# D. Micro-Simulation Modeling Results

## Introduction

Micro-simulation modeling was undertaken to estimate the conceptual benefits of the various ATM techniques. The study team used a VISSIM model developed as part of WSDOT's I-405 Corridor Program, which included the entire I-405 corridor (general purpose lanes, HOV lanes and ramps), from the northern boundary at I-5 to the southern boundary at I-5. The basic model parameters were not changed for the purpose of this study, but the model was coded to reflect the various ATM strategies. Not all of the ATM strategies could be modeled, such as dynamic re-routing, traveler information and hard shoulder running. However, algorithms and modifications for speed harmonization, queue warning and junction control were coded into the model and run for results. The initial modeling results were reviewed and the algorithms and coding refined to obtain conceptual-level results. Additional modeling efforts and further refinements to the algorithms are necessary to fully understand and maximize the expected benefits of each ATM technique.

## Model Modification

As mentioned previously, three ATM strategies were coded into the existing model: speed harmonization, queue warning and junction control. Detailed descriptions of each strategy are presented below.

### *Speed Harmonization*

The primary purpose of speed harmonization is to minimize spatial and temporal variations in speed. This can be achieved by reducing the speed limit in areas of congestion or incidents. Speed harmonization typically results in two distinct benefits. The first is a reduction in accidents due to sudden changes in speed, abrupt lane changes and decelerations. The second is that the highest throughput at a given section of roadway is achieved at a speed which is lower than the free flow speed. The quantifiable and unquantifiable benefits of speed harmonization are derived from the above two observations. Uniform traffic flow gives rise to smooth transitions across time and space which results in improved safety. On the quantitative side, speed harmonization attempts to maintain traffic at an optimal speed that provides maximum throughput. Recent studies on this topic have concluded that higher levels of throughput using speed harmonization are obtained partially because of the reduction in speed variation across all of the drivers.

### Algorithm and Equipment Locations

Detectors were located throughout the network at a spacing of approximately ½ mile. In order to capture the congestion pattern at the ramps, a set of detectors was placed 500 feet upstream of each ramp. As shown in Figure 1, the variable speed limit signs (noted by green squares) were located 200 feet upstream of each detector (indicated with red circles).

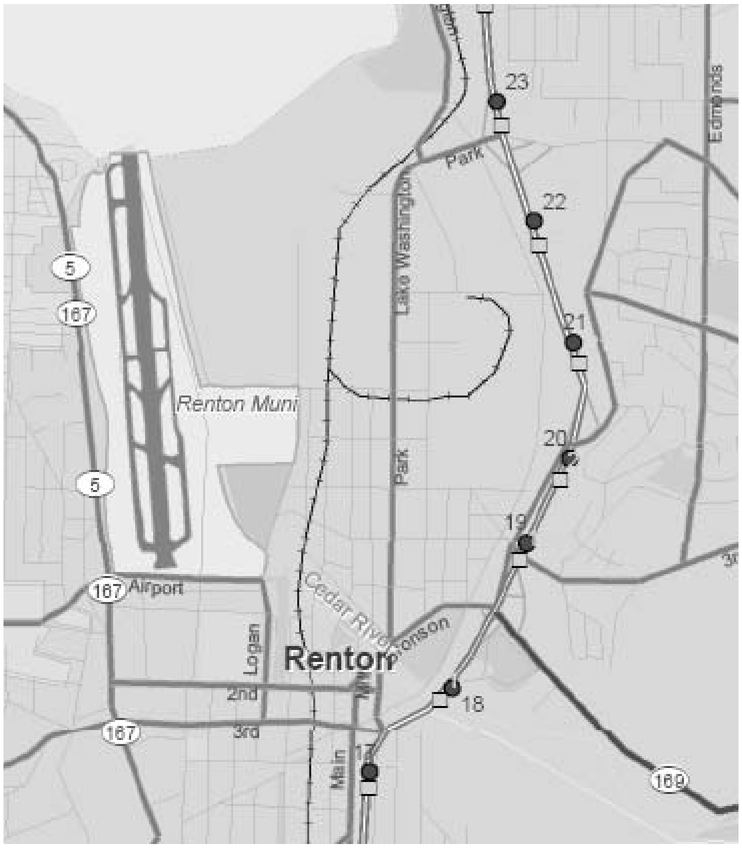

**Figure 1 - I-405 Northbound Roadway**

The posted speed limits can be any of three discrete values: 35 mph, 45 mph or 60 mph. The speed harmonization algorithm involves checking the average speeds at each of four detector locations in order to determine which speed limit would be posted or if it is to remain blank. For example, sign 21 on I-405 NB will display the lowest speed limit based on the speeds detected by the detectors using the following logic. If detector 21 shows a speed slightly less than or equal to 35 mph, then sign 21 would display 35 mph. However, if detector 21 shows a speed greater than 35 mph, but detector 22 shows less than 35 mph, the sign would display 45 mph. If the set of detectors show speeds greater than the upper threshold, the sign would remain blank.

Another check involves the upstream detector. If detectors 20 and 21 show speeds less than 35 mph, then sign 21 will be blank, but sign 20 will display 35 mph.

For traffic conditions where the speeds are increasing, the sign would be blank. For example, this would be the case for sign 21 if detector 20 shows a speed less than or equal to 35 mph, but detector 21 shows a speed greater than 35 mph.

Signs would only be turned on when the average speeds fall between designated thresholds. If the average speeds fall well below 35 mph, the signs would be turned off because traffic would already be moving much slower than the lowest posted speed limit allowed.

This algorithm was coded in the study area from I-90 in the North to I-5 in the South. Improving the performance (throughput) of the speed harmonization algorithm depends on the following:

> 1) Proactive versus reactive implementation: It is clear that the current form of algorithm allows traffic to "break down" before implementing a reduced speed limit. Thus, it does not attempt to maintain traffic at the maximum throughput level. In fact, the primary purpose of this algorithm is to reduce abrupt accelerations/decelerations (and hence lane changing) resulting in improved safety. Conversely, a proactive speed harmonization algorithm is based on an anticipated speed drop and becomes active before the traffic flow actually breaks down. Thus, it maintains the traffic flow at a speed that corresponds to maximum throughput. While a proactive approach may be implemented in the future, it was not considered practical for this study. This was partially due to the concern that drivers may consider such reduced speed limits frivolous, resulting in an extremely low compliance level. Therefore, the speed harmonization becomes active only after detection of a breakdown, defined as an existing speed of less than 35 mph.
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> 2) Thresholds for reducing speed limits and corresponding posted speed limits: In the above implementation, the threshold for all detectors is 35 mph whereas the posted speed limits could be 35 mph, 45 mph or 60 mph, depending on the traffic conditions.

As mentioned above, the focus of this study was to evaluate the benefits of ATM at a conceptual level. Therefore, no attempt was made to optimize the parameters described in the second condition. Only the reactive version of speed harmonization was modeled, and therefore the modeling runs did not show a reduction in total travel time. As described above, a proactive speed harmonization algorithm would have been more likely to show improvement. The safety aspect of speed harmonization is still very compelling and it is widely accepted that this ATM technique helps reduce the number of collisions, particularly those at the back of the queue. So, alternatively, incident delays were evaluated to indirectly estimate the potential travel time savings from speed harmonization.

## Modeling Results

A number of incident scenarios were modeled as part of this study. An incident scenario is defined by its location, severity and duration in the model. In all scenarios, the incident was located on SB I-405, approximately 2,000 ft downstream from the NE 44th Street on-ramp. Incidents durations that were modeled included 15, 30 and 90 minutes for the 2005 PM and 2014 PM scenarios. The 15- and 30-minute incidents started at 2:30 PM, while the 90-minute incident started at 4:30 PM. The total delay caused by these incidents is summarized below.

Incident delays for 2005 PM

15-minute incident: 50 hours of travel time delay
30-minute incident: 145 hours of travel time delay
90-minute incident: 4,000 hours of travel time delay

Incident delays for 2014 PM
  15-minute incident: 90 hours of travel time delay
  30-minute incident: 181 hours of travel time delay
  90-minute incident: 11,800 hours of travel time delay

The extremely high amount of delay for the 90-minute incident is somewhat unrealistic due to the lack of alternate routes in the model. However, it does clearly show the exponential growth in delay caused by incidents.

## *Queue Warning*

Queue warning systems provide early congestion warnings to drivers, encouraging them to change lanes earlier in order to avoid congested lanes. This phenomenon leads to better lane allocations resulting in improved throughput. Furthermore, it helps prevent dangerous and late-stage lane changing, which results in improved safety. Clearly, the former benefit is quantifiable through model runs whereas the safety aspect is difficult to assess using a traffic flow model. Therefore, the modeling effort for evaluating the benefits of queue warning primarily focused on delay reduction.

### Algorithm and Equipment Locations

Queue warning was tested at the I-405 SB off-ramp to southbound SR 167. Two signs were used to provide warning to drivers which were located ½ mile and 1 mile upstream of the exit ramp. Using Figure 2, sign #1 is located just south of Detector 26, approximately at S. 9th Street, while sign #2 is located in between Detectors 24 and 25, approximately at the Cedar Avenue South overpass.

Four detectors were used to provide traffic flow data to these two signs. The first detector (most downstream) was located 50 feet upstream of the gore area, while the second detector was located at approximately 2,450 feet from the gore (i.e. approximately 200 feet downstream of the first sign). The third and fourth detectors coincided with the signs (i.e. ½ and 1 miles from gore, respectively).

**Figure 2 - I-405 Southbound Roadway**

The queue warning algorithm involves checking the location of the back of the queue and comparing the right lane speed with the adjacent lane's speed at that location. The first sign is activated when both the queue extends about 200 feet onto the freeway and the speed in the right travel lane is 15 to 20 mph slower than the adjacent travel lane. If the queue between the second detector and the first sign (e.g. 700 feet south of the first sign), then both signs would be activated. When the queue reaches the first sign, it is then turned off. If the entire freeway is congested and the speed differential is minimal, then the signs would not be operational.

## Modeling Results

The simple implementation described above resulted in a savings of 85 hours at a compliance rate of 50 percent. The compliance rate is the fraction of drivers in the right lane that would be assigned to left lanes. It is critical to note that queue warning is a highly dynamic system and driver compliance would vary significantly from minute to minute depending on the average speed, density variation across lanes, and the individual driver's destination. Thus, compliance should be modeled as a fraction of drivers that would evaluate switching lanes because they would only execute lane changing if traffic conditions are such that it satisfied their goals. Unfortunately, VISSIM does not support such dynamic lane changing behavior and as a result, overreaction (or under utilization) may occur. In fact, overreaction was observed in the initial model run and the compliance rate was revised to more realistically assess the benefit. Based on visual inspection and analysis of the base case, the compliance rate was modified to 25 percent after 5:30 PM. This refinement resulted in a total savings of 110 hours. Further refinements in both parameters and algorithm construction are expected to result in higher levels of savings.

## *Junction Control*

As described in queue warning, efficient lane allocation leads to improved throughput and safety.  Junction control is another ATM technique that attempts to maximize throughput by modifying the directional volume pattern such that optimal lane allocation is achieved.  While queue warning is an advisory technique that attempts to improve lane use efficiency by encouraging drivers to switch lanes early enough to uncongested lanes, junction control achieves it more aggressively through regulatory signs, and its impact would be expected to be more pronounced than queue warning.  Ideal demand patterns (e.g. low volume on mainline, but a very high volume from the ramp) could result in a large amount of travel time savings.  However, junction control could adversely affect the system under other demand patterns.  Therefore, application of junction control should be applied very carefully at only those locations that satisfy its requirement and only for those time windows where the demand pattern is conducive for such control.

### Algorithm

Based on the above characteristics, the following two locations were selected for evaluation:

> 1) SR 518 and the North Airport Expressway on-ramp:  Junction control was applied between 9:30 AM and 11 AM and between 7 PM and 8 PM with a 95 percent compliance rate.  The time periods were chosen based on an analysis of time-dependent traffic patterns at this interchange.  The lane restriction consisted of closing the right lane at the eastbound to southbound exit to North Airport Expressway where the mainline transitions from three lanes down to two lanes. This then allows the right lane at the northbound to eastbound on-ramp merge from North Airport Expressway to be open.
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> 2) I-405 at the SR 167 Interchange:  Junction control was applied only in the morning from 5 AM to 7 AM with a 95 percent compliance rate.  Similar to the location above, this interchange was selected due to high on-ramp and low mainline volumes during this time period.  At SR 167, the right lane at the eastbound to southbound exit to SR 167 was restricted using red “X” indicators. This then opens the right lane at the northbound to eastbound on-ramp merge from SR 167.

### Modeling Results

Junction control is best applied at locations where the mainline volumes are low and priority can be given to the higher ramp volumes.  Each candidate location is determined based on its traffic volumes, roadway geometry, and specific traffic conditions at a given time period.  In the case of SR 518, this condition occurs during the airport peak which is a time window that is partially outside of the model’s peak periods for which it was designed.  The original model was developed to cover the peak periods from 5 AM to 11 AM in the morning and 3 PM to 8 PM in the afternoon.  Based on the known airport peak, which is roughly from 10am to 2pm and from 7pm to 11pm, more favorable results could have been achieved if the model would have covered these timeframes.

The modeling of the two locations did not show any quantifiable benefits, however, when the optimal conditions are not present in the model, a certain amount of judgment is required to interpret the results, particularly when evaluating merit.

## Summary and Conclusion

ATM techniques are known to produce both quantifiable and unquantifiable benefits; in many cases, unquantifiable benefits like improved safety can often outweigh the quantifiable ones such as delay reduction.  Equally important, the realistic assessment of quantifiable benefits also requires the optimal implementation of each technique and combination of techniques.  Because this study was undertaken to determine if applying ATM techniques had merit for further study, a detailed optimization of the algorithms was not completed.  VISSIM's limitations required indirect modeling methods to obtain quantifiable results.  However, even with the noted constraints, the modeling results showed significant benefits for queue warning and speed harmonization.  Additional modeling analysis is still needed to quantify the benefits of junction control.  In addition, a detailed analysis of time-dependent traffic patterns throughout the entire network would help in assessing realistic/optimal benefits for all ATM applications and identify other suitable locations and time windows in other corridors.

A CD that contains the above mentioned VISSIM model runs is included as part of this appendix.