THE APPLICATION OF A MICROSIMULATION MODEL SYSTEM TO THE ANALYSIS OF A LIGHT RAIL CORRIDOR: INSIGHTS FROM A TRANSIMS DEPLOYMENT

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ABSTRACT

The increasingly complex transportation challenges faced by urban areas around the country call for the use of new tools capable of microsimulating the movements of individual travelers and vehicles in multimodal networks. While there have been a number of microsimulation applications for highway networks, the number of such applications for transit or intermodal networks is relatively small. Given the emphasis that is being placed on multimodal transportation system development, and the desire to institute fixed guideway systems that operate in mixed traffic, there is a need to develop simulation processes capable of reflecting the performance of mixed multimodal transportation networks under a variety of planning and operations scenarios. This paper describes results from the application of TRANSIMS to a light rail corridor in the Greater Phoenix metropolitan area. Results of the simulation exercise are intuitive and provide insights on how microsimulation model systems can prove to be effective tools in analyzing alternative multimodal transport network strategies.

Keywords: planning applications, light rail simulation, microsimulation model, multimodal network, TRANSIMS application

INTRODUCTION

Over the past decade, the transportation modeling profession has increasingly moved in the direction of deploying models capable of microsimulating activity-travel patterns and location choices in the time-space domain (Axhausen and Garling, 1992; Vovsha et al, 2002; Waddell et al, 2003). On the demand side, major advances have been made in implementing activity-based travel microsimulation models (Jonnalagadda et al, 2001), while on the supply side, key developments have occurred in simulating network dynamics using dynamic traffic assignment models and traffic microsimulation models (Mahmassani, 2001). Microsimulation models are capable of reflecting dynamics inherent in transportation systems and provide richer sets of outputs for making informed policy decisions (Kitamura et al, 1998). In response to different policies and strategies, it is possible to see how traffic patterns may shift and various socio-economic market segments may be differentially affected (Murray and Davis, 2001).

Although considerable progress has been made in the microsimulation of automobile traffic on roadway networks, an equivalent amount of progress has not been made on the transit and multimodal front. There is a rich body of evidence about the dynamics of automobile traffic and the models are quite sophisticated, capable of capturing driver behavior in dynamic networks (Lawe et al, 2009; Raney et al, 2003). On the other hand, the transit domain has generally not witnessed the same level of advances. There are a multitude of reasons for this. First, the modeling of transit networks is inherently far more complex on multiple fronts. Transit service is available only during specific hours and at certain locations along certain routes, stops are located at specific places on the network, and schedule and route configurations may vary by time of day, with peak periods seeing higher and better levels of service. In addition, transit service usage inevitably involves access and egress legs that entail the use of different modes. People may walk, bicycle, park-n-ride, or kiss-n-ride when it comes to transit access and egress. In other words, transit trips are virtually always multimodal journeys with an access leg, an egress leg, and a line-haul journey (which may itself involve transfers across modes). Transit trips are constrained by time-space accessibility and connectivity offered by the transit service. Second, there is less data available about transit behavior. Although transit trips are reported in surveys, providing data needed to estimate demand, very little is known about transit route choice behavior of humans in multimodal contexts. As a result, transit network simulation has largely remained the domain of academic exercises (Shalaby et al, 2003; Matisziw et al, 2006).

This paper aims to address the gap in the body of knowledge related to transit simulation. The paper describes the application of a transportation microsimulation model system called TRANSIMS (Smith et al, 1995; Rilett, 2001) to the analysis of a light rail corridor in the Greater Phoenix metropolitan region in the United States. As congestion continues to rise in metropolitan areas around the country, many are looking to expand the multimodal options available to travelers. In this context, an option often considered is that of light rail which operates largely in mixed traffic on fixed guideway. As a result of such a mixed operation, the implementation of a light rail line often has impacts on traffic conditions on the roadway along the light rail corridor as well as neighboring corridors which may be impacted by traffic diverting to side streets to avoid conflicts with the light rail system. While TRANSIMS has been extensively tested and used to address highway network issues and scenarios, it has rarely – if ever – been used to simulate multimodal transit networks including light rail. This paper describes the application of TRANSIMS to a variety of light rail scenarios, and presents results of the application to provide insights on the ability of microsimulation models such as TRANSIMS to respond to multimodal network investments appropriately with specific emphasis on light rail corridors.

The remainder of this paper is organized as follows. The next section provides a description of the study area and the network scenarios analyzed. The third section provides a description of the microsimulation model system, TRANSIMS, with specific emphasis on the process employed to simulate transit networks. The fourth section presents results of the case study application. The fifth section summarizes the knowledge gained through this exercise and offers insights into future research directions in the transit microsimulation arena.

CASE STUDY APPLICATION CONTEXT

In 2009, Phoenix, Arizona was the fifth most populous city in the United States and the most populous U.S. state capital. The metropolitan area as a whole falls within the 15 largest in the country. The mild winter climate attracts a large number of retirees to the suburban cities, and the area's development pattern in the midst of the undeveloped Sonoran Desert has lead to considerable urban sprawl in every direction. Over the past two decades, the metropolitan area witnessed dramatic growth in population, housing, and employment. Much of the development occurred in the fringe areas, leading to large increases in vehicle miles of travel. Transportation planners in the region are concerned about the sustainability of the land use – transportation system and are seeking ways to enhance livability in the region.

In December 2008, Valley Metro, the transit authority in Maricopa County, began service on a 20-mile line of light rail transit (LRT). This LRT line serves Mesa, Tempe, and Phoenix, connecting inner suburban neighborhoods to central city jobs and attractions. The rail provides service to and from some of the most widely visited attractions in the area, including professional baseball and basketball facilities, Phoenix Sky Harbor Airport, the central business districts of both Phoenix and Tempe, and Arizona State University's main and downtown campuses. The Phoenix TRANSIMS implementation has focused on the transit element of the regional transportation network, namely, the rail line and its potential improvements. The experiments described herein consider potential network changes to the currently operational light rail line and the extent of effects, if any, that would potentially be experienced by the highway network and reflected in the outcome of the microsimulation.

The Maricopa County regional TRANSIMS network consists of 13,145 bi-directional and one-way links which represent approximately 5,500 miles of roadway. The network connects activity locations spread across 2,009 traffic analysis zones (TAZ's). There are 224 directional transit routes in service, including local buses, express or rapid buses, neighborhood shuttles, and light rail. The regional network accommodates approximately 15 million trips daily, approximately 77% of which are single-occupant personal vehicle trips. According to Valley Metro statistics, about 200,000 trips are made daily via the transit network, varying by month of year.

The first scenario to be considered in this experiment is the base year network. In this scenario, the LRT right of way is presented as it appears today, with service in either direction between

19th Avenue and Bethany Home Road in Phoenix and Main Street and Dobson Road in Mesa. The location of the base year LRT corridor is shown in Figure 1, falling between the two black lines as indicated. In the base network, LRT service is provided during the hours of 4:00 AM to 11:00 PM, with headways of 12 minutes during peak periods (6:00 – 9:00 AM and 3:00 – 6:00 PM) and 20 minutes during off-peak periods. In order to ensure that the differences in results are not simply due to random stochasticity of the simulation system, the base year scenario was simulated twice with identical random number seeds. These two simulations yield identical results for each individual link, similar to results reported in earlier work (Lawe et al, 2009; Ziems et al, 2011).

Aside from the base network, three regional network scenarios in which LRT service is improved in some way were considered. A network scenario was considered in which light rail service is added during night-time hours, making the LRT a 24-hour transit line, and headways during the day are reduced. In this decreased-headway scenario, peak hour headways are reduced to 8 minutes while headways in off-peak periods are reduced to 15 minutes. Another scenario is considered in which the light rail right of way is extended farther into Phoenix in the north and farther into Mesa in the east. This extended service rail line is also depicted in Figure 1, showing that light rail in this scenario serves travelers from 19th Avenue and Dunlap Avenue to Main Street and Center Street. In this extended service scenario, headways remain the same as those in the base year network. Finally, a combination network scenario is considered that takes into account network improvements from both previous scenarios. This combination scenario extends light rail service to the north and east as in the extended service scenario, and provides decreased headways as in the decreased-headway, extended-hours scenario.

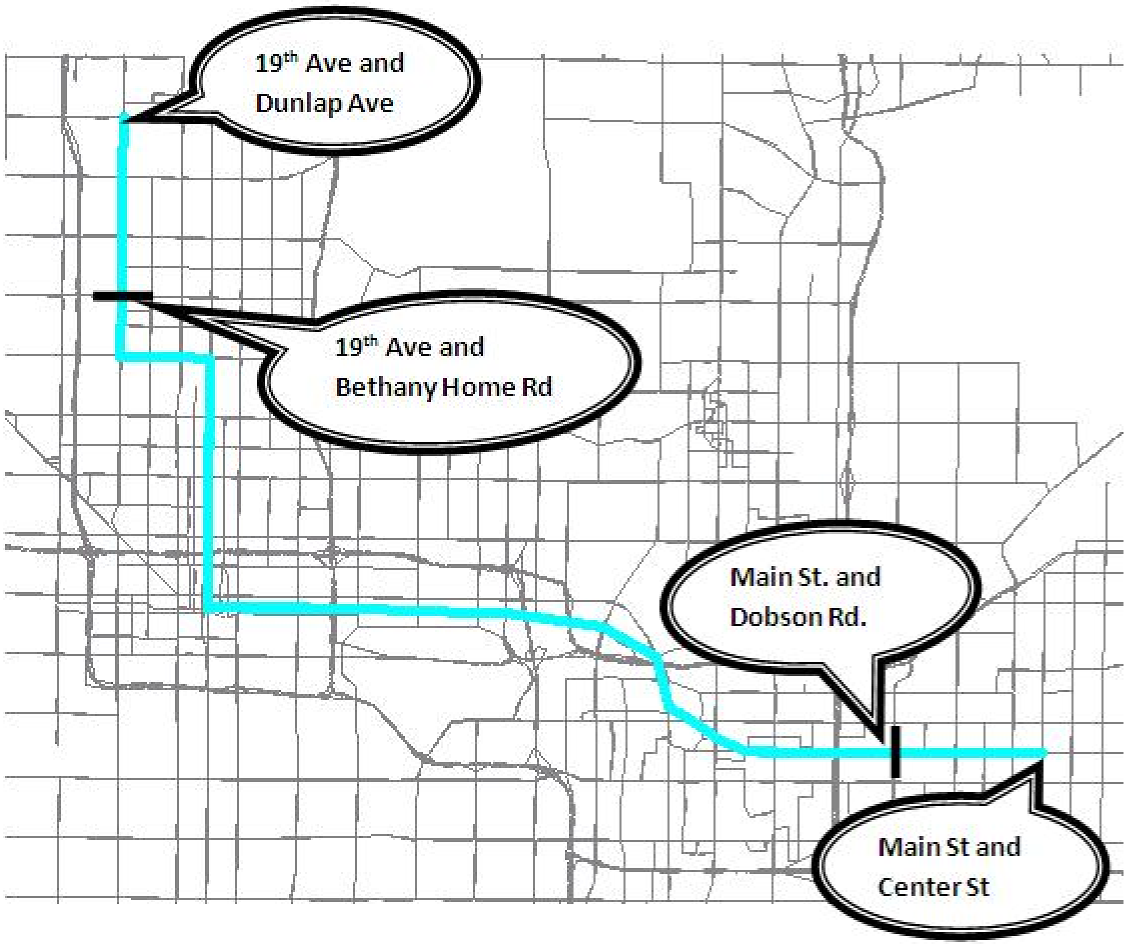

FIGURE 1 Light rail line in base year and extension scenario.

APPLICATION OF TRANSIMS

The TRansportation ANalysis and SIMulation System (TRANSIMS) is software originally developed at Los Alamos National Laboratories in response to U.S. legislation that called for more disaggregate methods for transportation modeling. Under the initiative of the Federal Highway Administration (FHWA), the system has since evolved and is now an open-source software package freely available to the public. The system has been applied in various contexts, although most of the studies are prototype experiments to test the feasibility of deploying the system for specific planning applications (e.g., Park and Kwak, 2011; Ullah et al, 2011; Zietsman and Rilett, 2002). TRANSIMS comprises a series of modules including a population synthesizer, an activity generator, a router, and a microsimulator, along with a few additional submodules that facilitate iterative processes during the simulation. One major recent development of the TRANSIMS enterprise is the release of a development environment called TRANSIMS Studio. This software, also an open source package, was used during the simulation portion of this scenario analysis.

The first step in a TRANSIMS implementation is to prepare the network. The network used in the Phoenix Area implementation was adapted from the network used by the Maricopa Association of Governments (MAG) four-step travel model. Using this network as a base, the TRANSIMS network was constructed to more closely replicate the real-world environment by deleting centroid connectors, which are not physically present, and by ensuring that speed and capacity on each link was set to an appropriate value. Though external network connectors are considered centroid connectors, they were not deleted from the network. Input link, node, and traffic analysis zone (TAZ) records were provided to the TRANSIMS network conversion tool, which in turn assigned signalized nodes, lane connectivities, and other functional network elements.

The transit network was also created using route stops and route characteristics from the four-step model network. The location of a route was defined by listing in order the nodes that a transit line passed from start to end point. If the route makes a stop at a particular node, it was given a dwell time greater than zero. Otherwise, dwell time remained zero and the node was considered a "pass by" node. The input file which defines route characteristics specified headways for each transit route and each service time period. Many adjustments were made to the network manually to accommodate the location of the light rail line in mixed traffic. The Valley Metro rail line links are not separated from the highway links, but rather each highway link along the rail corridor has one lane that is dedicated to light rail vehicles only. A lane use restriction file was used to force specific lanes on the links in the corridor to be classified as rail only for the entire 24-hour simulation. In addition to this, lane connectivity was manually updated to ensure than no auto travel lanes were connected to the rail lanes and vice versa.

For purposes of this study, origin-destination tables from the calibrated four-step travel model of the Maricopa Association of Governments were used to represent activity-travel demand by purpose and time-of-day. Origin-destination (O-D) tables were obtained, with separate tables for single-occupancy vehicle, high-occupancy vehicle (two passengers or more), local bus, express bus, light rail, and commercial vehicle trips. For each of these modes, aside from commercial vehicles and express bus, O-D tables were provided for each of six purposes. The express bus mode was considered only for the home-based work purpose. The result is a total of 44 O-D trip tables. The TRANSIMS trip conversion tool requires (for each trip table) a time of day distribution by which trip start and end times can be assigned to all trips. Six different time distributions were computed from the 2009 National Household Travel Survey of the United States, with one distribution for each travel purpose.

When using the TRANSIMS trip conversion tool, each O-D table must be given a mode according to the TRANSIMS built-in mode codes. The modes available for representing transit trips are "transit" and "transit with rail bias." Trials with different mode combinations in this particular region resulted in the most accurate number of transit boardings when all transit modes – be they bus or rail – were coded as "transit with rail bias." This allowed each transit traveler the option to choose rail or bus service, depending on the mode that would serve the trip with the least impedance. In other words, although the total number of transit trips does not change from one scenario to the next, the split of total transit trips between bus and light rail can change in response to changes in service parameters. The choice to simulate trips in such a way that transit demand does not change over network scenarios was made for two reasons. First, this design allows the microsimulation to be viewed as an operations microsimulation without consideration for potential mode shifts in demand that may occur as a result of changes in network level of service measures. Second, the activity generation module that is available through TRANSIMS assigns activities and their associated modes of travel based only on the activity distributions of a survey population and do not respond to changes made in either the highway or transit networks. Therefore, an experimental design that included activity generation would not provide any shifts between auto and transit modes as a result of network changes, but only as a result of random variation in the model. Although not accounting for all possible modal shifts is potentially a limitation of the study, it also provides a robust way to compare operational performance of the roadway corridors potentially impacted by the light rail line because the total transit demand is held constant across scenarios. Because of the uniformity in coding bus transit trips, the results of the simulation do not differentiate between the multiple types of bus service.

The simulation approach applied in the Maricopa County implementation used a 64-bit Windows machine and employed six processing cores, which is equivalent to six traveler partitions. One full microsimulation is completed in approximately 48 hours. In order to limit the computational expense of running full microsimulations, the team chose to analyze roadway performance measures seen only between the hours of 6:00 and 9:00 AM, which corresponds to the AM peak travel time. The approach used here completes one initial routing process and is followed by a number of stabilization and user equilibrium process iterations. In an initial routing process, every trip that is generated from the trip conversion tool described above is entered into the router. The router then assigns a specific route path to each trip in the region. These route paths are summed over every link using an executable called “Plan Sum.” This submodule produces initial link performance measures without employing a full microsimulation. The router stabilization process then chooses those trips that, according to the results of Plan Sum and a user-specified selection criterion, would benefit from changing travel routes. These trips are then re-routed and the entire list of trips is once again input to the Plan Sum submodule.

The TRANSIMS microsimulator is a software module that considers the position of each vehicle and traveler in the network at every second in the simulation time period. This is achieved using a cellular-automata framework. In a cellular automata model, every link in the system is divided into a number of cells, each the length of one standard vehicle. Each cell can accommodate only one vehicle at a time. If, at a certain time step, the cell in front of a vehicle becomes open, then the vehicle may advance into that cell. Otherwise, the vehicle must remain stationary. The microsimulator can be customized for a particular implementation by adjusting parameters for following distance, reaction time, and look-ahead distance.

The first step of the microsimulation stabilization process is to use the link performance measures obtained at the end of router stabilization to select trips that would benefit from a route change. These trips are then re-routed and the resulting plans are inputs to the microsimulator, which calculates detailed link performance measures. These measures are then put back into the router and the process is repeated. Microsimulation stabilization is in essence the same as router stabilization, described above, with the exception of the use of the microsimulator in place of the Plan Sum submodule. Once results from microsimulation are achieved that can be considered stable, several iterations of a user equilibrium process is run. Even though a stable solution from the microsimulator implies that additional iterations will not reduce individual travel times, there is still a chance that the user equilibrium process that is employed in this experiment can reduce the overall travel time across the region. The final resulting link performance file from the ultimate user equilibrium iteration is what is used here to report roadway characteristics.

The simulation for this report was designed in such a way that each of the three processes employed – router stabilization, microsimulator stabilization, and user equilibrium – reached a stable solution before moving on to the next process. After an initial trial and testing of each process it was found that 20 iterations of router stabilization, 15 iterations of microsimulator stabilization, and 10 iterations of user equilibrium were sufficient to meet requirements. During the first five iterations of router stabilization, trips were selected for re-routing based on the volume to capacity (V/C) ratio of links on the network. That is, if a trip traversed a link with a V/C ration greater than 1.25, that trip was selected for re-routing. In all subsequent stabilization iterations the selection criteria was a threshold difference between planned travel time and actual travel time. Figure 2 illustrates the stabilization of each simulation process across iterations in the base year. The router and microsimulator stabilization iterations (1 through 35) are compared with the number of households that are selected for re-routing while the user equilibrium iterations (36 through 45) show the number of trips with significant path changes.

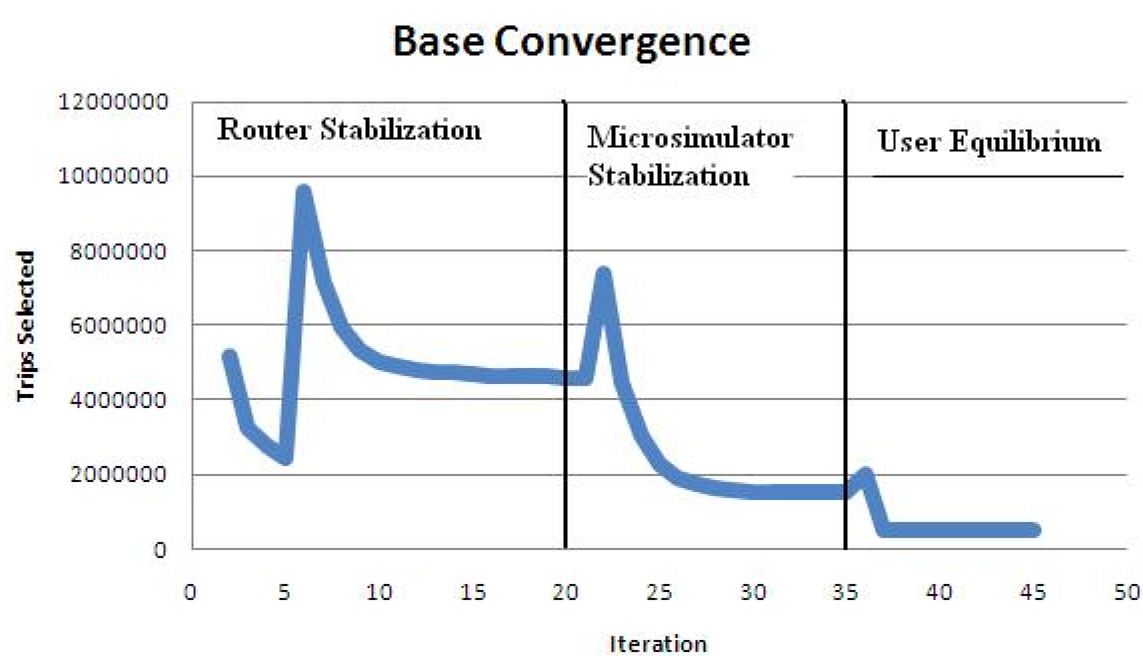

FIGURE 2 Convergence of simulation results over multiple iterations.

The Maricopa County implementation was validated based on the simulation process described above, and the results are reported in Table 1. As opposed to the process described above, however, in which trips were simulated only for the peak period, the simulation used for validation was over an entire 24-hour duration. The highway counts to which the TRANSIMS volumes are compared for validation were collected from the Maricopa County MAGTrans website. This site displays 24-hour vehicle counts at various locations across the network. The number of observations recorded is the number of vehicle counts on roadways of each specific facility type obtained from the MAGTrans website. The observed transit boardings were obtained from Valley Metro and represent 24-hour board counts for every transit route. The number of observations corresponds to the number of directional routes in the system. The results at this stage show that TRANSIMS is slightly under-estimating traffic on the highway network by about 12 percent. The results of transit ridership, however, show that TRANSIMS comes within 13 percent of replicating boardings in either mode and within three percent overall.

TABLE 1 Results of Calibration of TRANSIMS

Facility Type	Number of Observations	Observed Vehicle Counts	TRANSIMS Volume	% Difference
Auto Mode Calibration				
Collector	228	769,139	724,104	-5.86%
Expressway	69	598,068	640,409	7.08%
Freeway	49	3,451,424	2,175,169	-36.98%
Major	3,571	34,868,806	31,272,052	-10.32%
Total	*3,917*	*39,687,437*	*34,811,734*	*-12.29%*
Transit Mode Calibration				
Mode Type	Number of Routes	Observed Boardings	TRANSIMS Estimated Boardings	% Difference
Local/Express Bus	222	204392	214603	5.00%
Light Rail	2	40772	35618	-12.64%
Total	*224*	*245164*	*250221*	*2.06%*

The scenario analysis presented in this paper is meant to compare the results of microsimulation of various transit network changes, and not necessarily to replicate highway volumes. Therefore, the level of calibration achieved in Table 1 was considered sufficient to move forward with transit scenario analysis. Results are aggregated over the LRT corridor as well as over a corridor parallel to the LRT right of way. This is done in order to capture changes in highway performance that potentially propagate through space. The project team also has the ability to aggregate results of link performance over a buffer that surrounds the light rail. This buffer could vary in size and could be used to capture effects of network changes over a larger area. For the sake of brevity, this paper focuses exclusively on results along the LRT corridor and a close parallel corridor only. Figure 3 depicts the LRT and parallel corridors as well as a 1-mile buffer around the light rail. The results of the analysis reflect only the roadway characteristics with respect to auto traffic – transit vehicles are not included in the volume count, average speed, etc. One will note that there is a break in the continuity of the parallel corridor near the center of the right of way. On the light rail corridor, there is a section of rail line that is located along its own dedicated link. On this section no auto characteristics are available because no auto vehicles travel the segment. In order to accurately reflect an accurate comparison of traffic characteristics in the, a corresponding segment was also excluded from the parallel corridor.

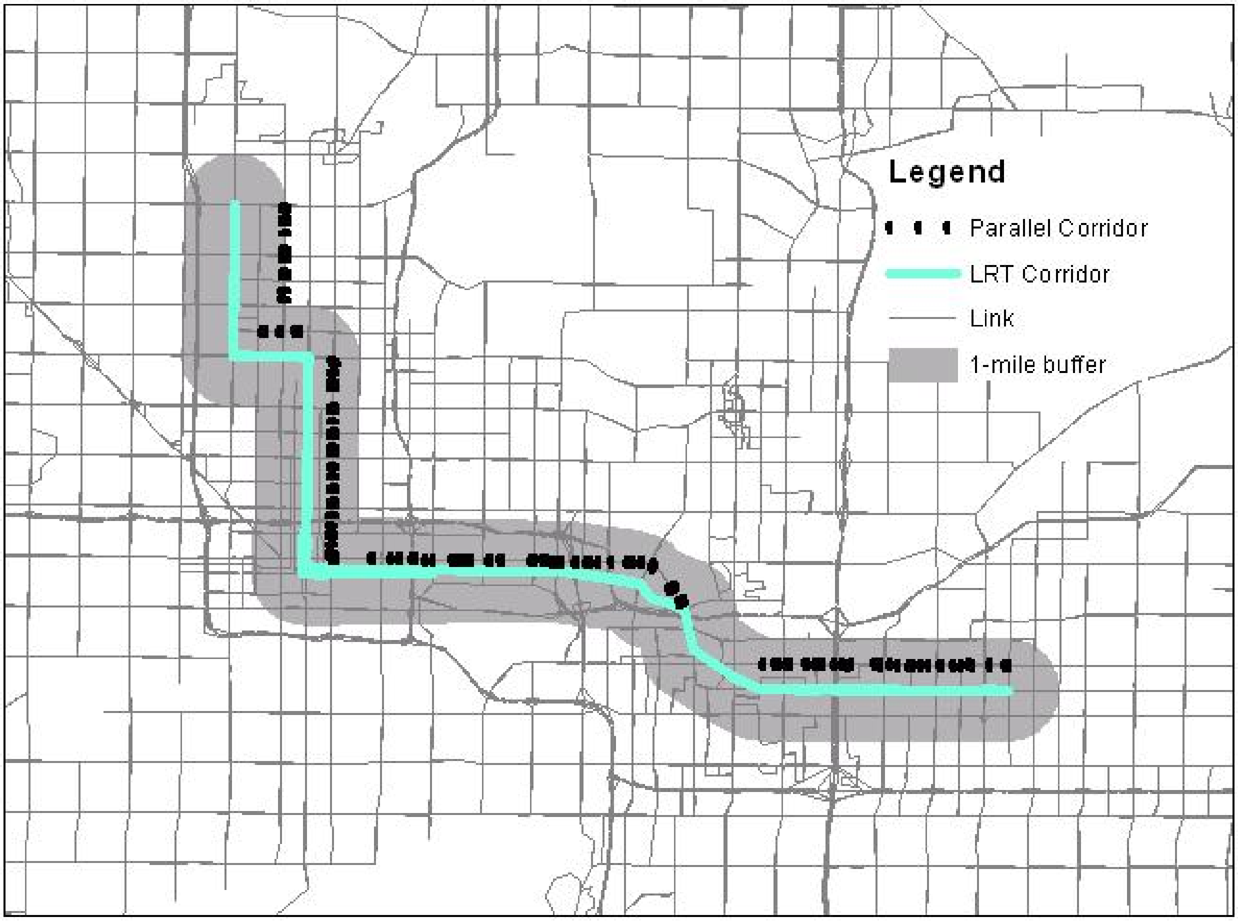

FIGURE 3 Rail corridor, parallel corridor, and buffer area for analysis.

RESULTS OF SIMULATION EXPERIMENTS

This section presents results of the simulation experiments conducted in this study. In order to examine how microsimulation models respond to different network investments, two scenarios and a combination scenario were considered. In one scenario, as previously described, light rail headways were greatly decreased. One could conjecture that the higher level of light rail service on the line would create more conflicts for traffic on links along the corridor and intersecting with the corridor leading to greater delays and congestion. The second scenario involved maintaining headways as in the base case, but extending either end of the light rail line as explained in the second section of this paper. The extensions provide a greater level of light rail connectivity and access for individuals traveling between origins and destinations that fall within the influence zone of the light rail line. The combination scenario is a blend of the schedule frequency increase and the physical extensions of the light rail right of way on either end of the line.

Table 2 shows the change in light rail boardings as a result of changes in service attributes in the different scenarios. With a doubling of frequency, the ridership (number of boardings) is found to increase by about 18 percent; this value is consistent with elasticity measures reported in the literature regarding the sensitivity of boardings to changes in headway (Evans, 2004). In general, one can expect a 33 percent increase in ridership for a doubling of schedule frequency. The percent change in light rail ridership seen in this study, with frequency that is less than doubled, is consistent with that figure and somewhat conservative, thus providing reasonable basis to assess the impact of synthetic service scenarios on simulated traffic performance measures. With light rail extensions, more households fall within the influence zone of the light rail line and there are greater levels of network connectivity and accessibility offered by the light rail. As a result, the number of light rail boardings is found to be substantially higher than the base scenario, increasing by 21 percent. Again, this figure is quite reasonable and consistent with expectations. In other words, it appears that the TRANSIMS routing and microsimulation process is able to effectively apportion transit trips between bus and light rail for this case study. Finally, with a combination scenario where headways are reduced and the light rail is extended on either end, the boardings are found to increase more dramatically by about 35 percent. While this figure may appear somewhat large, it should be noted that extending the light rail line on either end and drastically reducing headways could have a substantial synergistic effect.

TABLE 2 Comparison of Light Rail Boardings Across Scenarios

Route	Base	Headway Scenario	% Change	Extension Scenario	% Change	Combination Scenario	% Change
South/East Bound	1179	1393	18.15%	1426	20.95%	1595	35.28%
West/North Bound	1514	1747	15.39%	1799	18.82%	2013	32.96%
Total	*2693*	*3140*	*16.60%*	*3225*	*19.75%*	*3608*	*33.98%*

Schedule Frequency Change

Table 3 presents results of the scenario in which schedule frequency is increased on the light rail line. The table provides output results for the roadway along the light rail corridor, and for the immediate parallel corridor as described earlier in this paper. A variety of measures are examined to obtain insights on how the change of headway impacts traffic conditions. The total traffic volume is computed by aggregating time-of-day traffic volumes on each link of the corridor over the 3-hour simulation period and then averaging across all links that comprise the corridor. It is found that the daily volume on the roadway of the light rail corridor does not change appreciably in response to a doubling of light rail frequency. The average speed decreases nominally and the average travel time has a corresponding nominal increase. The average delay per vehicle, represented as the total accumulated travel time difference between free flow travel times and actual experienced travel times also experiences a nominal increase, although the delay itself remains negative. Essentially, the average delay measure is a gap function measuring the cumulative travel time deviation between free flow and actual conditions over all travelers in that stretch of roadway. The maximum queue at any point along the corridor is increases from 11 to 12 vehicles, a minimal change considering the doubling of schedule frequency. The total number of cycle failures (where a vehicle is not able to clear an intersection within one cycle), increases a great deal. Vehicle miles and vehicle hours of travel change as expected given the changes in volume, speed, and travel time.

What is interesting to note is that the drivers are not necessarily diverting to the parallel corridor. In fact, it appears that some drivers from the parallel corridor may be diverting as well, perhaps seeking to travel on roadways that are farther away from the light rail corridor. However, as opposed to the light rail corridor where service measures slightly deteriorate, most level of service measures show an improvement (nominally). It seems that, though volume is very slightly decreasing on both the light rail and parallel corridors, the diversion from the light rail corridor is not sufficient to improve travel characteristics whereas on the parallel corridor the opposite is true. The average speed is nominally higher while the average travel time is slightly lower. The average delay decreases, and the total cycle failures slightly increases. Total vehicle miles of travel actually goes down as does vehicle hours of travel, suggesting that there is less traffic. Overall it appears that the microsimulation model is able to capture very fine nuances associated with traffic diversions and network level of service changes. For the most part, though link service measure change very little over the short period of time being analyzed, the results indicate that traffic states at signalized intersections experience some deterioration. Note that these minor deviations are not due to the stochasticity of the process; the random number seeds are all the same from one scenario run to another and thus the differences seen in the tables are due to differences in network conditions. Following the line of reasoning established in prior studies of varied simulation results (Castiglione et al, 2003; Ziems et al, 2011), the changes seen here would likely become more substantial with an analysis of a greater period of time and therefore more traffic.

Light Rail Extension Scenario

As mentioned earlier, the light rail corridor was extended by a few miles at each end to examine how such extensions would alter traffic dynamics. It should be recalled that the setup of the experiments would not allow a demand shift from the auto mode to the transit mode, or vice versa. The overall number of trips for each mode of transportation was held constant across scenarios, except that a reallocation of transit trips between light rail and bus transit was permitted. Thus, in response to a light rail enhancement, bus trips would decrease and light rail ridership (boardings) would increase. The base scenario for comparison with the extended light rail scenario includes more links and traffic because one now needs to consider a longer stretch of roadway along which the light rail line operates. The results of the scenario analysis are shown in the middle section of Table 3.

With the extension of the light rail corridor service (essentially taking away more lane mileage from automobile traffic), it is found that daily volume on the light rail corridor nominally increases, implying that traffic is not diverting to parallel streets. With the slightly higher vehicular volume on the corridor, it is interesting to see that conditions have deteriorated to result in lower speeds and higher travel times. Average delays are higher and the number of cycle failures records a rather sharp increase, as does the maximum queue length. It appears that extending the light rail corridor into the high density areas of north Phoenix and downtown Mesa has an adverse impact on roadway traffic, similar to what was experienced with an increase in schedule frequency on the existing length of the light rail line. Again, it is important to note that the light rail extensions are literally taking away roadway traffic lanes and hence these results are quite behaviorally intuitive. The total vehicle miles of travel increases along the corridor, as does the total vehicle hours of travel, consistent with the change in volume and travel time.

Along the parallel corridor, the automobile volume slightly decreases, suggesting that some amount of traffic diversion has taken place away from the parallel corridor. Consistent with the slight decrease in volume, it appears that conditions become marginally better. The speed is marginally higher, the travel time is slightly lower, and average delay per vehicle is down. Likewise, the number of cycle failures and the total vehicle miles of travel show improvements relative to the base case. The maximum queue length and the vehicle hours of travel do not change. Here is another phenomenon taking place that could explain why the parallel corridor is experiencing slightly improved conditions. Investigation reveals that bus ridership is going down because light rail boardings increase in response to improved level of service for rail. The bus ridership that is most affected is that occurring on the light rail corridor itself and parallel to the corridor. Conditions are getting better potentially because slow moving buses which adversely impede traffic flow are now speeding up. They have less dwell time at stops because they have fewer boardings. The speeding up of the buses generally results in an overall improvement of traffic conditions along the parallel corridor. The multimodal traffic microsimulation model system is capable of capturing such fine adjustments that could impact traffic flow, ensuring the user that the software is sensitive even with respect to short time periods and marginal changes.

The Combination Scenario

Finally, the last part of Table 3 provides results from the application of TRANSIMS to the combination scenario. As expected, the results constitute an amalgamation of the findings reported in the context of the separate scenario runs. First, on the light rail corridor itself, there is a decrease in vehicular volume. This is reflective of the possible diversion that is taking place, both due to the increased schedule frequency and the extensions of the light rail line on either end. Thanks to this traffic diversion, the overall traffic speed decreases only very slightly; perhaps a greater deterioration in speed would have been observed had traffic diversion not occurred. The average travel time increases marginally as does the average delay per vehicle. The number of cycle failures and the maximum queue length increase, perhaps due to increasing conflicts and delays experienced at intersections. Due to the traffic diversion away from the light rail corridor, the total vehicle miles of travel on the corridor decreases.

What is happening on the parallel corridor is quite interesting. There is a decrease in volume along the parallel corridor as well, as has been the case in every scenario. In other words, the increase in schedule frequency is leading to traffic diverting to corridors beyond the immediate parallel corridor. As the parallel corridor is also potentially affected by the increased light rail schedule frequency, drivers are choosing to divert farther away to roadways that are virtually unaffected by changes in the light rail service frequency. Unlike the previous two scenarios, in this scenario the reduction of bus ridership on the parallel corridor does not speed up the flow of traffic. The speed nominally decreases, and the travel time increases. Average delay per vehicle slightly increases. Consistent with the other scenario in which headways decrease, the maximum queue length has increased and, consistent with the other scenario in which right of way is extended, the number of cycle failures has decreased. The reduction in volume is associated with a decrease in vehicle miles of travel and total vehicle hours of travel also records a slight decrease in a consistent way.

TABLE 3 Results of Scenario Analysis

Performance Measure	LRT Corridor			Parallel Corridor		
	Base	Scenario	% Change	Base	Scenario	% Change
Comparison of Base to Headway Change Scenario						
Daily Volume (veh)	399	398	-0.28%	373	372	-0.43%
Average Speed (mph)	43.09	42.95	-0.33%	42.38	42.44	0.15%
Average Travel Time (min)	47.05	47.26	0.45%	46.02	45.93	-0.20%
Average Delay (sec)	-458	-445	2.77%	-478	-484	-1.15%
Maximum Queue (veh)	11	12	9.09%	8	9	12.50%
Num. Cycle Failures (veh)	6	14	133.33%	11	12	9.09%
Total VMT (miles)	11670	11626	-0.37%	10613	10567	-0.43%
Total VHT (hours)	275	275	-0.03%	254	252	-0.58%
Comparison of Base to Extended Light Rail Scenario						
Daily Volume (veh)	392	393	0.39%	375	374	-0.25%
Average Speed (mph)	42.99	42.88	-0.27%	42.54	42.60	0.14%
Average Travel Time (min)	60.67	60.94	0.44%	58.79	58.74	-0.08%
Average Delay (sec)	-516	-500	3.14%	-541	-544	-0.55%
Maximum Queue (veh)	11	17	54.55%	8	8	0.00%
Num. Cycle Failures (veh)	7	12	71.43%	13	8	-38.46%
Total VMT (miles)	14893	14957	0.43%	13583	13572	-0.08%
Total VHT (hours)	353	355	0.63%	325	326	0.06%
Comparison of Base to Combination Scenario						
Daily Volume (veh)	392	390	-0.46%	375	373	-0.33%
Average Speed (mph)	42.99	42.92	-0.18%	42.54	42.49	-0.11%
Average Travel Time (min)	60.67	60.85	0.29%	58.79	58.93	0.24%
Average Delay (sec)	-516	-505	2.03%	-541	-532	1.55%
Maximum Queue (veh)	11	14	27.27%	8	11	37.50%
Num. Cycle Failures (veh)	7	13	85.71%	13	7	-46.15%
Total VMT (miles)	14893	14845	-0.32%	13583	13538	-0.33%
Total VHT (hours)	353	352	-0.26%	325	324	-0.26%

DISCUSSION AND CONCLUSIONS

In this paper, the application of a travel microsimulation model system has been demonstrated in the context of a transit network analysis. As urban metropolitan regions increasingly consider expanding transit services to offer greater mobility options to residents and meet sustainability goals and greenhouse gas emission reduction targets, it is clear that professionals will need to have the ability to accurately simulate network conditions under a wide range of multimodal scenarios. The Greater Phoenix region is no exception to this trend. With a rather new light rail line and much interest in the community to analyze its performance, its impact on traffic and the environment, and its role in shaping future land use patterns, there is considerable interest in the development and deployment of microsimulation model systems capable of providing rich information on network performance measures. Although there is considerable literature devoted to the application of microsimulation models for highway automobile traffic simulation, there is a paucity of literature dedicated to the application of transit network simulation models in a multimodal context. The motivation for this particular research study stems from the wave of interest in the United States to invest in fixed guideway light rail systems that operate in mixed traffic conditions. Many questions arise in this context. From a demand perspective, one is naturally interested in accurately forecasting ridership and boardings by stop by time of day. This paper is focused more on the operations side of the enterprise with a view to answering questions such as: How does a light rail line affect traffic congeston and delays along the corridor on which it operates and along the immediate parallel corridor to which traffic may divert? If traffic congestion and delays worsen, would the potential air quality benefits of a light rail line be partially offset by the increased emissions with cars stuck idling in congestion? How do traffic performance measures change in response to a variety of changes in service attributes of the light rail line? Are today's microsimulation systems sensitive enough to changes in network to provide a viable tool for decision support and planning?

In this study, the TRANSIMS microsimulation model system has been used to analyze the impacts of light rail on roadway corridor performance. The 20-mile light rail line in the Phoenix metro area constitutes the focus of this study. Using four-step travel model origin-destination tables (for 2009) from the regional metropolitan planning organization, AM peak period trips were routed and microsimulated for the entire Maricopa region. All of the bus and light rail trips from the 2009 origin-destination matrices were combined into transit, and TRANSIMS was allowed to apportion the transit trips between light rail and bus based on the best available option to execute each trip. Following an adequate calibration and validation process, TRANSIMS was applied to analyze the impacts of alternative light rail scenarios. It was the investigators' intent to obtain a sense of how sensitive a routing and microsimulation system such as TRANSIMS is to changes in network investment.

The analysis results show that TRANSIMS is able to capture micro-level adjustments that are taking place as a result of changes in light rail service attributes. When service headways are drastically cut (i.e., schedule frequency is greatly increased) or light rail right of way is extended, it is found that speed, travel time, delay, maximum queue length, and number of cycles failures consistently deteriorate as a result of greater light rail presence. This is true whether traffic diverts away from the light rail corridor or not. It appears that when traffic diverts, it diverts to streets farther away from the parallel corridor as volumes reduce on the parallel corridor in each scenario.

Conditions do not greatly deteriorate on the parallel corridor until the change in light rail service becomes substantial, as in the combination scenario examined here. When one considers a scenario where the light rail line is extended on either end, thus increasing network access and connectivity by light rail while taking away roadway lane capacity on the corridor, it is found that conditions conditions on the parallel corridor improve despite the increased presence of light rail vehicles for two reasons. First, as the traffic is diverting farther away from the parallel corridor, there are fewer personal and commercial automobiles competing for space on the corridor. However, in the case of the changed headway scenario, a greater light rail presence at the nearby rail corridor leads to a slight deterioration in intersection performance with respect to maximum queue length and number of cycle failures. Second, the conditions may be slightly improving because bus ridership on the parallel corridor drops considerably. The drop in bus ridership presumably leads to improved bus speeds and performance, and as traffic shares the same roadway capacity with buses, the improved bus performance gets reflected in improved traffic conditions overall. It is true that bus ridership (on the parallel corridor) falls in the case of the combination scenario as well, which does not show improvement of performance measures as the other two scenarios do. However, any improvement in bus performance in that scenario is neutralized by the increases in congestion and queues at intersections with cross street traffic (at least at some locations). As a result, there is a net deterioration in performance in the combination scenario.

Table 4 shows the impact of each scenario on bus boardings; it is seen that bus boardings decrease by 9, 32, and 46 percent on the rail corridors in the headway, extension, and combination scenarios respectively. Despite these vast reductions in bus boardings and therefore reductions in bus dwell times, roadway characteristics are marginally deteriorating on the rail corridors. It can be noted, however, that the extent of deterioration in speed, travel time, and delay decreases as the level of bus ridership reduction increases. Along the parallel corridor, the 14 percent and 6 percent reduction in bus ridership in the headway and extension scenarios respectively is sufficient to afford the corridor some slight improvements in service measures. In the combination scenario, even the 25 percent reduction in bus boardings is not enough to silence the slight deteriorating effects of increase light rail presence.

TABLE 4 Changes in Bus Boardings in Response to Changes in Light Rail Attributes

Corridor		Boardings	% Change from Base Boardings
Base Network	Rail Corridor	540	-
	Parallel Corridor	288	-
Headway Scenario	Rail Corridor	491	-9%
	Parallel Corridor	249	-14%
Extensions Scenario	Rail Corridor	366	-32%
	Parallel Corridor	271	-6%
Combination Scenario	Rail Corridor	289	-46%
	Parallel Corridor	215	-25%

The study has shown that microsimulation model systems can prove to be effective tools in analyzing complex inter-relationships that exist in multimodal transportation networks. The findings of this study should not necessarily be used to make policy decisions related to the implementation of changes in light rail service attributes, but should be viewed as indicative of the types of benefits and advantages that one would accrue from using state-of-the-art microsimulation models systems. There is much scope for additional research in this arena. Microsimulation model systems should be applied to larger scale transit networks to truly exercise the capabilities of the model and understand the types of information that they provide. Within this paper, the activity demand component of the modeling enterprise was not implemented. Changes in light rail service attributes did not result in modal shifts within the TRANSIMS implementation of this paper. If modal shifts had been properly reflected, it is likely that the results would have been different as some of the auto trips along the light rail corridor and parallel corridors would have shifted to light rail. In this paper, only a reallocation of transit trips between bus and rail was accommodated. Moving towards a truly integrated activity-travel demand and network supply microsimulation model system would provide a compelling framework to capture the full range of micro-adjustments in system performance that would result from a change in light rail service attributes.

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