Express Lane Genetic Algorithm Microsimulation Evaluation Part (2)
ELGAME 2

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February 2009

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LIST OF ACRONYMS

COM	Component Object Model
EL	Express Lanes
ELGAME	Express Lanes Genetic Algorithm Microsimulation Evaluation
GP	General Purpose Lanes
HOT	High Occupancy−Toll
HOV	High Occupancy−Vehicle
I-15	Interstate−15
OD	Origin−Destination
UDOT	Utah Department of Transportation
UTL	Utah Traffic Lab

EXECUTIVE SUMMARY

Innovative lane management offers the opportunity to levy fees for the premium road space. Express Lanes in Utah offer road users reduced journey times for a fee. The Utah Department of Transportation (UDOT) has converted the High Occupancy-Vehicle (HOV) lanes on Interstate 15 (I-15) from 600 North Street in Salt Lake City, Salt Lake County, to University Parkway (SR−265) in Orem, Utah County. Subscribers and HOVs now share the same lane, which is designated as an "Express Lane." This concept will be advanced further through the application of an electronic toll-collection system. Improper pricing policy for the High Occupancy-Toll (HOT) lanes could cause a large debate among travelers and potentially jeopardize success of the HOT deployment. Hence, UDOT management would like to make an informative decision about further HOT pricing. The I-15 VISSIM model presented, can serve as a decision support tool. This report presents a modified and calibrated I-15 VISSIM model that integrates HOT pricing. A separate HOT link has been created, adjacent to the General Purpose (GP) lane model. The model is calibrated by comparing the GPS travel times, which were obtained during the data collection, with the VISSIM travel times. This report proposes an algorithm for HOT pricing. The final results show that, while VISSIM travel times in express lanes closely resemble GPS travel times in both directions, the GP lanes also reflect travel times with the exception of a few intersections.

1. INTRODUCTION

1.1 Project Background

Utah Traffic Lab (UTL) built and calibrated a microsimulation VISSIM model of Interstate 15 (I-15) from 600 N in Salt Lake City to University Parkway in Provo, UT, during Phase I of this contract. UTL extended the original UDOT model and constructed two sub-models for AM and PM peak traffic conditions. The models have been calibrated and validated based on field data collection through numerous GPS travel time runs and other data collection methods. The purpose of this project (Phase II) is to modify the existing I-15 model in VISSIM to enable current HOT operations and future dynamic pricing of the HOT lanes.

1.2 Research Objectives

There are three research objectives:

1. Modify the existing VISSIM model of I-15 to support future HOT lanes operations.
2. Recalibrate and revalidate the modified I-15 VISSIM model in terms of HOT related performance measurements.
3. Integrate a dynamic toll pricing algorithm with the I-15 VISSIM model to enable real-time variable congestion pricing.
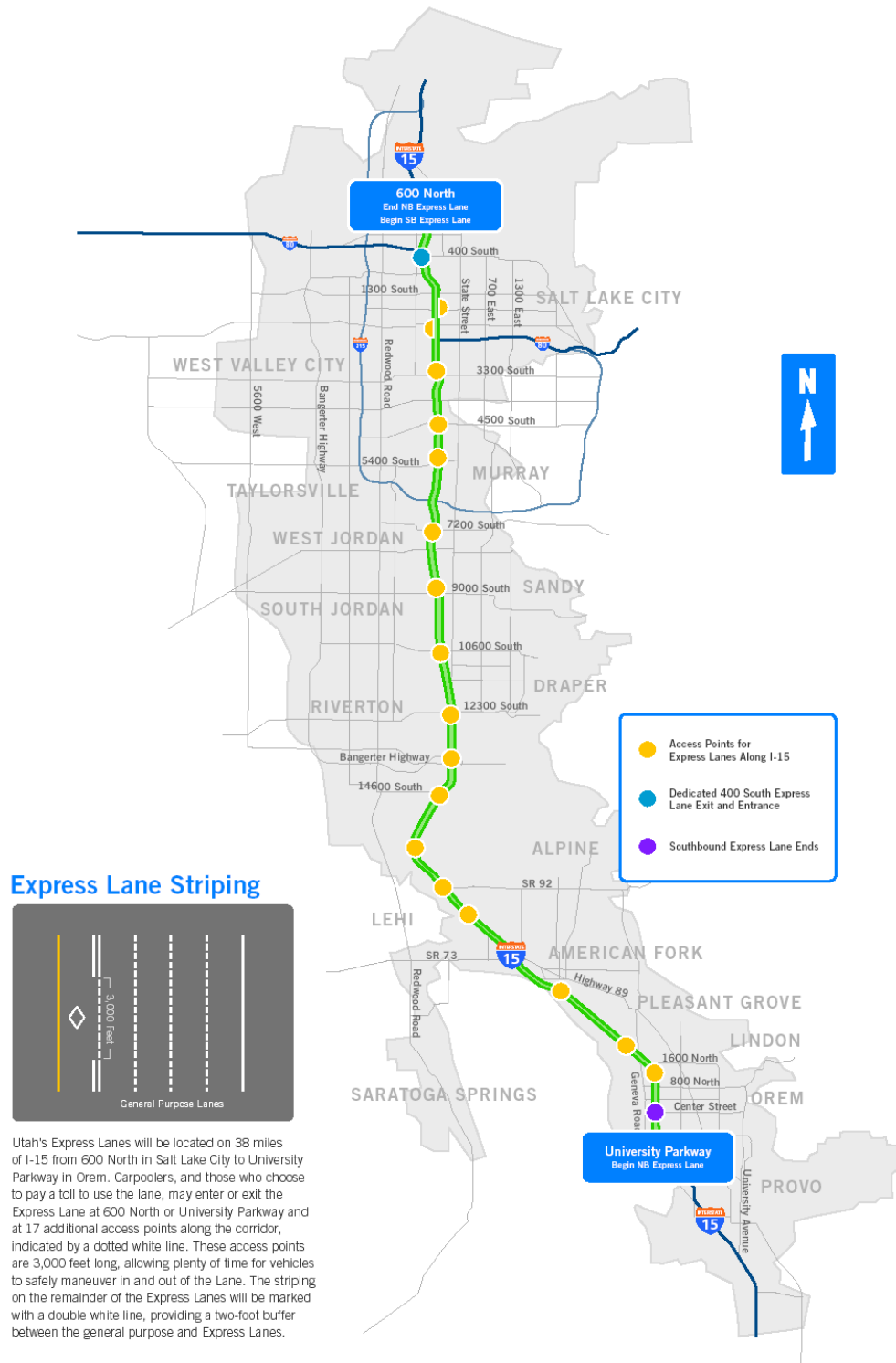
Figure 1.1 Express Lanes in Salt Lake Metropolitan Region.

1.3 Work Tasks

Work tasks are defined as follows:

1. Obtain UDOT's I-15 VISSIM model with HOT lane coded as separate facility.
2. Prepare a set of preliminary ideas to investigate variable congestion pricing on I-15 HOT lanes.
3. Meet with TAC to define project priorities.
4. Develop a detailed scope of the project.
5. Modify the existing VISSIM model to support current HOT operations (primarily by modifying links to restrict access to/from HOT lane).
6. Calibrate the model using the previously developed Genetic Algorithm for the VISSIM model calibration.
7. Validate the model based on a set of independent traffic data from the field. Use existing data that has already been collected. A small data collection effort to supplement existing data may be required for validation of the existing model.
8. Design a data collection plan and conduct the collection. A tentative plan for data collection may include the following:
    a. Driver/ passenger behavior surveys on I-15 to determine driver and passenger preferences, establish the price elasticity of demand, and calculate the relationship between price and level of service.
    b. Collection of travel times, travel delays, travel reliability, and travel costs. Much of these data sets are available from Phase I.
9. Investigate ways of rerouting vehicles to and from HOT lanes based on drivers' preferences and current HOT toll data. This task may require the following:
    a. Using VISSIM's dynamic assignment for rerouting vehicles due to variable congestion pricing.
    b. Developing an external program, which would deal with behavior travel choice model (used to reflect modal choice). This component will be a function of travel demand modeling and will be specific to the microsimulation model. It will address peak hour of travel and will not be able to capture time of day variables.
    c. Using outputs from the model will be used either with static or dynamic routing procedures in VISSIM to model shift in traffic demand between GP lanes and HOT lanes. It is intended to address Ramp Metering.
10. Develop set of congestion pricing scenarios that UDOT would like to investigate, such as:
    a. Dynamic Pricing: where the toll for E-ZPass vehicles changes relative to the lane's benefit at any point in time and the available capacity of the new mixed-mode lane. The benefit of the lane may be measured in travel time, average roadway speed, level of service, or other performance measures.
    b. Passenger Occupancy Pricing: where toll prices are designed to distinguish different toll rates for single-occupant autos and HOV autos (e.g. 2-plus, 3-plus, etc.) to encourage higher vehicle occupancy.
    c. Commercial Vehicle Pricing: where heavy vehicles or certain targeted segments of commercial market (e.g. small package delivery, etc.) are able to access the extra capacity of the new managed lane at designated time periods and prices.
11. Perform microsimulation runs.
12. Analyze results and perform statistical tests.
13. Report findings to UDOT.

2. LITERATURE REVIEW

The High Occupancy Vehicle (HOV) lanes concept was introduced in the last century to reduce the number of Single Occupancy Vehicles (SOVs) and to encourage drivers to ride in carpools, buses, etc., with the aim of decreasing traffic congestion. However, at times HOV lanes may be underutilized which can further increases traffic congestion in the adjacent General Purpose (GP) lanes. High Occupancy Toll (HOT) lanes could solve this problem. The concept could help to achieve the required traffic flow in HOV lanes and at the same time help Departments of Transportation in raising funds. With this novel approach, SOVs could use the HOV facility by paying toll so that the excess capacity can be better utilized (1).

Currently, there are HOT lanes working successfully to ease congestion in five states: California, Minnesota, Texas, Colorado, and Utah. More projects are planned for California, Texas, Florida, Virginia, and Georgia, as well as a further 17 projects that are going through environmental approvals across the United States. California's SR-91 opened in 1995 and was the first HOT lane project. Now, more than 250,000 vehicles travel the road each day. Since the lanes opened, SR-91 has logged more than 64 million vehicle trips, saving customers over 32 million hours of commuting time. In 1996 San Diego's I-15 was the first HOV facility to begin conversion to HOT lanes. The HOT facility has since proved successful with users reporting travel time saving of 20 minutes per trip. In Minneapolis, satisfaction among users of the I-394 MnPass HOT lanes is high – whether users are paying (SOVs) or not (HOVs). On a typical day, HOT lanes on I-394 attract 1,000 vehicles each morning and 600 vehicles each evening out of the regular lanes and into the HOT lanes. Houston's I-10 HOT lanes allow two-person carpools to use the I-10 West and U.S. 290 HOV-3 lanes during peak hours for a toll. The average travel time saving on the I-10 HOT lanes is around 20 minutes. In addition, options that include allowing solo drivers to use the lanes if they pay a toll are also being considered. The usage levels of I-25 express lanes in Denver are above the predicted use. In June 2006, the first month of operation, 21,551 vehicles used the HOT lanes. This increased by 73% to 80,665, in March 2007 (4).

However, HOT lane systems need to address theoretical and practical issues to optimize HOT lane system performance. Research evaluating the practical HOT lane systems is in its early stage and Zhang (1) has initiated recent development in this area. The microscopic traffic simulation software, VISSIM, has been utilized for his study, and an external HOT lane module was developed via VISSIM COM interface, using Microsoft Visual Basic, to facilitate HOT lane simulation. The Washington State Route (SR) 167 HOT Lane Pilot Project system was taken as the study area for investigation. The results have shown that the implementation of the HOT lanes can improve traffic efficiencies and benefit all users of the SR-167 corridor (1).

On the other hand, inferior tolling strategies may cause unforeseen problems. To handle this, Zhang et al. (2) proposed a new feedback-based tolling algorithm to dynamically optimize HOT lane operations. In this theory, based on the traffic speed conditions and toll changing patterns, the optimum flow ratio for HOT lane utilization was calculated using feedback control theory. An external HOT lane module was developed using Microsoft Visual Basic to implement the algorithm. Through optimal toll adjustment, SOVs were regulated to fully exploit the excess capacity of the HOT lane without degrading operation conditions for HOVs. In the current study, the HOT lane module expands on the proposed Washington HOT lanes project. The Washington model is modified to expand on the capital-to-travel-time ration.

3. RESEARCH METHODOLOGY

While, in reality, express lane vehicles can access and exit only at certain designated points along the highway, no access restrictions are in the existing simulation model. To modify the existing model and to simulate the current conditions in the field, the following methodology has been implemented.

Original I-15 VISSIM model from UTL

Modification of Geometry

Develop New Static Routes

Ramp Metering
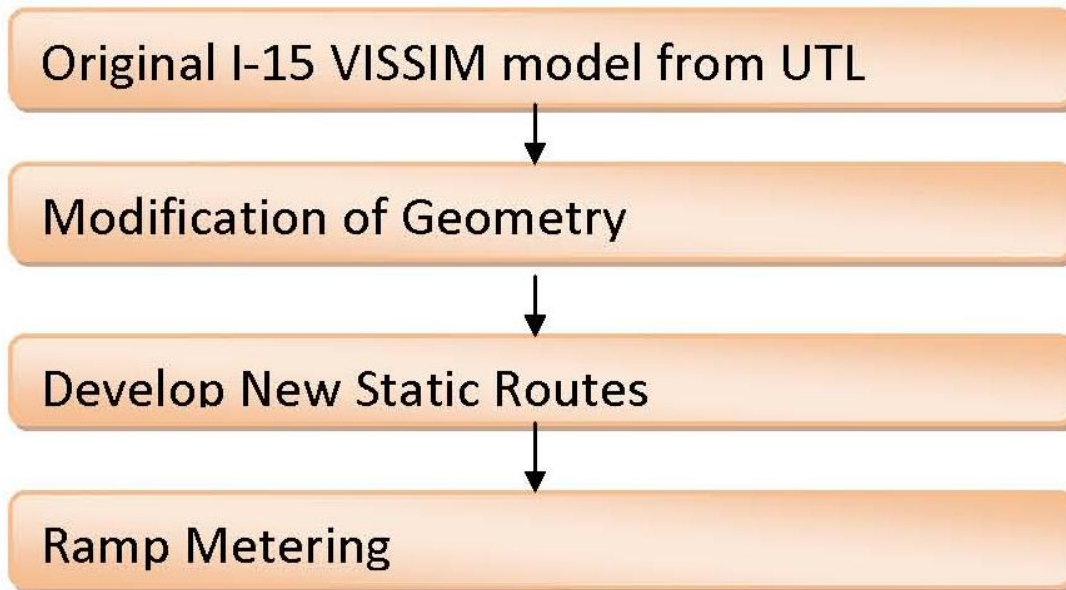
Figure 3.1 Basic Research Methodology.

4.   DATA COLLECTION

A variety of traffic data has been collected for both AM and PM peak during Express Lanes (6) project. This data includes lane-specific vehicle volume data (on both GP and HOV) at four intersections, travel times, and speeds. Traffic counts were available at the intersections of 2700 South, 5200 South, 10600 South, and Exit 278 in both directions. Lane-specific traffic volumes were used as the basis for the assumption of ratio of HOV and GP traffic volume for static routes on the remaining intersections. Throughout this process, the nearest available volume ratio was used for all intersections, where traffic volume data was not available.

Vehicle input on ramps, OD matrices, and details of ramp meter signal controllers were obtained from UDOT. Apart from these data sets, most traffic parameters, including the static routes, traffic compositions, desired speed decisions, coordinates of travel time segments, and driver behavior parameters already exist in the original model and are used as is.

5. VISSIM MODEL

The starting point for this study is the VISSIM model from Phase I. That model does not have designated access and egress locations — the HOT lane is accessible throughout its entire length. The Phase I model is adapted to reflect the real world layout, after which the network is calibrated to the measured traffic conditions.

5.1 Coding the Network

Coding of the network consisted of the following steps:
1. Modification of the links
2. Access and egress points
3. Static Routes
4. Ramp Meters

Each step was repeated for both the North-bound (NB) and South-bound (SB) directions, where the NB direction was modeled for morning peak and the SB direction was modeled for afternoon peak period.

5.1.1 Modification of Links and Access Points

HOT users may only access HOT lanes at certain points along the freeway. The lanes have 16 access points in each direction marked by a white dotted line, while the rest of the corridor is marked with a double-white solid line. Each point is 3,000 feet long, giving enough room for users to enter and exit the lanes.

The total number of lanes in the model includes both GP and HOT lanes. However, the HOT lane is not treated as a separate facility — it has the same properties as other GP lanes. Also, while in reality HOT users are only meant to enter and exit at these points, there are no access restrictions in the existing model.

To resolve these problems, additional link are created, parallel to existing geometry between access and egress points. Also, the number of lanes in the existing geometry decrease to one, as each new link for the HOT lane is created.

With respect to the access and egress points, a different methodology is applied to allow vehicles to move to and from the HOT lanes. For these points, only one link was necessary, but the virtual lane representing the HOT lane must be closed for GP vehicles (for vehicles not allowed in HOT lanes). Multiple connectors allow vehicles to move on and off the HOT lanes. Figure 5.1 is a graphical representation of how links are modified.
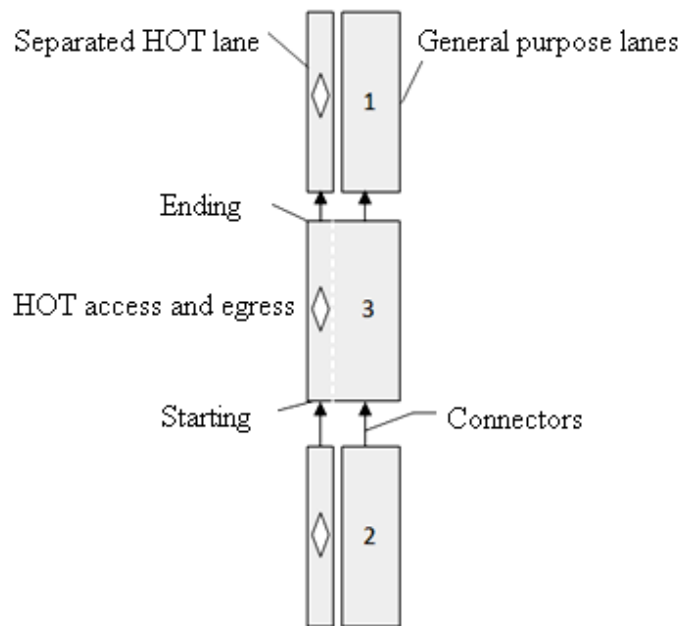
Figure 5.1 Graphical Representation of Modeling the Geometry of the Access and Egress Points.

5.1.2 Location of Access and Egress Points

The exact locations of access and egress points in the model are determined using Google Street View and Google maps, and have been crosschecked with the mile post information, provided by UDOT.

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Table 5.1 Milepost Information of Access and Egress Points for the HOT Lanes on I-15

North Bound		Mile Post		South Bound		Mile Post	
Number	Name	Ingress	Egress	Number	Name	Ingress	Egress
1	Center St	270.4	270.97	1	1300 South	306.48	305.91
2	1600 North	272.39	272.96	2	3300 South	303.63	303.06
3	S Pleasant Gr	275.04	275.61	3	4500 South	301.95	301.38
4	S 200 W	277.38	277.94	4	5300 South	300.51	299.94
5	N 300 W	280.85	281.42	5	7200 South	298.12	297.55
6	W 11000 N	283.73	284.3	6	9000 South	295.93	295.36
7	Point of Mt.	286	286.56	7	10600 South	293.92	293.35
8	14600 South	288.11	288.67	8	12600 South	291.66	291.09
9	Bangerter	289.55	290.12	9	Bangerter	290.11	289.54
10	12600 South	291.1	291.67	10	14600 South	288.48	287.91
11	10600 South	293.35	293.92	11	Point of Mt.	286.56	285.99
12	9000 South	295.36	295.92	12	Exit 285	284.3	283.73
13	7200 South	297.76	298.32	13	Exit 279	281.22	280.65
14	5300 South	303.13	303.69	14	Exit 275	277.96	277.39
15	4500 South	301.4	301.96	15	Unknown	275.61	275.04
16	3300 South	303.26	303.82	16	Exit 273	272.97	272.4
17	1300 South	306.11	306.68				

An example of finding the access and egress points at 9000 South, NB direction, is provided in Figures 5.2 to 5.4.

First, the beginning of the access point is located using the Google Street View (Figure 5.2); then, this point is identified on the Google map.

Figure 5.2 The Snapshot from the Google Street View: the Beginning of Access Point at 9000 South, in NB Direction on I-15.

In the same way, the end of the access point was found using Google Street View (Figure 5.3), and t is marked on the Google map. The distance between these points is verified to approximately 3,000 feet, which is the length of HOT access.
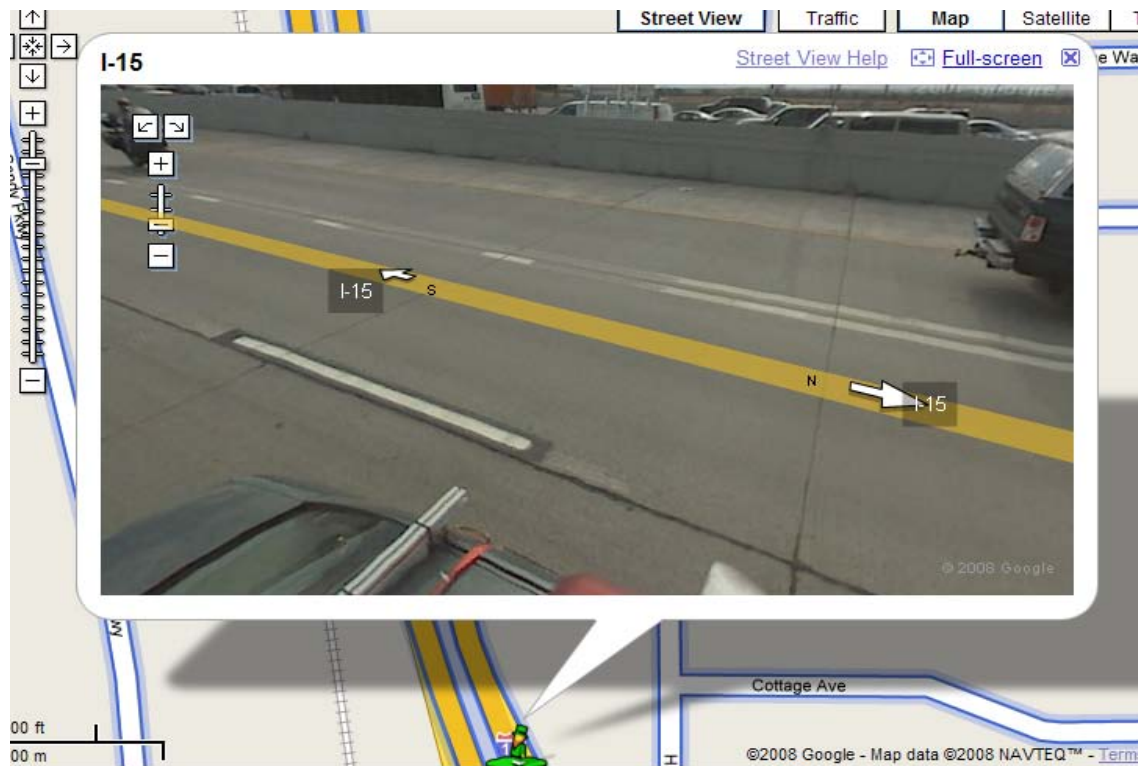

Figure 5.3 The Snapshot from the Google Street View: the End of Access Point at 9000 S, in NB Direction on I-15.

Figure 5.4 shows the marked beginning and end of the access and egress point at 9000 South, NB direction, on the Google map.
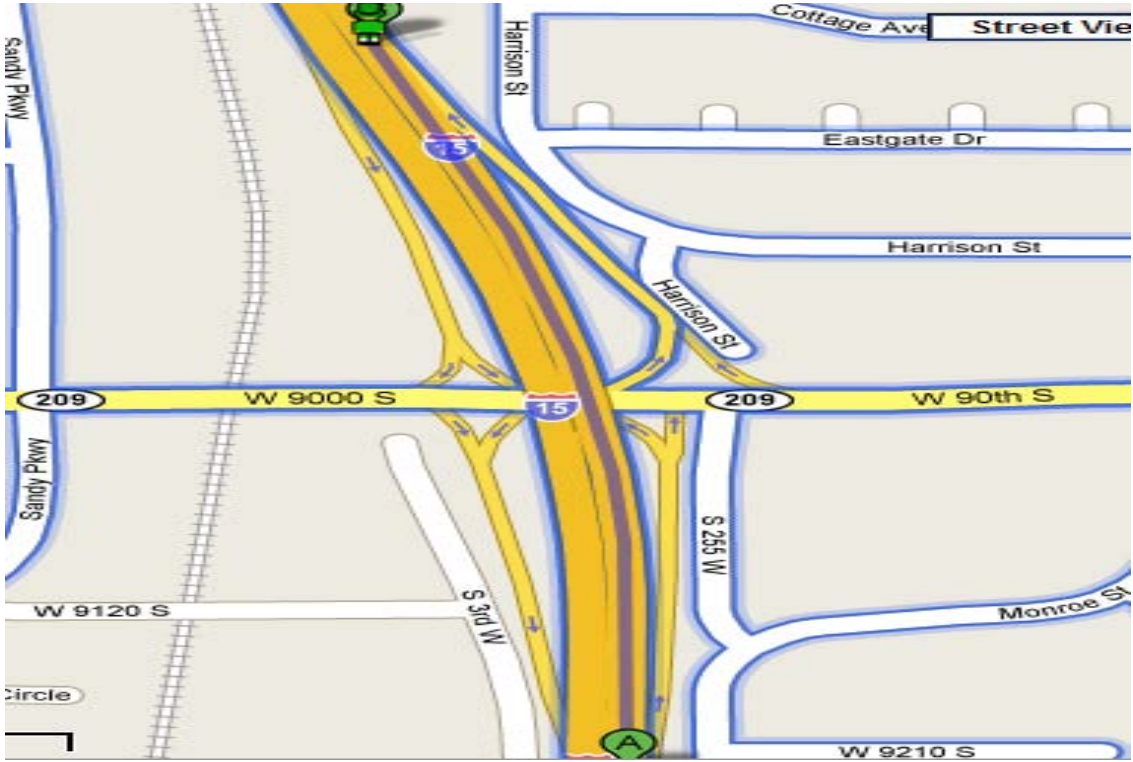

Figure 5.4 The Google Map View Showing the Access and Egress Point on 9000 South, NB Direction.

After exact location of the access and egress point has been marked, the image from the Google map is uploaded as a background to the network (Figure 5.5). This background image serves as an aid to create access/egress points in the network, and it is deleted after the creation of this point. The process is repeated for all 16 access and egress points in each direction.
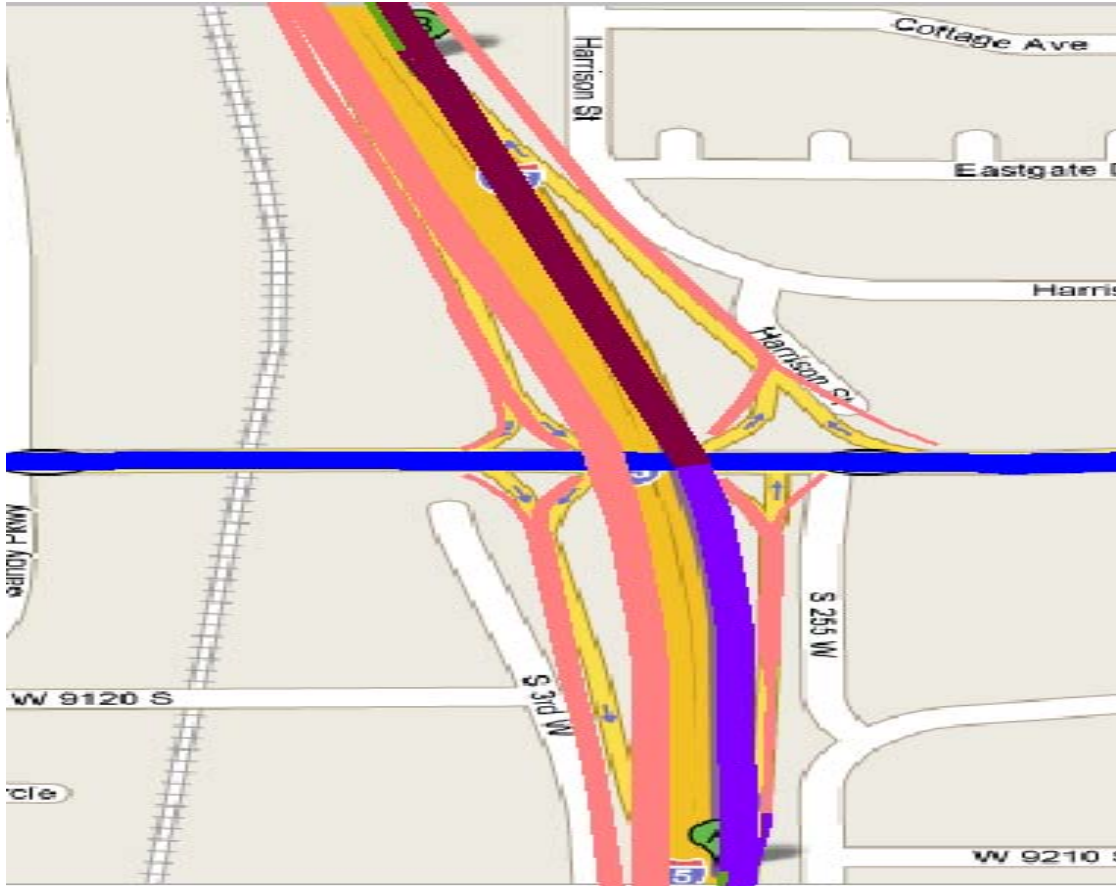
Figure 5.5 Upload of the Google Image into the Model to the Exact Scale.

5.1.3 Static Routes

The existing static routes need modification as the geometry of the network has changed. Also, new routes have been created for the HOT links. HOT traffic volume data is collected at four intersections, which are 5200 South, Exit 278, 10600 South and 2700 South. As there is no available data for the other HOT access points, the same proportion of traffic is assumed to apply to them. The nearest available data for traffic proportion has been used for all the other HOT access points. Throughout this process, care was taken not to change the original off-ramp traffic volume.

5.1.4 Ramp Meters

Data for ramp meter signal controllers in Salt Lake City were collected from UDOT servers in the Utah Traffic Lab (UTL) (5). The maximum and minimum green times and red clearance times were taken for each ramp meter. All other data not necessary for calibration were ignored. Ramp meters were

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investigated in the field to understand the signal operations. A few ramp meters were found to allow more than one vehicle per green in the NB direction. Using NEMA signal controllers in VISSIM, data were entered for all the existing ramp meters. These existing ramp meters are located at 12300 South, 10600 South, 9000 South, 5300 South, 4500 South, and 3300 South for both directions and 1300 South for the NB direction only. The signal timings were repeatedly calibrated until the models simulated the actual time conditions.

5.2   Calibrating the Network

5.2.1   Preliminary Results

For calibration purpose, travel times are taken as the measure of effectiveness and VISSIM travel times are compared with the GPS travel times obtained from the field. In the field, the travel times were typically collected from intersection to intersection. All these travel times sections have been exactly simulated in the model, according to GPS coordinates. Each model has 25 travel time sections for each category, for example, GP lanes and express lanes. Due to the stochastic nature of VISSIM's simulation model, numerous simulation runs with different random seeds to compute statistically reliable results (3).

North Bound Model. Simulations were run for AM peak (6:30 to 8:30 AM) on the NB model. Only the data collected during the month of August is used for analysis as a result of the work zone activities that took place from May to June 2007 because work zone data could have altered the modeling calibration. An additional lane was constructed, starting from 12300 South through to 10600 South, during the construction, and it was fully operational in August. The model is modified accordingly. Ramp metering plays an important role in calibrating the model, and the frequency of the vehicle input is changed to create or avoid congestion in those sections until the required travel times have been achieved.
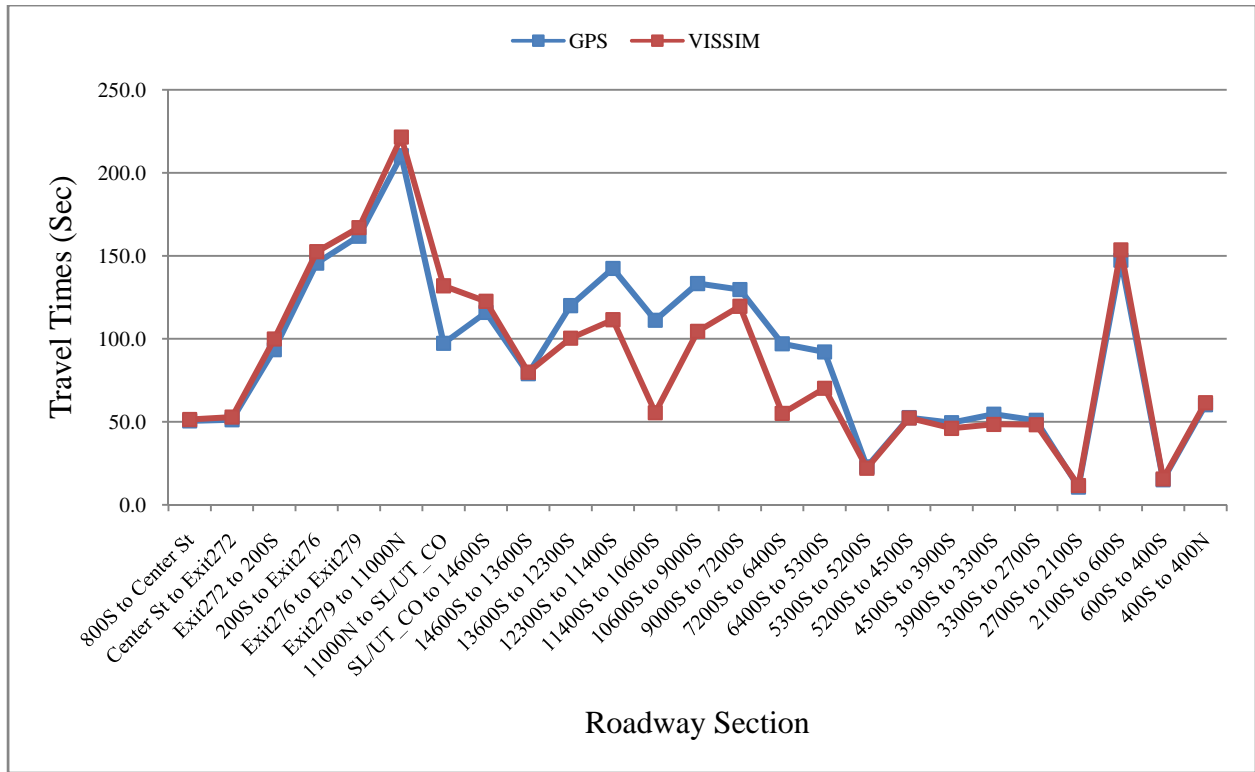
Figure 5.6 Travel Time Comparison for General Purpose Lane.
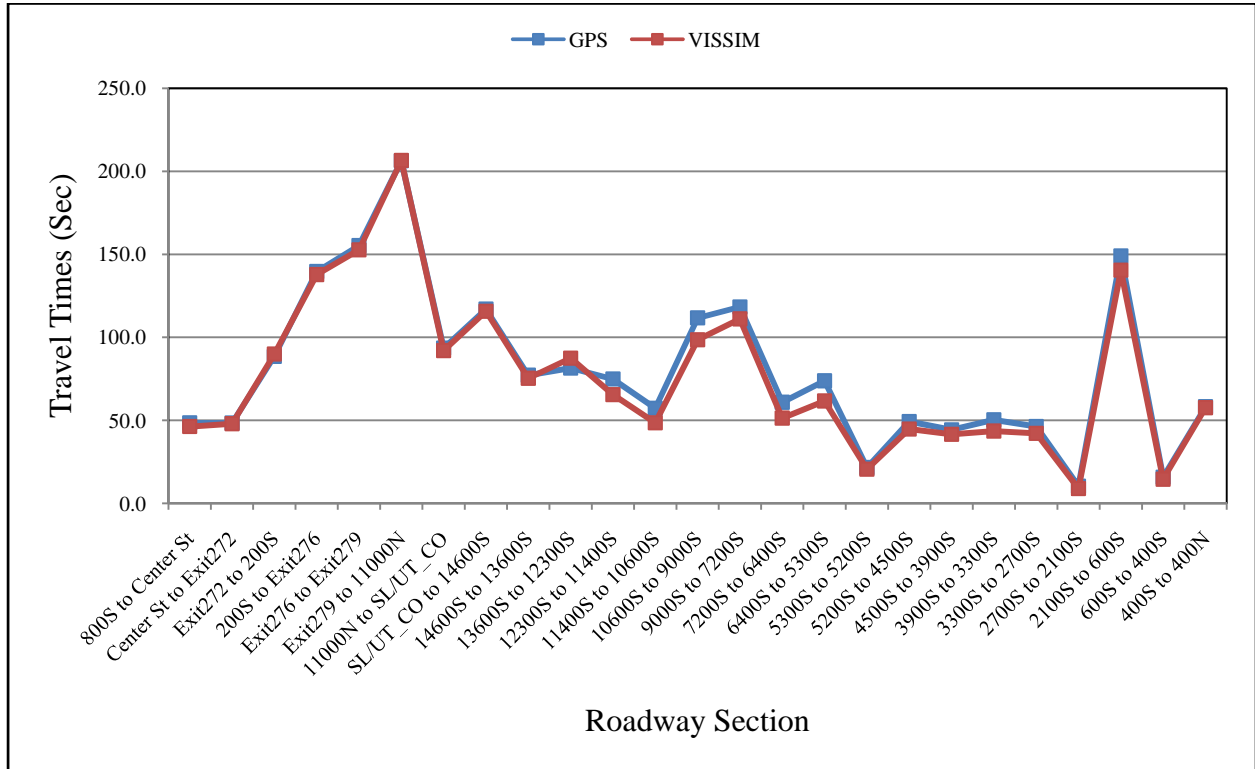
Figure 5.7 Travel Time Comparison for Express Lanes.

Southbound Model. Simulations were run for PM peak (4:00 to 6:00 PM) on SB model. As there were no construction activities in the SB direction throughout the data collection period, the original travel time data from all the months is used to calculate the average GPS travel times. The traffic volume data on the 400 South onramp were collected manually after identifying the original data to be inaccurate. Ramp meters also play a significant role in the calibration of the SB model. Traffic conditions on the 7200 South onramp, where one of the lanes is solely dedicated to EL vehicles, is closely simulated in the model.
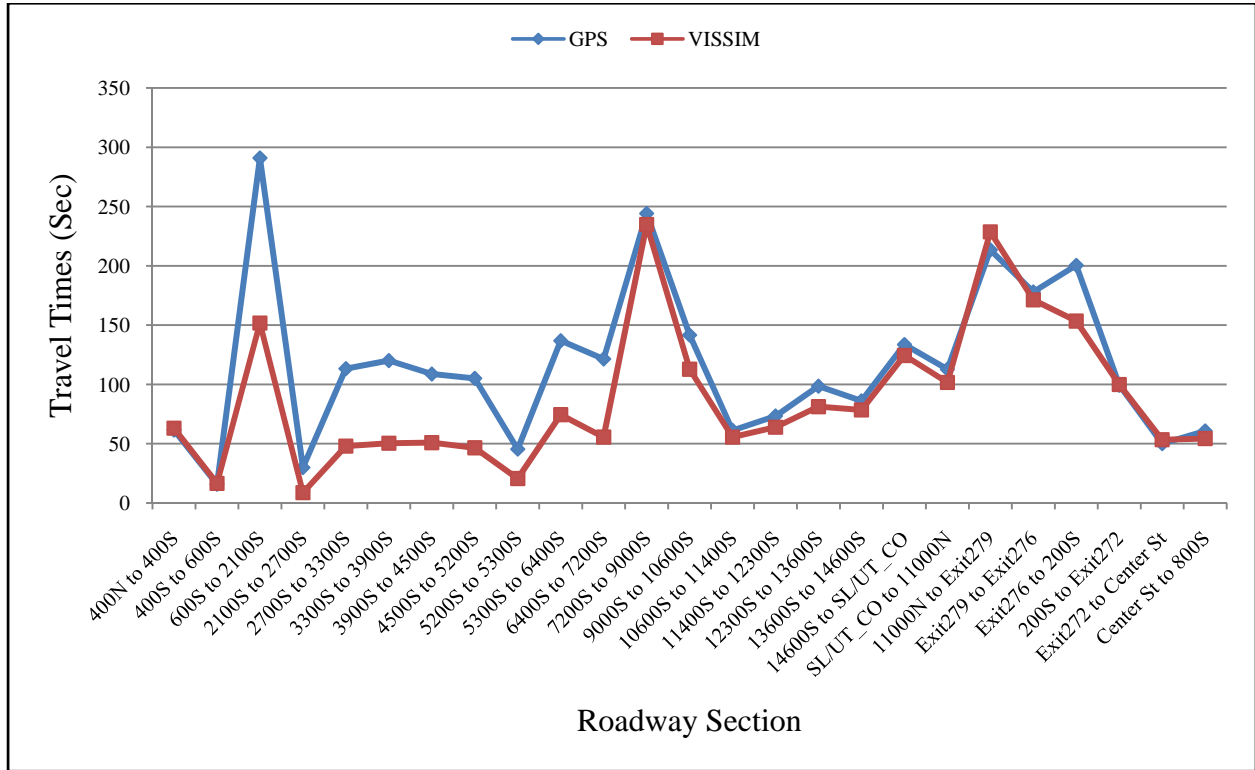
Figure 5.8 Travel Time Comparison for General Purpose Lanes in the Southbound Direction.
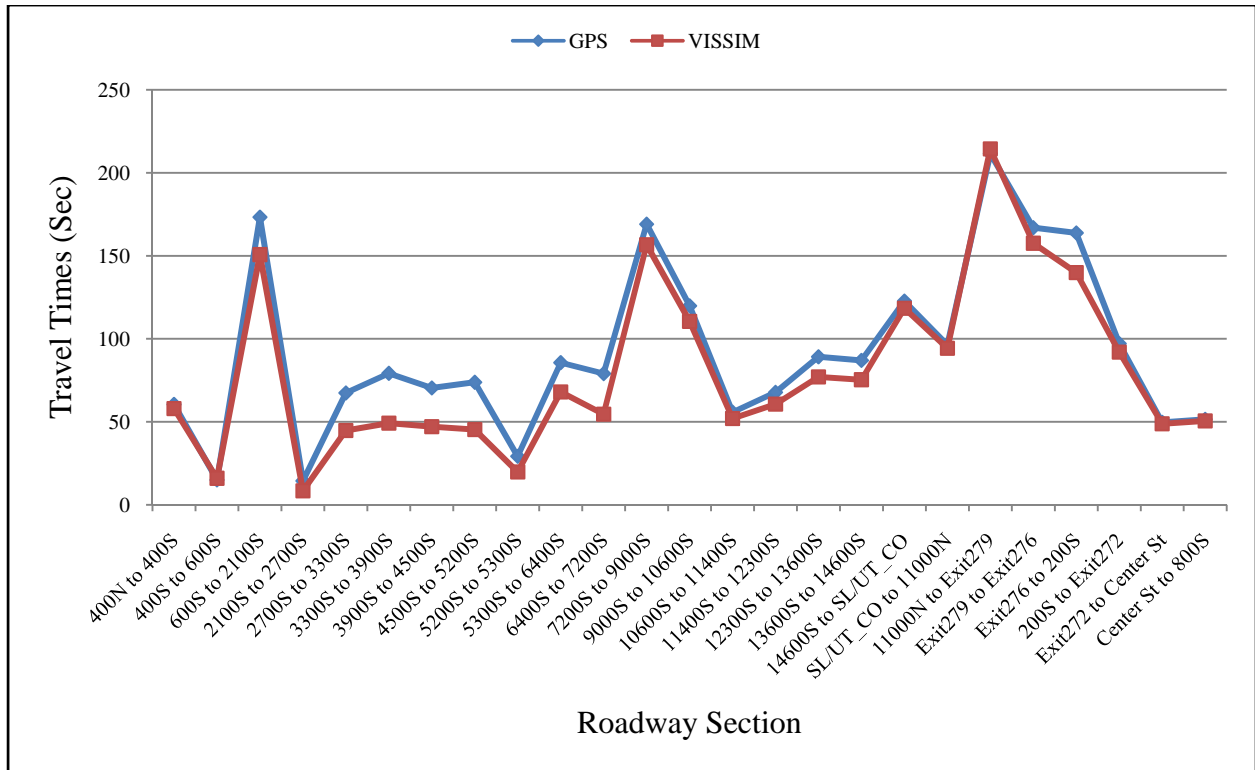
Figure 5.9 Travel Time Comparison for Express Lanes in the Southbound Direction.

5.3 Discussions

Although most of the real time traffic conditions can be simulated, some conditions cannot. The reasons for differences in the GPS and VISSIM travel times at some sections in the above graphs can be drawn as following.

1. I-15 traffic composition is assumed to be the same on every ramp, but field conditions may not always reflect this assumption.

2. The most common violators in the traffic composition are defined as the SOVs that travel in the express lanes and do not pay the required toll. However, there is another type of violator that crosses the solid double white lines, for example, those vehicles reaching a destination off-ramp before an available access and egress point. These violators cannot be simulated in the VISSIM model, because a separate link has been created for the express lane vehicles, and the violators cannot enter GP lanes until they reach an access point. This condition has a significant impact at the sections of road where excessive congestion exists.

3. Traffic volume data were collected at only a few intersections, on both the GP and express lanes. At each intersection, the traffic volume is assumed to have traffic proportions similar to the nearest intersection. But it might not be the same in real conditions.

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6.   DYNAMIC TOLLING AND TOLL PRICING

To accomplish the objective stated in the ELGAME2 Scope to "integrate a dynamic toll pricing model with I-15 VISSIM model, and to enable real-time variable congestion pricing," it is necessary to identify methods of rerouting vehicles to and from HOT lanes. These methods are based on drivers' preferences and a current HOT toll schedule. This task required the following:

1. Determine whether VISSIM's static routes can be used for rerouting vehicles due to variable congestion pricing, or, if not, use VISSIM's dynamic assignment protocol.
2. Develop an external program that would deal with behavior travel choice model (used to reflect modal choice).
3. Use outputs from the model either with static or dynamic routing procedures in VISSIM to model the shift in traffic demand between GP and HOT lanes.

6.1   Preliminary Research

VISSIM 5.0 alone is not capable of modeling the rerouting of vehicles to and from HOT lanes based on drivers' preferences and current HOT toll. Therefore, an external program is employed. This program is written in C++ and communicates with VISSIM through the VISSIM COM server. System architecture is composed of six steps and is shown in Figure 6.1. This system architecture has been adopted from a project conducted in Washington for proposed HOT lanes (1).
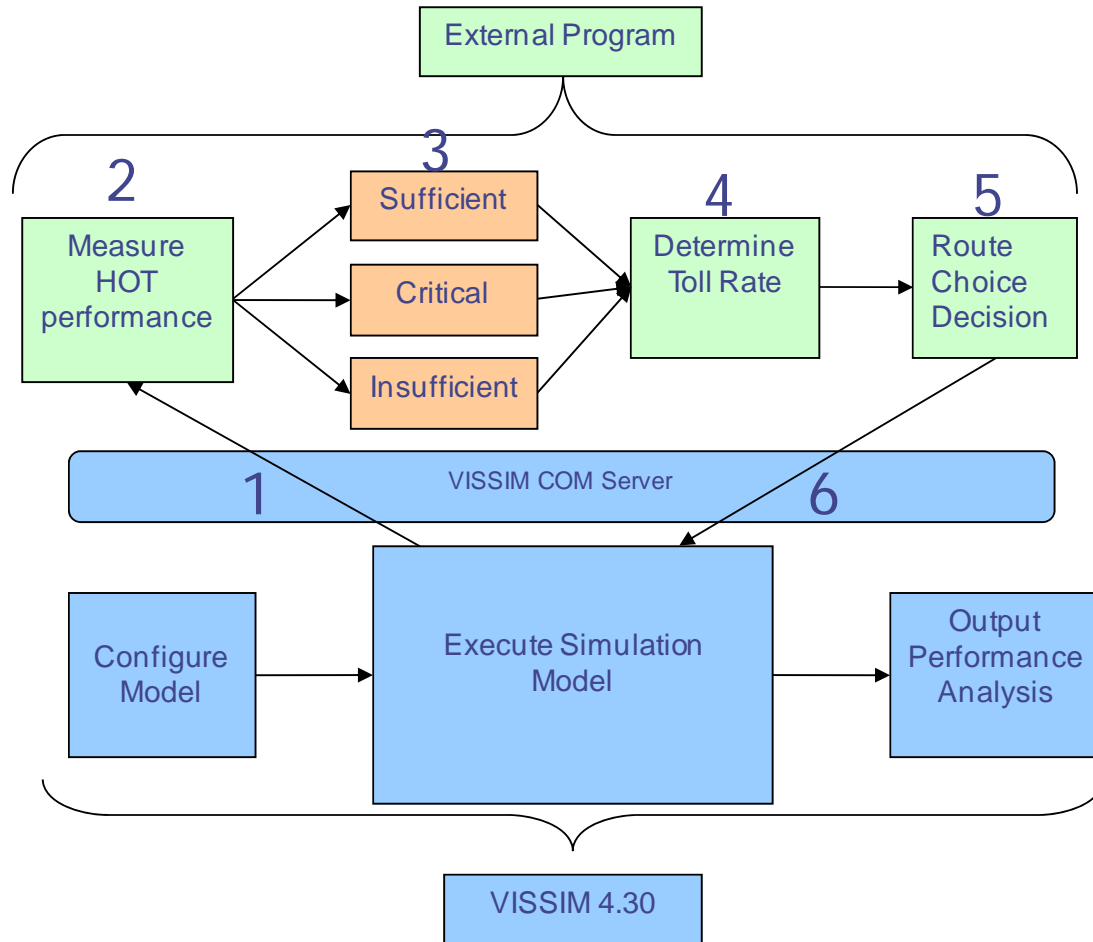
Figure 6.1 System Architecture for Connecting VISSIM with an External Program.

Steps for connecting VISSIM with the external program:

1. VISSIM Simulation Run and Output to COM Server. The VISSIM model is executed in single-step mode with the default frequency of one second. VISSIM then outputs values of space mean speeds for the GP and HOT lanes. Data collection points are used for collecting space mean speeds. The VISSIM COM server receives these values.

2. Measuring the Performance of HOT. Speed data from the previous step are aggregated in five-minute intervals. Five minutes is the length of a single iteration of the algorithm. Every five minutes, conditions on the freeway are assessed and a new toll rate is determined. The HOT lane speed is the basis for the toll calculations, and it is divided into three categories based on its value:

     i.   Sufficient capacity: $V_{HOT} > 50\ mph$
    ii.   Critical capacity: $50\ mph \geq V_{HOT} > 45\ mph$
   iii.   Insufficient capacity: $V_{HOT} \leq 45\ mph$

Alternatively these capacities can be defined by level of service; furthermore, these boundaries conditions can be changed.

3. Calculating Proportions. The proportion of vehicles that should be allowed in the HOT lane is determined. This number may change at the end of each five-minute time interval. The following equation is used to calculate the proportion of vehicles to allow into the HOT lane:

$$P_{HOT}(t+1) = P_{HOT}(t) + \Delta P_{HOT}(t)$$

Where:

(t) = Iteration counter.

$P_{HOT}(t+1)$ = Proportion of vehicles allowed in the HOT lane for the next iteration. This number must remain between zero and one.

$P_{HOT}(t)$ = Proportion of vehicle allowed in the HOT lane in the current time step. This number was calculated in previous time step $(t-1)$.

$\Delta P_{HOT}(t)$ = Change in proportion from the current proportion at time (t), to the next proportion at time (t+1). This number is calculated given the current conditions. If the result were a negative number, then the number of vehicles allowed into the HOT lane would decrease. Based on HOT lane performance (the capacity determined in step 2), there are three equations for calculating $\Delta P_{HOT}(t)$:

    i.   Sufficient capacity: $\Delta P_{HOT} = b_1 + k_1(V_{HOT}(t) - V_{GP}(t))$

    ii.   Critical capacity: $\Delta P_{HOT} = sign\left[b_2 + k_2(V_{HOT}(t) - V_{GP}(t))\right]$

    iii.   Insufficient capacity: $\Delta P_{HOT} = k_3(V_{HOT}(t) - 45)$

Where:

V_{HOT} = Space mean speed (aggregated every five minutes) in the HOT lane.

V_{GP} = Space mean speed (aggregated every five minutes) in the GP lanes.

k_1, k_2, k_3, b_1, b_2 – Constants that were determined experimentally (by the University of Washington research), and have the following values (2):

$$k_1 = 0.005, k_2 = 0.0012, k_3 = 0.03, b_1 = 0.075, b_2 = 0.024$$

$sign$ = determines whether ΔP_{HOT} is positive or negative based on the following criteria:

$$sign = \begin{cases} 1 & if \ \ P_{HOT}(t-1) > P_{HOT}(t) \\ 0 & if \ \ P_{HOT}(t-1) = P_{HOT}(t) \\ -1 & if \ \ P_{HOT}(t-1) < P_{HOT}(t) \end{cases}$$

4. Calculating the Toll Rate. This step determines the toll rate based on travel times for GP and HOT lanes and the proportion of vehicles calculated in step three. The expected rate is between $0.05 and $0.80 per tolling section. The travel times are calculated using the following formulas:

$$TT_{HOT} = \frac{Distance}{V_{HOT}}, \qquad TT_{GP} = \frac{Distance}{V_{GP}}$$

Where:

TT_{HOT} = Travel time in the HOT lane.

TT_{GP} = Travel time in the GP lanes.

5. *Distance*: Distance is defined as the length of the road from one tolling station to the next tolling station (assuming the distance traveled in both lanes is equal).

Finally, the toll rate is calculated based on the following formula:

$$TR_{HOT} = \frac{1}{\frac{1}{\alpha TT_{GP}} - ln\left(\frac{1 - P_{HOT}}{P_{HOT}}\right)} - (\alpha TT_{HOT})$$

Where:

TR_{HOT} – Toll rate in the HOT lane

α – Capital-to-travel time ratio for converting travel time into a monetary value, and is assumed to have a value of $14.79/hr$ or $0.00411/sec$ (2)

6. Route Choice Decision. Route choice decision is the probability of choosing the HOT lane, calculated based on the Logit model:

$$P_{HOT} = \frac{exp(U_{HOT})}{exp(U_{HOT}) + exp(U_{GP})}$$

Where:

U_{HOT} – Utility function for HOT lane choice, and is calculated as

$$U_{HOT} = \frac{1}{TC_{HOT}} = \frac{1}{\alpha TT_{HOT} + TR_{HOT}}$$

TC_{HOT} – Total cost of choosing the HOT lane

U_{GP} – Utility function for GP lane choice, and is calculated as

$$U_{GP} = \frac{1}{TC_{GP}} = \frac{1}{\alpha TT_{GP}}$$

Where:

TC_{GP} – Total cost of choosing the GP lane.

7. COM Server Interface. This external program accesses the relative flow of the VISSIM static routes through the VISSIM COM server. It then changes the relative flow to that of the probability calculated in step 5. VISSIM then randomly determines whether a specific vehicle will enter the HOT lane.

6.2 Tolling Strategy

The tolling strategy employed in this study is similar to zonal tolling in many respects. Customers are charged a dynamic rate to drive a single section of highway. The corridor is divided into 17 sections of varying length. The length and position of these sections represent current corridor conditions. The advantage of this method is that users are charged according to the length of their trips and the current conditions, as opposed to a flat rate system in which users with long trips pay the same as those with short trips. Additionally, the dynamic rate method provides natural boundaries for evaluating HOT lane performance. Finally, this method requires very little change to the VISSIM model. Unfortunately, this method has three drawbacks for actual implementation, one being the amount of physical infrastructure required every two to three miles. The second drawback is that this method makes it difficult for users to estimate the cost of their trips beforehand, since each section would have its own unique toll that varies

over time. The third potential problem is that this method does not attempt to mitigate users from weaving at the merging sections.

This method uses the difference in travel times between the GP and HOT lanes as the basis for calculating the toll rate. The time saved using the HOT lane over the GP lane is calculated and given a monetary value using a capital-to-travel time ratio, which becomes the toll rate.

6.3   Initial Test

The initial testing of the algorithm was performed a single iterative step at a time in Microsoft Excel. This procedure revealed some limitations with the algorithm. One limitation was that reasonable results could only be achieved if the distance was assumed to be one mile. As a result, it was decided to calculate the toll rate for the length of one mile, and then multiply that value with the length of the observed segment. This is accounted for within the programming.

The initial testing attempted to mimic the algorithm's response to degradation in velocities for both the HOT and GP lanes. This was accomplished through testing the algorithm for multiple iterations. During these initial tests artificial speed profiles where given as inputs, and the toll rate and probability were given as outputs. During these tests, some strengths and weaknesses where found in the Washington algorithm.

> Strengths. The Washington algorithm is a feedback-based algorithm, meaning it has the ability to adjust the toll rate quickly due to dramatic changes in traffic conditions; however, it adjusts the toll rate gently when HOT lane performance is classified as "critical." This prevents the algorithms from being over-sensitive or under-sensitive. It does this by using different coefficients for different performances categories.

> Weaknesses. If the HOT lane speeds remain above the upper bound of the critical performance level, the algorithm continues to increase the proportion of vehicles allowed in to the HOT lane past a value of one. This causes the natural log function within the toll equations to fail.

The algorithm would occasionally output negative or large toll rates; it would also occasionally produce proportions that were negative or larger than one. This would happen when the performance category would remain outside the "critical" category for a prolonged period of time. If any of these four conditions occurred, the algorithm would output erroneous data for the remaining iterations. The solution to this problem came in a series of fail-safes embedded within the programming. These fail-safes maintain the algorithm's variables and ensure the outputs are correct when the traffic conditions are not ideal for the algorithm.

It was concluded that because the input velocities were artificial and static, they do not accurately represent the change in proportion due to an increase in the toll rate. Therefore, to accurately validate the algorithm, simulations and real time estimations needed to be preformed.

6.4   Programming

A parent program or "main function" manages the algorithm, as well as the interaction between VISSIM and the algorithm. The algorithm is split into two helper functions, called "proportion calc" and "probability calc," respectively. The program architecture is shown in Figure 6.2. For a more detailed explanation of the code see Appendix A, *ELGAME 2 Pseudo Code*.

The main function controls every aspect of the simulation that is not specifically controlled by VISSIM 5.0. The main function uses the VISSIM COM to boot VISSIM, load the model, and load the VISSIM parameters, such as simulation resolution and random seed. The parent program also loads algorithm parameters, such as constants and initial variables. The main function extracts the mean speed from VISSIM and loads the new relative flows for specific static routes.

The two helper functions take the place of the algorithm. The "proportion calc" function takes the velocities of the HOT and GP lanes as well as the proportions for the two previous iterations. The function then outputs the proportion for the next iteration. The "probability calc" function takes as inputs the velocities of the HOT and GP lanes as well as the proportions for the next iteration. It then calculates the roll rate and the utility of each lane, and then outputs the probability of a vehicle entering the HOT lane.
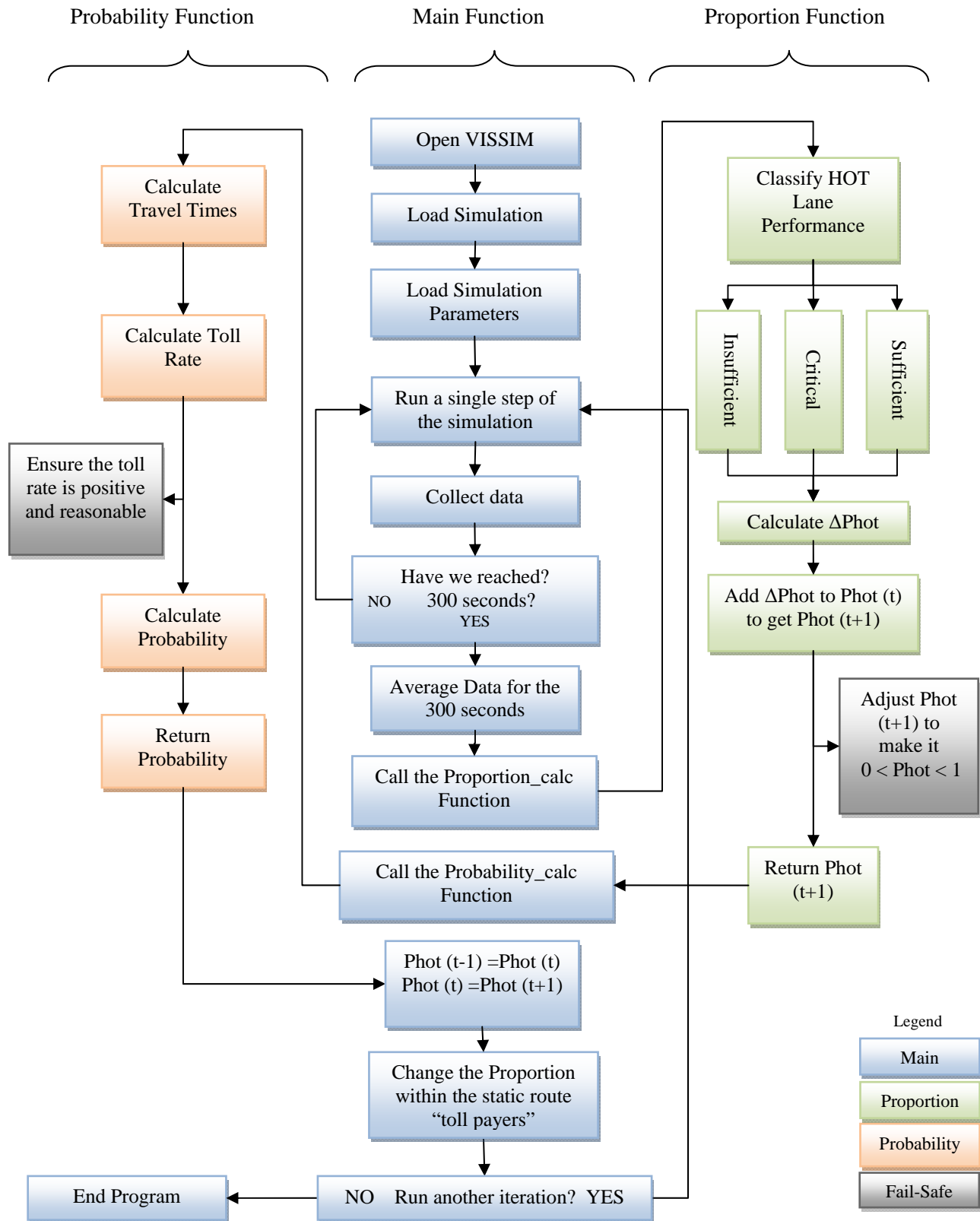
Figure 6.2 Program Architecture.

6.5 Initial Simulations

A simple VISSIM model accurately tests the algorithm. The model includes a single tolling section comprised of a merging section .6 miles long, three 2.5 miles long GP lanes, and one 2.5 miles long HOT lane. After many simulations, the results are deemed inconclusive. This occurred after numerous attempts at creating congestion on the simple model had failed. As the input volume is increased past 2200 vehicles per hour per lane, the free flow speed remains on both the GP and HOT lanes. However, large queues form in the merging section. It is concluded that the algorithm is not accurately tested due to the measure of performance not decreasing below the sufficient classification.

6.6 Accommodating Dynamic Pricing on the Existing Model

To adapt the algorithms to the larger model, a few changes are made to both the model and to the program for the sake for proper functionality. The first is a change in the vehicle classes. The original model contains two vehicle classes. One vehicle class is for the express lane, such as HOV, HOT, violators, busses, and motorcycles. The second vehicle classification is for the GP lanes; it includes everything else, such as HGV, HGV doubles, trucks, SUVs, cars, and sport cars. For the new model, a new vehicle class called "toll payers" is created. The HOT vehicles from the Express lane vehicle class are moved to the new toll payer class. These are the vehicles the algorithm controls.

The second change is the creation of 17 new static routes. These static routes are specifically for the toll payer vehicle class, and will route the HOT vehicles in and out of the HOT lane. The algorithm controls the relative flow of these routes. The number of tolling stations is assumed to be one per merging section, resulting in 17 tolling stations based on current highway striping.

The final change was made to the input composition of the model. Estimates are made that place the number of vehicles with transponders between 7,000 and 17,000. To accurately represent the future conditions of I-15, the input vehicle compositions need to be changed to account for the increase in potential HOT vehicles. The total percentage of HOT vehicles increases from 1.8% to 20%. To accommodate this increase in HOT vehicles, the number of cars, sports cars and SUVs was decreased. The complete changes are summarized in Table 6.1.

Table 6.1 Vehicle Composition Change

Vehicle Type	Old Composition (%)	New Composition (%)	Change
Cars	35	25.7	-9.3
Sports Cars	5	1	-4
SUVs/ Vans	19	15	-4
Trucks	10	15	5
HGV (single)	5	2.6	-2.4
HGV (double)	3	0.2	-2.8
Bus	0.8	0.5	-0.3
HOT	1.8	20	18.2
HOV	18.2	18	-0.2
Violators	2	2	0

6.7 Results

Simulations run on the full size model of I-15 provide varied results. In areas of the model where there is little to no congestion, the algorithm is found to work properly and deliver an anticipated toll rate which varies as expected based on the length of the tolling section.
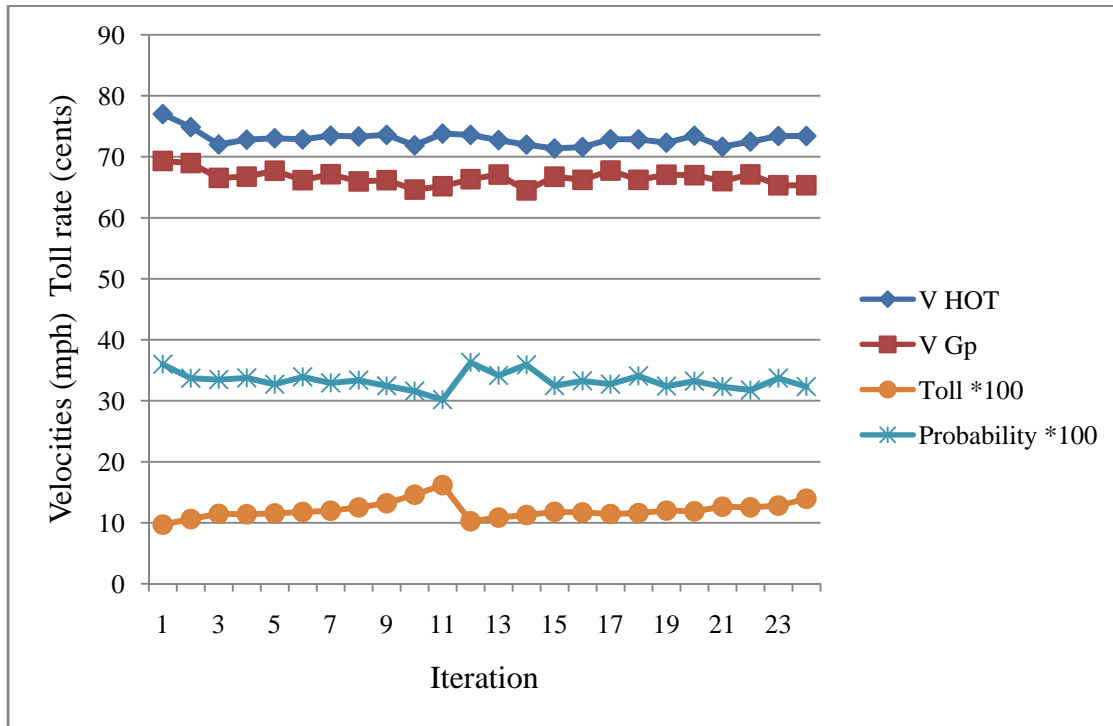
Figure 6.3 No Congestion (One iteration equals five minutes).

In sections of the model where the congestion is found to be mild, the algorithm increases the toll and decreases the proportion of HOT vehicles accordingly. The HOT lane speed does not dip below the minimum speed of 45 mph. Nevertheless the toll is increased and the speed of the HOT lane is maintained.
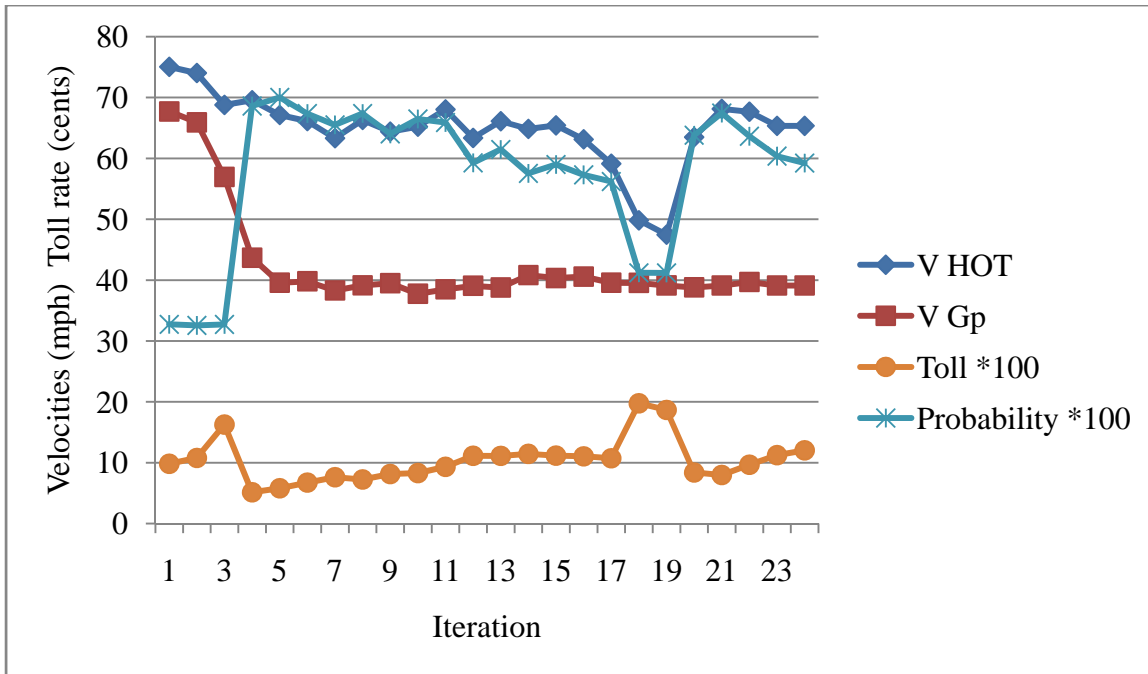
Figure 6.4 Mild Congestion (One iteration equals five minutes).

In simulations with moderate congestion, the algorithm works well. Once the speed of the HOT lane drops below the minimum performance level of 45 mph, the algorithm classifies the lane as "insufficient," and increases the toll more rapidly, as seen in iterations 16 and 17 of Figure 6.5.
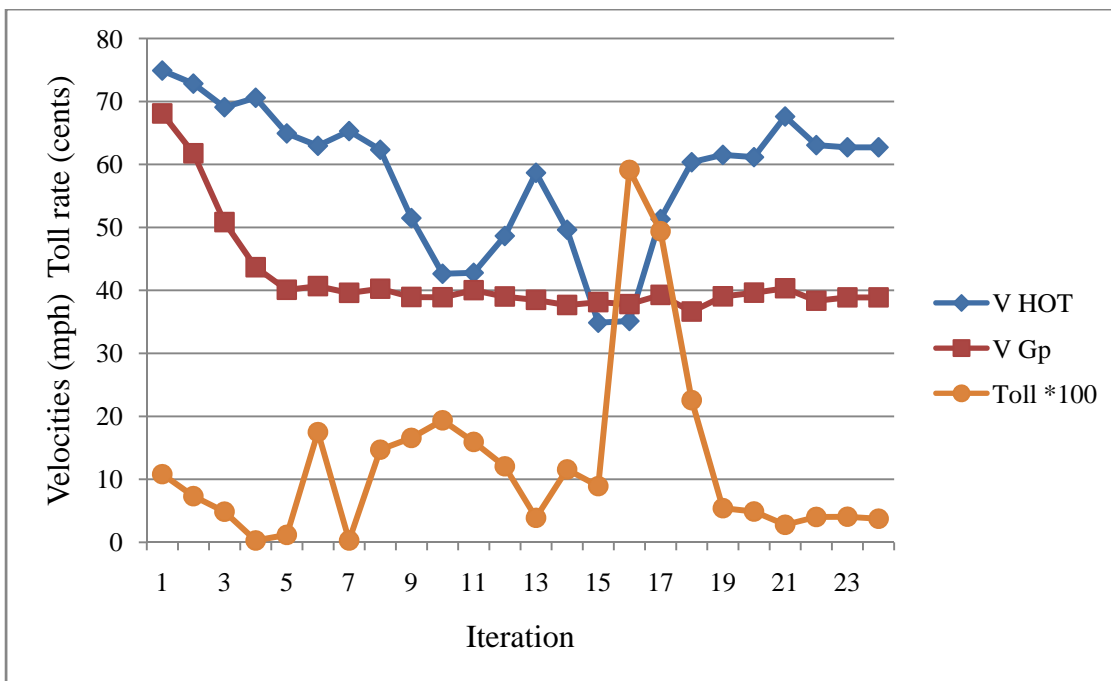
Figure 6.5 Moderate Congestion (One iteration equals five minutes).

However, in some simulations the algorithm fails to function properly. These situations are observed when the congestion exceeds the control of the algorithm. In simulations of heavier congestion, the algorithm is unable to maintain the minimum speed of 45 mph. This appears to be the fault of the model and not that of the algorithm. Figure 6.6 shows the maximum toll rate as the speed of the HOT lane continues to drop.
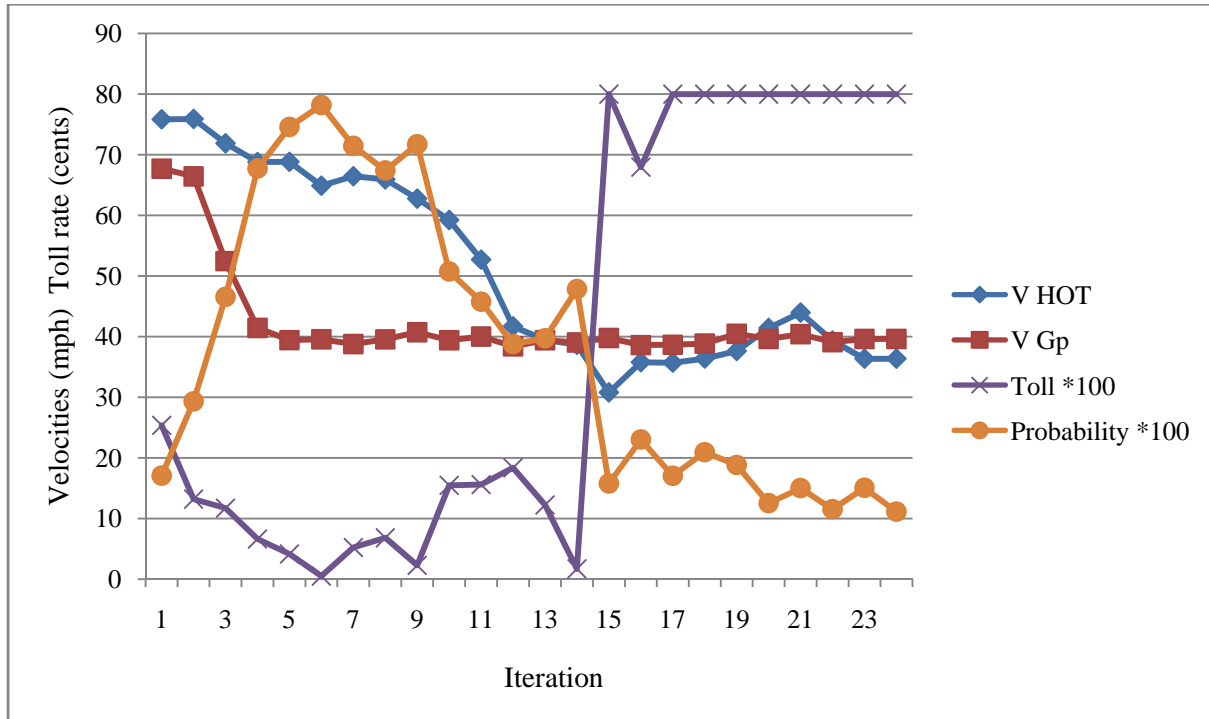
Figure 6.6 Heavy Congestion (One iteration equals five minutes).

7.   CONCLUSIONS

This project presents a modified pre-existing VISSIM model of I-15 to support future HOT lanes operations. It has been recalibrated and revalidated in terms of HOT related performance measurements. The literature shows that there is little scholarship that has been published. The most promising comes from the State of Washington. This report shows that the "Washington Algorithm" serves as the basis for simulating toll measures for the I-15. The algorithm was originally developed for a simple condition, and the work presented here shows how it has been modified and expanded to address a much more complex network.

The initial results are promising, indicating a capability of modeling tolls for speeds above 45 mph. The instability of the algorithm below this speed remains the subject of further research.

REFERENCES

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5. Utah Department of Transportation, *UDOT Server in UTL*, Internet Explorer, Ramp Meter Signal Controllers in Salt Lake City. \\utstsrtcns51\Installations\ATMS Explorer Documents\Ramp Meter. SL. XPL.

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APPENDIX A

ELGAME 2 ALGORITHM Pseudo Code

- Load "include files" and libraries **(COMPLETE)**

```
#define _WIN32_DCOM
#include <time.h>
#include <math.h>
#include <cstdlib>
#include <iostream>
#include <fstream>
using namespace std;
#include <stdlib.h>
#include <stdio.h>
#include <iomanip>
#include <windows.h>
#import "c:\Program Files\PTV_Vision\VISSIM430\Exe\VISSIM.exe"
using namespace VISSIM_COMSERVERLib;
```

- Load both helper functions

(1) `proportion_calc ( Vhot, Vgp , photcurrent, photprevious)` **(COMPLETE)**
   o Define all variables

```
double b1              = .075;
double b2              = .024;
double k1              = .005;
double k2              = .0012;
double k3              = .03 ;
double Vhotmin         = 45.1;
double deltaphot       = 0;
bool critical          = false;
double photdecrease    = .2;
double photnext        = 0;
```

   o Classify HOT lane performance and calculate the proportion of vehicles to let into the HOT lane **(COMPLETE)**

```
if (Vhot > 50)
      {
      deltaphot = (b1 + k1*(Vhot-Vgp));
      }
else if (Vhot <= 50 && Vhot > 45)
      {
      deltaphot = (b2 + k2*(Vhot-Vgp));
      critical = true;
      }
else
      {
      deltaphot = (k3*(Vhot-Vhotmin));
      }

if (critical==true && photprevious < photcurrent)
      deltaphot = deltaphot * -1;
```

o Add the proportion of the current iteration to the change in proportion to obtain the proportion for the next iteration **(COMPLETE)**

```
photnext = deltaphot + photcurrent;
```

o Ensure that "photnext" is positive; doing so should fix the any problems with the LOG function contained within the *Probility_calc* helper function. Under normal conditions these two "if" statements should be false. However they are in place as a backup in case "photnext" is too large or too small. **(COMPLETE)**

```
if (photnext < 0)
        {
        photnext = photnext * -1;
        printf ("+++++ WARNING: PHOT WAS NEGATIVE ++++++++++ \n");
        }
if (photnext > 1)
        {
        printf ("+++++ WARNING: PHOT WAS GREATER THEN ONE +++ \n");
        while (photnext > 1)
                {
                photnext = photnext - photdecrease;
                }
        }
```

o Return the "photnext"

```
return photnext;
```

(2) **probability_calc (Vhot, Vgp, photnext)** **(COMPLETE)**
o Define all variables

```
double distance        = 1;
double TTHOT           = 0;
double TTGP            = 0;
double tollrate        = 0;
double alpha           = 0.00411;
double probability     = 0;
```

o Calculate the Travel times
```
TTHOT = distance/Vhot*3600;
TTGP  = distance/Vgp*3600;
```
o Calculate the Toll rate **(COMPLETE)**

```
tollrate = ((1/((1/(alpha*TTGP))-(log((1-photnext)/photnext))))-
(alpha*TTHOT));
```

$$TR_{HOT} = \frac{1}{\frac{1}{\alpha TT_{GP}} - \ln\left(\frac{1-P_{HOT}}{P_{HOT}}\right)} - (\alpha\, TT_{HOT})$$

o Ensure that the toll rate is positive. Under normal conditions this "if" statement should be false. However it is in place as a backup in case the toll rate is negative.
(COMPLETE)

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```
if (tollrate < 0)
{
        tollrate = tollrate*-1;
        printf ("+++++ WARNING: TOLLRATE WAS NEGATIVE+++++++ \n");
}
```

o   Calculate the probability of a vehicle being let in to the HOT lane   **(COMPLETE)**

```
probability = (exp(1/(TTHOT*alpha + tollrate))) /
(exp(1/(TTHOT*alpha + tollrate))+ exp(1/(TTGP*alpha)));
```

$$P_{HOT} = \frac{\exp{(U_{HOT})}}{\exp{(U_{HOT})}+\exp{(U_{Gp})}}$$

o   Return Probability   **(COMPLETE)**

The Main Function: `int main()`

o   Define all variables   **(COMPLETE)**

```
//simulation parameters
int Period                   = 7200*5;
int Resolution               = 5;
int Speed                    = 1000;
int number_of_simulations    = 6;
int iteration_time           = 300;

//algorithm parameters
int i                        = 0;
int seconds                  = 0;
double Vhot                  = 53;
double Vgp                   = 48;
double photcurrent          = 0;
double photprevious         = 0;
double photnext             = 0;
double tollrate             = 0;
double probability          = 0;
double numberofvelocities   = 0;
double VolumeHOT            = 0;
double VolumeGP             = 0;
```

o   Open VISSIM   (**COMPLETE**)

```
        IVissimPtr spVissim(__uuidof(Vissim));
```

o   Load Simulation   **(COMPLETE)**

```
        spVissim->LoadNet ("C:\\Documents and
        Settings\\jimries\\Desktop\\North Bound-13\\dynamic tolling
        test road static.inp", 0);
```

o   Load Simulation Parameters   **(COMPLETE)**

```
        spSim->PutPeriod(Period);
        spSim->PutResolution(Resolution);
```

```
                    spSim->PutSpeed(Speed);
```

o Run simulation in single step mode   **(COMPLETE)**

```
        for (int seconds = 1; seconds < Period+1; seconds++)
        {
        spSim->RunSingleStep();
        ....
```

▪ Collect data   **(COMPLETE)**

```
        dc1 = dcs->GetDataCollectionByNumber(1);
        dc18 = dcs->GetDataCollectionByNumber(18);
```

```
mean_speed_HOT1 = dc1->GetResult((_bstr_t)"SPEED",(_bstr_t)"MEAN",(long)0);
mean_speed_GP1 = dc18->GetResult((_bstr_t)"SPEED",(_bstr_t)"MEAN",(long)0);
```

o Stop simulation after 300 seconds (This is the length of a single iteration.)**(COMPLETE)**

```
        if (Seconds % iteration_time == 0)
```

▪ Average the data collected above   **(COMPLETE)**

```
        for (int vel = 0; vel < 25; vel++ )
            {
            VolumeHOT = VolumeHOT + VHOT[vel];
            VolumeGP  = VolumeGP  + VGP [vel];
            Numberofvelocities
            VHOT[vel-1] = VHOT[vel-1] -2;
            VGP [vel-1] = VGP [vel-1] -3;
            }
            Vhot = VolumeHOT / numberofvelocities;
            Vgp  = VolumeGP  / numberofvelocities;
```

▪ Call the Proportion_calc function`(1)`   **(COMPLETE)**

```
        photnext = proportion_calc (Vhot, Vgp, photcurrent,
        photprevious);
```

▪ Call the probability_calc function (2)   **(COMPLETE)**

```
        probability = probability_calc ( Vhot, Vgp, photnext);
```

▪ Move current proportion to the previous proportion , and next proportion to
current proportion   **(COMPLETE)**
```
        photprevious = photcurrent;
        photcurrent  = photnext;
```

▪ Change the route choice proportion of "*Tollpayers*" to the value
Probablity   **(COMPLETE)**

```
        IRoutingDecisionPtr rdc1  = rdcs->GetRoutingDecisionByNumber(43);
```

```
rdc1->PutAttValue1("RELATIVEFLOW", 1,relotive_flow_hot1);
rdc1->PutAttValue1("RELATIVEFLOW", 2,relotive_flow_gp1);
```

- Begin next iteration   **(COMPLETE)**

- Contiunue runing simulation   **(COMPLETE)**