Simulating Performance for One-Dedicated-Lane Light Rail System—A Case Study

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Abstract This paper develops a study of the concept of a one-dedicated-lane light rail system with real world data from the Valley Transit Authority (VTA) two-dedicated-lane rail system using a simulation model. The model analyzed 14 train stations in the San Jose area that included the downtown plaza. The results showed that a one-dedicated-lane is feasible even at the different service time periods that the VTA light rail encounters throughout a weekday. Statistical analysis (ANOVA) was performed on the two different track configurations, different headways, and service-time periods to determine the effect they have on train speed. From the analysis, the results showed that headway has a significant effect on train speed. Our results demonstrated a promising potential of the concept of a one-dedicated-lane Bus Rapid Transit (BRT) or light-rail system for efficient operation, as an end-state or as an intermediate state of a two-dedicated-lane, space-efficient system, i.e. 150–250 words.

Keywords Simulation · One-dedicated lane transit systems · ProModel

1 Introduction

Traffic congestion remains a big problem in many urban areas. Light-rail or subway system is the classical and conventional mass transit system used in most developed countries while the Bus Rapid Transit (BRT) is a new mass transit system that has been adopted by both developed countries, such as the U.S., and emerging economies, such as China and Brazil [1–4].

In many urban or suburban commute corridors, right-of-way sufficient for a two-dedicated-lane BRT or light-rail system simply does not exist. For example, portions of the Eugene-Springfield BRT, named "EmX Green Line", in Oregon, U.S are implemented with only one dedicated lane [5]. To developing countries such as China, the

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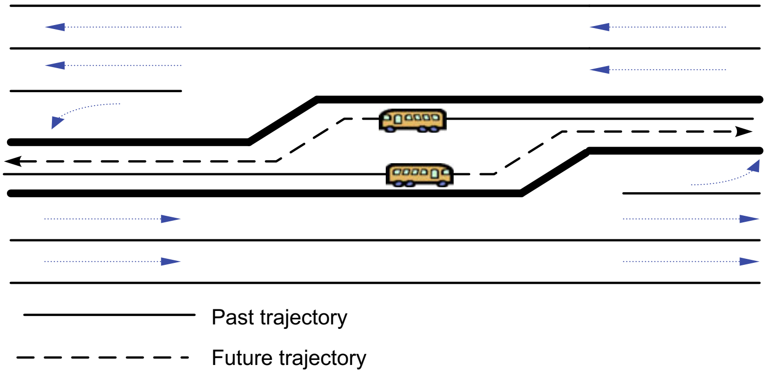

Fig. 1 Slanting of the dedicated lane and the crossing operation

construction and development of BRT or light-rail system requires significant amount of investment, which sometimes is a big hurdle to the development of an efficient mass transit system. These "chicken-and-egg", right-of-way and cost problems motivated Tsao et al. [6] to develop the concept of one-dedicated-lane BRT or light-rail train (LRT) system, which effectively requires only one dedicated but dynamically reversible lane in the median of an arterial serving a busy commute corridor with regular provision of left-turn lanes and significantly reduces the requirement of land and funding.

Conceptual design options and geometric-configuration sketches for the bus stop and crossing space have been reported in Tsao et al. [7]. for the dedicated lane and the crossing operation. Figure 1 illustrates the slanted geometric design of the dedicated lane and crossing operation. For busy commute corridors that have sufficient right-of-way but do not have sufficient demand to warrant dedication of two mixed-use lanes to public transportation, the proposed system could be very useful as an intermediate step toward a two-dedicated-lane system because of its potential for facilitating transit-oriented development. When the demand increases to such an extent that a two-dedicated-lane system is warranted, the one-dedicated-lane system can be expanded easily to a two-dedicated-lanes system proposed in Tsao and Pratama [8].

Computer simulation proves to be a very powerful tool for analyzing complex dynamical problems such as congested roads as shown in [9]. A potential use of the simulation framework to model the dynamics of a BRT system was presented in [10]. An overview of literature on the available analytic models for performance analysis of BRT systems along with a new dynamic microsimulation model implemented using Arena Rockwell Software to simulate and evaluate different BRT system configurations are given in [11]. Commercial speed is one of main parameters to evaluate public transport service performance. A simulation model is developed in [12] for one-dedicated lane BRT/light rail systems with different speed control rules to absorb the impact of stochastic demand on the performance of a closed system (with the surrounding traffic ignored or its effect negated) based on the commercial simulation software ProModel.

The objective of this paper is to build on the operating rules already developed in [12] and use real world data to simulate a real case scenario of a one-dedicated-lane light rail system to test the feasibility of a one-dedicated-lane light rail system. The demand of passengers alighting the trains was considered and the real-world data used for this project was obtained by the Santa Clara Valley Transportation Authority (VTA). The VTA is an independent special district that provides transportation options throughout the Santa Clara county. One of the transportation options offered by the VTA is light rail services. This light rail service system used a dual-track. Light rail services are offered seven days a week for San Jose, Santa Clara, Mountain View, Sunnyvale, and Campbell [13]. A section of downtown San Jose light rail system, starting from the Convention Center station and ends at the Tasman station, is the focus of this case study. Real world data was used to simulate a 24-h weekday in September 2015 on the light rail route 902. For this purpose, in Sect. 2 ProModel simulation model of [12] along with the necessary modifications is presented followed by input data modeling in Sect. 3. In Sect. 4 simulation results are analyzed along with statistical comparison of two-dedicated lanes system with the one-dedicated lane system. Finally, conclusions are presented in Sect. 5.

2 Simulation Model

This real case study follows route 902 and only focusing on the stations starting from the Convention Center to Tasman (see Fig. 2). This path was chosen because it is a straight path and included the downtown area of San Jose.

The system has fourteen passing nodes connected by thirteen links. The backbone the single-track train and passenger system in the ProModel software is use of location objects. These location objects serve the function of allowing a space for the entities to arrive, exit, route, and interact. Two types of locations were used: “Benches” and “Train stops”. Two types of entities were used: “People” and “Train”. The people entities are also known as the passengers entering the system by arriving at a train stationX then move onto a pre-selected destination and finally exiting the system upon arrival to their desired station. The train entities that can only travel between train stops along the predefined bidirectional path network at variable speeds. A path network is used to represent the path that the trains use to travel between locations. The distance between locations in the path network was obtained from data from the VTA and was converted to feet. This study focuses on which train station the trains are crossing (i.e., passing), how frequently and how this affects the headway goal. This network will ignore the effects of traffic signaling and private car interference on the model. Signal priority given to public transportation is assumed and should minimize the effect of traffic signaling on the model. Speed was adjusted by the simulation but final speed results will be compared to trains speed limitations in the real world. Arrivals of people occur at the fourteen train stops and one train arrives at TSI Convention Center location and one arrives at TS14 Tasman location at the

Fig. 2 Section of route 902

start of the simulation. These two train stations are located at the beginning and the end of the route path respectively. Attributes, global variables, and passenger arrival distributions are appropriately defined to simulate the single-tracked system using as much real world data possible.

Past LRT/BRT performance analysis and studies focus on developing models to estimate the average train speed in the system and use it as a parameter to evaluate a LRT's service performance [11]. In general, LRT system has variables such as signal priority, vehicle technologies, fleet size, and schedule design that can affect train speed. The overall structure of this ProModel simulation integrates both a LRT model and a passenger model. This model was developed to analyze LRT system downtown San Jose assuming signal priority, and with no private car interference.

3 Input Data Modeling

Table 1 summarizes various types of inputs used by the model. Details of each type of input is given next. Data for the selected route for 2015 measured an average ridership of 34,935 on a weekday [13]. The section of route 902 consists of 14 train stations. From this ridership data, the arrival patterns of passengers at each station were analyzed.

Data from the month of September was used to get enough information regarding the interarrival times of passengers boarding the light rail at each station during the four services time periods (5:00 AM to 9:00 AM Peak AM; 9:00 AM to 3:00 PM Midday, 3:00 PM to 7:00 PM Peak PM, and 7:00 PM to 5:00 AM off peak). The

Table 1 Inputs for ProModel

Limits	Demand	Trains	Traffic control	Service goals
Distances between train stations (excluding traffic lights)	Passenger's arrival/demand distribution at every train station	Train distance length for every segment	Not applied in this study	Scheduled departure headways

daily interarrival times of each weekday were averaged at each station and for each service time period. These average interarrival times were used to estimate statistical distributions of interarrival times at each station for each service time.

Distance between stations strongly affects the train speed. In this case study, each road segment between train stations has its own unique value. The distances between train stations were measured using Google Maps and verified with documentation from VTA Facts of the Current LRT System Data. Total Route being analyzed is 6.7 miles.

VTA LRT specifications were considered in the simulation. VTA has 100 vehicles currently operating. Length of each train is 90 feet. Capacity per cart is 66 seated and 105 standing passengers for a maximum capacity of 171 passengers per cart. Trains usually travel with two carts allowing for a total capacity of 342. VTA LRT do not stop at a station if no passengers are waiting to load/unload but for this project the LRT will stop at each station.

Currently the VTA LRT System has implemented a speed and safety program where they have identified low-speed zones along the route 901/902. The LRT operates at 35 mph (3080 fpm) from TS1 Convention Center to TS14 Tasman except between the three stations TS2 San Antonio and TS4 Saint James in the downtown area where the LRT travels at 10 mph (880 fpm). Maximum speed in freeway median is 55 mph (4840 fpm).

Headway is the time between consecutive services. For example, if you catch a train that "comes every half hour," then the service you catch has a headway of 30 min.

VTA LRT route 902 runs for 20 h on a weekday with trains arriving at 15, 30, 60 min depending on the time of the day. The earliest train leaves at 5:08 AM and the last train drops off the last passenger at 12:41 AM. Headway encompasses travel train speed, distance length, passenger boarding and alighting time. A relationship between a headway and the required average transit-vehicle speed has been previously developed, given the values of some important operational parameters. All LRTs in model are assumed to have an identical acceleration rate and an identical deceleration rate, but they may have a different travel speed. The travel speed of a train, after acceleration at the common constant rate but for a varying required duration, varies to accommodate the difference in section length and the difference in passenger boarding and alighting counts. This study looked at 2–3 min headways used by VTA LRT system train schedule to determine the needed train speed to ensure passengers did not wait longer than 15 min for the next train.

4 Results and Discussion

The simulation was run for 4 different service time periods. To model a weekday, the peak service periods the simulations were run for 4 h and the midday and off peak periods of the simulation were run for 6 h. Eight hours of warm up time was added to the beginning of the simulation run-time to ensure we reach a steady state.

The average time that a passenger spent in the system was about 29 min. From the VTA schedule the average time for a passenger to go from station 1 (Convention Center) to station 14 (Tasman) would be about 30 min. Our results showed a realistic time for the passengers to be in the system.

The Peak service periods had less passengers exit the system which is expected since the simulation was run for 4 h instead of 6 h and therefore passengers had more time to exit the system in the Midday and Off Peak periods. The one-lane simulation could handle even the most demanding time of day which is the morning Peak time. The total number of passengers that went through the system was 17,919. This number is consistent with the average ridership from the VTA data. The time that passengers waited for a train was about 15 min which once again is consistent with VTA data since trains are scheduled to arrive at a station every 15 min.

The results show the averaged steady state of the number of passengers on the LRT while in motion. The VTA LRT capacities state that that each cart can hold up to 171 passengers a combination of 66 seating and 105 standing. Usually two carts per LRT are dispatched on route so our total LRT capacity is 342 passengers. In this simulation, there are two LRTs running at a time on the track and going in different directions, increasing our total capacity for passengers on to 684. The maximum number of passengers the two trains carried were 531.20, 534.80, 391.00, 641.60 for the service periods Peak AM, Midday, Peak PM, and Off Peak respectively. None exceeded the LRT's passenger capacity.

From the VTA Data there is a 2 or 3-min travel time between stations. Train speed experiments were done using the simulation by changing the headway from ±1 min in increments of 30 s to determine the speed of the trains to get to the next station on time. Combination numbers (1, 2), (1.5, 2.5), (2, 3), (2.5, 3.5), and (3, 4) were assigned to the headway pairs (Headway2, Headway3). For example, combination 1 assigned Headway2 segment a value of 1 min and Headway3 segment a value of 2 min. These headway experiments were done for all four service times. As the headway was decreased the train speed increased to compensate. Inversely when the headway time was increased the required train speed was lower (see Eq. (1)). This is because of the function that is used to calculate train speed.

The attribute "aTrainSpeed" is a real number and is equal to the speed the train must travel to reach the next station. The speed is determined by several global variables as defined in the following equation:

$$aTrainSpeed = \frac{PathDistanceX}{(HalfHeadwayZmin - X)} \tag{1}$$

PathDistanceX is the distance between locations and HalfHeadwayZmin is the time it takes a train to load/unload and travel to the next train station. The variable X works to compensate for the time that the train spends at the train station loading/unloading passengers. This model assumed that the train will stop at each station regardless if there are passengers waiting to load/unload.

From the simulation results for the average train speeds at all the path segments for the service time Peak AM, we conclude that there is not much opportunity for further improvements on the headway when going from a two-track system to a one-track system. Looking at the train speeds it is not possible for the LRTs to ever function using the combination 1 headways. As mentioned before the maximum LRTs speed in a freeway median is 55 mph (4840 fpm) and the trains exceed that value in almost all the path segments in this combination.

For the one track and using headway combination 3, the global variable "vTrainSpeedXtoY" showed that the train speed was the slowest at a speed of 5 mph (453 fpm) on the path segment from station 2 to station 3. The fastest speed the trains travelled were at a speed of 27 mph (2474 fpm) on the path segment from station 9 to station 10. Some path segments showed an increase in speed as opposed to others because the time to load/unload passengers might have resulted in less time to get to the next station. These speeds fall within our real case scenario requirements. The Downtown San Jose transit mall has a maximum light rail speed of 10 mph. Stations 2–4 are part of Downtown and the simulation showed the speed at both these path segment to be right under 10 mph.

A three-way ANOVA was run to examine the effect of the factors, service time (A), headway (B), and the number of tracks (C) had on train speed. The number of tracks used were single and dual. The data was analyzed in Minitab. All the interactions (AB, AC, BC, ABC) showed no significance since the F-value < F-critical and the P-value > 0.05. Only the factor headway showed a significant effect on train speed since the F-value = 35.59 > F-critical = 2.389 and the P-value = 0 < 0.05. Thus, different headway combinations produce a significantly different train speed.

5 Conclusion

A real-world simulation study of the concept of a one-dedicated-lane light rail system with real world data from the VTA two-dedicated-lane rail system was presented. The model showed only one instance when the trains had to wait at train station 7 to pass each other and the wait was about 20 min. Further changes to scheduling can be done to optimize the headway to decrease the model's WaitXCtr time. The results showed that a one-dedicated-lane is feasible even at the different service time periods that the VTA light rail encounters throughout a weekday. Statistical analysis (ANOVA) results showed that headway has a significant effect on train speed. Our results demonstrated a promising potential of the concept of a one-dedicated-lane BRT or light-rail system for efficient operation, as an end-state or as an intermediate state of a two-dedicated-lane, space-efficient system.

Traffic signal logic can be added to improve the model's real-world simulation of the San Jose downtown area. As of this study there are 34 traffic lights along the path of the route. To add more realism to this scenario the model can be adjusted with actual data used by the VTA for signal prioritization of light rail trains. VTA gives some LRT signal priority at certain areas along the system. More research will be needed to denote which of the 34 traffic lights give signal priority to the LRT versus those that do not. This will greatly affect the train headway and train speed. Traffic demand patterns for the areas surrounding the light railways would also add another layer to the realism of this model.

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