Identifying and Assessing Key Weather-Related Parameters and Their Impacts on Traffic Operations Using Simulation

(6000Words+5 Tables*250+1 Figure*250=7500 words)

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Abstract

Adverse weather conditions can have a dramatic impact on the operations and quality of traffic flow. With the advent of advanced traffic management systems (ATMS), there is an opportunity to develop traffic management strategies that seek to minimize the negative weather-related impacts on traffic operations. Although simulation models are widely used in the evaluation of various traffic management strategies, its application to evaluate ATMS strategies under adverse weather conditions needs to be explored.

This paper introduces a study conducted at Traffic Research Laboratory to identify how weather events impact traffic operations, assess the sensitivity of weather-related traffic parameters in the CORridor SIMulation (CORSIM) traffic microsimulation model, and develop guidelines for using the CORSIM model to account for the impacts of adverse weather conditions on traffic operations.

A high-level conclusion from this project is that CORSIM can adequately be used to model the impacts of weather events on traffic operations. This conclusion is based on the fact that a majority of the generic weather-related parameters identified are currently available in CORSIM, and that the key weather-related parameters are adequately sensitive in producing model outputs in-line with that expected from adverse weather.

INTRODUCTION

Background

Inclement weather changes road environment and driving behaviors. Those changes slow down the traffic and reduce roadway capacities. Lower speed and reduced capacity translate to extra traffic delays and therefore lower the quality of traffic operations. Goodwin points out that there are 10-50 percent more delays under inclement weather conditions compared to ideal conditions (*1*). In addition, it is estimated that approximately 21 percent of crashes happened during inclement weather (*2*).

With the advent of advanced traffic management systems (ATMS), there is an opportunity to develop traffic management strategies that seek to minimize the negative weather-related impacts on traffic operations. For instance, a weather event that reduces the average operating speeds on an arterial can be mitigated by quickly shifting the offset of coordinated intersections. Perrin's research indicates that traffic signal re-timing for inclement weather could result in 18 percent lower travel times, nine percent fewer stops and 28 percent less delay compared with the existing timing plan (*3*).

Those strategies usually require a detailed and accurate method to understand the relationship between weather events and traffic operations. A microscopic simulation tool can model individual vehicles on a roadway network, typically on a second-by-second basis or less. Simulation models have the benefit of being able to model driver behaviors, complex roadway geometries, traffic control devices, and vehicle configurations that are beyond the limitations of a macroscopic Highway Capacity Manual-style analysis (*4*).

However, modeling microscopic driver behavior is difficult under ideal weather conditions, let alone under adverse weather conditions. Little research has been conducted on how weather events impact driver behavior logic such as lane changing and vehicle following, both of which are crucial to the accuracy of a microscopic traffic simulation model. In addition, there are a vast number of user-input parameters within simulation models that can be changed. Knowing which key parameters within a simulation model should be changed under various weather conditions would greatly aid in the development of weather-responsive traffic management strategies. Therefore, this paper focuses on identifying and assessing key weather-related parameters and their impacts on traffic operations using the CORridor SIMulation (CORSIM), a traffic simulation package sponsored by Federal Highway Administration (FHWA) (*5*).[1]

Study Objective

The objectives of the study were to identify how weather events impact traffic operations, assess the sensitivity of weather-related traffic parameters in CORSIM, and develop guidelines for using the CORSIM model to account for the impacts of adverse weather conditions on traffic operations. More specifically, this study was tasked to do the following:

- Research the relationship between weather events and traffic operations.
- Identify which types of simulation parameters could be affected by weather events.
- Conduct a sensitivity analysis on selected CORSIM simulation parameters to identify the key weather-related parameters that most affect traffic operations.
- Develop basic guidelines on how weather events can be modeled using CORSIM.
- Identify gaps in the CORSIM model regarding modeling weather events.
- Recommend key parameters needing further research to quantify the proper values under adverse weather events.

It is realized that how the weather events affect simulation parameters is very important. The complexity of this subject and budget constrain of the project limited our efforts to literature search and some common sense analysis. We proposed this subject should be further studied in the future (76).

[1] It should be emphasized that CORSIM is not the only microscopic software. The reader should follow FHWA's guidelines to choose the appropriate simulation software for their specific project (7). This should apply to any weather related simulation modeling as well. In addition, we did not test other simulation software, this does not mean that other simulation package does better/poorer job than CORSIM on this regard.

This paper is a condensed report on the major findings of the study. For the interest of most TRB readers, the sensitivity analysis and the guidelines on modeling weather events in CORSIM is discussed in this paper. The interested reader may contact the Traffic Research Laboratory (TReL) for a copy of the full report (*6*).

General Relationship Between Weather Events and Traffic Operations

To better understand the relationship between weather events and traffic operations, the term "traffic operations" is divided into two subparts: traffic parameters (or characteristics) and quality of traffic flow. Traffic parameters are quantitative values that are typically used as inputs to a traffic analysis model. These parameters account for how drivers and their vehicles interact and respond to the roadway network, including the response to other vehicles, traffic control devices, roadway geometry, weather, and other environmental conditions. The quality of traffic flow is the output from a traffic analysis model and is calculated using measures of effectiveness (MOEs). MOEs measure the overall performance of the transportation system, which is directly related to how well drivers and their vehicles respond to the surrounding factors (traffic parameters). Common MOEs include average speed, average density, average delay per vehicle, and number of stops.

Conceptually, in traffic operations, variations in traffic parameter cause changes in the MOEs. Weather events alter the traffic parameters and, therefore, weather events deteriorate the MOEs in the traffic operations.

Literature Review on Weather and Traffic Parameters

Past research on the simulation of traffic operations under adverse weather conditions can be organized into two main groups: those focusing on the link between weather events and traffic parameters (i.e., heavy rain reduces free flow speeds by 30 percent), and those focusing on the link between weather events and the quality of traffic flow (i.e., heavy rain increases delays by 40 percent). This review focuses on the former, as knowing the impact of weather events on traffic parameters is the key to using microsimulation to model weather events.

Very little research focusing on the roadway environment impacts are found. This lack of information is probably due to the difficulty in understanding why motorists respond to a weather event (i.e., is a reduction in free-flow speed really due to a reduction in pavement friction or reduction in visibility?). The literature review yielded information on the impacts of weather events on the following traffic parameters: free flow speed, start-up lost time, saturation headway, and traffic demand.

A number of studies have shown that adverse weather events reduce the mean free-flow speed, which is defined as the desired speed of drivers in low volume conditions and in the absence of traffic control devices (*4*). Kyte, *et al.* (7) studied the free flow speed on a rural freeway during wet and snow-covered pavement, high wind (greater than 24 km/h), and low visibility conditions (less than 0.28 km). They found the free flow speed reduced by approximately 8-15% during wet pavement, snow-covered pavement, during high wind or low visibility. During a combination of the above scenarios, the reduction could be as high as 38%. May (*9)* showed the approximately the same results. Lamm, *et al.* (10) found that on a study of two- lane rural highways, drivers did not adjust their speeds much under light rain or wet pavement, but they did when visibility becomes obstructed, such as during a heavy rain. Ibrahim and Hall (*11*) also found that in Canada free flow speed was noticeably decreased during heavy rain (up to 10 km/h reduction) and snow (up to 50 km/h reduction). Perrin, *et al.* (*12*) directly measured 10% free flow speed reductions on wet pavement, 25 percent on wet and slushy pavement and 30 percent on pavement with slushy wheel paths on signalized intersections.

Start-up lost time is defined as the additional time consumed by the first few vehicles in a queue at a signalized intersection beyond the saturation headway (*4*). This additional time is due to the time to react to the start of the green phase and for the vehicle to accelerate from a stopped position. Under ideal conditions, the HCM recommends using 2.0 seconds for start-up lost time. Maki (*14*) and Perrin, *et al.*, (*12*) measured a start-up lost time increase from 25 to 50 percent during inclement weather.

Saturation headway, or discharge headway, is defined as the average headway between vehicles occurring after the fourth vehicle in a signalized intersection queue and continuing until the last vehicle in the initial queue clears the intersection (*4*). Saturation headway (sec/veh) is the inverse of saturation flow rate (veh/sec or veh/hr). The HCM recommends a discharge headway of 1.9 seconds under ideal conditions. Perrin, *et al.*, (*12*) Maki (*14*) Botha and Kruse (*16*) measured an increase of 6 to 20 percent in saturation headway during inclement weather.

Maki (*14*) measured a reduction in traffic volumes of 15 to 30 percent during adverse weather conditions when compared to ideal weather conditions. The reduction in traffic volumes is attributed to various reasons, including shifting work arrivals and departures, and an avoidance of discretionary trips. Traffic demand changes are highly dependent on the severity of the weather conditions and the driver's comfort in adverse weather conditions. For example, drivers in Chicago will react differently to a snowstorm than drivers in Miami do.

Identifying Simulation Parameters Affected by Weather Events

The above literature review documents a number of traffic parameters found to be impacted by weather events. However, there are numerous other microsimulation parameters that have not been measured empirically but are logically believed to behave differently during adverse weather. Table 1 lists the range of potential simulation parameters that may be used to model adverse weather conditions in a microsimulation model. These parameters are categorized into five groups: road geometry, traffic control and management, vehicle performance, traffic demand, and driver behavior. The possible impact of these parameters by weather events is described in the table, along with a description of whether and how the parameter is handled by CORSIM. The table functions as a basis for the parameters in this study and will be discussed in the next section.

CORSIM SENSITIVITY ANALYSIS

The purpose of the sensitivity analysis was to determine which weather-related traffic parameters have the greatest impact on the quality of traffic flow. Identifying the most sensitive weather-related parameters is needed for the development of the guidelines for using CORSIM in modeling adverse weather conditions in the next section and for the identification of simulation parameters needing further empirical research.

MOEs used to quantify the effects of parameter changes on the quality of traffic flow are defined and shown in Table 2.Although some of the parameters may have a major impact on MOEs, they are already known to be very sensitive parameters. For example, reducing the number of lanes from three to two due to a lane blockage, changing a signal control to emergency flashing due to a power outage, or reducing the traffic demand by 20 percent due to a major snowstorm all have major impacts on the quality of traffic flow. Such events are easily discernable as having a major affect on traffic flow, but the more subtle changes in car following and lane changing behavior are not quite as obvious and thus are the focus of this sensitivity study.

For those parameters included in the sensitivity analysis (Table 3), each is tested at the default value (baseline), along with four other values representing incrementally more conservative driver behavior, as would be the case with increasingly severe weather conditions. The sensitivity study focused on changing one parameter value at a time, regenerating the MOEs, and comparing the new MOEs to the baseline case. As a result, the sensitivity tests are "one-sided" in that they only tested values to one side of the default value. However, a few parameters are tested on both sides because it is not clear which side represented the more conservative driver behavior (e.g., Anticipatory Lane Change Distance).

It should be emphasized that our entire study is based on change one parameters at a time. Additional efforts could have been added to do a multiple parameter sensitivity analysis. Due to the budget constrains of this project, this option was not carried out. Although the later may generate more realistic and more interesting results, we think our approach still be able to help us to identify key parameters.

The baseline networks were assumed to have ideal conditions as defined in the HCM (*1*), including 12-foot travel lanes, level grade, no horizontal curves, and no heavy trucks. Also, an analysis period of one hour was used for all simulation runs.

A number of different geometric scenarios, or networks, were developed to test the sensitivity of the parameters under various roadway configurations using the FRESIM model (used for modeling freeways) and the NETSIM model (models surface streets) in CORSIM. For example, a parameter may not show any sensitivity on a basic freeway segment, but show high sensitivity on a short weaving area. The networks developed for the FRESIM and NETSIM sensitivity analysis are shown in Table 3 and Table 4.

FRESIM Analysis Methodology

All freeway segments are assumed to have a free flow speed of 70 mi/hr, while all on- and off-ramps are assumed to have a free flow speed of 45 mi/hr. For each roadway network, the sensitivity of four different congestion levels is tested by incrementally increasing the entering volume (or traffic demand) on the freeway. The HCM estimates the capacity of a basic freeway segment with a free flow speed of 70 mi/hr to be 2400 veh/hr/lane assuming ideal conditions (*4*). In FRESIM, the upper bound of capacity can be limited by using the Minimum Separation for Generation of Vehicles parameter. For the sensitivity tests, this value is fixed at 1.5 seconds (default is 1.6 seconds), which equates to a maximum entering volume of 2400 veh/hr/lane. The four congestion levels tested were low (1000 veh/hr/lane), medium (1500 veh/hr/lane), high (2000 veh/hr/lane), or very high (2400 veh/hr/lane).

NETSIM Analysis Methodology

For each test network, the sensitivity to four different congestion levels was tested by incrementally increasing the entering volume (or traffic demand) on the entry links. The HCM does not provide guidance on the segment capacity of arterial streets, mainly because the capacity on arterials is determined by traffic signals and not the segment characteristics between traffic signals. However, it is clear that the segment capacity of arterials is generally lower than on freeways due to the lower free flow speeds and increased friction effects (driveway access, on-street parking, narrow lanes, turning vehicles, etc.). Thus, a capacity of 2000 veh/hr/lane was assumed for the basic arterial test networks, based on a free flow speed of 45 mi/hr. This is close to the HCM intersection ideal capacity as well (1900 veh/hr/lane when granted the right of way all the time). Even though this is just an estimate, it is important to remember that the purpose of this study is to test relative sensitivity of different parameters and not to determine the absolute value of capacity or other MOEs. For the single suburban intersection, single urban intersection, and system network, the entering demand volume on all approaches was incrementally increased to achieve V/C ratios of approximately 0.6, 0.8, 1.0, and 1.1. The highest volume scenario was limited to a V/C ratio of 1.1 because ratios higher resulted in queue spillback beyond the limits of the network and, thus, the MOEs would not reflect the extent of the congestion.

Data Processing Procedure

Overall, approximately 45,000 individual CORSIM simulation runs are processed for the sensitivity analysis: 25,000 in FRESIM and 20,000 in NETSIM. The need for the large number of runs becomes clear when considering the following for the scenarios:

- **Parameters** - 18 total FRESIM and 23 total NETSIM parameters were tested.
- **Parameter values** - each parameter was tested using the default value and four additional values representing incrementally more conservative driver behavior as would be expected under adverse weather.
- **Networks** - each parameter was tested on up to ten FRESIM networks (basic one, two and three lane segment networks; two and three lane merge, diverge, and weaving networks; and a freeway system network). Each NETSIM parameter was tested on up to five networks (two lane basic, three lane basic, suburban intersection, urban intersection, and arterial system network).
- **Congestion level** - each network was tested at four different congestion levels for both FRESIM and NETSIM, as discussed in previous sections.
- **Simulation runs** - Ten simulation runs were performed for each scenario to take into account the stochastic variations of the simulation model.

Due to the large number of simulation runs, the process of creating the CORSIM input files and summarizing the output files was largely automated. The data processing was completed through four steps as described below.

1. Create the CORSIM input files (TRF files). A customized script (in both Visual Basic and C++) is created that automatically generated new TRF files by taking a base TRF file and changing one or more parameters at a time. As a result, thousands of TRF files could be created with a single Do Loop command, changing the value of one or more parameters multiple times. A spreadsheet is created with all the desired network-congestion level-parameter value combinations, which is read by the script to create the TRF files.
2. Run CORSIM ten times for each input file and create an output file summarizing the relevant MOEs from the ten runs. The multi-run function available in TSIS 5.1 (the simulation environment that includes CORSIM) is used to run CORSIM ten times for each input file. The Output Processor function available in TSIS is also used

to create an output file in Excel format summarizing the mean and standard deviations of the MOEs for the ten runs. The random number seeds are changed for each of the ten runs.

3. Copy all relevant MOE data from the output files into a single database. Customized Visual Basic macros are created that copied the relevant MOE data from the thousands of output files into two databases, one each for the FRESIM and NETSIM runs. The macros also calculated t-values to test the statistical significance of the results (at a 95 percent confidence interval).
4. Create a one-page summary of MOEs for each parameter-network combination. One-page summaries for each parameter-network combination (e.g., sensitivity of the car-following factor on basic two-lane freeway) are created using customized Visual Basic macros that read the values from the database created in Step 3.

The end product of the data processing was a one-page summary for each parameter-network combination (e.g., medium congestion level on basic one-lane network). These one-page summaries provided a great tool for visually evaluating the sensitivity of each parameter. A sample of the summary is shown in Figure 1.

Sensitivity Analysis Results

Table 3 **s**ummarizes the general sensitivity of each freeway parameter tested based on the sensitivity group and general level of sensitivity. Low, medium, or high sensitivity levels are based on an evaluation of the overall sensitivity of the parameter values in each network-congestion level scenario. These labels are based on relative differences between the parameters and not an absolute sensitivity level. The sensitivity groups of “expected”, “inconsistent”, or “no effect” were based on the general expectation that the MOEs would degrade consistently when changing the parameter values to represent more conservative driver behavior. Those parameters in the “expected” group means the one-sided parameter changes resulted in an expected degradation in MOEs, while parameters labeled “inconsistent” means the MOEs occasionally improved and occasionally degraded in an inconsistent manner. “No effect” means changing the parameter had no measurable effect on the MOEs. A number of general trends are observed by evaluating the summary pages in Appendix A of reference (6) and Table 3.

- Most of the parameters showed no sensitivity at the lower congestion levels (entering volumes of 1000 and 1500 veh/hr/lane). In only a few instances do the most extreme sensitivity values produce a statistically significant difference (at a 95 percent confidence interval) from the default values.

- An entering volume of 2000 veh/hr/lane (approximate V/C ratio of 0.83) experienced more sensitivity within the parameters than that shown with 2400 veh/hr/lane (approximate V/C ratio of 1.0). This trend is likely caused because the at-capacity condition allowed less variability in driver behavior due to more closely spaced vehicles and less maneuverability.

- Average delay was the most sensitive MOE. Average speed and average density, were equally sensitive and less sensitive than average delay, while throughput and vehicle-miles of travel were the least sensitive.

- Overall, the parameters became more sensitive as the network type became more complex. Thus, the system network generally experienced more sensitivity than the basic three-lane network, which in turn experienced more sensitivity than the basic one-lane network.

The one-page summaries for each NETSIM parameter-network scenario are displayed in Appendix B of reference (6). Table 4 summarizes the general sensitivity of each network parameter tested based on the sensitivity group and general level of sensitivity. The evaluation of the summary pages resulted in the following trends:

- The number of lane changes was the most sensitive MOE relative to the other MOEs. Average delay and average speed both showed moderate sensitivity, while throughput and vehicle-miles of travel displayed the least sensitivity relative to the other MOEs.

- For the basic segment networks, the parameters became increasingly sensitive as the V/C ratio increased. However, like the freeway parameters, the arterial parameters were generally slightly more sensitive at the just-below capacity (V/C ratio around 0.8) than the at-capacity conditions. This trend is thought to occur because the at-capacity condition allowed less variability in driver behavior due to more closely spaced vehicles and less maneuverability.

- For the intersection networks, the MOEs degraded dramatically when the V/C ratio approached 1.0.

Table 3 and Table 4 summarize the tested parameters that may have an impact on the MOEs for FRESIM and NETSIM, respectively. One interesting result of the study was that a number of parameters had little or no effect on the MOEs:11 of the 15 lane changing parameters in NETSIM showed no sensitivity. These non-sensitive parameters should be the focus of further research because it is not clear why many of them did not have a greater impact on the MOEs. However, this study does not prove that these parameters have no sensitivity whatsoever. In addition to the non-sensitive parameters, a number of FRESIM lane changing parameters had an "inconsistent" impact on the MOEs. These parameters should also be the focus of more-detailed research to further determine how they function within the various model algorithms and exactly what impact they have on traffic operations.

Table 3 and Table 4 also summarize those parameters that had both an expected effect on the MOEs and are categorized as either having a medium or high effect on the MOEs (relative to the other parameters). Those tables are important because they identify the key weather-related driver behavior parameters that should be altered when trying to model weather events in CORSIM. As stated earlier, this study does not recommend specific values to use for these parameters during various weather events, but it does identify these parameters as the most sensitive and therefore should be the focus when calibrating a model for a specific weather event. A traffic analyst should first focus on the parameters with a high sensitivity level, and then if further calibration is needed could use those with a medium sensitivity level.

Due to the large number of networks and variables tested in the sensitivity study, a number of additional findings and recommendations are made that are somewhat unrelated to the task of determining the most sensitive parameters, but nonetheless are thought to be important for CORSIM users in general. These findings can be summarized as follows:

- The Minimum Separation for Generation of Vehicles parameter is a useful parameter in calibrating the capacity of basic freeway segments, but users should realize that changing the driver behavior parameters (specifically the Car Following Sensitivity Multiplier) can also limit the freeway capacity in some cases.
- The Minimum Separation for Generation of Vehicles parameter is only available on freeways (FRESIM) and not on surface streets (NETSIM). As a result, arterial volumes up to 2700 veh/hr/lane can be modeled in NETSIM, which is not realistic for arterials. However, the capacity will likely be limited by traffic signals on arterials, but nevertheless traffic analysts should be careful to model realistic traffic volumes on arterial streets.
- In FRESIM, the Maximum Emergency Deceleration and Leader's Maximum Deceleration as Perceived by Follower parameters are identical parameters, as they produced exactly equal results in the sensitivity analysis.
- Changing the distribution of speeds for the Free Flow Speed Multiplier is not recommended because they produced inconsistent (and unrealistic for a distribution with very low standard deviation) impacts on the MOEs. In addition, changing the distribution of Discharge Headways and Start-Up Delays in NETSIM is also not recommended because altering them had no effect on the MOEs.
- Future consideration should be given to widening the allowable range for the Deceleration of Lead Vehicle and Deceleration of Following Vehicle parameters given that they are two of the only NETSIM lane changing parameters that have a quantifiable impact on MOEs. Currently, the allowable range is 10 to 15 ft/sec/sec with a default value of 12 ft/sec/sec.
- The Highway Capacity Manual recommends a default mean start-up delay of 2.0 seconds, which is defined as the extra time consumed by the first few vehicles in a signalized intersection queue. In the absence of localized field data, it is recommended that CORSIM users use this value of 2.0 seconds, which means the default Mean Start-Up Delay value should be changed to 1.3 seconds (currently 2.5 seconds) because 0.7 seconds of start-up delay is already "hard-coded" into the model for the second and third vehicles in the queue.

GUIDELINES FOR MODELING WEATHER EVENTS IN CORSIM

The purpose of this section is to provide practical guidelines for modeling the effects of adverse weather on a roadway network using CORSIM. The guidelines presented here are based on *Guidelines for Applying Traffic Microsimulation Modeling Software* (*17*), a FHWA guidance document on the proper development and application of microsimulation models. The guidance document shows the seven-step process recommended in the guidelines for developing a microsimulation model and how to apply the model to analyze various alternatives:

1. Scope the project,
2. Collect field data,
3. Develop the base model,
4. Check the model for errors,
5. Calibrate the model to local conditions,
6. Analyze alternatives, and
7. Produce a final report.

Even though this seven-step process was not designed specifically for modeling weather events, a traffic analyst intent on modeling weather effects should not forget the importance of the above seven steps. The steps set the foundation for the development and application of an accurate and valid CORSIM model regardless of whether a weather event is being modeled. However, there are a few steps in the process that a traffic analyst should approach slightly differently when modeling adverse weather in CORSIM. These differences are highlighted in the remainder of this section.

Step 1 – Scope Project

It is important to define the project scope in any application of a microsimulation model. However, when using the model to include the effects of adverse weather, a few additional considerations are necessary, including:

- Does the selected microsimulation software package have an adequate number of weather-related parameters that can be appropriately adjusted to accurately model the weather impacts?
- What type of weather event(s) will be modeled (e.g., snow, rain, fog, sun glare, or some combination)?
- What is the severity of the weather event(s) being modeled (e.g., two inches or two feet of snow)?
- What is the duration of the weather event(s) being modeled (e.g., will it last the entire simulation period, or just for a short period)?
- What is the extent of the weather event(s) being modeled (e.g., will it cover the entire simulation model area, or just a portion)?

These are important questions that should be answered and agreed on by all parties involved with developing and reviewing the model before beginning the actual model coding. The first question listed may be the most important of the entire project because it determines whether the selected software package is able to successfully include the effects of adverse weather.

Step 2 – Data Collection

In light of this, if field data collection during the weather event(s) being modeled is not possible or practical, then traffic analysts could use the findings of past research (see Literature Review subsection) as a starting point when altering traffic parameters to more accurately reflect weather events.

Step 3 – Base Model Development

This step includes the initial setup and coding of the microsimulation model and inputting the data collected in the field into the model. When including a weather event in the model, the following additional steps are necessary during the base model development:

1. Identify which traffic parameters are impacted by the weather event.
2. Determine the appropriate values for these weather-impacted parameters either by (in order of preference): field data collection, findings of past research, or engineering judgment.

For the first step, Table 1 should be referenced to identify which traffic parameters are generally impacted by weather events and how and whether CORSIM addresses the parameter. Then, Tables 4 and 5 should be referenced to identify the most sensitive weather-related parameters in FRESIM and NETSIM, respectively.

Once the weather-impacted CORSIM parameters are selected from Tables 1, 4, and 5, then the proper value for them needs to be determined. The best option is to collect weather-related traffic data at the site being modeled; however, if resources and budget do not allow this, then using the results of past research is the next best option. It is important to only use past research results that was collected on roadway facilities, congestion levels, and other field characteristics similar to the site characteristics being modeled. Finally, in the absence of field data collection and past research, engineering judgment can be used to estimate the correct parameter values. For example, it is difficult to collect lane changing parameter data in the field, and there are no past studies regarding lane changing behavior in adverse weather. Thus, in this case, changing the lane changing parameters to represent slightly more conservative driver behavior (as would likely happen in adverse weather) would probably be a reasonable choice based on engineering judgment.

While Table 1 shows the range of traffic parameters impacted by weather events, it may not be possible or practical to change all of the impacted parameters due to various reasons. With these limitations in mind, a handful of key traffic parameters have been identified, based on past research and the sensitivity study summarized in this report, to be the most important weather-impacted parameters, in terms of their impact on MOEs. Even when resources and budgets are tight, these CORSIM parameters at a minimum should be altered to appropriate values when modeling weather events:

- Mean Free Flow Speed (freeways and arterials),
- Car Following Sensitivity Multiplier (freeways),
- Mean Discharge Headway (signalized intersections),
- Mean Start-Up Delay (signalized intersections), and
- Traffic demand, in terms of reduced demand during more severe weather events (freeways and arterials).

Step 5 – Model Calibration

Model calibration is an iterative process where the model parameters are altered until the model results (MOEs) adequately match the field measured MOEs. Calibration is needed because often the default parameter values do not result in model MOEs close to those measured in the field. This is especially true when including a weather event in the model, as all microsimulation software packages assume ideal weather conditions in the default values. Even after adjusting the weather-impacted parameters to appropriate values as described in the previous section, calibration is likely still needed to ensure the best model parameters are used.

The most accurate way to calibrate a model that includes adverse weather would be to collect field MOEs during the weather event being modeled. However, this can be a difficult task given finite resources and budget. If field MOEs are not collected during the modeled weather event, then a secondary method for calibrating the weather-related model is possible. In this method, the first step is to develop and calibrate the model assuming ideal weather conditions. After developing a calibrated ideal-weather model, then only the weather-related parameters would be adjusted to account for the adverse weather. The weather-related parameters would be adjusted based on the discussion in the previous section (i.e. adjustments based on field data, then past research, and finally engineering judgment). While such an approach would not produce a model specifically calibrated to the weather event, it would at least produce a reasonably adequate adverse-weather model because it was already calibrated to ideal weather and only a few parameters were adjusted thereafter.

SUMMARY

This paper summarizes the methodologies, findings, and conclusions for the sensitivity study and suggests guidelines to model weather events using traffic simulation. A high-level conclusion from this study is that CORSIM can adequately be used to model the impacts of weather events on traffic operations. This conclusion is based on the fact that a majority of the generic weather-related parameters identified are currently available in CORSIM, and that the key weather-related parameters are adequately sensitive in producing model outputs in-line with that expected from adverse weather.

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List of Figures

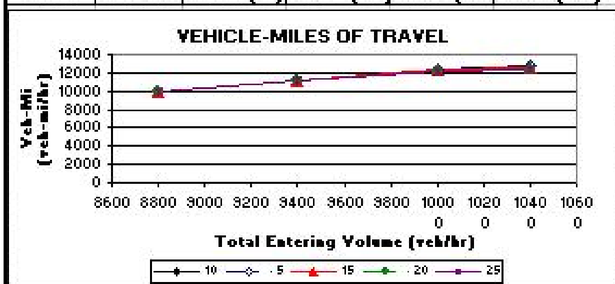
Figure 1 Sample One Page Summary Report

Sensitivity of Time to React to Sudden Deceleration of Lend Vehicle on System Network

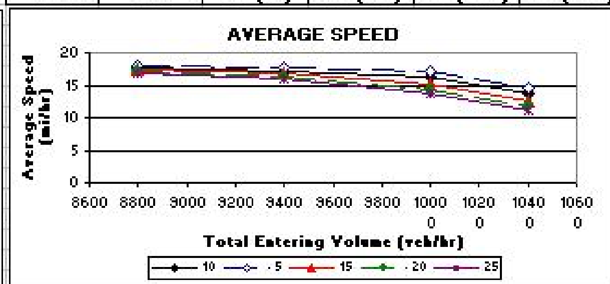
General Information		**Test Network**		
Parameter Name:	Time to React to Sudden Deceleration of Lead Vehicle	Analysis Area: Major street approaches		
Parameter Type:	Car Following/Lane Changing	Traffic Signals:		
Test Network:	System	Coordinated		
Model:	Netsim	Semi-actuated		
Input Level:	Network	120 sec. Cycle		
TRAFED Location:	Network menubar->"Netsim Setup"->"Lane Changes (Driver Behavior)" tab		Major St.	Minor St.
Record Type/Field(s):	Record Type 81/Field(s) 2	Lanes:	2 Th/1 LT	1 Th/1 LT
Default Value:	10	Link Length:	2000 ft	2000 ft
Sensitivity Range:	5, 10, 15, 20, 25	Free Flow Speed:	45 mph	30 mph
Definition:	The amount of time for a driver to begin decelerating after the leader begins a sudden deceleration due to perception/reaction time.			

Results

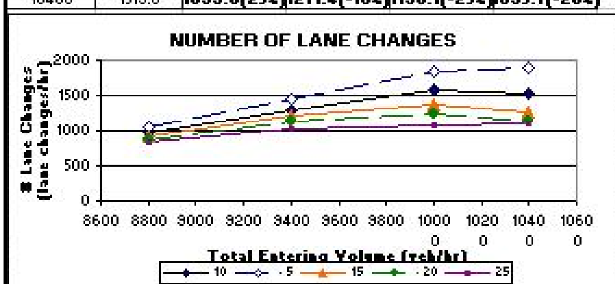
Entering Volume (veh/hr)	VEHICLE-MILES OF TRAVEL (veh-mi/hr)				
	Time to React to Sudden Deceleration of Lead Vehicle				
	10 *	5	15	20	25
8800	9932.4	9937.4(0%)	9930.8(0%)	9926.8(0%)	9928.5(0%)
9400	11209.2	11203.5(0%)	11208.4(0%)	11200.8(0%)	11193.6(0%)
10000	12438.7	12460.3(0%)	**12363.1(-1%**	**12259.7(-1%**	**2188.5(-2%)**
10400	12758.4	**12856.1(1%)**	**12614.9(-1%**	**2436.8(-3%**	**2298.5(-4%)**



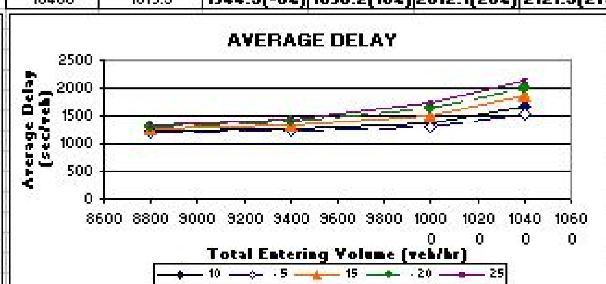
Entering Volume (veh/hr)	AVERAGE SPEED (mi/hr)				
	Time to React to Sudden Deceleration of Lead Vehicle				
	10 *	5	15	20	25
8800	17.7	**18(2%)**	**17.3(-2%)**	**17(-4%)**	**16.8(-5%)**
9400	17.3	**17.7(2%)**	**16.8(-3%)**	**16.3(-6%)**	**15.9(-8%)**
10000	16.3	**17(5%)**	**15.1(-7%)**	**14.2(-13%)**	**13.6(-17%)**
10400	13.6	**14.6(7%)**	**12.5(-8%)**	**11.7(-14%)**	**11.2(-18%)**



Entering Volume (veh/hr)	NUMBER OF LANE CHANGES (lane changes/hr)				
	Time to React to Sudden Deceleration of Lead Vehicle				
	10 *	5	15	20	25
8800	978.5	**1043(7%)**	**920.4(-6%)**	**877.5(-10%)**	**846.1(-14%)**
9400	1298.6	**1440.1(11%)**	**1203.4(-7%)**	**1124.5(-13%**	**030.7(-21%)**
10000	1567.8	**1835.6(17%)**	**379.6(-12%**	**229.7(-22%**	**088.5(-31%)**
10400	1519.8	**1893.8(25%**	**1271.4(-16%**	**1136.1(-25%**	**095.7(-28%)**



Entering Volume (veh/hr)	AVERAGE DELAY (sec/veh)				
	Time to React to Sudden Deceleration of Lead Vehicle				
	10 *	5	15	20	25
8800	1233.2	**1201.9(-3%)**	**1274.8(3%)**	**1310.8(6%)**	**1342.6(9%)**
9400	1276.7	**1235.6(-3%)**	**1333.2(4%)**	**1392.6(9%)**	**1438.7(13%)**
10000	1372.3	**1296.3(-6%)**	**1507.1(10%)**	**1633.4(19%)**	**1717.2(25%)**
10400	1675.3	**1544.3(-8%)**	**1850.2(10%)**	**2012.1(20%)**	**2121.9(27%)**



Notes:
* = Default value.
(XX%) = Percent difference from default value.
Bold Value = Value is statistically different from default value (95% confidence level).

There are 4 MOEs in this *Network*, each MOE are tested with different volume levels and different parameters. The cell corresponds to the volume level and the parameter is referred to as a *Case*.

List of Tables

Table 1 CORSIM Parameters Impacted by Weather Events

Generic Traffic Parameter	Roadway Environment Impact	CORSIM Parameter(s)	Details
ROAD GEOMETRY PARAMETERS			
Pavement condition	Reduced pavement friction	Pavement Condition	Available in FRESIM (freeways) only. Parameter creates an upper bound for the mean free flow speed.[1]
Number of lanes	Blocked lanes	Number of lanes	Can reduce the number of lanes based on the weather event.
Lane width	Blocked lanes	Lane width	Available in NETSIM only. Only changes the graphical display and not traffic operations.
Lane taper length	Blocked lanes	None	No parameter for length or type of taper, but can reduce the length of Deceleration/ Acceleration lanes (in FRESIM) themselves as surrogate.
Shoulder width	Blocked lanes	None	No parameter for shoulder width in FRESIM or NETSIM.
TRAFFIC CONTROL AND MANAGEMENT PARAMETERS			
Traffic signal/ Ramp meter	Reduced visibility	Forward Sight Distance	No parameter to reduce the visibility of a signal/meter itself. Forward Sight Distance parameter specifies sight distance from a stop line at a NETSIM intersection, used by TRAFVU only.
	Failed traffic control devices	Traffic signal/ Ramp meter properties	Can change the control to all-way or two-way stop to simulate flash or black-out conditions. For ramp meter, can turn off the meter for specific time periods.
Roadway signs (regulatory, warning, traveler info).	Reduced visibility	Anticipatory Lane Change Distance, Off-Ramp Reaction Point	No parameter specifically for reducing the visibility of a sign itself. Can change the Anticipatory Lane Change Distance and Off-Ramp Reaction Point as surrogates to seeing exit signs on freeways.
Surveillance detectors	Failed communications	Detector properties	Can delete detectors to simulate failed detector communications.
On-street parking	Blocked lanes	Curb Parking	Can disallow on-street parking for specific time periods.
VEHICLE PERFORMANCE PARAMETERS			
Accel./Decel. Capability	Reduced friction/stability	Acceleration Tables	Can change acceleration tables, including max. acceleration, using RT 173.
Turning radius	Reduced friction/stability	Minimum Drawn Radius of Curvature	Only changes the graphical display and not traffic operations.
TRAFFIC DEMAND PARAMETERS			
Vehicle demand	All[2]	Entry volume and turning volume	Entry volumes for each entering link can be adjusted as appropriate, and turning volumes can be adjusted depending on the weather event.
Route choice	All[2]	Traffic assignment properties	Available in NETSIM only. Cannot change impedances for individual links to simulate weather events.

Generic Traffic Parameter	Roadway Environment Impact	CORSIM Parameter(s)	Details
DRIVER BEHAVIOR PARAMETERS			
Car following	All[2]	See Table 3 and Table 4for key parameters.	
Lane changing	All[2]		
Free flow speed	All[2]	Mean Free Flow Speed and Multipliers	Mean Free Flow Speed on all affected links should be changed according to the weather event.
Discharge headway	All[2]	Mean Discharge Headway and Multipliers	Mean Discharge Headway (at signalized intersections) should be changed according to the weather event.
Start-up delay	All[2]	Mean Start-Up Delay and Multipliers	Mean Start-Up Delay (at signalized intersections) should be changed according to the weather event.
Intersection gap acceptance	All[2]	Acceptable Gap in Oncoming Traffic (AGOT), Cross-Street Traffic Acceptable Gap (CSTAG)	Change AGOT for turns at a traffic signal (permitted left turns and right turns on red) and CSTAG for movements at stop signs.
Turning speed	All[2]	Max. Allowable Left/Right Turn Speed	Can change max. left and/or right turn speeds in NETSIM.
Response to yellow interval	All[2]	Amber Interval Response	Defines the acceptable deceleration for a vehicle to stop at a traffic signal.

Notes: 1. Check CORSIM manual for more details (*11*).
2. All roadway environment changes could impact the parameter.

Table 2 MOEs for Sensitivity Analysis

Measure of Effectiveness	Description
Throughput (veh/hr/lane)	Measures the volume of vehicles traveling through a uniform segment. By gradually increasing the entering demand volume, the capacity of the segment is estimated by noting at what point the actual volume no longer matched the entering demand volume. However, it is not used for the system network. For FRESIM, this MOE is used for the basic, merge, diverge, and weave networks.
Vehicle-Miles of Travel (veh-mi/hr)	Measures the number of vehicles traveling through a segment or multiple segments while taking into account the length of the segments. This MOE, which is often used for system analyses, is only used for the system network as a surrogate to throughput, as it indirectly measures the capacity of the system while also taking into account the length of the network.
Average Speed (mi/hr)	Measures the average space mean speed over the entire network. This MOE is used on all test networks except the signal intersection in NETSIM network, as stopped delay is deemed a more appropriate MOE at an intersection level.
Average Density (veh/mi/lane)	Measures the average density over the entire freeway network. This MOE is used on all FRESIM test networks.
Average Delay (sec/veh)	Measures the difference in actual travel time and desired travel time (based on the free flow speed). This MOE is used on all test networks.
Stopped Delay (sec/veh)	Measures the time spent stopped due to the effects of a traffic signal. This MOE is used on the single NETSIM suburban and urban intersection networks because it measures the quality of service given by a traffic signal. Control delay is not used here because it is a function of the free flow speed, and free flow speed is a parameter in the sensitivity analysis. Thus, control delay would not give a consistent comparison when testing the free flow speed.
Number of Lane Changes (lane changes/hr)	Measures the total number of lane changes made on the network. This MOE, used on all NETSIM networks, is not a direct measure of the quality of traffic flow, but it is included because it is a helpful measure in understanding why the other MOEs did or did not change significantly and the effects the parameters have on lane changing behavior.

Table 3 General Sensitivity of FRESIM Parameters

Parameter	Sensitivity Group	Sensitivity Level
FRESIM Car Following Parameters		
Car Following Sensitivity Factor	No Effect	Low
Car Following Sensitivity Multiplier	Expected	High
Pitt Car Following Constant	Expected	Medium
Lag Acceleration /Deceleration Time	Expected	Medium
Jerk Value	No Effect	Low
FRESIM Lane Changing Parameters		
Time to Complete Lane Change	Expected	Medium
Advantage Threshold for Discretionary Lane Change	No Effect	Low
Discretionary Lane Change Multiplier	No Effect	Low
Gap Acceptance Parameter	No Effect	Low
Percent Cooperative Drivers	No Effect	Low
Maximum Non-Emergency Deceleration	Inconsistent	Medium
Maximum Emergency Deceleration	Inconsistent	Medium
Leader’s Maximum Deceleration as Perceived by Follower	Inconsistent	Medium
Anticipatory Lane Change Distance	Inconsistent	Medium
Anticipatory Lane Change Speed	Inconsistent	Medium
FRESIM Free Flow Speed Parameters		
Mean Free Flow Speed	Expected	High
Free Flow Speed Multiplier	Inconsistent	Medium

- **Bold** font parameters represent those that had little or no effect on the MOEs.
- *Italic* font parameters represent those parameters that had both an expected effect on the MOEs and are categorized as either having a medium or high effect on the MOEs (relative to the other parameters).
- Sensitive Level

High: In all network configurations (Table 3), most MOEs are statistically tested differently from the MOEs generated by default parameter values. Specifically, the conditions below have to be satisfied for three out of four MOE tables in each network configuration. In one of the three tables, MOEs from 50% cases (See Figure 1) are 10% greater than those generated by the default value and 30% of cases are 20% greater than those generated by the default value.

Low: In most cases, the MOEs are statistically tested. The tests reject the assumption that the MOEs were different from those generated by default values of parameters at 95% of significance. There are less than 5% of the cases under which generates 20% difference for all combinations of network configurations for all MOEs.

Medium: The rest of the cases are medium.

Table 4 General Sensitivity of NETSIM Parameters

Parameter	Sensitivity Group	Sensitivity Level
NETSIM Car Following Parameters		
Time to React to Sudden Deceleration Of Lead Vehicle	Expected	High
NETSIM Lane Changing Parameters		
Driver Type Factor	No Effect	Low
Urgency Threshold	No Effect	Low
Minimum Deceleration for a Lane Change	Expected	Medium
Difference in Minimum/Maximum Deceleration for Mandatory Lane Changes	No Effect	Low
Difference in Minimum /Maximum Deceleration for Discretionary Lane Changes	No Effect	Low
Safety Factor	No Effect	Low
Headway at Which All Vehicles Attempt Lane Change	No Effect	Low
Headway at Which No Vehicles Attempt Lane Change	No Effect	Low
Time to React to Sudden Deceleration Of Lead Vehicle	Expected	High
Duration of a Lane Change	No Effect	Low
Percent Drivers Who Cooperate With Lane Changer	No Effect	Low
Distance Over Which Drivers Perform Lane Change	No Effect	Low
Distribution of Distance to Attempt a Lane Change	No Effect	Low
Deceleration of Lead Vehicle	Expected	Medium
Deceleration of Following Vehicle	Expected	Medium
NETSIM Free Flow Speed Parameters		
Mean Free Flow Speed	Expected	High
Free Flow Speed Multiplier	Inconsistent	Medium
NETSIM Discharge Headway Parameters		
Mean Discharge Headway	Expected	High
Discharge Headway Multiplier	No Effect	Low
NETSIM Start-Up Delay Parameters		
Mean Start-Up Delay	Expected	High
Start-Up Delay Multiplier	No Effect	Low
NETSIM Turning Speed Parameters		
Max. Allowable Left Turn Speed	Expected	Medium
Max. Allowable Right Turn Speed	Expected	Medium

- **Bold** font parameters represent those that had little or no effect on the MOEs.
- *Italic* font parameters represent those parameters that had both an expected effect on the MOEs and are categorized as either having a medium or high effect on the MOEs (relative to the other parameters).
- Sensitive Level
  See Table 3 for explanations.

Table 5 Sensitivity Analysis Networks

Network Name	Description
FRESIM	
1-lane basic segment	1-lane freeway with no on- or off-ramps, 1 mile in length.
2-lane basic segment	Same as the 1-lane basic segment, except with 2 freeway lanes.
3-lane basic segment	Same as the 1-lane basic segment, except with 3 freeway lanes.
2-lane merge area	2-lane freeway with a single on-ramp, with a ramp volume of 500 veh/hr and 750-foot acceleration lane.
3-lane merge area	Same as the 2-lane merge area, except with 3 freeway lanes.
2-lane diverge area	2-lane freeway with a single off-ramp, with an exiting ramp volume of between 300 and 750 veh/hr (fixed at 15 percent of freeway volume) and 750-foot deceleration lane.
3-lane diverge area	Same as the 2-lane diverge area, except with 3 freeway lanes.
2-lane weave area	2-lane freeway with an on-ramp and off-ramp separated by 1000 feet, on-ramp volume of 500 veh/hr, off-ramp volume of between 375 and 825 veh/hr (fixed at 15 percent of freeway volume), and single auxiliary lane connecting the on- and off-ramps.
3-lane weave area	Same as the 2-lane weave area, except with 3 freeway lanes.
System	3.2 miles, 3-lane freeway system including 2 merge areas (each with 500-foot acceleration lanes), 1 diverge area (with a 500-foot deceleration lane), and 1 weave area (with a 1000-foot auxiliary lane).
NETSIM	
1-lane basic segment	1-lane arterial segment (no intersections or driveways) of 1-mile in length and free flow speed of 45 mi/hr.
2-lane basic segment	Same as the 1-lane basic segment, except with 2 arterial lanes.
3-lane basic segment	Same as the 1-lane basic segment, except with 3 arterial lanes.
Single suburban intersection	5-lane arterial with free flow speed of 45 mi/hr intersecting a 3-lane collector street with free flow speed of 30 mi/hr. The intersection is controlled by a fully actuated traffic signal with protected left-turn phasing, 250-foot left turn bays on all approaches, and a maximum cycle length of 120 seconds (if all phases max-out). This intersection is typical of those found on major arterials in a suburban setting.
Single urban intersection	3-lane collector intersecting a 2-lane collector, both with free flow speeds of 30 mi/hr. The intersection is controlled by a pre-timed traffic signal with 2-phases (one for each roadway with permitted left-turn phasing), 150-foot left turn bays on all approaches, and a fixed cycle length of 80 seconds. This intersection is typical of those found in urban or downtown settings.
System	2.0-mile arterial corridor with 4 traffic signals at 2000-foot spacing. The arterial has a free-flow speed of 45 mi/hr with 2-through lanes in each direction and 250-foot left turn bays at the traffic signals, and the intersecting minor streets are 1 lane in each direction with 250-foot left and right turn bays at the intersections. The traffic signals are controlled by a semi-actuated, coordinated plan with a 120-second cycle.