Impacts of Weather on Urban Freeway Traffic Flow Characteristics and Facility Capacity

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ABSTRACT

Adverse weather degrades the capacities and operating speeds on roadways, resulting in congestion and productivity loss. Without a solid understanding of the mobility impacts of weather on traffic patterns, freeway operators do not have the estimates of speed and capacity reductions to predict and simulate the impacts of traffic management strategies. Nearly all traffic engineering guidance and methods used to estimate highway capacity assume clear weather. However, for many northern states, inclement weather conditions occur during a significant portion of the year.

This paper describes how the authors quantified the impact of rain, snow, and various pavement surface conditions on freeway traffic flow for the metro freeway region around the Twin Cities. The research database includes four years of detector occupancy information from roughly 4,000 detectors, weather data over the same period from 3 automated surface observing systems (ASOS) at nearby airports, and two years of pavement surface condition data from 5 road weather information systems (RWIS) sensors in close proximity to the freeway system. Our research classifies the rain and snow events by their intensity levels and identifies how changes in precipitation intensity impacts the speed, headways, and capacity of roadways.

Results indicate that severe rain and snow cause the most significant reductions in capacities and operating speeds. Heavy rains (more than 0.25 inch/hour) and heavy snow (more than 0.5 inch/hour) showed capacity reductions of 10%–17% and 19%–27% and speed reductions of 4%–7% and 11%–15%, respectively. Speed reductions due to heavy rain and snow were found to be significantly lower than those specified by the Highway Capacity Manual (2000).

Key words: capacity—freeways—operating speeds—precipitation
INTRODUCTION

Adverse weather impacts on freeway traffic operations have become a growing concern for federal and state transportation agencies. Although it is obvious that inclement weather conditions reduce freeway capacities and slow traffic, little research has been conducted to quantify the impacts of rain and snow in the United States. In addition, the results obtained from studies outside the United States or rural freeway segments within the United States may not be applicable to urban freeway segments due to different roadway and driver characteristics. For example, the decrease in capacity for rural freeway segments of I-35 in Iowa during heavy snowfall may not be same as the urban freeway segments of I-35 in the Twin Cities.

The effect of inclement weather is important in northern metropolitan areas (e.g., Minneapolis/St. Paul, Denver, Salt Lake City, Detroit, and Buffalo), where appreciable snowfalls (more than 0.1 inch/hour) occur frequently (averaging 38, 35, 34, 39, and 62 days per year, respectively) and heavy snowfalls (more than 2 inches/hour) occur about 8, 7, 10, 7, and 12 times per year, respectively (United States Snow Climatology 2004). A precise estimate of capacity and speed reductions due to adverse weather can be useful in managing freeway systems using control, advisory, and road treatment strategies. Operational efficiency can therefore be maximized.

LITERATURE REVIEW

Chapter 22 in the Highway Capacity Manual (2000) provides information regarding speed and capacity reductions due to rain or snow of light and heavy intensities. The manual recommends between 0% and 15% reductions in capacities and 2%–14% and 5%–17% reductions in speeds due to light and heavy rains, respectively. Similarly, it recommends 5%–10% and 25%–30% percent reductions in capacities and 3%–10% and 20%–35% percent reductions in speeds because of light and heavy snow conditions. However, the manual does not consider these effects by precipitation intensities, which is important for freeway operators to optimize capacities and operating speeds due to anticipated precipitation (rain or snow) using intelligent transportation system (ITS) devices (e.g., dynamic message signs, ramp metering).

A study on I-35W (Ries 1981) estimated and compared capacities for rain and snow and concluded that the slightest amount of precipitation (also called a trace amount) either in the form of rain or snow reduces capacity by 8%. The study also found that snow caused 2.8% and rain caused 0.6% additional reduction in capacity for every 0.01 inch/hour increase in precipitation (measured in water equivalents) exceeding trace precipitation. Hall and Barrow (1988) examined the impacts of adverse weather conditions on the flow-occupancy relationship for Queen Elizabeth Way near Hamilton, Ontario. They found that the congested portion of the flow-occupancy curve was random due to lower headways, incidents, weaving sections, etc. Therefore, the authors used the uncongested portion of the flow-occupancy curve and concluded that adverse weather reduces the slope of the flow-occupancy linear relation, thereby resulting in reduced capacity. However, this research (Hall and Barrow 1988) did not classify rain and snow by intensity, and, further, obtained weather data from remote weather stations (greater than three miles). A study (Okamoto et al. 2004) on 19 sites of the Tokyo-Nagoya expressway in Japan categorized rainfalls intensity groups (0.0, 0.01–0.06, 0.07–0.12, 0.13–0.24, 0.25–0.48, and 0.49–0.96 cm/hour) instead of categorizing rains by light and heavy rainfall. This study concluded that freeway capacity was reduced by 0%, 5%, 11%, 14%, 25%, and 33%, respectively, for increasing precipitation intensities. Also, it emphasized that highway capacity can be better estimated using both rain intensity and design variables (curvature and grades).

Prior research (Brilon and Ponzlet 1996) concluded that wet roadway conditions cause a reduction of 9.5 km/h (6 mph) on four-lane highways, and 12 km/h (7.5 mph) on six-lane highways. As a result, Brilon
and Ponzlet concluded that freeway capacities were reduced by 350 vehicles per hour (vph) and 500 vph, respectively. However, the study was conducted in Germany, where there are no maximum speed limits on freeways and driver behavior and expectancies may differ from U.S. counterparts. Previous research (Smith et al. 2004) also emphasized the importance of rainfall intensity values in capacity and average operating speeds. They classified rain into none, light, and heavy (less than 0.01, 0.01–0.25, and greater than 0.25 inch/hour, respectively) and used Scheffé’s method to compare the statistical significance of differences in capacities and speeds for various intensity categories. A text by Neter et al. (2000) explains that Scheffé’s method uses an equal variance assumption when comparing the means of data groups, which may not be appropriate to adverse weather conditions.

Prior research by Ibrahim and Hall (1994) used dummy variable multiple regression analysis for rain and snow. This study concluded that light rain and snow resulted in similar reductions in speeds (3%–5%), but heavy rain caused 14%–15% and heavy snow caused 30%–40% reductions in speeds. Although Ibrahim and Hall defined rain and snow in light and heavy categories, they did not specify intensity ranges within these categories. Duration of weather data was also quite limited (they used only six clear, two rainy, and two snowy days). Liang et al. (1998) explored a 75-km (45-mile) rural section of I-84 and found that mean speed was reduced by 8 km/h (5 mph) and 19.2 km/hr (12 mph) for fog and snow events, respectively. Similarly, a study by Kyte et al. (2000) found that light rain or snow resulted in 50% higher reductions in speed, but heavy snow caused 20% lower speed reductions than the values stated in the Highway Capacity Manual (HCM 2000). Interestingly, the Kyte study used the same freeway section of I-84 (with a larger quantity of weather and traffic data). Both studies were limited to rural freeway sections, and did not classify precipitation by intensity.

**PROBLEM STATEMENT**

Although previous research efforts provide substantial evidence that speeds and capacities can be quantified for snow and rain, the following issues regarding adverse weather impacts on freeway capacities and speeds remain unaddressed and require further study:

- Much of the research pertaining to weather impact is obtained from studies outside the United States. Also, few studies were conducted on urban freeway segments. Thus, research should be conducted to expand the limited guidance about the impacts of weather on traffic flow for urban freeways, while they operate at or near capacity.
- It is necessary to relate measures of weather intensity to traffic flow, as there has been limited research on this issue.
- Prior studies used short-term data, primarily on heavy rain or snowfall. Long-term data sets are needed to quantify weather’s impacts on traffic flow and highway capacity.

**RESEARCH OBJECTIVES**

The main objective of this research was to quantify the relationship between weather and traffic flow variables, thereby providing an analytical basis for the future development of objective guidelines for practitioners. A second objective was to evaluate the adequacy of automated surface observing systems (ASOS) and road weather information systems (RWIS) data for such research. The authors set out to statistically assess reductions in operating speeds and capacities due to various intensities of rain and snow. Finally, this research compared findings with suggested values obtained from the Highway Capacity Manual (2000).
METHODOLOGY

The study area, a portion of the freeway road network of the Twin Cities that is managed by the Traffic Management Center, contains a number of roadside and in-pavement ITS field devices and includes several interstates and trunk highways with segments built to freeway design standards. Unlike prior research, this study used a larger dataset of four years (January 2000 to April 2004) of traffic and weather information, and categorized the impacts of precipitation (rain and snow) by intensities.

Data Collection

The study area has around 4,000 detector loops installed in freeway lanes that collect traffic data (volume and occupancy) for every 30-second time interval. These data were archived from the Traffic Management Center by the University of Minnesota, Duluth. Weather records were obtained from five RWIS sites operated by the Minnesota Department of Transportation (Mn/DOT) and three ASOS sites managed by the National Climatic Data Center.

The locations of detectors in the vicinity of RWIS environmental sensors were identified using maps obtained from the freeway operations division of Mn/DOT. To obtain the detectors near ASOS sites, a buffer region with a radius of 2.5 miles around ASOS sites was created using ArcView GIS 3.2. The detectors along the freeways and state trunk highways in the buffer region were selected for further analysis. The researchers also ensured that the selected detectors were not on highway segments with transitional geometries (e.g., lane drops, weaving sections, significant grades) to avoid biases in results due to road geometries. Table 1 shows the list of detectors and the detectors’ field lengths used to estimate flow, speed, and density.

Extraction of Traffic Data

As Mn/DOT does not maintain speed detectors on the freeway system, but instead estimates speeds using flow and occupancy data, the following equations were used to calculate speed, flow, and density for 10-minute time intervals using volume and occupancy data:

\[
\begin{align*}
\text{Flow} &= \text{Vehicles/Hour} = (\text{Vehicles/10 minutes}) \times 6 \\
\text{Density} &= \text{Vehicles/Mile} = (5,280 \times \text{Occupancy})/ (\text{Field length} \times 100) \\
\text{Speed} &= \text{Flow/Density}
\end{align*}
\]

(1) (2) (3)

Even though the detectors’ field lengths may also change over time due to variation in construction, design, and age of detectors, this research used a constant field length of detectors to compute flow, speeds, and density (Mn/DOT did not maintain field length history for each detector). While this limitation may introduce a few errors, speed and flow measurements at the same detector were found to be consistent over time. Therefore, as long as comparisons were made for the same detectors with or without the effects of weather, relative capacities and speeds should be consistent for the analysis.
Table 1. List of selected detectors and their field lengths

<table>
<thead>
<tr>
<th>RWIS site</th>
<th>Detector location</th>
<th>Detector ID</th>
<th>Field length (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>330.84</td>
<td>I-35 and Minnetonka Blvd</td>
<td>1874</td>
<td>23.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1875</td>
<td>27</td>
</tr>
<tr>
<td>330.85</td>
<td>I-35 and Minnesota River</td>
<td>257</td>
<td>24.5</td>
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<tr>
<td></td>
<td></td>
<td>267</td>
<td>23.5</td>
</tr>
<tr>
<td>330.86</td>
<td>I-494 and I-94</td>
<td>2953</td>
<td>33.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2864</td>
<td>27.4</td>
</tr>
<tr>
<td>330.88</td>
<td>I-35 E and Cayuga St. Bridge</td>
<td>2462</td>
<td>24.2</td>
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<tr>
<td></td>
<td></td>
<td>2391</td>
<td>23.8</td>
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<tr>
<td>330.89</td>
<td>I-494 and TH-110</td>
<td>2879</td>
<td>18.9</td>
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<tr>
<td></td>
<td></td>
<td>2940</td>
<td>24</td>
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</table>

<table>
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<tr>
<th>ASOS site</th>
<th>Detector location</th>
<th>Detector ID</th>
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<tr>
<td>Minneapolis St. Paul International Airport</td>
<td>Nicollet Ave (I-494)</td>
<td>890</td>
<td>21.18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>891</td>
<td>20.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>893</td>
<td>18.75</td>
</tr>
<tr>
<td></td>
<td>TH 13</td>
<td>3273</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3298</td>
<td>14.3</td>
</tr>
<tr>
<td></td>
<td>TH 77 and Minnesota River</td>
<td>3281</td>
<td>20.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3279</td>
<td>23.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3292</td>
<td>21</td>
</tr>
<tr>
<td>Minneapolis Crystal Airport</td>
<td>TH 169 and 63rd Ave</td>
<td>3005</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>TH 169 and Bass lake Road</td>
<td>3041</td>
<td>30.8</td>
</tr>
<tr>
<td></td>
<td>I-94 and Brooklyn Blvd.</td>
<td>971</td>
<td>26.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>972</td>
<td>26.97</td>
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<td></td>
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<td>974</td>
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<td>977</td>
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<td>27.22</td>
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<td></td>
<td></td>
<td>960</td>
<td>29.65</td>
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<tr>
<td>St. Paul Downtown Airport</td>
<td>I-94 and TH-52</td>
<td>3191</td>
<td>31.4</td>
</tr>
<tr>
<td></td>
<td>I-35E and Victoria Street</td>
<td>3240</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3431</td>
<td>28.7</td>
</tr>
</tbody>
</table>

Integration of Weather and Traffic Data

This step was accomplished by combining traffic and weather data with constraints of similar date, hour, and 10-minute intervals. Different datasets were prepared and analyzed for each pavement surface condition (dry, wet, and snow/icy) with traffic data at 10-minute intervals.

RWIS data (January 2002 to April 2004) were collected for 10-minute time intervals. Prior research (Hunt and Yousiff 1994; Smith and Ulmer 2003) concluded that time intervals between 5 and 15 minutes are appropriate to compute flow rates for an hour. This research assumed a 10-minute time interval to collect weather and traffic data for the similar time periods, because this time interval is sufficiently long to average out short-lived peaks in flow rates.

An analysis of the database containing pavement conditions and traffic data was conducted to investigate the flow-occupancy relationship for each pavement condition (dry, wet, and icy, as measured by the RWIS pavement sensors). The results obtained for each category were found to be similar to those shown in Figure 1. Figure 1 presents the flow-occupancy relationship during dry conditions. It is clearly evident that what is being observed is the flow-capacity relationship during two different sets of conditions. It is
likely that the set of points in the cluster to the left were recorded during dry weather. The cluster to the right exhibits lower maximum flow rates and, therefore, there were probably inclement conditions when these data points were collected. In other words, it appears the RWIS road sensors are providing false readings. Therefore, due to the prevalence of false readings, the use of the RWIS weather data was rejected and the analysis proceeded through the uses of weather information from ASOS sites.

![Image](144x392 to 447x642)

**Figure 1. Flow vs. occupancy for dry pavement surface conditions**

The weather data reported by ASOS sites are not organized by a specific time interval, but provide information on the amount of precipitation (inches/hour) and the start and end timings of precipitation. The weather data were integrated with the traffic data using a few rules. For example, if the weather data indicate that rain started at 7:23 a.m. and ended at 7:53 a.m., and the hourly precipitation was 0.2 inches. The time intervals for traffic data from 7:20 a.m. to 8:00 a.m. are assigned a precipitation intensity of 0.4 inches/hour (it actually rained 0.2 inches for 30 minutes, which equals and intensity of 0.4 inches/hour).

This research classified rain and snow by their intensities to understand their quantitative impacts on traffic flow variables, as shown in Table 2. This study used similar classifications of rain intensities recommended by Smith et al. (2004), except including the “Trace” category. Prior research did not classify snow events by their intensities and only categorized them by light or heavy snow. Thus, this research classified snow intensities based on the availability of an adequate dataset to assume appreciable speed-flow (parabolic) and flow-occupancy relationships (linear) for increasing snow intensities.

<table>
<thead>
<tr>
<th>Table 2. Snow and rain intensity classifications</th>
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</thead>
<tbody>
<tr>
<td><strong>Snow category</strong></td>
</tr>
<tr>
<td>None</td>
</tr>
<tr>
<td>Trace</td>
</tr>
<tr>
<td>Light</td>
</tr>
<tr>
<td>Moderate</td>
</tr>
<tr>
<td>Heavy</td>
</tr>
</tbody>
</table>
Flow-occupancy and speed-flow relationships were examined for various weather conditions. An example is shown in Figure 2 for clear weather. The lightly shaded data points in the dashed circle are the top 5% of flow measured for the weather condition. Similar analyses were conducted for varying rain and snow intensities.

**Estimation of Freeway Capacities**

This research used the maximum observed throughput approach, as described by Smith et al. (2004). Prior research (Smith et al. 2004) found that the mean of the highest 5% of the observed flow rates by a detector would represent the effective freeway capacity. This method of estimating capacity is chosen because it ensures that a freeway segment will be able to clear the maximum number of vehicles at least 95% of the time. This method also requires prior examination of the flow-occupancy and the speed-flow relationships to ensure that system demand was sufficiently met to reach congestion, as shown in Figures 2(a) and 2(b). Additionally, this approach fits with the primary objective of this research to determine the percent changes in freeway capacities and operating speeds due to various categories of rain and snow. The collected data were further modified by removing records containing data where very low occupancies (less than 5%) or very high occupancies (greater than 50%) existed. Low occupancies are expected only when the freeway is operating well below capacity and very high occupancies are only like to occur after total breakdown of flow caused by a freeway incident. Finally, the freeway capacity for each detector for a selected weather category (e.g., snow intensity between 0.11 and 0.5 inches/hour) was obtained by calculating the average of the top 5% flow rates.

**Estimation of Operating Speeds**

Previous studies (Hall and Barrow 1988; Ibrahim and Hall 1994) showed that the uncongested portion of speed-flow relationships could be used to compare the adverse weather impacts on average operating speeds. The uncongested portion of the speed-flow relationship was examined for the expected relationship (parabolic), as shown in Figure 2 (b). Also, traffic theory noted that speeds are relatively insensitive to the increasing flow rates for the uncongested portion (speed greater than 45 mph) until congestion is started. Therefore, to compare the changes in speeds due to each weather type and category, a weighted average of speeds (between 45 and 80 mph) by flow rates was calculated to compute the average operating speed. The lower limit of 45 mph was used as a minimum uncongested speed and an upper limit of 80 mph was considered to exclude the errors in the data for 10-minute intervals. This approach is more meaningful for this research because many discrepancies can be avoided using weighted mean values. For example, speed values that are many times higher might be indicated for 10-minute intervals during periods of low-volume conditions (e.g., off peak hours) for a particular weather intensity range (e.g., rain intensity between 0.01 and 0.25 inch/hour), and results might be misleading by just calculating an average of speed values.

Finally, when capacities and operating speeds were calculated for different snow and rain categories, the next step was to compare the differences using the Bonferroni method (significance level of $\alpha$ equal to 0.05). The Bonferroni method was selected because it does not require an assumption of equal variances among compared datasets.
Figure 2. Flow-occupancy (a) and Speed-flow (b) for clear weather conditions
RESULTS

Once the data were collected and examined for appreciable flow-occupancy and speed-flow relationships, freeway capacities and operating speeds were computed as discussed above. The next step was to calculate an average of freeway capacities and speeds for all detectors near an ASOS site for every weather category. These average values were then compared to evaluate the percent reductions in freeway capacities and speeds due to varying rain and snow intensities.

Rain

The rain data were divided into four categories (0, less than 0.01, 0.01–0.25, and greater than 0.25 inches/hour) for the analysis of the impacts of rain on freeway capacities and speeds. The database contained approximately 50,000, 1,400, 1,250, and 200 records for the above-defined rain categories by intensity values for each selected detector. Using these data, capacity and speeds were calculated, and statistical analyses were conducted as described below.

The freeway detector sites near the airports (Minneapolis-St. Paul International [MSP], Minneapolis Crystal [MIC], and St. Paul Downtown [STP]) were selected for this research. These sites showed average capacity reductions of 1%–3%, 5%–10%, and 10%–17%, for trace, light, and heavy rain conditions, respectively, as shown in Figure 3.

Statistical testing indicated that reductions in capacities were statistically significant when compared with no rain conditions, except trace precipitation conditions. Prior research (Ries 1981; Smith et al. 2004) indicated similar results for reductions in freeway capacities due to light rain conditions. However, this study showed lesser reductions in capacity (10%–17%) than the reductions of 25%–30% obtained by the study (Smith et al. 2004).

Similarly, speed reductions of 1%–2%, 2%–4%, and 4%–7% were found for freeway sites near the airports (MSP, MIC, and STP) for trace, light, and heavy rain, respectively. Statistical analysis showed that differences in speeds for light and heavy rain (0.01–0.25 and more than 0.25 inches/hour) were not statistically significant. Previous research (Smith et al. 2004) also found similar speed reductions (3%–5%) for both light and heavy rain (0.01–0.25 and more than 0.25 inches/hour) were statistically significant compared with clear weather conditions. In contrast, the differences in operating speeds during light and heavy rain (0.01–0.25 and more than 0.25 inches/hour) were not statistically significant. Thus, they concluded that heavy rain effects on operating speeds are similar to those of light rain.
Figure 3. Effects of varying rain intensities on capacities and speeds for freeway sites near the MSP (a), MIC (b), and STP (c) airports
Snow

Datasets on snowfall events were categorized into five categories of none, trace, light, moderate, and heavy (0, less than/equal to 0.05, 0.06–0.1, 0.11–0.5, and greater than 0.5 inches/hour, respectively). The database contained approximately 50,000, 900, 550, 300, and 125 records for these snow categories for each selected detector. Reductions in capacities and speeds were found, as shown in Figure 4.

Statistical analysis using the Bonferroni method indicated that capacity and speed reductions were statistically significant for each weather category when compared with no precipitation conditions. However, differences in capacities and speeds for light and moderate snow conditions were not statistically significant for many detectors.

The Highway Capacity Manual (2000) shows that light snow causes 5%–10% reductions in capacity, and this study shows reductions of 3%–5%, 6%–11%, and 7%–13% for trace, light, and moderate snow. Also, capacity reductions of 19%–27% for heavy snow (more than 0.5 inches/hour) compare with the 25%–30% reductions because of heavy snow, as recommended in the Highway Capacity Manual (2000).

Additionally, speed reductions of 3%–5%, 7%–9%, and 8%–10% for trace, light, and moderate snow, respectively, were obtained, which quantifies reduction in speeds better than recommended speed reductions of 8%–10% in the Highway Capacity Manual (2000) due to light snow only. In contrast, speed reductions of 11%–15% percent for heavy snow (more than 0.5 inches/hour) significantly differ from the recommended speed reductions (25%–35%) in the Highway Capacity Manual (2000). This larger variation in speed reductions for heavy snow from this study can be attributed to differences in freeway locations, driver familiarity, moderate occurrences of snowstorms, or better winter maintenance activities in the Twin Cities region. Thus, this difference indicates that reductions in speeds due to heavy snow might be overstated in the Highway Capacity Manual (2000) for urban freeway segments.
Figure 4. Effects of varying snow intensities on capacities and speeds for freeway sites near the MSP (a), MIC (b), and STP (c) airports.
Summary of Findings

The results of this research were compared with the current information found in the Highway Capacity Manual (2000), because it is important for traffic operators to understand the extent of reductions in capacity and speeds for urban freeway locations due to varying rain and snow intensities. Results indicate that the manual underestimates or overestimates the impacts, as listed below:

- This research found that light rain (0.01–0.25 inches/hour) has a significantly greater impact (5%–10%) on capacity as opposed to no reductions mentioned in the Highway Capacity Manual (2000).
- The results indicate that reductions in operating speeds due to light rain are comparable with recommended reductions in the Highway Capacity Manual (2000). However, the reductions in operating speeds due to heavy rain may be overstated in the manual.
- Light and moderate snow categories show almost similar capacity and speed reductions, which are similar to reductions by light snow as stated in the Highway Capacity Manual (2000). Thus, these two categories can be merged into one category.
- Heavy snow shows similar reductions (19%–28%) in capacity as stated in the Highway Capacity Manual (2000). However, speed reductions due to heavy snow obtained from this study were significantly lower (19%–25%) than those recommended by the manual.

CONCLUSIONS

Overall, the results of this analysis show how various weather and weather intensities affect traffic flow variables. This research shows that impacts of rain and snow on freeway traffic operations in urban regions are different than recommended in the Highway Capacity Manual (2000). Additionally, this research concluded that the quality of weather data obtained from RWIS sensors was not appropriate for the analysis. Thus, this research provides additional guidance to freeway traffic operators regarding quantitative estimates of capacity and speed decreases due to varying intensities of rain and snow.
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