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Ridership estimation procedure for a transit corridor with new bus rapid transit service

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SUMMARY

Ridership estimation is a critical step in the planning of a new transit route or change in service. Very often, when a new transit route is introduced, the existing routes will be modified, vehicle capacities changed, or service headways adjusted. This has made ridership forecasts for the new, existing, and modified routes challenging. This paper proposes and demonstrates a procedure that forecasts the ridership of all transit routes along a corridor when a new bus rapid transit (BRT) service is introduced and existing regular bus services are adjusted. The procedure uses demographic data along the corridor, a recent origin–destination survey data, and new and existing transit service features as inputs. It consists of two stages of transit assignment. In the first stage, a transit assignment is performed with the existing transit demand on the proposed BRT and existing bus routes, so that adjustments to the existing bus services can be identified. This transit assignment is performed iteratively until there is no adjustment in transit services. In the second stage, the transit assignment is carried out with the new BRT and adjusted regular bus services, but incorporates a potential growth in ridership because of the new BRT service. The final outputs of the procedure are ridership for all routes and route segments, boarding and alighting volumes at all stops, and a stop-by-stop trip matrix. The proposed ridership estimation procedure is applicable to a new BRT route with and without competing regular bus routes and with BRT vehicles traveling in dedicated lanes or in mixed traffic. The application of the proposed procedure is demonstrated via a case study along the Alameda Corridor in El Paso, Texas. Copyright © 2015 John Wiley & Sons, Ltd.

KEY WORDS: bus rapid transit; transit ridership; geographic information systems; systems dynamics; transit assignment

1. INTRODUCTION

Bus rapid transit (BRT) is a high-speed, high-capacity bus mode that combines a variety of infrastructure and operational features not found in regular bus service. The definitions and characteristics of BRT, with a focus on implementation in the USA, have been reviewed by Galicia *et al*. [1]. In general, BRT is relatively low cost and faster to implement than other mass transit systems. Its route is relatively flexible than rail systems. Under certain operating and infrastructure conditions, BRT could reach similar peak-hour capacities as light rail systems [2]. When planning for a BRT route, ridership estimation is an important step in revenue forecast and helps to decide vehicle capacity and service headway. In many cases, ridership alone can determine if a BRT project is economically feasible. The US Federal Transit Administration requires ridership estimations in the base year and usually up to 20 years after the base year for all potential transit projects, including BRT [3].

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Bus rapid transit ridership estimation is not a common practice in the USA. There are several papers and reports that document BRT ridership estimation methodologies in the US Chapter 3 of the Transit Cooperative Research Program Report 118 "Bus Rapid Transit Practitioner's Guide" [4] summarizes the BRT estimation approaches that are related to the traditional regional travel demand models, including mode choice models, pivot-point (incremental logit models), and elasticities. Only a few other tools are developed specifically for BRT ridership forecast, and they will be reviewed with limitations highlighted in the next section.

The challenges in BRT ridership estimation, for a new BRT route without a competing regular bus route (hereafter simply referred to as bus route), have been discussed by Galicia and Cheu [5]. Because of the differences in infrastructure and operational features, ridership estimation for a BRT route is different from a bus route, even if both routes are mutually exclusive along the same transit corridor. Therefore, several models [5–9] have been developed specifically for BRT ridership estimation. The BRT ridership estimation problem is more complex if the planned BRT route overlaps with existing bus routes, thereby competing for the same set of passengers but also provides opportunities for passengers to transfer between the routes. In addition, with the implementation of the BRT service, an existing bus route, its vehicle capacity or service headway may need to be modified. None of the few existing transit ridership estimation tools [5–9] is comprehensive enough to enable planners to forecast ridership along a corridor when a new BRT service (with a variety of service features, including traveling in mixed traffic) is to be introduced and some of the existing bus services (routes, capacities, and headways) modified.

This research proposes a procedure that forecasts ridership of all routes along a corridor when a new BRT service, with dedicated lanes or in mixed traffic, is introduced and existing bus services modified. The procedure uses demographic data along the corridor, a recent transit origin–destination (O-D) trip matrix, and the new BRT and existing bus service features as inputs. The procedure consists of two stages of transit assignment. In the first stage, a transit assignment is performed with the existing trip demand on the proposed BRT and existing bus routes, so that adjustments to the existing bus services can be identified. This transit assignment is performed iteratively until no more service adjustment is deemed necessary. In the second stage, transit assignment is carried out with the new BRT and adjusted bus services, but with a potential growth in transit ridership due to the new BRT service features. The final outputs of the procedure are ridership for all transit (BRT and bus) routes and route segments, boarding and alighting volumes at all stops, and a stop-by-stop trip matrix.

The remaining parts of the paper are as follows. After this introduction, a review of existing transit ridership estimation tools applicable to BRT is provided. The proposed procedure is then introduced in the next section. After this, the application of the proposed procedure to a case study along the Alameda Corridor in El Paso, Texas, is described. This paper then ends with a summary that also highlights the contributions, limitations, and directions for future research.

2. REVIEW OF RIDERSHIP ESTIMATION TOOLS APPLICABLE TO BUS RAPID TRANSIT

There are several approaches and tools that may be used to estimate BRT ridership. Most of the approaches rely on geographic information system (GIS) to provide demographic, socio-economic, and transit network data.

The conventional approach of BRT ridership estimation is to use the logit model or nested logit model (which has been mentioned in the previous section [4]). This approach is commonly used in the mode choice step of the four-step urban transportation planning systems. This approach is the one most transportation planners are familiar with. However, as BRT has many unique service features that are different from the regular bus mode, several specialized tools have been developed to predict BRT ridership.

The Transit Boarding Estimation and Simulation Tool (TBEST) is developed by the Florida Department of Transportation to predict transit ridership at the stops, segment, route, and system levels [6]. This tool uses a numeric scoring system of 0 to 5 to represent each four BRT features, namely vehicle, station, guideway, and branding, when estimating stop-level ridership. It also simulate the competition (split) and complementary (transfer) of ridership between routes. There are two TBESTs: the original,

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calibrated using data from Portland, Oregon, and the newer TBEST Land Use Model developed for Jacksonville, Florida. The TBEST User Guide [6] cautions users to “re-estimate and re-calibrate the various equations” using local census, land use, and stop-level ridership data, when applying TBEST to other cities. This implies that using TBEST in a new city may require considerable investment in time and effort to calibrate and validate its internal components.

A suite of software named TransitTools$_{CS}$™ has been developed by Cambridge Systematics Inc. for transit service market analysis [7]. TransitTools$_{CS}$™ may be used to predict impacts of service changes, identify factors and policies of local authorities that influence ridership, and others. TransitTools$_{CS}$™ has three components: (i) Transit Market Segmentation that identifies unique behavioral market segments based on shared attitudes towards travel; (ii) Service Planning Tool that forecasts ridership changes caused by changes in service features; and (iii) Competitive Index Tool that evaluates the transit potential for a local area or corridor. Because TransitTools$_{CS}$™ is a proprietary commercial software, the document of its internal components are not publicly available. Without a thorough understanding of the internal logic, it is difficult for an analyst to apply TransitTools$_{CS}$™ to estimate the BRT and bus ridership when both services are competing along the same corridor.

Federal Transit Administration has developed Simplified Trips-on-Project Software (STOPS) to forecast ridership of new transit projects with fixed guideways [8]. STOPS basically follows the four-step urban transportation planning systems. It replaces the trip generation and trip distribution steps with a trip table taken from the Census Transportation Planning Package. Users may scale the trip demand by population and employment growth factors. For the mode choice step, STOPS uses data from the General Transit Feed Specification to represent the transit networks. The users have the options to add new services and modify existing bus services to meet local design conditions. STOPS has been calibrated using ridership data in six cities in the U.S. and validated with data in nine other cities in the USA. However, this software can only be used for BRT routes with dedicated lanes, not BRT traveling in mixed traffic (as in the case study presented in this paper).

Cervero *et al*. developed a stop-level BRT ridership (boarding and alighting combined) estimation tool using data from 69 BRT stops in Los Angeles County [9]. They call this direct ridership model (DRM). This fitted multiple linear regression equation has the following 10 terms: a constant term, number of BRT services/day, number of feeder bus services/day, number of feeder rail services/day, population density ($\leq$0.5-mile buffer); distance to the nearest BRT stop, and four interactive terms. Each of the interactive terms is the product of dedicated BRT lane (with value of 0 or 1) and number of feeder bus services/day, number of feeder rail services/day, population and employment density ($\leq$ 0.5 mile), and park-and-ride lot capacity, respectively. This DRM incorporates feeder services and park-and-ride that attract more riders. All the attribute coefficients, except the constant, are positive values. The estimated stop-level BRT daily ridership may be aggregated to a corridor or route’s total daily ridership. This model is developed using data from 69 BRT stops, including 13 Orange Line stops, which are also served by a few bus routes that acted as Orange Line’s competitors and/or feeders. It appears that, from the model’s attributes, the DRM only takes into account the BRT service frequency, population and employment density, average walking distance to the stops, park-and-ride, and transfer passengers. The process of applying DRM to stops with competing bus service is not yet clear. Similar to TBEST, the model’s coefficients may need to be re-calibrated if DRM is to be applied to other cities.

Geographic information system business analyst (GIS-BA) combines GIS-based analysis tool and visualization capabilities with an extensive data package, including demographic and socioeconomic attributes. Although GIS-BA is designed for and has been used in commercial site location evaluation, market penetration, or customer profile, the tool has been used by Galicia and Cheu [5] in BRT ridership forecasting. GIS-BA can also supply demographic data as inputs to other ridership estimation tools, such as the DRM. It is noted that GIS-BA is a data management and visualization tool, not a ridership estimation tool.

System dynamics (SD) is a modeling approach that allows planners to perform simulation of dynamic systems over time that involve many variables with feedback loops, some of which the relationship may not be well-defined. The SD approach is now used in many fields to simulate the outcomes of economic, public policy, environmental studies, defense, management, and transit mode

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share. The SD approach, combined with GIS-BA, was named the SD-BRT model and has been used to forecast BRT ridership along the Mesa Corridor in El Paso, Texas [5]. The model defines, around each BRT stop, two buffers (<0.25 mile, and between 0.25 and 0.50 mile) as the catchment or service coverage area (SCA). Within the SCA, the following 12 inputs are derived from the data provided by GIS-BA in the base year:

- Population (<0.25 mile, and between 0.25 and 0.50 mile)
- Population growth rate (<0.25 mile, and between 0.25 and 0.50 mile)
- Employed population (<0.25 mile, and between 0.25 and 0.50 mile)
- Employment growth rate (<0.25 mile, and between 0.25 and 0.50 mile)
- Number of household (<0.25 mile, and between 0.25 and 0.50 mile)
- Household growth rate (<0.25 mile, and between 0.25 and 0.50 mile)

These data are entered into the SD-BRT model, which then simulates the year-to-year changes in ridership along the BRT corridor. In addition, the SD-BRT model receives seven inputs that represent the BRT service features. The inputs are related to limited, moderate, or aggressive phases of BRT implementation as described in [1]. Depending on the level of implementation, the SD-BRT model forecasts an increase in BRT ridership. The output is the BRT's total daily ridership (TDR) along the corridor from the base year to the target year. Two limitations of the SD-BRT model are (i) it assumes that there is no bus service along the corridor that competes with the BRT for riders and (ii) it does not consider riders who transfer from another route to the BRT and vice versa. These limitations, especially the first one, have motivated the development of the procedure proposed in the next section.

When proposing a ridership estimation procedure (to be elaborated in Section 3), a major initial decision is to select a tool that could estimate the corridor's TDR. Based on the aforementioned discussions, the DRM and SD-BRT model are the two best candidates. Between these two tools, the authors have selected the SD-BRT model because (i) the SD-BRT model has been validated with data from the Las Vegas MAX and the Los Angeles Orange Line BRT systems, while the performance of DRM in cities/regions other than Los Angeles County is unknown; and, (ii) if a planned corridor has no exclusive BRT lane, the DRM only has number of BRT services/day, number of feeder bus services/day, number of feeder rail services/day, population density (within 0.5 mile), and distance to the nearest BRT stop as inputs. The model lacks other BRT features to distinguish it from regular bus service, and (iii) it is not clear if DRM is developed for BRT without competition or BRT competing with bus service along the same corridor. On the other hand, the SD-BRT model does not include riders who make transfers from/to feeder routes and those who park and ride. The new ridership estimation procedure introduced in Section 3 is capable of handling transfer passengers. However, the issue of incorporating park-and-ride passengers in the ridership estimation procedure will be addressed in the last section of this article.

3. PROPOSED RIDERSHIP ESTIMATION PROCEDURE

The proposed ridership estimation procedure for an existing transit corridor with the introduction of a new BRT service is graphically depicted in Figure 1. The procedure requires six major inputs:

- Corridor's demographic data
- Existing transit O-D trip matrix
- Proposed BRT route (including stops)
- Proposed BRT service features (vehicle capacity, headway, fare. etc.)
- Existing bus routes (including stops)
- Existing bus service features (vehicle capacity, headway, fare, etc.)

Before applying this procedure, the analyst needs to define (i) the transit corridor, which is the proposed BRT route and (ii) the existing bus routes, which have at least one stop along the corridor. These are the routes that either compete or provide transfer opportunities for passengers using the proposed BRT, (iii) the bus routes that cross the corridor, which supply or attract transfer passengers. The BRT's rider catchment area is termed Service Coverage Area (SCA). The SCA is defined by the Transit

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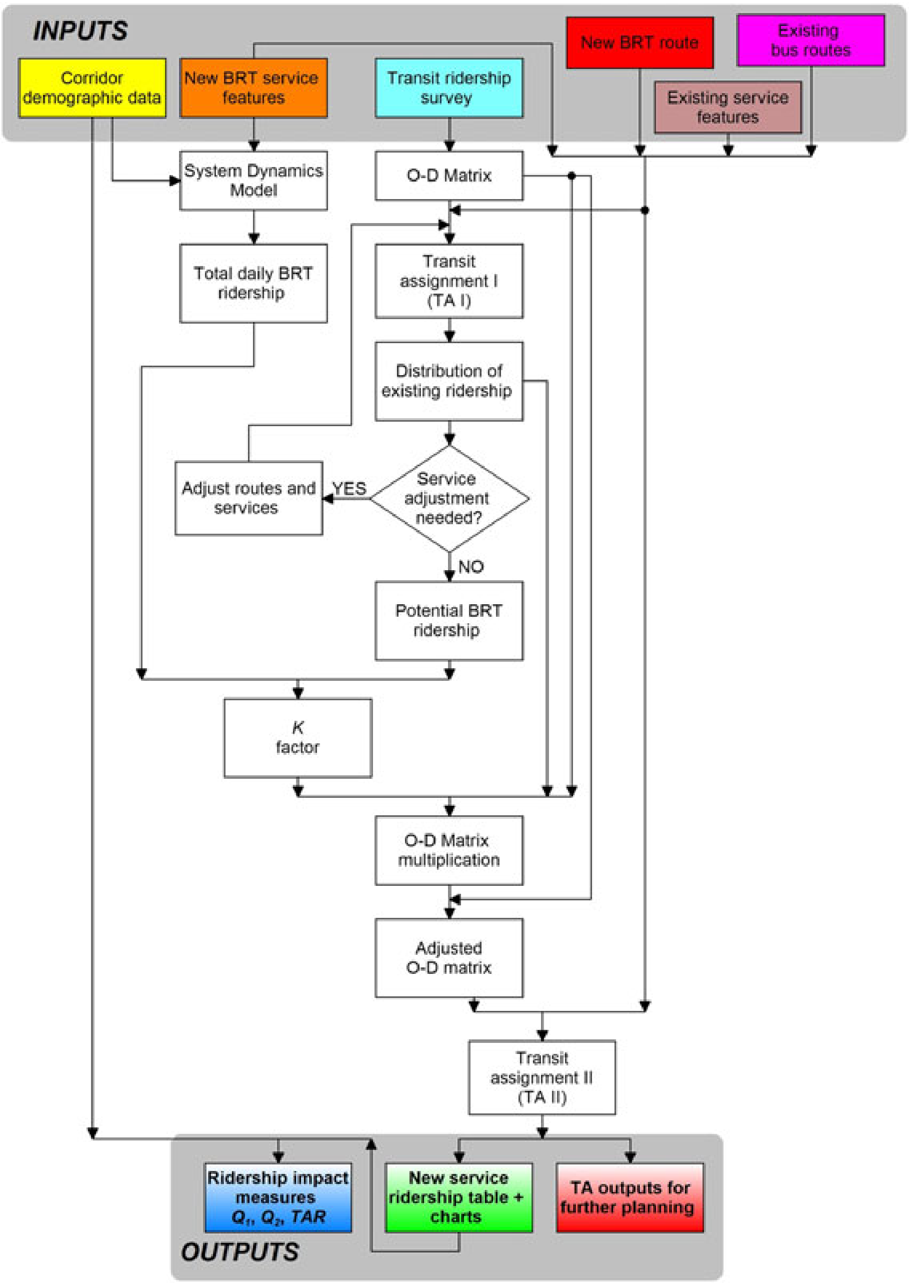

Figure 1. Proposed ridership estimation model.

Capacity and Quality of Service Manual as the area within 0.5 mile radius of air distance from the proposed BRT stops [10]. The study area is the area that bounds (i) the new BRT route and (ii) all the existing bus routes that have at least one stop along the corridor or crosses the corridor. Thus, SCA is part of the larger study area.

The corridor's demographic data extracted from the SCA and the new BRT service features provide inputs to the SD-BRT model [5]. The SD-BRT model estimates the corridor's TDR that will use the BRT when there is no competing bus service. The estimated TDR includes new riders who are attracted to use the BRT because of its features. For the inputs to the SD-BRT model and its TDR estimation procedure, readers may refer to [5].

The proposed BRT route, existing bus routes and their service features are coded in a GIS-based transit assignment tool.

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The existing transit O-D trip matrix, which may be obtained from a transit ridership survey on existing bus routes, is next loaded into the transit network in the study area (which includes existing routes plus the new BRT route). This step is called transit assignment I (TA I). The outputs of TA I are the passenger load in each transit route and route segment (between two adjacent stops). These outputs give the analyst an idea on how many existing passenger-trips will be shifted from the existing bus routes to the BRT route and the number of passenger-trips that will remain on the existing bus routes. However, the implementation of a new BRT service is usually accompanied by some changes to the existing bus routes and/or their service features. For example, an existing bus route that runs along the corridor may be removed, rerouted to serve as a feeder route, or have its headway increased. TA I provides an indication of how many passenger-trips will be affected if there is any change to an existing bus service. If any adjustment to an existing route or service feature is considered, the TA I step is repeated until the analyst does not make further change. The end results of this iterative process are the BRT and adjusted bus routes, service features, passenger load in each route and route segment. At the end of the service adjustments, some of the existing bus routes that run along the corridor may still remain to compete or complement the BRT service.

Transit assignment I uses only the existing transit O-D demand in the study area in the base year. It has not taken into account the additional users that may be attracted from other modes (except bus) to the BRT in the base year and the growth of transit ridership from the base year to the target year. To account for these new riders, a factor K is proposed. The factor K represents the ratio of additional ridership to the existing ridership (for trips generated and ended within the SCA). It is defined as

$$K = \frac{\text{TDR} - \sum_{i \in \text{SCA}} \sum_{j \in \text{SCA}} T_{ij}}{\sum_{i \in \text{SCA}} \sum_{j \in \text{SCA}} T_{ij}} \tag{1}$$

where TDR is the total daily ridership estimated by the SD-BRT model for the target year; T_{ij} is the number of passenger-trips traveling from stop i to stop j in the base year (from the existing O-D matrix). Note that, if the analyst sets the target year to be the same as the base year, K then represents the fraction of additional ridership immediately after the implementation of the BRT. When computing K, only the T_{ij} with the origin–destination pairs that are both within the SCA are considered. These i and j stops may be the existing bus stops or the proposed BRT stops, but they are all located within the SCA. In TA I, these T_{ij} trips may be assigned to the BRT routes or adjusted bus routes. However, it is expected that majority of the trips will be assigned to the BRT route.

The computed K factor is then used to add additional trips to the existing O-D matrix. The adjusted O-D matrix will be calculated from

$$T_{ij}^{\text{adj}} = \begin{cases} T_{ij} + KT_{ij} & i, j \in \text{SCA} \\ T_{ij} & \text{otherwise} \end{cases} \tag{2}$$

where T_{ij}^{adj} is the adjusted number of passenger-trips traveling from stop i to stop j. The above adjustment applies to all the i and j stop pairs within the SCA. Therefore, it assumes that the growth in riderships comes only from the SCA.

With the adjusted O-D matrix (that describes the transit demand in the study area for the target year), transit assignment is performed again. This step is called transit assignment II (TA II). The network used in TA II is the one with the new BRT route and adjusted bus routes in the study area. The outputs of TA II are passenger load in each route and route segment, and boarding and alighting volumes at each stops, from which three ridership impact indicators may be calculated.

The first indicator Q_1 measures the ratio of potential and existing riderships in the entire study area. It is defined as

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$$Q_1 = \frac{\sum_{\forall i} \sum_{\forall j} T_{ij}^{\text{adj}}}{\sum_{\forall i} \sum_{\forall j} T_{ij}} \quad (3)$$

The size of the study area relative to the SCA affects the value of Q_1, and this fact should be taken into account in interpreting the Q_1 value.

The second indicator Q_2 measures the ratio of potential and current riderships along the corridor such that only trips that originated and ended within the SCA are included. It is defined as

$$Q_2 = \frac{\sum_{i \in \text{SCA}} \sum_{j \in \text{SCA}} T_{ij}^{\text{adj}}}{\sum_{i \in \text{SCA}} \sum_{j \in \text{SCA}} T_{ij}} \quad (4)$$

If the values of Q_1 and Q_2 are greater than 1, the effect of the proposed change in transit service leads to an increase in overall ridership in the study area and SCA, respectively.

To express the growth of ridership by the actual number of passenger-trips per day, total additional ridership (TAR) is used. This measure is the difference between the total passenger-trips in the adjusted and original O-D matrices in the study area.

$$\text{TAR} = \sum_{\forall i} \sum_{\forall j} T_{ij}^{\text{adj}} - \sum_{\forall i} \sum_{\forall j} T_{ij} \quad (5)$$

4. CASE STUDY

4.1. Background

The City of El Paso is located at the western end of Texas, at the USA–Mexico border. It is the 19th most populated city in the USA, with 672 538 inhabitants in 2012 [11]. The main form of public transportation in the city has been the conventional bus service provided by Sun Metro [12]. The City of El Paso has planned to introduce a BRT system named Brio along four major transit corridors [13]. At the request of Sun Metro, this case study focused on the so-called Alameda Corridor for the target year 2016.

The new BRT route of interest in this case study runs along Alameda Avenue between the Downtown Transfer Center (DTC) and Mission Valley Transfer Center (MVTC). The route is 14.5 miles each way, with most of the stops located along Alameda Avenue. The portion of Alameda Avenue between the DTC and MVTC is therefore known locally as Alameda Corridor [14]. Figure 2 shows the two transfer centers with the Alameda Corridor highlighted in light green (currently served by bus route 61). This figure also highlights bus routes 3, 7, 21, 22, 62, 66, and 204, which have at least one stop along the Alameda Corridor. These routes have headways that range from 16 to 65 min. Riders on 12 other bus routes (routes 4, 23, 24, 25, 42, 55, 60, 63, 65, 67, 69, and 84) may also be affected as these routes cross the Alameda Corridor, providing/attracting potential transfer passengers. The transit network formed by the above 21 routes (proposed BRT plus 20 bus routes) is the study area.

4.2. Input data

4.2.1. Origin–destination survey

A transit O-D survey was conducted in 2012 in El Paso. This survey covered all the Sun Metro routes and captured the stop-to-stop ridership per day. All the data were collected, processed, and summarized by the contractor [15]. The aggregated data was provided to the authors through Sun Metro.

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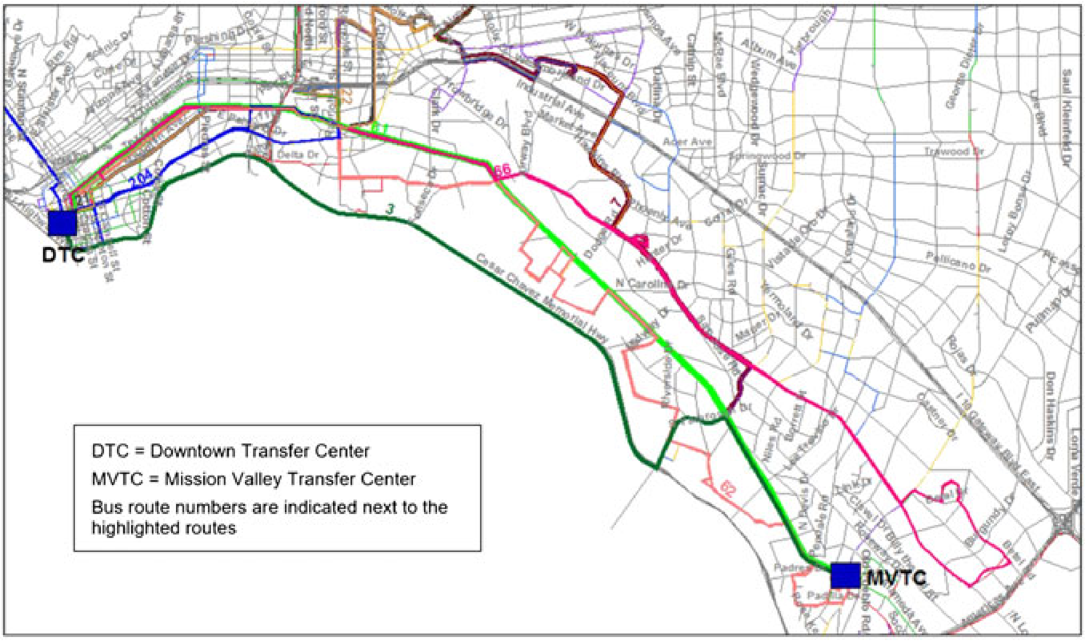

Figure 2. Existing transit routes along Alameda Corridor.

The eight bus routes (routes 3, 7, 21, 22, 61, 62, 66, and 204) that ran along the Alameda Corridor had a total of 6088 passenger-trips/day (including the trips from/to stops outside the SCA). The 20 routes in the study area had 12 209 passenger-trips/day. The stop-to-stop O-D passenger counts for the 20 selected bus routes were aggregated to form the O-D matrix between pairs of stops. However, this survey did not capture data about transfers. Therefore, there is no data for passengers that transferred between the routes.

4.2.2. *New service characteristics*

The proposed BRT route has been mentioned in the previous section (Section 4.1). The route will have 19 stops in the outbound direction (DTC to MVTC) and 19 stops in the inbound direction. The BRT vehicles will be 60-feet low-floor articulated buses each with a capacity of 58 sitting and 25 standing passengers, running in mixed traffic. Each vehicle has space for three bicycles and two wheelchairs. Arrival time information will be provided to passengers through three in-vehicle screens and digital tables at BRT stops. Passengers on board will be able to use free wireless internet. The headway is 10 min during the peak period and 15 min during the off-peak period [13, 14]. Ticketing machines will be installed at all the stops for off-board fare collection.

4.2.3. *Demographic data*

The demographic data was mainly taken from ArcGIS-Business Analyst [15]. It was used to generate population, employed population, and number of households for years 2011 and 2016. The population, household, and employment growth factors were computed from the predictions obtained in these 2 years. Figure 3 shows the BRT stops and SCA defined by two buffer zones (0.25 mile radius and between 0.25 and 0.50 mile ring) around each stop. The demographic statistics generated are summarized in Table I. The ArcGIS-Business Analyst report [16] did not provide information about employment in SCA. Therefore, the 2011 El Paso County population of 820 790 and employment of 397 184 were taken from [17] to calculate the fraction of the employed population out of the total population. The calculated ratio of 0.4839 was then applied to the SCA. To project the employment from 2011 to 2016, the employment growth factor was adopted from the SD-BRT model developed for the nearby Mesa Street Corridor [6].

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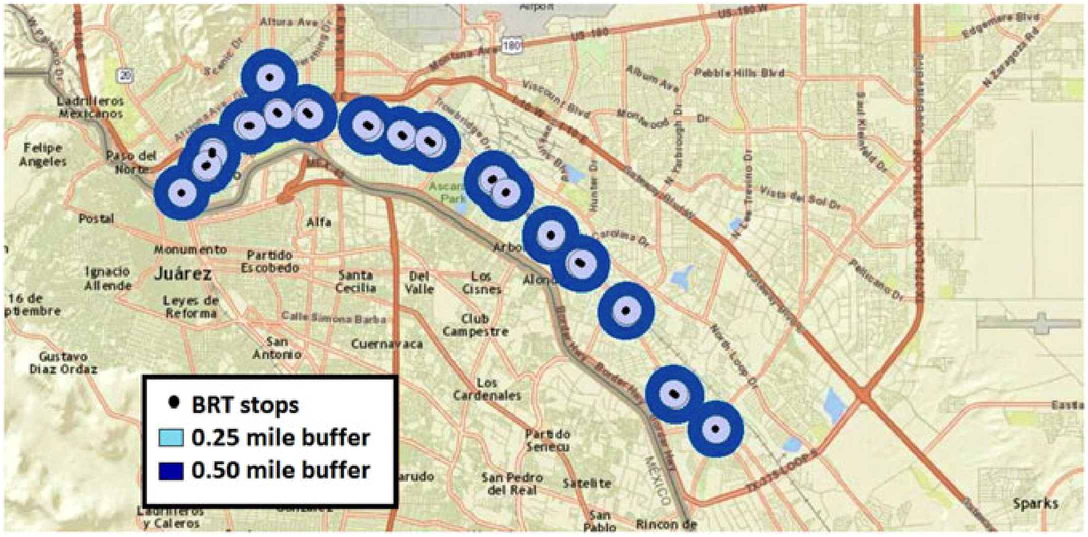

Figure 3. Proposed bus rapid transit stops and service coverage areas.

Table I. Demographic statistics of service coverage area.

Service coverage area buffer	Population (persons) 2011	Population (persons) Growth rate	Household (families) 2011	Household (families) Growth rate	Employment (persons) 2011	Employment (persons) Growth rate
<0.25 mile	17 128	0.00738	5938	0.01147	8288	−0.00432
0.25 to 0.50 mile	22 404	0.01737	3454	−0.02387	19 130	−0.00580

4.3. Application of system dynamics bus rapid transit model

This section briefly describes the application of the SD-BRT model, introduced by Galicia and Cheu [5], to estimate the proposed BRT route's TDR in 2016 (the target year) assuming no competing bus service. The accuracy of the SD-BRT model has been validated with data from the Las Vegas MAX and Los Angeles Orange Line BRT corridors [5]. It is assumed that the SD-BRT model's TDR prediction is reasonably accurate for the case study in El Paso. The inputs to the SD-BRT model for this case study are the data compiled and presented in Table I. Because of limited right of way, the proposed Alameda Corridor's has BRT vehicles traveling in mixed traffic. It also has relatively simple shelters and limited park-and-ride possibilities. Therefore, the proposed BRT service is closer to the limited phase implementation described in [1]. With the inputs in Table I, the SD-BRT model predicted TDR of 4050 passenger-trips/day in 2016. Details of the execution of the SD-BRT model have already been described in [5], and therefore, it is not elaborated here.

4.4. Transit assignment I

The study area consisted of the new BRT route, eight existing bus routes that have stops along the Alameda Corridor, and 12 existing bus routes that cross the corridor. For transit assignment, the authors adapted the regional Metropolitan Transportation Planning (MTP) model provided by El Paso Metropolitan Planning Organization [18]. The MTP model had been coded and provided in the TransCAD environment [19]. Bus stops and bus routes were added to the MTP model. The Pathfinder method in TransCAD was used to perform the assignment of transit trips (specified in the transit O-D matrix) to the BRT and bus routes, with the following settings:

- The speeds of bus services were estimated from the travel times between stops in Sun Metro's published schedule.

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- The BRT speed was assumed to be the minimum of (i) the posted speed of a link and (ii) 1.5 times of the bus services. The 1.5 times of bus speed was assumed based on the combination of BRT features: limited stops, transit signal priority, and off-board fare collection.
- The existing Sun Metro's fare structure was used: $1.50 per ride including one free transfer on all bus routes.
- The same fare structure was applied to the Alameda Corridor's BRT. In fact, Sun Metro has used the same fare structure for the Mesa Street Corridor, the first BRT route in El Paso, which began operation in October 2014.
- The value of travel time was assumed to be $12/hour, based on [20].

Other parameters such as waiting times, access times were also assumed after making site observations.

The purpose of TA I was to load the trips in the existing O-D matrix (obtained from the ridership survey) onto the existing bus routes plus the new BRT route in the study area. This enables the analyst to visualize how many passenger-trips will be shifted from the existing bus routes to the new BRT route and to provide input for the adjustment of existing bus services. The estimated daily ridership for the routes along the Alameda Corridor are presented in Table II(b). The new BRT route and route 204 (downtown circulator) have the highest ridership. The passenger volumes on the routes that run along the Alameda Corridor are visualized in Figure 4(a).

Table II(a) lists the daily ridership for all the bus routes in the study area before the introduction of the BRT service. This route level data is obtained from the ridership survey. By comparing

Table II. Estimated daily ridership after transit assignment I.

Route	Daily ridership (passenger-trips/day)		Highest segment* daily ridership (passenger-trips/day)	
	Outbound	Inbound	Outbound	Inbound
	(a) Actual ridership survey data before TA I, with route 3			
3	487	382	205	163
7	398	367	160	132
21	57	61	25	50
22	62	77	50	44
61	292	356	93	153
62	167	116	186	29
66	229	221	122	58
204	508	422	296	353
BRT	—	—	—	—
	(b) After TA I with route 3			
3	304	160	286	142
7	797	712	364	249
21	139	72	85	38
22	167	80	94	40
61	509	420	158	129
62	380	254	106	55
66	610	398	331	113
204	881	858	434	559
BRT	1046	937	720	733
	(c) After TA I without route 3			
3	—	—	—	—
7	801	719	367	247
21	169	67	125	34
22	197	75	153	36
61	558	388	133	114
62	445	294	120	73
66	618	403	337	118
204	880	858	434	559
BRT	1045	1097	859	892

*A segment is defined as a part of a route between two adjacent stops.

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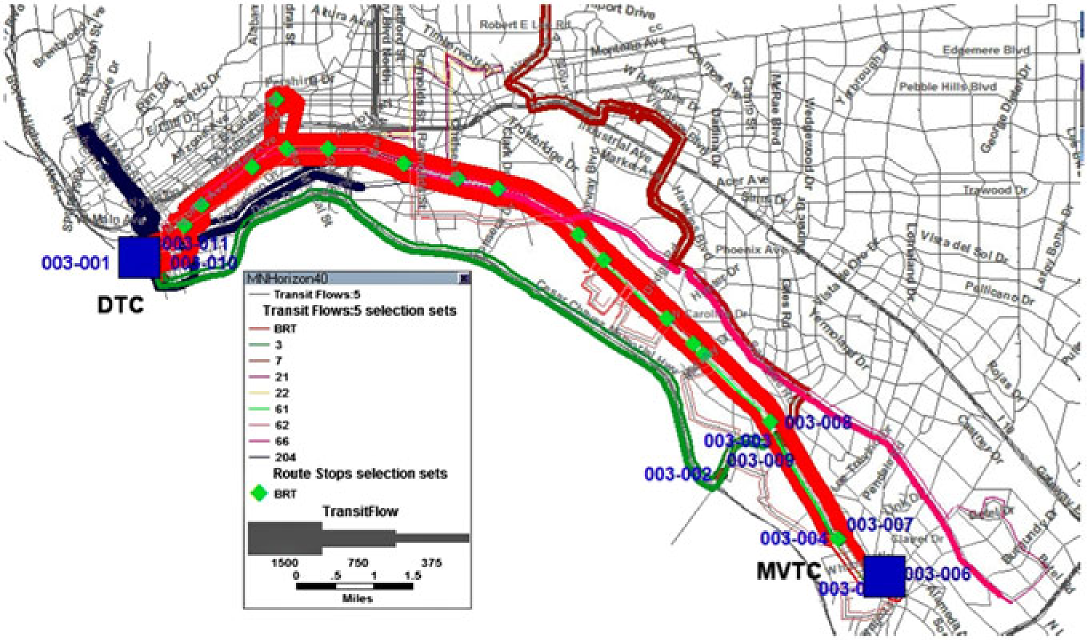
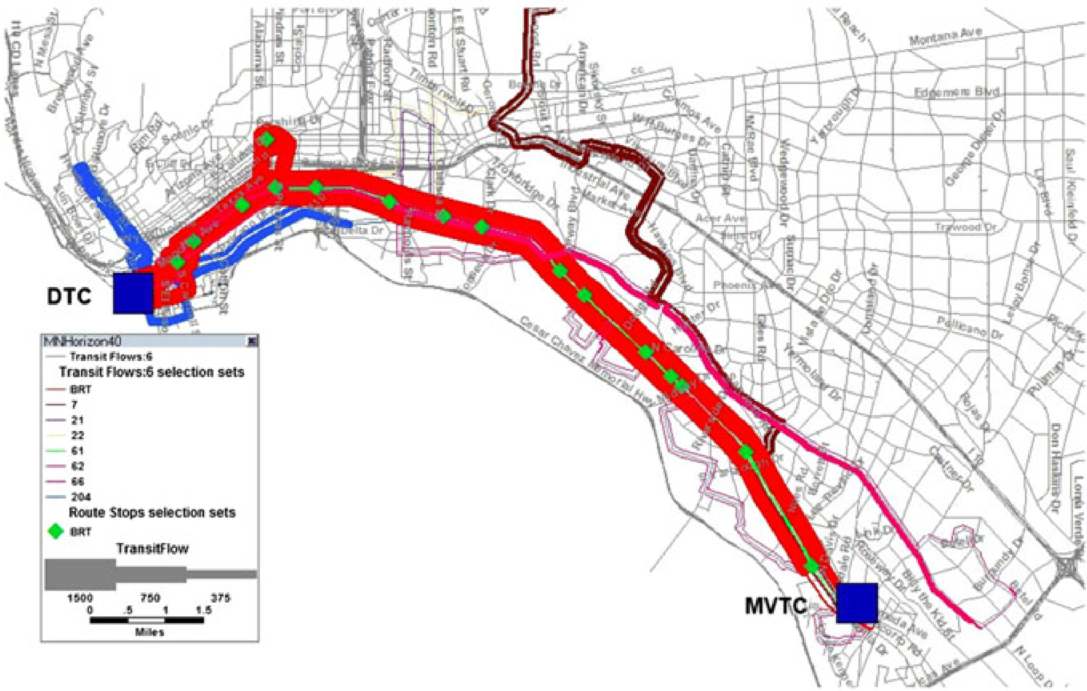


(a) with Route 3



(b) without Route 3

Figure 4. Passenger volumes on routes along Alameda Corridor after transit assignment I.

Table II(a) with (b), examining Figure 4(a) and stop-by-stop volume analysis, it was determined that route 3 (a semi-express service between DTC and MVTC) and the proposed BRT route have service overlap, that is, they share the same terminals, and compete for the same set of riders. Figure 4(a) also shows the stops that are served by route 3 (numbered 003-xxx) to illustrate that route 3 is an express service when it runs along Cesar Chavez Memorial Highway, Route 61,

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which runs along the Alameda Corridor, has many overlapping road segments with the BRT, but route 61 has many more stops (and shorter distance between the stops). A closer examination of the TA I output found that trips that were assigned to route 61 did not share the same O-D pairs as the BRT. After presenting these facts to Sun Metro representatives, it was jointly decided that A10 route 61 should be retained but route 3 may be canceled. The 12 passengers who are using the three stops along route 3, which are not served by the proposed BRT, will have the possibility to use routes 23 or 67.

With the cancellation of route 3, TA I was performed again. The assigned passenger volumes among the available routes that run along the Alameda Corridor are presented in Table II(c) and Figure 4(b). Comparing Table II(b) and (c), it can be observed that most of the inbound trips using route 3 have been diverted to the BRT route, but the outbound trips using route 3 have been re-assigned to routes 21, 22, 61, 62, and 66.

4.5. Adjustment of origin–destination matrix

After TA I and before TA II, the O-D matrix was adjusted by using (1) and (2) to account for the additional ridership in the SCA that will be attracted to use the transit system in 2016. At the end of TA I, the following statistics were obtained:

- TDR in 2016, estimated from the SD-BRT model: TDR = 4050 passenger-trips/day;
- Total number of trips in the base year O-D matrix with origins and destinations both within the SCA: $\sum_{i \in SCA} \sum_{j \in SCA} T_{ij} = 2{,}010$ passenger-trips/day. This value is smaller than the ridership provided in Table II because it does not include trips originated and/or ended outside SCA.

Therefore, the calculated K factor is 1.015, which means that additional 101.5% increase in transit ridership. The O-D matrix that covers the study area was then adjusted by this factor. The adjusted O-D matrix has a total of 14 249 passenger-trips/day.

4.6. Transit assignment II

Next, the transit assignment was performed by loading the adjusted O-D matrix onto the BRT routes, and all the remaining bus routes (except route 3) in the study area. This step is termed TA II. The computed ridership impact measures are: $Q_1 = 1.169$, $Q_2 = 1.234$, and TAR = 2040 passenger-trips. The daily ridership on routes along the Alameda Corridor in 2016 is listed in Table III. The assigned passenger volumes among the available routes are plotted Figure 5. From the results, it is obvious that the route with the highest ridership is the BRT route, which provides the backbone service for the corridor. Comparing Table III with Table II(c), the increase in ridership is most obvious for the BRT route. However, other bus routes (except route 62 outbound) also experience an increase in ridership. This is because some of the new trips, which begin and end in SCA, are assigned to the bus routes.

The output of TA II includes a ridership table for every route. Figure 6 show the volumes of passengers boarding and alighting the new BRT service along the routes, in the inbound and outbound

Table III. Estimated daily ridership after transit assignment II.

Route	Daily ridership (passenger-trips/day)			Highest segment* daily ridership (passenger-trips/day)	
	Outbound	Inbound	Total	Outbound	Inbound
7	857	823	1680	378	321
21	185	79	264	132	38
22	213	88	301	160	40
61	831	591	1421	235	193
62	602	418	1019	129	107
66	662	493	1154	353	161
204	886	872	1757	434	559
BRT	2051	2129	4180	1696	1736

*A segment is defined as a part of a route between two adjacent stops.

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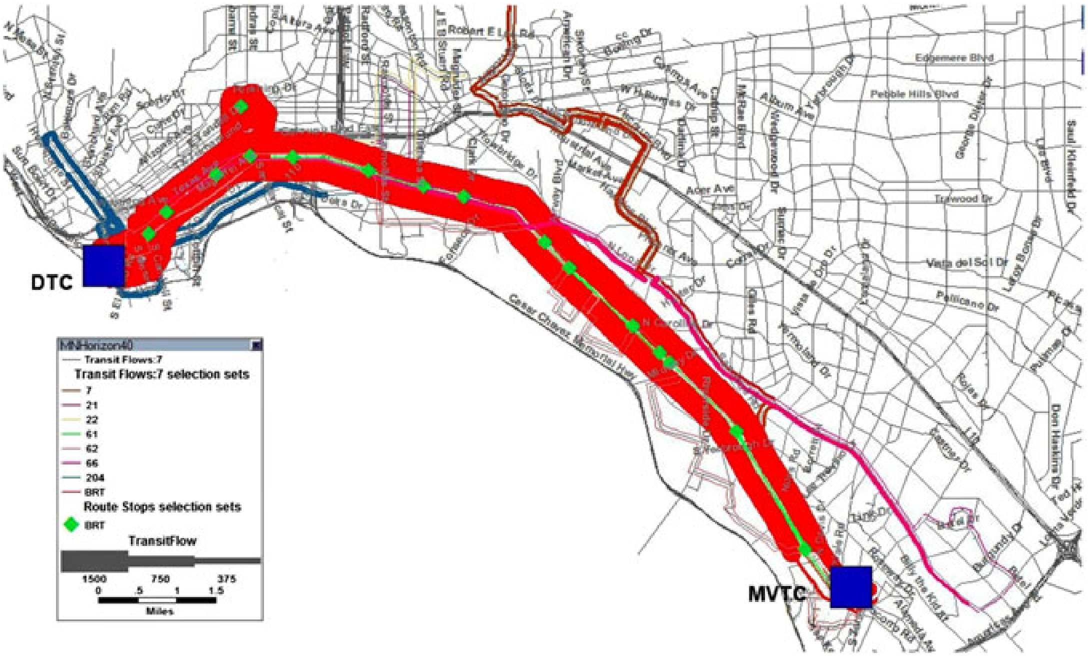

Figure 5. Passenger volumes on routes along Alameda Corridor after transit assignment II.

directions, respectively. The most used stops are the DTC, MVTC, and the intersection of Alameda Avenue at Davis Drive.

5. SUMMARY, CONTRIBUTIONS, LIMITATIONS, AND FUTURE RESEARCH

5.1. Summary

This research has developed a transit ridership estimation procedure. The procedure may be used by planners to estimate transit ridership along a corridor that already has bus service but with the addition of a BRT route. The procedure makes use of the corridor's demographic data, an existing transit O-D trip matrix, the planned BRT, and existing bus services as inputs. It first uses transit assignment to iteratively assign the existing transit demand to the new BRT, existing, and adjusted bus routes. It then applies the SD-BRT model to forecast the BRT ridership in the target year. A growth factor is derived to adjust the O-D matrix for the increase in ridership along the corridor from the base year to the target year. The transit assignment is then performed again using the adjusted O-D matrix, on all the routes (including the proposed BRT route, adjusted bus routes that serve the study area, and the remaining competing bus routes along the corridor). In addition to projected volumes along the routes, this procedure also provides three ridership impact measures. The application of this procedure has been demonstrated in a case study along the Alameda Corridor in El Paso, Texas, which has a planned BRT route with buses traveling in mixed traffic, with 2016 as the target year.

5.2. Contributions

The key contribution of this research is the introduction and demonstration of a procedure (as shown in Figure 1) to estimate transit ridership along a corridor with existing regular bus services but with a new BRT route. The procedure can also be applied to a proposed BRT corridor with or without existing regular bus service and with dedicated lanes or in mixed traffic. It also caters for the adjustment of bus services with the introduction of the BRT. The forecasts are made in the base year and with the growth in ridership in the target year. This ridership forecast procedure has the following innovative components:

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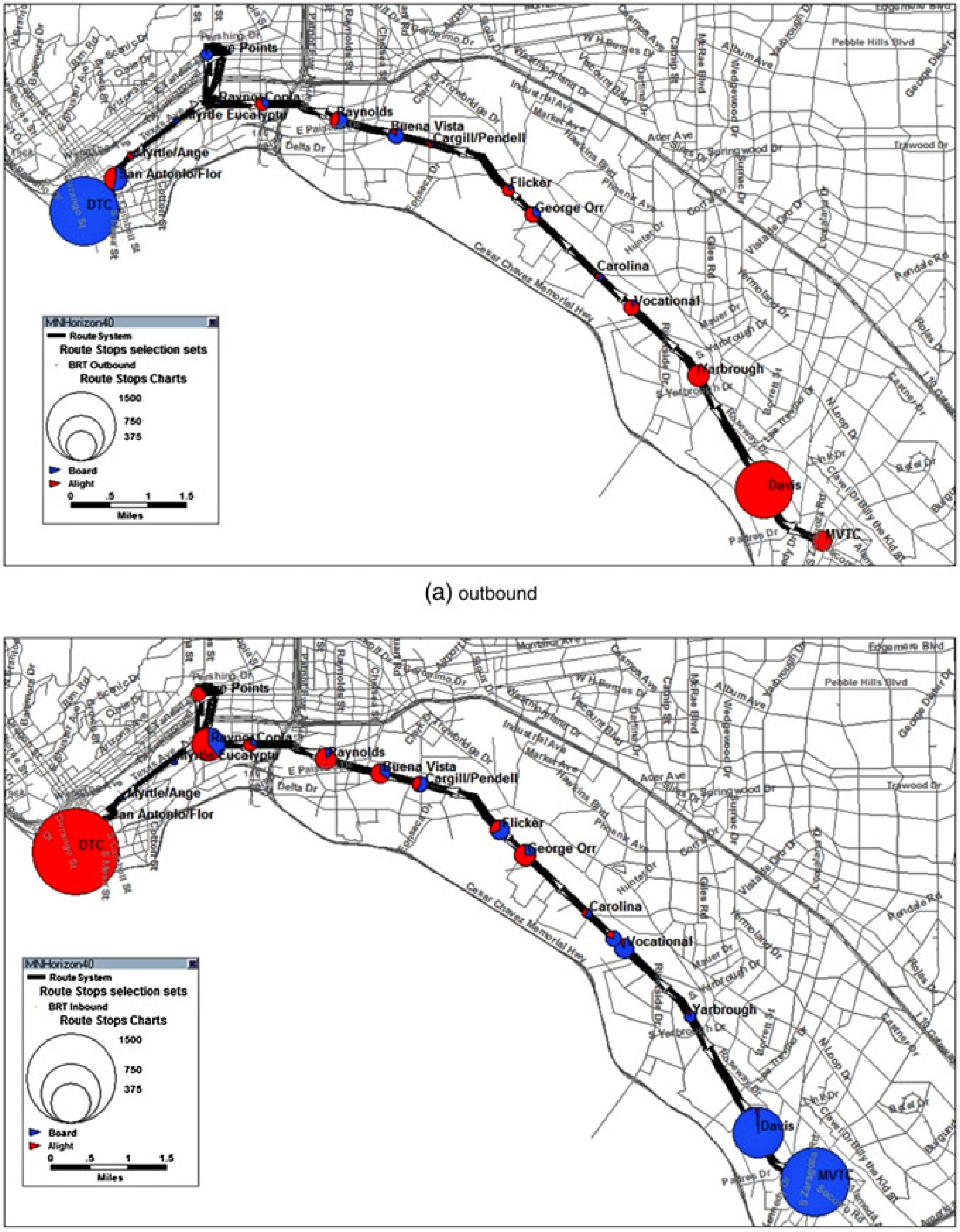

(a) outbound

(b) inbound

Figure 6. Boarding and alighting passenger volumes for new bus rapid transit service.

- A methodology of combining a transit O-D survey for a study area and GIS-based demographic and socioeconomic data along a transit corridor for ridership estimation.
- A two-stage transit assignment (TA I and TA II) to predict ridership in existing regular bus routes after the introduction of BRT service, from which the under-utilized bus route may be identified, removed/modified, and corridor ridership forecast repeated with the revised routes.
- A methodology to adjust the O-D matrix, to reflect the increase in BRT trip demand from the base year to the target year.

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5.3. Limitations and future research directions

Although the procedure is one of the few in forecasting ridership of a new BRT service along a corridor, with adjustments to existing bus services, there are several limitations that should be addressed in future research.

The first limitation is its data intensive nature, especially the need of a transit O-D trip matrix in the base year. However, this may be easily obtained by an on-board automated fare collection system (at boarding and alighting stops). Otherwise a comprehensive ridership survey will need to be conducted.

The second limitation is that the growth in ridership from the base year to the target year is restricted to the trips made by the BRT within the SCA, that is, there is no growth in the demand of bus trips within the SCA and transit trips that originated or ended outside the SCA. A new O-D matrix adjustment methodology may be developed to fill this gap.

An apparent shortcoming of the case study is that there is no data on passengers who transferred between routes. This is the limitation of the ridership survey conducted in El Paso and not the proposed procedure. It is highly likely that a passenger who made a transfer within the study area was surveyed as two separate trips. However, if such transfer data is available, it should be reflected in the O-D matrix (as one trip instead of two) and the transit assignment is able to model the transfer between routes. In the case study, because the route modification is minimal (only route 3 is canceled), the impact of not capturing transfer trips in the O-D survey is negligible.

Another limitation of the procedure and the case study is the lack of park-and-ride trips. There are two possible ways of handling park-and-ride trips:

(1) If such trip exists in the base year, they will be captured by the O-D survey and included in the O-D matrix. In this case, one can assume that the park-and-ride lots are at the BRT stops along the corridor. However, there is no existing mechanism in the SD-BRT model to estimate the TDR with the addition of park-and-ride trips. Adding the capability to estimate park-and-ride trips in the SD-BRT model is a potential research topic.
(2) If there is no park-and-ride in the base year, but the facilities will be added later, one could use an additional forecasting tool [21] to estimate the park-and-ride trip generation, attraction and distribution, and added the trip interchanges to the adjusted O-D matrix.

The ridership estimation procedure is also capable of accommodating any change in BRT infrastructure and operational features in the future. To do so, the analyst simply needs to update the inputs to the SD-BRT model, use the TDR forecasted by the SD-BRT to adjust the O-D matrix, and repeat the TA I and TA II. When performing the TA I and TA II procedure, the BRT's link travel time may need to be revised to reflect the new infrastructure and operational features.

Because the proposed procedure is for ridership forecasting in the target year, no actual ridership data is available to validate its accuracy. However, the important internal components of the procedure have either been validated with field data elsewhere, or the procedure will use local field data as inputs. The SD-BRT model's output should be reasonably accurate because (i) the SD-BRT model, which is used to estimate TDR along the corridor in the target year, has been validated with field data in the Las Vegas MAX and the Los Angeles Orange Line BRT corridors; (ii) actual O-D data obtained from a comprehensive field survey in the study area in the base year has been used; (iii) the transit assignment is well-accepted by planners and researchers. In the future, after the new BRT service has been in operation and existing bus services adjusted, another field survey should be conducted to collect ridership data to validate the procedure.

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