Weather Impacts on Arterial Traffic Flow

Lynette C. Goodwin
Mitretek Systems, Inc.
December 24, 2002

INTRODUCTION

This paper synthesizes literature regarding weather effects on traffic flow along signalized arterial roadways. Generally, weather impacts traffic by reducing visibility, decreasing pavement friction, as well as impacting driver behavior and vehicle performance (e.g., traction, stability, maneuverability). In the following sections weather effects on roads and traffic are presented, relevant literature is reviewed, and findings from the literature are summarized in the conclusion.

WEATHER EFFECTS

Weather events affect driver behavior, roadway safety, and roadway mobility. During inclement weather—particularly snowy and icy conditions—drivers increase headway (or spacing between vehicles), decrease acceleration rates, and reduce speeds. Weather can impact safety by increasing crash frequency and crash severity. Weather effects on mobility include increased delay and congestion, lower traffic volumes and speeds, increased speed variance[1], and reduced roadway capacity[2]. On arterial routes, adverse weather can have an impact on the effectiveness of traffic signal timing plans. Timing plan parameters (e.g., cycle lengths[3], splits[4], and offsets[5]) for normal conditions may not be optimal under inclement conditions. Table 1 lists impacts of weather events on the roads and traffic (7).

Table 1 – Weather Impacts on Roadways and Traffic Operations

Weather Events	Roadway Impacts	Traffic Operation Impacts
Rain, Snow, Sleet, Hail & Flooding	• Reduced visibility • Reduced pavement friction • Lane obstruction & submersion • Reduced vehicle performance • Infrastructure damage	• Reduced roadway capacity • Reduced speeds & increased delay • Increased speed variability • Increased accident risk • Road/bridge restrictions & closures
High Winds	• Reduced visibility due to blowing snow/dust • Lane obstruction due to wind-blown debris & drifting snow • Reduced vehicle performance	• Increased delay • Reduced traffic speeds • Road/bridge restrictions & closures
Fog, Smog, & Smoke	• Reduced visibility	• Reduced speeds & increased delay • Increased speed variability • Increased accident risk • Road/bridge restrictions & closures
Lightning & Extreme Temperatures	• Infrastructure damage	• Traffic control device failure • Loss of power/communications services

[1] *Speed variance* is a measure of speed uniformity.
[2] *Capacity* is the maximum rate at which vehicles can travel.
[3] *Cycle length* is the time required for complete sequence of signal phases.
[4] A *split* is the percentage of cycle length allocated to each phase in a cycle.
[5] An *offset* is the relationship between a portion of coordinated phase green and a reference point.

LITERATURE REVIEW

Several research projects have focused on the effects of weather on arterial traffic flow or mobility. Many of these studies quantified changes in speed, documented saturation flow rate[6] reductions, and assessed traffic delay by measuring travel time variability, start-up delay[7], and the number of vehicle stops[8]. Analysis results from studies conducted in Washington, D.C.; Salt Lake City, Utah; Anchorage, Alaska; Minneapolis/St. Paul, Minnesota; and in the United Kingdom are discussed below.

Mitretek Systems examined weather impacts on 33 road segments in metropolitan Washington, D.C. from December 1999 to May 2001 (1). Eighteen of the segments were freeways and 15 roads were major arterials (covering 239 miles). Reported travel time data and weather observation data were combined and utilized in a two-step regression analysis to predict travel time impacts under adverse road weather conditions. Initially, travel times were regressed against selected weather variables. In the second step, linear regression models for each road segment were reduced and used to predict normal travel time as well as increased travel time due to weather. Weather variables included precipitation (none, light rain/snow, heavy rain, or heavy snow/sleet), wind speed (<30 mph or ≥30 mph), visibility distance (≥0.25 miles or <0.25 miles), and slick pavement conditions (dry, wet, snowy, or icy).

The average increase in arterial travel time was more than 12% when adverse weather occurred during a two-hour, off-peak period. To estimate off-peak travel times in extreme weather, reduced regression models were also applied to a day in January 2000 during a widespread snowstorm. The predicted increase in arterial travel time during the snowstorm event was over 48%.

Perrin and Martin analyzed traffic flow at two intersections in Salt Lake Valley, Utah during winter 1999/2000 (2, 4). Over 30 hours of speed, flow rate, and start-up delay data were collected on 14 days with inclement weather. As shown in Table 2, free-flow speed and saturation flow rate reductions were observed in adverse road weather conditions. Snow and slush accumulation were associated with the greatest decline in vehicle performance. The analysis also indicated that start-up delay on wet pavement and snowy pavement was 5% and 23% higher, respectively, than delay on dry pavement.

Table 2 – Traffic Impacts at Utah Signals

Road Weather Conditions	Speed Reduction	Flow Rate Reduction
Dry	0%	0%
Rain	10%	6%
Wet & Snowing	13%	11%
Wet & Slushy	25%	18%
Wheel Path Slush	30%	18%
Snowy & Sticking	36%	20%

Analysis results were used to develop a traffic simulation model of a nine-intersection corridor in downtown Salt Lake City. The model demonstrated that vehicle stops would increase by 14% and that travel time would rise by 50% if normal signal timing plans were utilized in inclement conditions. The simulation also revealed that use of weather-related signal timing plans could improve traffic operations. When compared to normal signal timing in adverse weather, weather-related plans could decrease stops by 9% and reduce travel time by 18%.

6 *Saturation flow rate* is the maximum rate at which vehicles can travel per hour of green time per lane.
7 *Start-up* delay is the time to initiate movement of queued traffic from a stop to the maximum flow rate.
8 The number of *vehicle stops* is a measure of traffic signal timing effectiveness.

It was recommended that normal timing plans be modified for inclement conditions by reducing saturation flow rates by 20%, lowering speeds by 30%, increasing start-up delay by 23%, increasing red time by one second, and extending amber time by 10% to 15% based on intersection size. Suggested implementation criteria for weather-related plans included storm severity, storm duration (i.e., at least 20 minutes), affected area (i.e., sufficient corridor length), and traffic flow (i.e., volume and speed reductions).

Bernardin Lochmueller and Associates examined weather impacts in Anchorage, Alaska to determine if operation of a 24-signal network, with five major arterials, could be improved in the wintertime[9] (3, 4). Signal timing plan parameters were investigated for summer, winter, and extreme conditions (i.e., <22 degrees F, snowfall or freezing rain, slick pavement, and low visibility). It was concluded that, due to slower travel speeds, signal timing parameters used in the summer were not appropriate in winter or extreme conditions. Based upon field observations of major street through movements, major street left turn movements, minor street through movements, and upgrades (>2%); the authors proposed that the saturation flow rate in summer timing plans be reduced by 13%, 11%, 15% and 15%, respectively. The investigators recognized that weather impacts would vary for different road facilities and lane uses. While snow removal may keep through lanes on major streets clear, left turn lanes and minor streets are frequently snow covered.

Analysis results were used to produce weather-related timing plans. With traffic signal simulation software, weather-related plans were created and compared to existing summer timing plans. The simulation anticipated that travel speeds would increase by 12%, travel time would be reduced by 13%, average delay and total delay would decrease by 23%, and that vehicle stops would increase by 6% if weather-related plans were implemented.

For the Minnesota Department of Transportation, Maki assessed the impact of adverse weather on a signalized corridor and determined if weather-related timing plans would improve operations (5). The study area encompassed five coordinated, actuated, traffic signals along a three-mile corridor in the Minneapolis/St. Paul area. During winter 1998/1999, travel time and speed data, volume and occupancy data, as well as start-up delay and saturation flow rate measurements were collected during peak periods in normal and adverse weather. (Adverse weather was defined as a “snowstorm with three or more inches of snow, resulting in difficult driving conditions.”)

With normal signal timing in adverse weather, traffic volumes were 15% to 20% lower during the peak period (3:00-8:00 PM), and 15% to 30% lower in the peak hour (5:00-6:00 PM). In inclement conditions, the average speed fell by 40% from 44 mph in normal conditions to 26 mph. The saturation flow rate decreased by 11% and start-up delay increased by 50% in poor road weather conditions. These observations were used to simulate coordinated traffic signal operation with weather-related timing plans.

Simulation results indicated that, compared to normal timing plans, signal delay per vehicle would be reduced by nearly 8% and that average stops per vehicle would decrease by nearly 6% if weather-related plans were utilized. Maki concluded that traffic operations along the study corridor were not “drastically affected” by adverse conditions. Although travel speeds decreased, vehicle delay did not increase significantly due to fewer vehicles on the road (i.e., reduced volume).

[9] In Anchorage, winter typically begins on October 15th and ends on April 15th.

Gillam and Withill investigated weather impacts on adaptive traffic signal systems in four urban areas of the United Kingdom (6). Traffic flow under dry and wet pavement conditions was analyzed from March to November 1991. The authors found that travel time delay and congestion increased by an average of 11% when roads were wet. The saturation flow rate was reduced by 6% with wet pavement. They also concluded that reductions in driver and/or vehicular performance contributed to increased congestion in inclement weather.

CONCLUSION

In this section findings from the literature review are summarized by traffic flow parameter. Measures of traffic volume, traffic speed and traffic delay are compared under normal and adverse conditions. In adverse weather, arterial traffic volumes or flow rates were found to be between 6% and 30% lower than those under normal conditions, depending on road weather conditions and time of day (2, 3, 4, 5, 6). Speed reductions under inclement conditions ranged from 10% to 25% in rainy, wet pavement conditions and from 30% to 40% with snowfall and snowy/slushy pavement (2, 5).

Travel time delay on arterial roads increased by 11% in wet pavement conditions (6), and by more than 12% in the presence of precipitation, high winds, low visibility, or slick pavement (1). Travel time increased by as much as 50% during extreme weather events, such as widespread snowstorms (1, 2). For coordinated traffic signals start-up delay was 5% higher in wet pavement conditions, 23% higher in snowy pavement conditions (2), and 50% higher during snowstorms (5). The number of vehicle stops in adverse weather was 14% higher than stops in normal conditions.

Traffic operations on arterial roadways can be improved in inclement conditions by utilizing weather-related signal timing plans, which accommodate changes in driver behavior. Use of weather-related timing can increase speeds by 12% (3). These specialized plans may decrease travel times by 13% to 18% (2, 3), reduce average delay by 8% to 23% (3, 5), and decrease the number of vehicle stops by 6% to 9% (2, 5).

The literature documented volume, speed, and delay impacts associated with adverse weather on arterial roads. Poor weather and pavement conditions cause reductions in traffic volumes and speeds, and increased delay and congestion. This weather-related delay can be mitigated by implementing special signal timing plans that account for slower travel speeds and lower traffic flow rates or volumes.

REFERENCES

1. Mitretek Systems, "*Analysis of Weather Impacts on Traffic Flow in Metropolitan Washington, DC*", for presentation at the 2003 American Meteorology Society Annual Meeting, 2002.

2. Perrin, J. & P. Martin, "*Modifying Signal Timing during Inclement Weather*", University of Utah Traffic Lab, presented at the 2002 Institute of Transportation Engineers Annual Meeting, 2002.

3. Martin, P., et al, "*Inclement Weather Signal Timings*", University of Utah Traffic Lab, 2000, http://www.ndsu.nodak.edu/ndsu/ugpti/MPC_Pubs/pdf/MPC01-120.pdf.

4. Bernardin Lochmueller and Associates, et al., "*Anchorage Signal System Upgrade – Final Report*", 1995.

5. Maki, P., "*Adverse Weather Traffic Signal Timing*", Short Elliott Hendrickson, 1999, http://www.trafficware.com/documents/1999/00005.pdf.

6. Gillam, W. & R. Withill, "*UTC and Inclement Weather Conditions*", Leicestershire County Council & the University of Nottingham in the United Kingdom, presented at the Institute of Electrical and Electronics Engineers Conference, pp. 85-88, 1992.

7. Pisano, P., & L. Goodwin, "*Surface Transportation Weather Applications*",Federal Highway Administration (FHWA) in concert with Mitretek Systems, presented at the 2002 Institute of Transportation Engineers Annual Meeting, 2002.

8. FHWA, "*Traffic Control Systems Handbook*", Publication No. FHWA-SA-95-032, U.S. DOT, 1995.

9. Niittymaki, J. & Pursula, M., "Saturation Flows at Signal Group-Controlled Traffic Signals", Transportation Research Record 1572, pp. 24-32, 1997.