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Benefits of Route Guidance System in a Combined Modeling Framework with Variance in Intervals and Equipped Demand

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ABSTRACT

The traffic congestion in large urbanized areas around the globe is a major issue faced by the transportation planning professionals. The traffic engineers and planners are exploring new ideas to tackle the issue. From the perspective of congestion mitigation, the transportation research is focused on development of solutions that increase the efficiency of existing infrastructure. In this context, the development and implementation of Route Guidance Systems (RGS) has been the topic of extensive research for the last two decades. Many solution algorithms and implementation efforts have been well documented. Past research on RGS suggests that the information to drivers on prevalent traffic conditions can impact their route choice, and it may benefit the traffic system in reducing traffic congestion. The paper evaluates the benefits of RGS in a traffic system using Combined Traffic Assignment and Control Framework (CTAC). Nine scenarios were tested with different proportions of RGS equipped demand and varying intervals of RGS, under Dynamic Traffic Assignment (DTA) and vehicle actuated traffic controls. The test results suggest that system- wide travel time improvements and delay reductions can be achieved through the use of RGS. The travel time improvement and delay reduction benefits were the minimum in Scenario with only 25% RGS equipped demand, and the benefits were the maximum in the scenario with 100% RGS equipped demand. Further studies are needed to investigate the drivers' response behavior on information through RGS, and to test the benefits of RGS in even larger study area networks.

KEY WORDS: Route Guidance, Traffic Assignment, Traffic Controls, Route Choice, Dynamic Assignment.

INTRODUCTION

Congestion Management is one of the most pressing issues for research in transportation planning. Large metropolitan areas around the globe are facing congestion mitigation challenges, especially when infrastructure expansion is out of question in those areas. Consequently, the transportation research is emphasized to develop transportation systems that could efficiently use existing infrastructure. The recent advancements in computer technology have impacted the field of transportation in many folds. Especially, the latest technology gadgets like in-vehicle navigation systems and Route Guidance Systems (RGS) are available for use by drivers, and may help them to find a cost efficient alternative route if available. RGS is a way of aiding drivers in route choice decision making/re-routing while en route using information on prevailing traffic network conditions. RGS if available to drivers, have the potential to inform the drivers of any changes in traffic conditions, and may impact their route choice behavior.

There are many algorithms and heuristics that have been investigated for the development and implementation of RGS. Some of the initial algorithms on RGS originated from simple static algorithms that could calculate path for the shortest distance [Boyce, 1988]. The static algorithms later evolved to robust algorithms that take travel times into account based on past travel experience of the drivers or historical data [Ben-Akiva et al, 1991]. Some of the latest RGS algorithms are capable of establishing real-time communication between the vehicle and the traffic operation centers for frequent updates on travel times, traffic congestion, and bottle neck conditions [Mahmassani and Jayakrishnan, 1991]. In a typical traffic system, if the drivers possess little or no information regarding their travel route-choices, and are not informed of prevailing road conditions, this may lead the drivers to make costly route choices with respect to the cost of associated with the trip making during traffic congestion. Information provision thus has the potential of reducing or eliminating poor route choices and consequently diminishing excess travel time. The solution algorithms and model formulations of the RGS have been the topic of

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academic research for the last two decades, yet very little has been done on quantifying the benefits of using RGS. Lack of advanced computer technology until late 1990s' was a hindrance in modeling and simulating RGS equipped demands on complex networks. With the availability of advanced computers and robust micro-simulation software like VISSIM [Bloomberg and Dale, 2000], DYNASMART [Abdelfatah and Mahmassani, 1998], and CUBE-DYNASIM [Yaldi and Yue, 2006], it is now possible to test and implement RGS on complex traffic network simulations.

The objective of this paper is to quantify the benefits of RGS in terms providing the drivers with information on prevailing network traffic conditions while they are en route. A Combined Traffic Assignment and Control (CTAC) framework [Meneguzzer, 1997] built in VISSIM software was used with Dynamic Traffic Assignment (DTA) and vehicle actuated controls. The combined modeling framework will be able to capture the interaction between driver's route choice and traffic controls (control-driver interaction). A portion of Salt Lake City, Utah highway network was used as a test network. In addition to DTA, VISSIM based RGS module was used in the simulations.

LITERATURE REVIEW

Some of the earliest efforts on the effects of RGS on drivers' route choice behavior started in mid 1980s. This included experiments to test the impacts of network information on driver's behavior [Streeter et al, 1985]. Some efforts investigated RGS in terms of road-telematics [(Jeffery, 1988), (Stergiou and Stathopoulos, 1989)]. Other efforts also investigated the impacts of network information on driver's route choice on theoretical scale [(Dingus et al, 1989), (Davis and Schmandt, 1989)]. Most of the initial efforts investigating the impacts of information on driver's route choice used basic concept of in-vehicle navigation system in their investigations. 1n 1991, Walker et al used the Federal Highway Administration's (FHWA) Highway Simulator (HYSIM) to investigate the driving performance associated with RGS. Another effort investigated the human factors on in-vehicle navigation system [Green, 1991].

In early 1990s, the theoretical and conceptual studies on RGS transitioned to computer simulation based investigation. In a separate effort, the impact of information to drivers on reduction of traffic congestion was also investigated [Arnott and Lindsey, 1991]. The purpose of the study was to question the presumption that RGS and information systems necessarily reduce traffic congestion. The study suggested that the information on network can impact the drivers' route choice depending on how credible the information is to the drivers. In 1991 Mahmassani and Chen presented a comparative assessment of origin-based and en route real-time information under alternative-user behavior rules. The study suggested that real time information to drivers could lead to system wide benefits. Another study investigated the influence of route guidance advice on drivers' route choice in urban networks[Bonsall, 1992]. Dynamic route guidance system based on historical and current traffic pattern was also investigated [Lam and Tong, 1992]. In 1993 Mahmassani and Peeta investigated the implications for traveler information system with network performance under system optimal and user equilibrium dynamic assignment. Walting and Van Vuren in 1993 followed a similar route by investigating the modeling of dynamic route guidance systems. The fault free analysis to route guidance system was performed by Yang et al in 1994.A separate effort investigated the potential of advanced traveler information systems (ATIS) in a road network in which incidents are generated in random fashion [Emmerink et al, 1995]. In 1995 Shimizu et alinvestigated a simplistic route guidance system based on evaluation algorithm of mean travel time.

In 2001 dynamic route guidance system based on real traffic data was investigated by Wahle et al. The study proposed a two-step procedure. First online simulations were performed with real time traffic data. Afterwards the data was processed in route guidance system allowing optimization of drivers' route choices. Behavioral component of route guidance system using neural networks was also investigated in a separate effort [Khaled et al., 2003].In 2005, Park and Yoo developed a location-based dynamic route guidance system of Korea highway cooperation. In 2006 Zhang and Xu investigated Dynamic route guidance using neuro-dynamic programming. Zou et al. investigated application of genetic algorithm in Dynamic Route Guidance System in 2007. Park and Leeassessed the sustainability impacts of route guidance system under cooperative vehicle infrastructure environment in 2009.

To summarize, the past research on RGS suggests that the network information provided to drivers may change their route choice behavior. While several investigations on development and implementation of RGS have been well documented, more studies are needed to quantify the benefits of RGS for system wide travel time improvements and delay reductions.

METHODOLOGY

Description of Test Scenarios

Nine scenarios were tested though simulations on VISSIM software. DTA coupled with VISSIM based RGS, and vehicle actuated controls were used in simulations. The built in "base data traffic characteristics" menu in VISSIM allows the user to define vehicle types in the traffic demand by different vehicle characteristics like RGS, speed or any other user-specified characteristics. For this paper, the traffic demand was divided into RGS equipped and NO-RGS equipped types. The "traffic composition" tool in VISSIM allows the user to set proportion/share of equipped and non-equipped traffic demand. VISSIM software also allows the user to specify the RGS Interval. RGS Interval defines the time interval at which the RGS in simulation triggers. Two sets of scenarios were modeled with 120 minutes, and 60 minutes as time intervals. Modeling RGS at different intervals will allow us to gauge the impacts on benefits in different interval gaps.Using the traffic composition tool in VISSIM, the proportion of RGS equipped peak period demand was changed in each scenario set. Starting from 0% RGS equipped demand in Scenario 1, the percentage of RGS equipped demand was increased by 25% in each scenario until 100% RGS equipped demand in Scenario 5 and Scenario 9. In Scenario 2 to 5 RGS Interval of 120 minutes was used. In Scenario 6 to Scenario 9, the RGS interval of 60 minutes was used.Scenario 1 was used as base scenario for both cases (120 minutes RGS interval, and 60 minutes RGS interval). Consequently, each 25% increment in RGS equipped demand was compensated by 25% reduction in NO-RGS Equipped demand in the scenarios to keep the sum of total demand in OD matrix to 100%. Table 1 part a) and part b) describe the test scenarios.

Table 1: Test Scenarios a) Scenarios with 120 minutes Route Guidance System Interval b) Scenarios with 60 minutes Route Guidance System Interval

a)

Scenarios	RGS Interval (minutes)	NO RGS Equipped (%)	RGS Equipped (%)
1	N/A	100	0
2	120	75	25
3	120	50	50
4	120	25	75
5	120	0	100

b)

Scenarios	RGS Interval (minutes)	NO RGS Equipped (%)	RGS Equipped (%)
1	N/A	100	0
6	60	75	25
7	60	50	50
8	60	25	75
9	60	0	100

OVERVIEW OF TRAFFIC ANALYSIS TOOLS

Modeling and Simulation Software

The PTV Vision software VISUM and VISSIM were used to test the scenarios. VISUM 9.4, software for travel demand modeling was used to calibrate OD matrix by using VISUM based OD matrix correction module. The OD matrix correction module has been proven reliable [Ambadipudi et al, 2006]. VISSIM 5.00-08 simulation software was used to mimic realistic traffic system in the simulation. VISSIM has been proven as a reliable micro-simulation tool [Fellendorf et al, 2001].

Route Guidance System

In VISSIM based DTA simulation, the drivers choose their routes from origin to destination based on general cost information collected in the preceding iterations of the simulations. In addition to DTA, VISSIM software through RGS module, offers an option of re-routing vehicles while en route based on prevailing traffic conditions in each simulated-iteration. The rerouting caused by the VISSIM based RGS module is not restricted to fixed positions on the road network. Instead, the equipped vehicles are rerouted in the fixed time interval, a user defined attribute. At the current state of the implementation in VISSIM 5.00-08, the action triggered by the system is always to search the best route from the current vehicle position to the destination parking lot.

The criteria for the re-routing search are the general cost with travel times measured in the current simulation. The travel times taken into account for the re-routing are not necessarily the most recent travel times but travel times measured sometimes ago based on user defined offset. The offset is introduced to model the processing time of typical route guidance systems i.e. the time from measurement on the road until the data is available to the route guidance equipment in the vehicles. Whether a vehicle type is equipped with RGS can be selected while defining the vehicle type characteristics. The traffic composition, with proportions on equipped and non-equipped vehicles in the traffic demand can be defined using traffic composition tool of VISSIM software. For this paper, RGS was tested with 25% increments of equipped traffic demand starting from 0% equipped to 100% equipped. Two sets of scenarios were tested. The first set of tests had RGS interval of 120 minutes, and the second set of scenarios tested had 60 minutes RGS interval. The offset was set to 30 minutes. In the base scenario, 0% of the demand was equipped with RGS.

Route Guidance System Interval and Offset

In VISSIM software, the Route Guidance System is triggered on user defined intervals. VISSIM manual suggests that the RGS interval duration depends on several factors including type of network, communication technology, and time period of simulation. For this paper, the RGS was evaluated for time interval of 120 minutes with 30 minutes offset in Scenarios 2 to 5, and 60 minutes interval with 30 minutes offset for Scenarios 6 to Scenario 9. With 60 minutes interval, and 30 minutes offset; the offset starts 30 minutes before the RGS is triggered. The offset time of 30 minutes accounts for information collection on travel times, and provision to drivers before the RGS triggers.

Once the RGS triggers, the equipped traffic is re-routed to shortest travel routes using newly calculated travel time information based on prevalent travel conditions. Figure 2 outlines the example of three hours PM peak period RGS progression in a simulation with 60 minutes RGS interval, and 30 minutes offset.Due to 60 minutes RGS interval, the RGS system triggers after every 60 minutes during the 3 hours PM peak simulation, and the drivers had opportunity to get information on prevalent network travel times after every hour. Due to the offset of 30 minutes, the information on prevalent travel times was collected, processed, and was available to the drivers in the same time frame at the trigger of each RGS interval. Figure 1 outlines the Route Guidance System Interval and Offset process for 60 minutes RGS interval and 30 minutes offset.

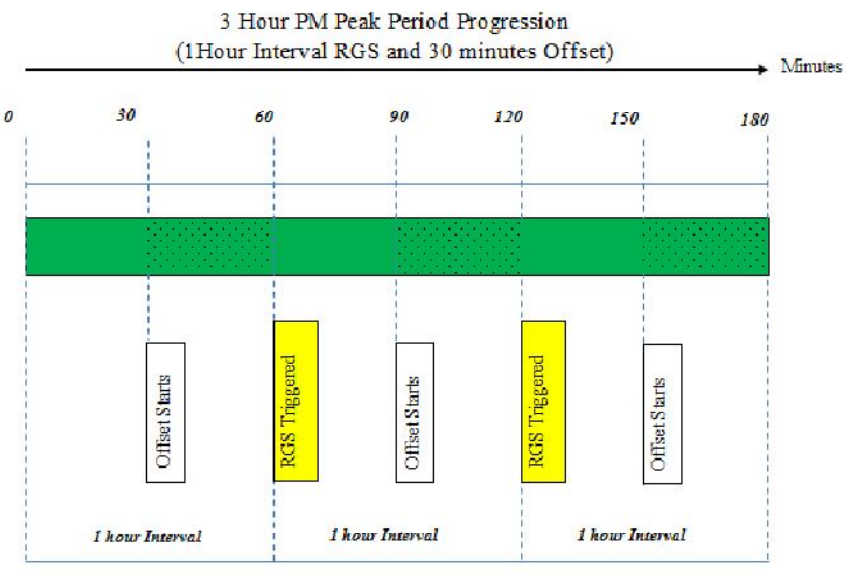


Figure 1 Peak Period Progression with Route Guidance System Interval and Offset

Combined Traffic Assignment and Control Framework (CTAC)

The traffic engineering practice tends to keep traffic assignment and traffic control optimization strategies as two separate processes. The travel demand models do not include traffic controls in the assignment process due to their macroscopic nature. Similarly, the traffic flows are considered fixed input to the control optimization process and the impacts of post optimization traffic flows are not considered. By keeping the two processes separate, the practice tends to ignore the interaction between the drivers' route choice and traffic controls. Combined Traffic Assignment and Control (CTAC) method based models can capture the interaction between driver's route choice and traffic controls in a single modeling framework [Meneguzzer, 1997]. Several solution algorithms, model formulations, and implementation efforts of CTAC based models have been well documented [Taale and Zuylen, 2001]. For this paper, the CTAC framework in combination with DTA, Vehicle Actuated Controls, and RGS was used. Figure 2 outlines the typical traffic analysis process with no traffic controls and no feedback on post assignment travel costs, and a CTAC modeling framework with flow responsive traffic controls and feedback on post assignment travel costs.

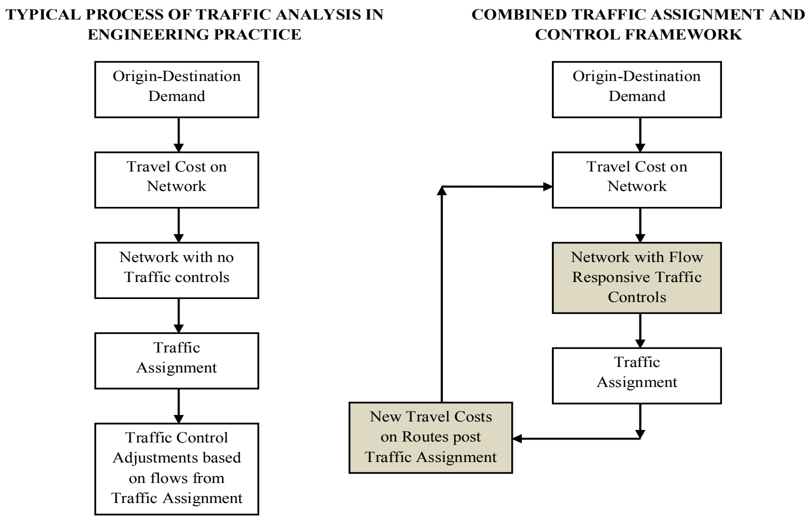


Figure 2 Typical Traffic Analyses vs. Combined Traffic Assignment and Control Framework a) Typical Traffic Analysis, b) Combined Traffic Assignment and Control Framework

Dynamic Assignment

In VISSIM software, DTA is an iterative simulation process. The route choice made by the drivers in each run is based on their travel experience in the previous run. The best paths in each run of DTA based simulation is computed based on travel cost. The travel cost can be in terms of travel time, trip length, toll, or any other user-specified cost. Any change in traffic conditions during the simulation may impact the travel cost. Thus more choices of routes with better cost are available in next run. For convergence, VISSIM requires that all paths must have a relative change lower than the defined threshold. Acceptable convergence criteria define indicators such as verifying that 95% of all paths are within 10 to 15% [VISUM 9.0 Manual, 2004]. Other standard practices look at mean errors of the non-converging paths.

For this paper, the travel time on paths was used as cost in DTA. A convergence criterion of 5 % travel time difference on paths was used. In current state of implementation, for each run of DTA simulation, VISSIM compares the travel time on paths to the previous run. If the travel time difference on all paths is less than or equal to 5%, the convergence criteria is met. Otherwise, the simulation continues until it reaches the maximum number of runs specified by the user or the convergence criteria whichever comes first. Travel time evaluation files containing travel time for each OD pair were written for every run of DTA simulation using the “Evaluation Files” feature of VISSIM.

Signal Control Emulator

A National Electrical Manufacturers Association (NEMA) Standard Signal Control Emulator was used for traffic controls in test scenarios. This controller is available in North American releases of VISSIM and emulates common signal controllers used in North America. With this controller VISSIM can simulate fully actuated signal control as well as coordinated and vehicle-actuated coordinated signal control. The interface to the controller is accessed through VISSIM but saves its settings to an external data file with the extension (NSE). To use the NEMA standard emulator in VISSIM, traffic control programs for each intersection in the study area network were exported to NEMA format using VISUM software.

Traffic Controls

Vehicle-Actuated Controls were used in all the test scenarios. Vehicle-actuated controls differ from fixed control because they can respond to variations in traffic flow and are typically used is in situations with irregular traffic flow. The actuated controls can be grouped into two types: semi-actuated and fully actuated. Semi actuated controls primarily apportion the green time to the major movement of the traffic and minor streets are served at vehicle detection. Fully Actuated control systems detect vehicles on all approaches of the intersection and make adjustments according to the flow.

The vehicle actuated controls were used with the limitations that offsets and cycle lengths would not change, and only green splits within the given cycle length framework could be adjusted. The changes in green split could respond to the variation in traffic flow due to different route choices of drivers in DTA simulation. For this paper, the traffic control program data for each intersection was collected from the Traffic Operation Center (TOC) of Utah Department of Transportation (UDOT) for the 3 hour pm peak period in consideration starting at 4 p.m. to 7 p.m.

STUDY AREA

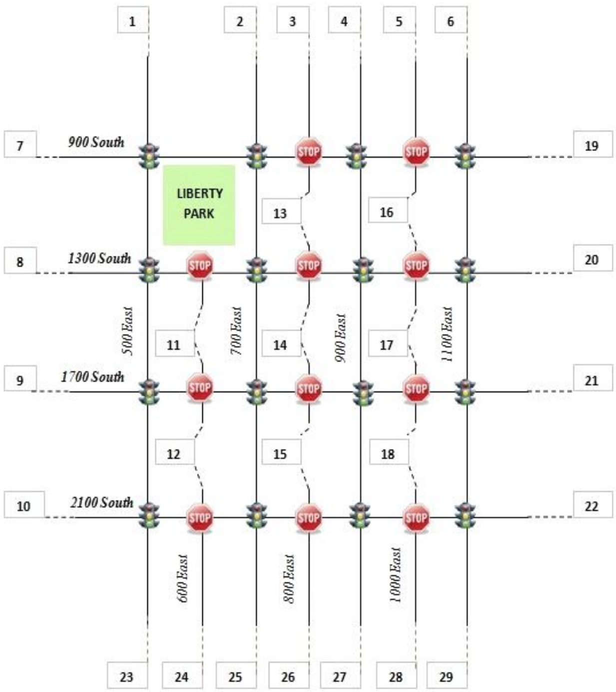
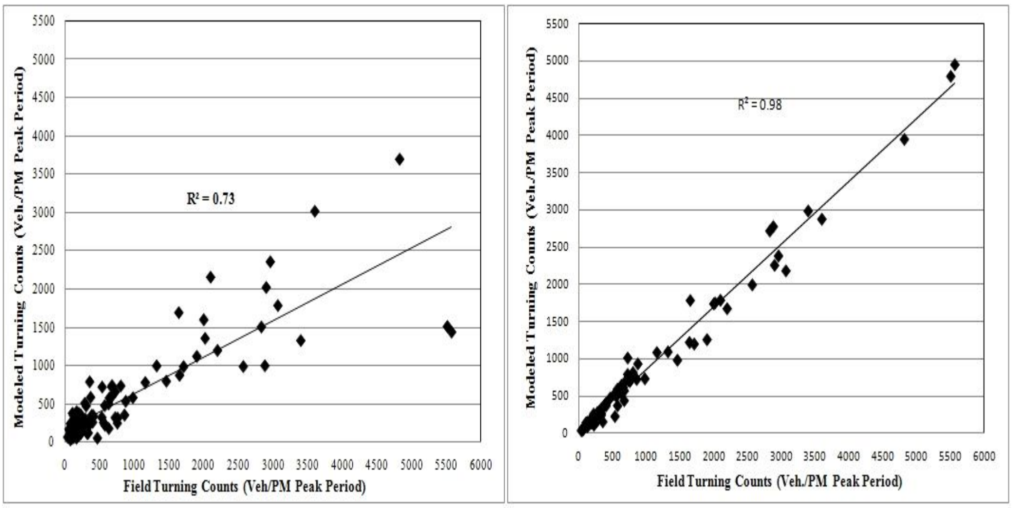


Figure 3 Study Area from Salt Lake City Area

A portion of urban area from Salt Lake City, Utah was selected for testing. The area consists of sections of collectors spanning 500 East to 1100 East in the East-West direction including principal arterial 700 East. In the North-South direction the study area spans from 900 South to 2100 South with cross roads 1300 South and 1700 South in between. The network consists of 56 nodes including 16 signalized intersections and 11 intersections with 2-Way stop signs, and 29 zonal nodes. Figure 3 describes the study area network. Turning movements and traffic control data were collected from Utah Department of Transportation (UDOT). The turning movements' data was then assembled for 3 hour p.m. peak period starting at 4 p.m. to 7p.m. Figure 3 displays the study area network.

CALIBRATION OF ORIGIN-DESTINATION DEMAND MATRIX

Initial origin-destination demand (OD) matrix for the selected pm peak period was obtained from the calibrated regional travel demand model version 6.0 of Wasatch Front Regional Council (WFRC). Due to the macroscopic nature of the WFRC model, study area OD information extracted was susceptible to some errors. The comparison of modeled volumes to field counts was therefore necessary. VISUM has several routines to assign travel demand specified in OD-matrix. A multi-equilibrium assignment routine was used to assign demand in initial OD matrix. Volume-Delay functions were specified as Bureau of Public Roads (BPR) curves. The assignment process did not give a close match of modeled volume to the field counts. In order to better fit the field-counts, the initial OD matrix was calibrated using VISUM based TFlowFuzzy matrix correction module. The matrix correction module is based on well-known entropy maximization algorithm [van Zuylen and Willumsen, 1980]. The output from each run of OD matrix correction is a synthetic matrix, which by assignment reduces the difference between the counts and modeled data. For this paper, the matrix was calibrated for the turning-movement counts only. The counts included left-turns, right-turns, and through movements. The process with 72 iterations led to an OD matrix that gave a close match of modeled volume to the counts. Figure 4 parts a) and b) display the scattered plot for modeled versus count data for initial and calibrated OD matrices.



a) b)

Figure 4 Calibration of Origin Destination Matrix: a) Modeled vs. Field counts from Initial OD Matrix b) Modeled vs. Field counts from Calibrated OD Matrix

MODEL CALIBRATION FOR MICRO-SIMULATION

Microscopic simulation models have been widely used in both transportation operations and management analyses because simulation is safer, less expensive, and faster than field implementation and testing. While these simulation models can be advantageous to engineers, the models must be calibrated and validated before they can be used to provide meaningful results. Microscopic simulation models contain numerous independent parameters to describe traffic control operation, traffic flow characteristics, and drivers' behavior. These models contain default values for each variable, but they also allow users to input a range of values for the parameters. Changes to these parameters during calibration should be based on field-measured conditions and should be justified by the user. The paper is an extension of a previous investigation on Route Guidance Systems [Farhan et al, 2010]. The calibration and validation process was performed to closely match a) travel times data, b) speed data and c) validation to match traffic counts. The field data on counts, travel times and speeds were collected from the UDOT and WFRC.

RESULTS AND DISCUSSION

Evaluation of Results

Table 2 part a) and part b)outlines the average total travel time improvementsand average total delay reductions for the simulation runs from Scenario 1 to Scenario9 (Scenario 1 to 5 in part a, and Scenario 6 to 9 in part b. The data in both part and part b is compared to Scenario 1 with 100 % NO-RGS equipped demand. Table 2 part a) and part b) also describe the travel time improvements and delay reductions with respect to Scenario 1 (Scenario with No RGS Equipped Demand). Scenario 1 although had the highest average travel time and highest mean total delay did reach convergence after 27 iterations. On the other hand, the scenarios with RGS equipped demand (Scenario 2 to Scenario 11) though show improvements in average total travel time and average total delay yet never converged, even after 100 iterations.

Table 2 Total Travel Time Improvements and Delay Reductions a) Scenarios with 120 Minutes Time Interval b) Scenarios with 60 Minutes Time Interval

a)

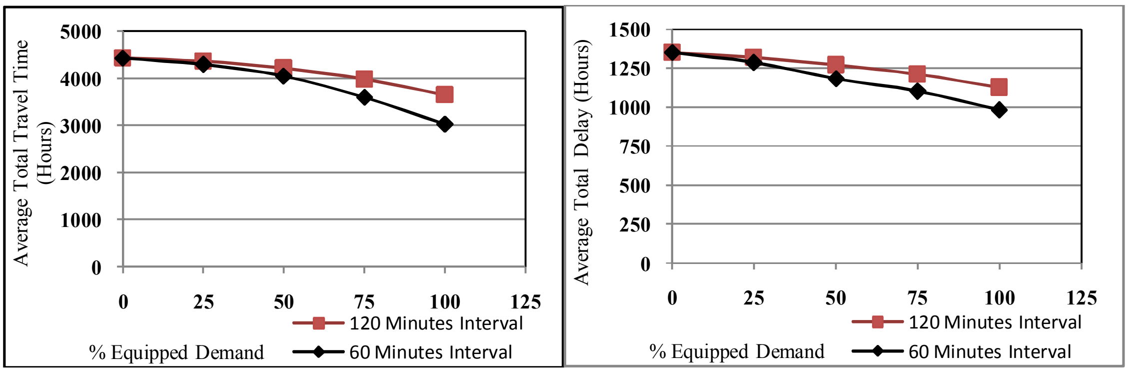
Scenario	Intervals	RGS Equipped Demand	Average Total Travel Time (Hours)	Average Total Travel Time Standard Deviation	Average Total Delay (Hours)	Average Total Delay Standard Deviation	Average Total Travel Time Improvements (%)	Average Total Delay Reductions (%)
1	N/A	-	4,425	557	1,349	1,204	N/A	N/A
2	120	25	4,355	531	1,320	1,189	-1.6	-2.1
3	120	50	4,211	501	1,271	1,173	-3.3	-3.7
4	120	75	3,975	491	1,209	1,152	-5.6	-4.8
5	120	100	3,643	471	1,125	1,139	-8.3	-6.9

b)

Scenario	Intervals	RGS Equipped Demand	Average Total Travel Time (Hours)	Average Total Travel Time Standard Deviation	Average Total Delay (Hours)	Average Total Delay Standard Deviation	Average Total Travel Time Improvements (%)	Average Total Delay Reductions (%)
1	N/A	-	4,425	557	1,349	1,204	N/A	N/A
6	60	25	4,291	510	1,287	1,162	-3.0	-4.6
7	60	50	3,955	486	1,181	1,127	-7.8	-8.2
8	60	75	3,884	454	1,102	1,108	-1.8	-6.7
9	60	100	3,821	408	1,025	1,094	-1.6	-7.0

Table2 part a) and part b) show that the total travel time improvements and delay reductions were the best with 100 % RGS equipped demand in the case when scenarios were tested with 120 minutes RGS interval (Scenario 5), as well as in the case when the scenarios were tested with 60 minutes RGS interval (Scenario 9).However, the travel time improvements and delay reductions benefits were relatively higher in the tests with 60 minutes RGS interval as compared to the 120 minutes RGS interval. This suggests that more information on prevalent traffic conditions to driver may help improve the traffic congestion as the driver may use the information on prevalent traffic conditions to their benefit in making route choices that are less costly.

In scenarios with RGS equipped traffic demand, on each day of travel, the drivers may choose to change their route choices while en route due to RGS information, in comparison to their "actual" route choice based on past travel experience. Thus with RGS equipped demand, on each day (in each run) the drivers may find a new set of "best cost" route choices based on the information on prevalent traffic conditions through RGS. While these best cost choices may help reduce the system wide travel time in congested traffic network, they may not be the most efficient route choices compared to previous day travel experience of the drivers. Figure 5 part a) and part b) outlinethe improvements in average total travel time and reductions in average total delay for each scenario with 120 minutes and 60 minutes RGS interval. Figure 5 part and part b show that RGS based information improved the traffic system for travel time and delay, and the improvements were the best with 60 minutes RGS interval.



a) b)

Figure 5 Total Travel time Improvements and Total Delay Reductions 120 and 60 minutes Interval: a) Total Travel Time Improvements b) Total Delay Reductions

CONCLUSION

Past research suggests that information on prevalent traffic conditions if available to the drivers by RGS, may impact their route choice. Many solution algorithms and model formulations on RGS are well documented, and the past research insists on the use of RGS applications in practice. This paper evaluated the benefits of RGS on a traffic system using combined traffic assignment and control framework. RGS Intervals of 120 minutes and 60 minutes were used on two sets of test scenarios. Overall nine scenarios were tested using VISSIM simulations, starting from 0% RGS equipped demand in Scenario 1 to 100% RGS equipped demand in Scenario 5 with RGS Interval of 120 minutes and increment of 25% RGS equipped demand in each scenario. The tests were repeated in Scenario 6 to 9 with RGS interval of 60 minutes. The benefits were quantified in terms of travel time improvements and delay reductions. The test results suggest that providing drivers with information on prevailing traffic conditions may impact their route choice, and in turn help improve the system wide total travel time and reduce total delay. The test results also suggest that the travel time and delay benefits were the minimum when the proportion of RGS equipped demand was the minimum (25%), and the benefits were the maximum when 100% of the traffic demand was RGS equipped. The results also suggest that the shorter RGS interval bring more benefits in terms of travel time and delay reductions. With growing use of RGS technology in advanced automobiles, the need for modeling methods that can quantify the benefits of RGS is growing. The traffic models that can capture the impacts of RGS on traffic systems therefore, can play an important role in congestion mitigation projects in practice. Further studies are needed to investigate the impacts of RGS on traffic system, especially with emphasis on drivers' response behavior to RGS based information and on how accurately the prevalent traffic conditions information can be relayed to the drivers through RGS.

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