Validation of Simulation Software for Modeling Light Rail Transit

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As the engineering and planning communities continue their progress toward managed and integrated transportation systems, transit will play an increasing role. Light rail transit (LRT) has already been selected and implemented by 15 U.S. cities as a rail transit alternative. As new or expanded systems are planned and designed, it is essential that engineers have the means to make the best decisions for LRT placement and operations. The purpose of this research study was to investigate the use of the TRAF-Network Simulator (NETSIM) program and JRH Transportation Engineering's TransSim II™ tools for agencies interested in planning and developing LRT systems. NETSIM is one of the few available traffic analysis programs with the flexibility to model the operations and mobility impacts of transit. Similarly, TransSim II™ can model the impacts of transit and has been developed for this purpose. To evaluate NETSIM and TransSim II™ for simulating traffic in pretimed and actuated arterial networks, outputs from the models were compared with real-world field data from Los Angeles and Long Beach, Calif. and Portland, Oreg. The results indicated that the models could produce moderately accurate estimates of field-stopped delay and percent-stops for individual intersections within studied networks. On a systemwide basis, the models produced reasonably reliable, accurate estimates of network travel times and could reproduce most traffic characteristics observed in the field. The models performed well in simulating the control impacts and behavior of LRT in the modeled systems.

While planning a future light rail transit (LRT) system, or even for examining operational alternatives for an existing LRT system, it is essential that tools are available to assess the impacts of transit on the existing transportation system. Measures of effectiveness (MOEs) describe these effects, which include delay to motorists and transit riders, fuel consumption, emissions, and overall mobility. With such information, selecting the best alternatives for implementing LRT is possible. To produce the necessary data base of MOEs, analysts use models that simulate the LRT system operations. These models can range from mathematical procedures to computer simulation. Computer simulation is often used to process the necessary information and maintain records of the myriad variables describing the interaction between drivers, vehicles, and the roadway.

For traffic engineering applications, the Federal Highway Administration's TRAF-NETSIM (TRAFfic-NETwork SIMulator) is perhaps the most flexible computer simulator. NETSIM can simulate networks under control strategies ranging from sign control to fully actuated signal control. The model can provide MOEs for a variety of traffic scenarios and can simulate LRT in urban environments using a variety of methods. Proprietary software has also been developed to determine the network impacts of LRT. JRH Transportation Engineering's TransSim II™ can simulate LRT using a variety of control and priority schemes for transit and providing MOEs for network traffic.

After the development of a simulation method for computing LRT effects, any shortcomings in the procedure can lead to a failure of the planned system. Therefore, it is essential that the model produce accurate and reliable results. Model calibration and validation ensure that the model outputs accurately represent the effects of the planned LRT system. For this report, calibration consists of adjusting NETSIM and TransSim II™ model inputs and default parameters to model as accurately as possible the true data from field observation. The validation procedure statistically tests and assesses the ability of the model to replicate real-world conditions.

Considerations for Modeling LRT

The model inputs and embedded parameters for simulation of LRT in an urban street system include the location of the transit line with respect to the roadway, the environment in which LRT will run, general aspects of LRT operations, traffic control devices, and possible priority schemes.

Crossing Configurations

Four major at-grade configurations exist for LRT-roadway intersections: (a) isolated crossings, (b) isolated crossings with a nearby traffic control device, (c) crossings where LRT is adjacent to a parallel street, and (d) crossings for LRT median operation (*1*). For each type of crossing, there are modeling concerns such as the presence and handling of turning vehicles, the need to prevent cross-street vehicles from encroaching on the LRT tracks, the priority provided for light rail vehicles (LRVs), and optimal signal timing. Also important are the effects of altering the signal timing for an LRV when the signal is timed for arterial progression.

The LRT Physical Environment

LRT right-of-way and environment describe the purpose and exclusivity of the corridor in which the LRT line will be located. The land on which the line is or will be constructed may be devoted entirely to the transit facility and its appurtenances, it may be shared with a freight rail line, or it may even be in the right-of-way of a municipal street. Within the corridors, varying at-grade LRT track placements have been used in cities around the country. Despite this diversity, five general classes of track locations define and classify a vast majority of these placements. Ranging from least to greatest interaction with automobile traffic, these locations are: (a) grade

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separation, (b) exclusive right-of-way, (c) side of street, (d) median of street, and (e) mixed traffic. Grade separation is included in this discussion as many predominantly at-grade LRT lines are grade-separated at intersections where much automobile congestion exists.

LRT Operations

Providing accurate information about the vehicle's features and operations ensures accurate representation of the LRV within the model. The list here includes vehicle characteristics, headways, dwell time, operating speed, and time factors at roadway crossings (including blockage time, clearance time, and lost time).

Traffic Control Devices

Pursuing the discussion of LRT roadway crossings, another topic is the type of control used at the crossing. The crossing may exhibit crossbucks only, flashing lights with crossbucks, flashing lights with gates and crossbucks, or standard traffic control devices (*1*). Each control option has different blockage, clearance, and lost times, and all differences must be accounted for as accurately as possible within the model.

Control Strategy

In addition to the reproduction of the physical aspects and features of the modeled environment, incorporation of the control strategy found in the network is also necessary. Where LRVs and automobiles are considered equally, no modifications are required; however, where transit is given special treatment, signal priority for the LRV must be considered in the model.

DATA COLLECTION

For each modeled network under investigation, two separate sets of data were collected. Analysts used the first set to calibrate NETSIM and TransSim II™ for use with LRT. They used the second set to validate the model's ability to recreate the modeled environment. Since the data were specifically being collected for input to NETSIM and TransSim II™, the models defined the data collection requirements.

Information gathered at the field data collection sites used in this study consisted of network description data, travel time information collected using a portable computer, and videotapes of at least one major intersection within each of the study networks. The video allowed for later reduction of intersection measures of effectiveness. Study data were organized around the five geographic data collection sites. Networks 1 and 2 were located along Washington Boulevard in Los Angeles, California; Network 3 was located along Pacific Avenue in downtown Long Beach, California; Network 4 was located in Portland, Oregon along Holladay from Martin Luther King to 13th; and Network 5 was located along Burnside in Portland from 102nd to 122nd.

In the Los Angeles and Long Beach networks (Networks 1, 2, and 3), the light rail operated without priority in the median of a pretimed arterial system. In the Portland networks (Networks 4 and 5), light rail operated in the median or on the side of the street with full priority. Light rail approach "calls" were received early enough to ensure that cross-street vehicular and pedestrian minimum times were served. The intersection then dwelled in phases that did not conflict with the LRV until the LRV "checked out" or was "timed out" of the intersection.

NETSIM

The NETSIM model (*2*) performs a microscopic simulation of traffic flow in an urban street network. It is designed for traffic engineers and researchers as an operational tool for evaluating alternative network control and traffic management strategies. NETSIM allows the designer to simulate the performance of traffic under a number of alternative control strategies.

NETSIM application to LRT simulation is not new. Simulation of the Downtown Area Rapid Transit (DART) North Central Light Rail Line was accomplished using a modified version of the software (*3*). The original software did not readily accommodate the complex, frequently changing signal sequences found in the "window"-limited priority scheme proposed for the DART line. Restrictions in NETSIM that limited the signal transition flexibility were identified and their influence on the simulation was mitigated. NETSIM was used, with TRANSYT-7F and the Highway Capacity Software, to identify the delay impacts of LRT and the presence, if any, of residual queues after LRV passage.

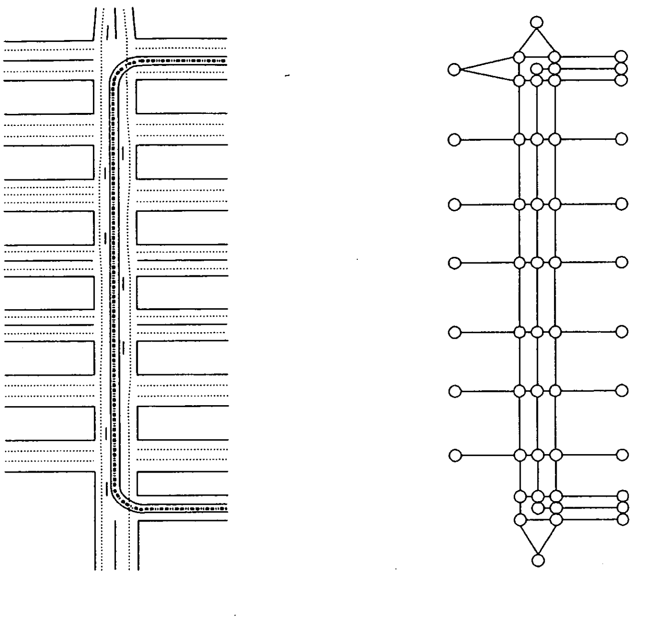
NETSIM was also used (*4*) to evaluate the relationship between an intersection crossing volume and the average automobile delay at an isolated LRT crossing. In NETSIM, the LRT was modeled as a single-lane roadway, and the grade crossing as a two-phase, fully actuated intersection. LRVs' arrivals were modeled as buses using specified headways. The model, however, gave unconditional priority to the LRT vehicles and made no allowances for signals and progression (*4*).

Coding the Modeled Environment in NETSIM

The described geometric, traffic volume, and signal timing information was input into the model using files that contained series of cards. Each card contained information about a particular feature of the modeled environment. Special card types used in the model to simulate bus operations were used to model the LRT in NETSIM.

For each of the pretimed networks (Networks 1, 2, and 3), the required input data was readily processed for entry into the model. Once the necessary information was assembled, the physical features of the roadway environment, the traffic volumes and turning percentages, and the traffic signal data were input via NETSIM's card-type format. The few exceptions to this rule include: (a) any links to the left of left-turn bays cannot be moving links (making it impossible in this scenario to directly model median-running LRT) and (b) links in the model have a minimum length of 15 m (50 ft). Modeling the median-running (or side of street running) LRT given the constraint of the minimum link length requirement produced a network that not only was more complex to model, but also one that required cross-street vehicles and arterial street left-turning vehicles to travel distances that were not present in the modeled environment (see Figure 1).

The coordinated actuated (Network 4) and fully actuated (Network 5) networks used the same LRT node format as the pretimed



Field Environment NETSIM Representation

FIGURE 1 NETSIM Representation of an existing median-running LRT network.

networks. Since the LRT and traffic nodes were separated, the approach of LRVs did not directly influence signal control at the traffic nodes. While vehicles conflicting with the LRT still received green time at modeled vehicular nodes in the presence of an LRV, the vehicles were not able to advance across the median "tracks" at the LRT node. This coding allowed reasonably accurate modeling of field traffic, LRV, and controller behavior except the dwell time in coordinated phases found in the field in Network 4. Coordinated phase dwell time was used in the field environment to "resync" controllers that were unsynchronized by the priority of the approaching LRV, giving extra green to the coordinated cross-street phases. Since dwell time could not be replicated in the model, some green time for the cross streets was not reproduced in the model.

Calibration

Initial calibration of the model consisted of using field-observed means and distributions of start-up lost time and queue discharge headway rather than NETSIM default values for these parameters. Also, repeated link "free flow" speed adjustments were made to the model to coordinate downstream arrivals in the model with patterns observed in the field. Improvement caused by changes to the model was monitored by comparing the modeled output with a calibration field data set. Changes were easily noted since components of the summary output provided by NETSIM were directly comparable to observed calibration field data MOEs. The primary cause of discrepancies between the model and the calibration field data appeared to involve the queue discharge and platoon dispersion behavior in the model. NETSIM tended to "spread out" the platoon earlier and to a greater extent than observed behavior in the field.

Validation

Following calibration, the model was run to produce a simulation data set for comparison to the validation field data. Three categories of comparisons were made for traffic: (a) individual link travel times, (b) network directional travel times, and (c) individual intersection MOEs. Individual link and directional travel time analyses were also performed for LRT.

Analysis showed that 40 percent of modeled individual links displayed travel times within ±20 percent (judged an acceptable range of accuracy) of the validation field data. Link travel times from the field and NETSIM are presented in Figure 2. Network directional

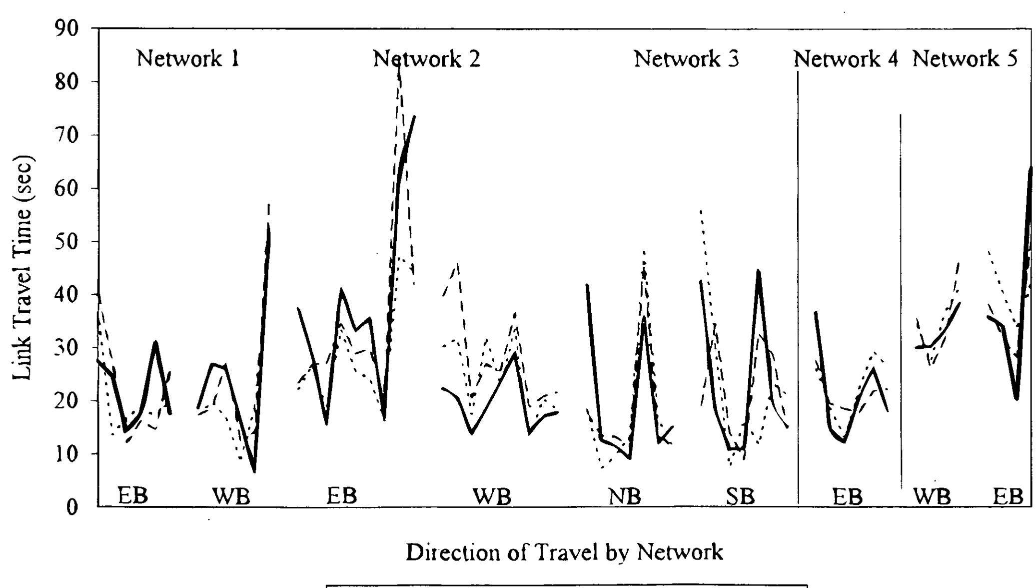


FIGURE 2 NETSIM and TransSim II™ traffic travel time comparison to validation data.

travel time analysis showed that eight out of nine systemwide travel times were accepted at the 95-percent confidence level. Platoon effects present in the field environment that could not be wholly accounted for in the calibration procedure were identified as the major cause of the discrepancy between the model and field link travel times. As the model tended sometimes to predict arrivals earlier and sometimes later than the field, the directional travel times "averaged" out these effects and the model estimates of directional travel time were more accurate than the link measures.

Individual intersection MOE analysis was performed on the stopped delay and percent stops output from NETSIM. Correlation analysis indicated a moderately strong correlation between field- and model-stopped delay and a moderate correlation between field and model percent stops. The stopped delay estimates from NETSIM and the comparison field data are shown in Table 1.

Priority for the LRT in Networks 4 and 5 made the travel times for LRVs vary from the travel times for traffic. The calibration for transit was similar to the calibration for traffic. To validate field travel times for transit, LRT travel time through the actuated networks was compared to the same values from the model (Figure 3). As with the analysis for traffic, the individual link travel time estimates from the model were not as accurate as the directional travel times. Thirteen of the 20 individual LRT link travel times, or 65 percent, were within the ± percent criteria, while three of the four directional LRT travel times were accepted at the 95-percent confidence level.

The graphics component, GTRAF, included in the TRAF software was an invaluable asset throughout the research investigation. Both the static and animated graphics supplied by the model assisted in describing how the input data were accepted by the model, in finding coding errors in the input data sets, and in clarifying the queue discharge behavior of the model.

TRANSSIM II™

TransSim II™ is a program developed by JRH Transportation Engineering of Eugene, Oreg. After identifying the shortcomings mentioned in current software for modeling LRT, JRH developed a program specifically designed for modeling LRT or bus transit in urban networks. The program is microscopic with respect to LRT (or bus) behavior and movement within the modeled system and macroscopic with respect to traffic performance. The computation of MOEs for traffic is accomplished within TransSim II™ using a methodology similar to the TRANSYT program.

TABLE 1 NETSIM and Field Intersection MOEs

	Mean Stopped Delay		Mean Percent Stops	
Intersection	Validation Data	Model w/ LRT	Validation Data	Model w/ LRT
Flower & Washington				
EB Approach	2.27	4.47	13	12
NB Approach	29.99	16.74	83	77
Central & Washington				
EB Approach	6.13	5.22	24	38
NB Approach	21.28	32.62	80	68
First & Pacific				
NB Approach	10	6.37	56	78
SB Approach	7.36	5.32	45	29
Broadway & Pacific:				
NB Approach	16.19	5.03	71	20
SB Approach	20.86	18.28	68	51
MLK & Holladay				
SB Approach	6.01	5.61	28	33
122nd & Burnside				
NB Approach	31.41	25.53	73	74

Inputs to the program include features of the roadway environment, including geometrics, traffic volumes, and signal phasing, and information about the transit route, including stations and intersections. Operating speeds and station dwell times can vary to simulate realistic transit operations. The analyst enters data in a pull-down menu format under the entries of system data, route data, link data, and signal data. A variety of types and degrees of priority are available and each can be easily selected by the user, facilitating the evaluation of alternative control strategies for the networks.

No unusual configuration was necessary for the five modeled networks and the signal control type was specified by selecting the priority level (a defined code with a variety of control types possible for selection) for the intersection. The selection of a priority level for transit and the entry of subsequent control and phasing information for this priority level were the main differences in coding between the pretimed, nonpriority networks (1, 2, and 3) and the semi-actuated and fully actuated priority networks (4 and 5, respectively).

Coding the Modeled Environment in TransSim II™

Geometric, traffic volume, signal timing, and LRT information necessary for input into TransSim II™ was entered using the pull-down menu driven data entry format of the program. The program main screen displays five menu options; (a) File, (b) Edit, (c) Schedule, (d) Run, and (e) Result and Graphics *(5)*. Data were entered using the Edit and Schedule menus.

Calibration

Following the entry of the geometric, traffic volume, and signal timing data, few adjustments were required to run the model. Several inputs, including entries for LRV acceleration and deceleration, start-up lost time, and average speeds for LRVs and automobiles, enabled adjustment of the model's environment parameters to field conditions. The one model parameter that did require adjustment through iterative runs of the program was the location of the detector that notified the downstream intersection of an approaching LRV in the priority networks (Networks 4 and 5). This distance was nominally the braking distance of the LRV plus any remaining distance required to produce the time equivalent of the minimum phase duration on the cross street.

A number of information elements were required to model LRT in TransSim II™ accurately. Because the program treats LRV behavior microscopically (i.e., LRVs are tracked through the system and detected to receive priority calls), any physical or control elements impacting the LRV had to be identified and entered.

Validation

Following data entry and detector calibration for the priority networks, the final TransSim II™ runs were made. The output data set was then statistically compared with the validation data.

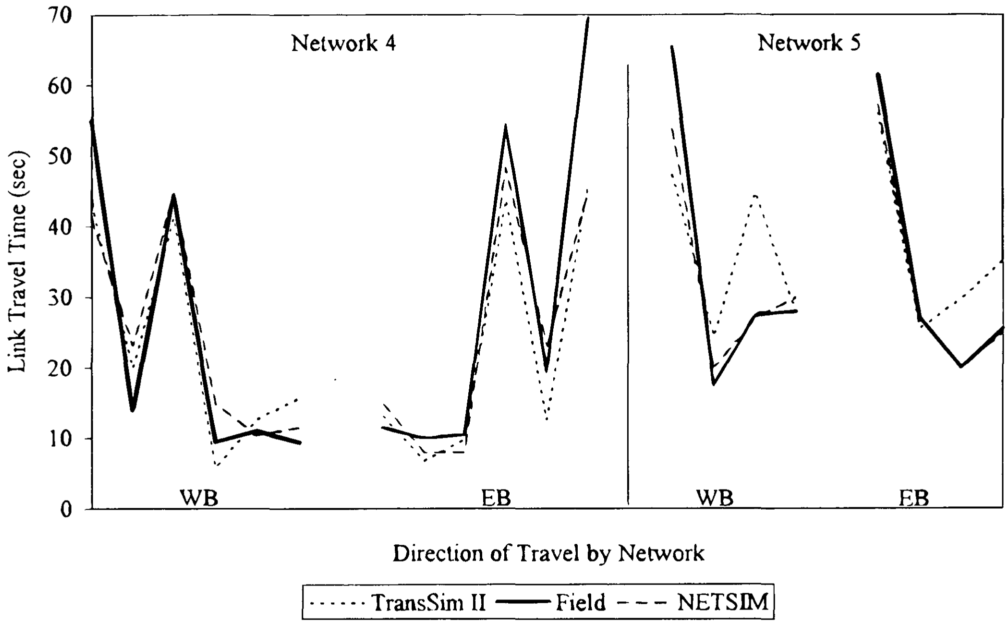


FIGURE 3 NETSIM and TransSim II™ LRT travel time comparison to validation data.

Traffic travel time comparisons showed that the model moderately replicated individual link travel times and accurately represented the system directional travel times (Figure 2). Thirty-eight percent of the individual link travel times were accepted at the ±20-percent criteria established for comparison with the field data. In the directional travel time comparison, however, eight of the nine modeled directional traffic travel times were accepted at the 95-percent confidence level. As a measure of the individual intersection modeling performance of TransSim II™, stopped delay from the model was compared with the field data (Table 2). Correlation analysis indicated a moderate relationship between model and field stopped delay.

TABLE 2 TransSim II™ and Field Intersection MOEs

	Mean Stopped Delay	
Intersection	Validation Data	Model w/ LRT
Flower & Washington		
EB Approach	2.27	9.74
NB Approach	29.99	9.91
Central & Washington		
EB Approach	6.13	9.95
NB Approach	21.28	29.01
First & Pacific		
NB Approach	10	12.38
SB Approach	7.36	12.04
Broadway & Pacific		
NB Approach	16.19	10.07
SB Approach	20.86	19.12
MLK & Holladay		
SB Approach	6.01	1.78
122nd & Burnside		
NB Approach	31.41	17.29

LRT link travel time in Networks 4 and 5, presented in Figure 3, consisted of LRV travel time at ideal speed plus time delayed at signals in the network, LRV acceleration and deceleration at signals and stations, and the dwell times at stations to service passengers. This information was taken from the TransSim II™ output by adding the LRT delay at each intersection to the ideal travel time along transit links and, for links with stations, also adding the time for passenger service and time lost during deceleration and acceleration. Similar to the results for the traffic analysis, the directional travel times for LRT were more accurate than the individual link travel times. Eight of the 20 individual link travel times were within ±20 percent of the field data, and three of the four directional travel times were accepted at the 95-percent confidence level.

The graphics could be viewed for an individual intersection or for the entire transit corridor being modeled. Inspection of the graphics for each intersection showed the simulation time, signal status for each approach, queue buildup during red indications, presence of LRVs, and priority calls and recovery periods attributable to transit. The systemwide view afforded by the graphics helped identify coding errors and contributed to an understanding of LRT treatment in the model.

CONCLUSIONS

The performance of the calibrated models investigated in this study was assessed by comparisons of link travel times, network directional travel times, and individual intersection MOEs to field-observed values. NETSIM and TransSim II™ could replicate the general trends of link travel times, but were only able to reproduce roughly 50 percent of link travel times within ±20 percent. Both models performed well for directional travel time comparison to the validation data. Eight out of nine directional travel times were accepted at the 95-percent confidence level for each model.

Individual intersection model-stopped delay and percent-stops output from NETSIM correlated with their field counterparts in a moderate and strong relationship, respectively. TransSim II™ was a moderate predictor of individual intersection-stopped delay. For the LRT modeling investigation, both models were accurate in replicating systemwide travel time and moderately accurate in estimating link travel times.

Based on the results of this research, analysts concluded that both models could simulate the systems and control behavior of the LRT networks simulated. Model outputs were more representative of field data for systemwide travel times than for MOEs at individual intersections. Strengths of NETSIM include the ability to monitor queue spillback conditions and provide realistic modeling of oversaturated traffic conditions. Advantages of using TransSim II™ are realized in the ease of modeling the LRT environment and the explicit modeling of controller behavior and LRT priority algorithms.

This research has simulated LRT in nonpriority pretimed networks and full priority semiactuated and fully actuated networks. Other types of priority exist between these extremes and there are a variety of means to recover green on cross streets given up during priority calls. These additional priority types should be investigated and simulated using NETSIM and TransSim II™ to determine the best simulation configuration and format for each model.

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