruction (due to wind-blown snow, debris)	• Traffic speed • Travel time delay • Accident risk	• Vehicle performance (e.g., stability) • Access control (e.g., restrict vehicle type, close road) • Evacuation decision support
Precipitation (type, rate, start/end times)	• Visibility distance • Pavement friction • Lane obstruction	• Roadway capacity • Traffic speed • Travel time delay • Accident risk	• Vehicle performance (e.g., traction) • Driver capabilities/behavior • Road treatment strategy • Traffic signal timing • Speed limit control • Evacuation decision support • Institutional coordination
Fog	• Visibility distance	• Traffic speed • Speed variance • Travel time delay • Accident risk	• Driver capabilities/behavior • Road treatment strategy • Access control • Speed limit control
Pavement temperature	• Infrastructure damage	N/A	• Road treatment strategy
Pavement condition	• Pavement friction		• Vehicle performance

	• Infrastructure damage	• Roadway capacity • Traffic speed • Travel time delay • Accident risk	• Driver capabilities/behavior (e.g., route choice) • Road treatment strategy • Traffic signal timing • Speed limit control
Water level	• Lane submersion	• Traffic speed • Travel time delay • Accident risk	• Access control • Evacuation decision support • Institutional coordination

Weather Impacts on Safety

- On average, there are over 5,748,000 vehicle crashes each year. Approximately 22% of these crashes - nearly 1,259,000 - are weather-related. Weather-related crashes are defined as those crashes that occur in adverse weather (i.e., rain, sleet, snow, fog, severe crosswinds, or blowing snow/sand/debris) or on slick pavement (i.e., wet pavement, snowy/slushy pavement, or icy pavement). On average, nearly 6,000 people are killed and over 445,000 people are injured in weather-related crashes each year. (Source: Ten-year averages from 2005 to 2014 analyzed by Booz Allen Hamilton, based on NHTSA data).
- The vast majority of most weather-related crashes happen on wet pavement and during rainfall: 73% on wet pavement and 46% during rainfall. A much smaller percentage of weather-related crashes occur during winter conditions: 17% during snow or sleet, 13% occur on icy pavement and 14% of weather-related crashes take place on snowy or slushy pavement. Only 3% happen in the presence of fog. (Source: Ten-year averages from 2005 to 2014 analyzed by Booz Allen Hamilton, based on NHTSA data).

Table: Weather-Related Crash Statistics (Annual Averages)

	Weather-Related Crash Statistics	
	10-year Average (2005-2014)	**10-year Percentages**
Weather-Related* Crashes, Injuries, and Fatalities	1,258,978 crashes	22% of vehicle crashes
	445,303 persons injured	19% of crash injuries
	5,897 persons killed	16% of crash fatalities

*** "Weather-Related" crashes are those that occur in the presence of adverse weather and/or slick pavement conditions.**

Table: Weather-Related Crash Statistics (Annual Averages)

Road Weather Conditions	**Weather-Related Crash Statistics**		
	#REF	**10-year Percentages**	
Wet Pavement	907,831 crashes	16% of vehicle crashes	73% of weather-related crashes

	352,221 persons injured	15% of crash injuries	80% of weather-related injuries
	4,488 persons killed	13% of crash fatalities	77% of weather-related fatalities
Rain	573,784 crashes	10% of vehicle crashes	46% of weather-related crashes
	228,196 persons injured	10% of crash injuries	52% of weather-related injuries
	2,732 persons killed	8% of crash fatalities	47% of weather-related fatalities
Snow/Sleet	210,341 crashes	4% of vehicle crashes	17% of weather-related crashes
	55,942 persons injured	3% of crash injuries	13% of weather-related injuries
	739 persons killed	2% of crash fatalities	13% of weather-related fatalities
Icy Pavement	151,944 crashes	3% of vehicle crashes	13% of weather-related crashes
	38,770 persons injured	2% of crash injuries	9% of weather-related injuries
	559 persons killed	2% of crash fatalities	10% of weather-related fatalities
Snow/Slushy Pavement	174,446 crashes	4% of vehicle crashes	14% of weather-related crashes
	41,597 persons injured	2% of crash injuries	10% of weather-related injuries
	538 persons killed	2% of crash fatalities	10% of weather-related fatalities
Fog	28,533 crashes	1% of vehicle crashes	3% of weather-related crashes
	10,448 persons injured	1% of crash injuries	3% of weather-related injuries
	495 persons killed	2% of crash fatalities	9% of weather-related fatalities
Weather-Related *	**1,258,978 crashes**	**22% of vehicle crashes**	
	445,303 persons injured	**19% of crash injuries**	
	5,897 persons killed	**16% of crash fatalities**	

***** "Weather-Related" crashes are those that occur in the presence of adverse weather and/or slick pavement conditions.

- By crash type (not shown in above table) for an average year, roughly 15% of fatal crashes, 19% of injury crashes, and 23% of property-damage-only (PDO) crashes occur in the presence of adverse weather and/or slick pavement. That is on an annual basis, nearly 5,100 fatal crashes, over 304,800 injury crashes and nearly 922,200 PDO crashes occur in adverse weather or on slick pavement. (Source: Ten-year averages from 2005 to 2014 analyzed by Booz Allen Hamilton, based on NHTSA data).

Weather Impacts on Mobility

- Capacity reductions can be caused by lane submersion due to flooding and by lane obstruction due to snow accumulation and wind-blown debris. Road closures and access restrictions due to hazardous conditions (e.g., large trucks in high winds) also decrease roadway capacity.
- Weather events can reduce arterial mobility and reduce the effectiveness of traffic signal timing plans. On signalized arterial routes, speed reductions can range from 10 to 25 percent on wet pavement and from 30 to 40 percent with snowy or slushy pavement. Average arterial traffic volumes can decrease by 15 to 30 percent depending on road weather conditions and time of day. Saturation flow rate reductions can range from 2 to 21 percent. Travel time delay on arterials can increase by 11 to 50 percent and start-up delay can increase by 5 to 50 percent depending on severity of the weather event. (Sources: *"Weather Impacts on Arterial Traffic Flow* (PDF 92KB)" and "*Weather-Responsive Traffic Signal Control* (DOC 399KB)")
- On freeways, light rain or snow can reduce average speed by 3 to 13 percent. Heavy rain can decrease average speed by 3 to 16 percent. In heavy snow, average freeway speeds can decline by 5 to 40 percent. Low visibility can cause speed reductions of 10 to 12 percent. Free-flow speed can be reduced by 2 to 13 percent in light rain and by 6 to 17 percent in heavy rain. Snow can cause free-flow speed to decrease by 5 to 64 percent. Speed variance can fall by 25 percent during rain. Light rain can decrease freeway capacity by 4 to 11 and heavy rain can cause capacity reductions of 10 to 30 percent. Capacity can be reduced by 12 to 27 percent in heavy snow and by 12 percent in low visibility. Light snow can decrease flow rates by 5 to 10 percent. Maximum flow rates can decline by 14 percent in heavy rain and by 30 to 44 percent in heavy snow. (Sources: "*Highway Capacity Manual 2000*" Chapter 22, "*Capacity-Reducing Occurrences*", "*Driver Response to Rainfall on an Urban Expressway*", "*Impact of Weather on Urban Freeway Traffic Flow Characteristics and Facility Capacity*", *Empirical Studies on Traffic Flow in Inclement Weather: Summary Report*".

Table: Freeway Traffic Flow Reductions due to Weather

Weather Conditions	Freeway Traffic Flow Reductions			
	Average Speed	Free-Flow Speed	Volume	Capacity
Light Rain/Snow	3% - 13%	2% - 13%	5% - 10%	4% - 11%
Heavy Rain	3% - 16%	6% - 17%	14%	10% - 30%
Heavy Snow	5% - 40%	5% - 64%	30% - 44%	12% - 27%
Low Visibility	10% - 12%			12%

- It has been estimated that 23 percent of the non-recurrent delay on highways across the nation is due to snow, ice, and fog. This amounts to an estimated 544 million vehicle-hours of delay per year. Rain—which occurs more frequently than snow, ice, and fog—leads to greater delay. During adverse weather average travel time delay increases by 14 percent in Washington, D.C. and by 21 percent in Seattle, WA. During peak periods in Washington, D.C. travel time increases by roughly 24 percent in the presence of precipitation. (Sources: " *Highway Capacity Manual 2000" Chapter 22,* "*Temporary Losses of Highway Capacity and Impacts on Performance*", " *An Investigation into the Impact of Rainfall on Freeway Traffic Flow*" and "*Analysis of Weather Impacts on Traffic Flow in Metropolitan Washington DC*" (PDF 1.4MB))

Weather Impacts on Productivity

- Adverse weather can increase operating and maintenance costs of winter road maintenance agencies, traffic management agencies, emergency management agencies, law enforcement agencies, and commercial vehicle operators (CVOs).
- Winter road maintenance accounts for roughly 20 percent of state DOT maintenance budgets. Each year, state and local agencies spend more than 2.3 billion dollars on snow and ice control operations. (Sources: *"Highway Statistics Publications, Highway Finance Tables SF-4C and LGF-2," 1997 to 2005, https://www.fhwa.dot.gov/policy/ohpi/hss/hsspubs.cfm*)
- Each year trucking companies or CVOs lose an estimated 32.6 billion vehicle hours due to weather-related congestion in 281 of the nation's metropolitan areas. Nearly 12 percent of total estimated truck delay is due to weather in the 20 cities with the greatest volume of truck traffic. The estimated cost of weather-related

delay to trucking companies ranges from 2.2 billion dollars to 3.5 billion dollars annually. (Source: "*Analysis of Weather Incident Effects on Commercial Vehicle Mobility in Large U.S. Cities," Mitretek Systems*).

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