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A Framework of Modeling and Forecasting Stop-Level Transit Patronage

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Abstract

This paper presents a framework of modeling and forecasting stop-level transit patronage for service planning. The paper describes this framework in terms of its three most important features in relation to existing frameworks in the literature. It models and forecasts transit boardings at the individual stop level. It separates direct boarding from transfer boarding for both modeling and forecasting, and, it treats inter-relationships in a transit network through measures of accessibility to opportunities for potential activity participation. The paper specifies a model structure that reflects these features, describes the Tri-Met data from Portland, Oregon, and estimates a set of Poisson models for both direct and transfer boardings for the weekday morning peak. In addition, the paper discusses both the advantages of this framework and the challenges to its implementation. This framework is in the process of being implemented into T-BEST, a user-friendly software package.

Key words: Boarding, transfer, service planning, transit stops, accessibility, modeling, forecasting

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I. Introduction

Transit agencies strive to be able to predict the impacts of changes to their network or service levels on transit patronage. Some of these changes are modifications to existing services while others represent proposed new services. Transit agencies need to know these impacts for a variety of reasons (*1*). There are always competing demands for adding new services or maintaining existing services. Information on these impacts provides a basis on which to allocate resources. Transit agencies need to know these impacts in order to prepare budget requests for proposed new service plans to their governing board. In this case, cost and revenue forecasting must be reasonably accurate. Finally, these impacts are important inputs into detailed network and scheduling planning, particularly for new service plans.

The traditional four-step process is ineffective for assessing such impacts. First there are accuracy and relevancy challenges (*1*). The four-step process was designed as a planning tool for large-scale, capital intensive changes. The unit of analysis is typically at the zonal level. Errors from this process may be larger than the impacts of low-cost, operational changes. In addition, low-cost transit changes typically have little impact on the diversion of automobile trips to transit. While new ridership may be generated, it often comes from people making new trips and diverting from walking or biking. The magnitude of ridership has virtually no impact on the highway level of service in most cases. Besides accuracy and relevancy, the traditional four-step process lacks flexibility in capturing the possible changes to a transit network or services that a transit agency can explore and implement.

While simplified versions of the traditional four-step process have been developed for specifically accessing these impacts (*2*-*3*), most previous work has focused on direct demand models at the route-level (*4*-*9*). While these route-level models avoid some of the problems with the traditional four-step process, they have their own difficulties (*4*). They assume homogeneous service levels and land use along each route. This assumption is particularly problematic along long routes that start at the central business district and go into distant suburbs. They are ill equipped to deal with inter-relationships in a transit network that occur at the sub-route level. The inter-relationships in a transit network show how the different elements of a transit network, including the routes, the route segments, the stops, and route directions, relate to each other.

Modeling and forecasting transit patronage has recently been advanced to the segment-level (*10*-*11*). Segments may be defined by time-point stops (*11*) or by fare zones (*10*). This advance recognizes the spatial variation of patronage and service supply across route segments. It has been aided by geographic information systems (*12*) as well as by the availability of patronage data at the segment level from automated passenger counters (APCs). It has allowed the assessment of new policy instruments such as service reliability (*11*). It has also gained new insights into inter-relationships in a transit network and their effects on patronage that traditional route-level analyses were unable to provide (*10*).

The segment-level models still share some of the difficulties of route-level models (*10*-*11*, *13*). The socio-demographics along a route segment are assumed to be homogeneous. It is difficult for segment-level models to take into account important stop-level characteristics such as pedestrian access, stop amenities, and special generators. It is difficult to represent the competing effects in a transit network at the segment level. It is also difficult to represent some service variables at the segment level and it may be necessary to address the simultaneous determination of both patronage and service levels. Many of these limitations result because transit patronage is analyzed at the route-segment level but is realized at the stop level.

The only previous documented attempt to model and forecast patronage at the stop level is by (*14*). They use fuzzy inference for modeling and predicting transit patronage at directionless stops. This approach is similar to the traditional cross-classification approach to trip generation modeling (*15*), with the boundaries of the discrete classes being fuzzy. While it does serve as an alternative to other methods, there is little advantage over traditional regression-based methods. In fact, the sensitivity of predictions to changes in continuous factors influencing patronage is limited as a result of using them in a few discrete categories.

This paper develops a detailed framework for both modeling and forecasting transit patronage at the stop level. In addition to the stop-level analysis, this framework has two other important features. It separates direct boarding from transfer boarding, and it treats inter-relationships in a transit network systematically through the use of a set of accessibility measures. Finally, this framework also offers a significant amount of flexibility to transit planners to evaluate service changes and their effects on transit patronage.

Section II of this paper discusses inter-relationships in a transit network and how they can be captured through a stop-level analysis. Section III focuses on the measurement of accessibility to opportunities for potential activity participation via the transit network. Section IV focuses on the separation of transfer and direct boarding for both modeling and forecasting. It specifies the model structure reflecting the three features of the proposed framework. Section V describes data from Tri-Met, Portland, Oregon, and estimates Poisson models for both direct and transfer boardings for the weekday morning peak. The last section concludes the paper with discussions on the advantages of the proposed framework and challenges to implementation.

II. Inter-Relationships in a Transit Network

Introduction

The biggest advantage of modeling and forecasting transit patronage at the stop level is the ability to capture the various inter-relationships in a transit network. This ability leads to more accurate assessment of the impacts of service changes that influence these inter-relationships. This ability also provides a stop-level analysis and more flexibility to transit planning in terms of the type of service changes that can be assessed for their patronage impacts.

The proposed framework defines individual stops by their spatial location, route association, and travel direction. This level of disaggregation is necessary to represent service frequency at a location served by several routes with different frequencies. This level of disaggregation is also necessary to aggregate stop-level patronage to the route-segment level or to the route-level in forecasting. Modeling and forecasting transit patronage by both route and direction is not new (*10*, *16*). What is new in this framework is its use of individual stop locations in addition to the use of individual routes and directions.

Previous Work

Previous research had largely assumed that the various routes in a transit network are independent from each other in terms of boarding until *10*, *17-18*. Since much of the earlier work focuses on the route level, it is difficult to take into account the inter-relationships in a transit network. The inter-relationships are largely realized at the segment and stop levels. While some work (*4, 6*, *19*) do explicitly treat transfers in a separate equation of a system of equations, the inter-relationships are not satisfactorily treated either.

More recent work (*10*, *17-18*) deals with inter-relationships explicitly. They do so by defining three inter-route relationships: independent, complementary, and competing. These are defined through the stop buffers along individual routes. A stop buffer is typically a circular area centered at the subject stop to represent the potential market of boardings at the subject stop. Specifically, if no stop buffers along two routes overlap, they are considered to be independent. If two routes overlap at one point but with at least one end of each route different from the other, they are considered to be complementary. An example of complementary routes is the relationship between a radial route and a cross-town route. The impact of one route upon the other is complementary in that each may feed transfer riders to the other at the point where they intersect. If two routes overlap linearly, they are considered to be competing. Essentially, two routes are complementary if users can transfer between them to get to different destinations, while two routes are competing if users can use either to get to the same destination. These relationships are reflected in modeling as follows. Boarding along a segment on a subject route is modeled as a function of alighting along the intersecting segments of all complementary routes and boarding along the intersecting segments of all competing routes. Boarding along a segment on all competing routes is a function of supply along the intersecting segment on the subject route as well as the population in overlapped buffers between the competing routes as a percent of the total population along competing routes.

This approach to dealing with the inter-relationships in a transit network represents significant advancement over previous research. However difficulties remain. Inter-route relationships do not seem to be meaningful under a pure radial or grid network. Under a pure radial network, all routes are complementary but no two routes are either independent or competing. Under a pure grid network where parallel routes are sufficiently apart, no two routes are competing; any pair of vertical and horizontal routes is complementary; and all parallel routes are independent.

The approach used by Peng et al. (*10*) for defining inter-route relationships based on whether and how much two routes overlap is rather arbitrary. Two routes in the same transit network are rarely independent from each other. Most routes influence each other. Two routes may not overlap directly. But they are still dependent on each other through a third route that intersects both. The difference is in the degree of dependence. Are two routes independent if their overlapping does not exceed ten percent of all buffer areas along them? Are two routes complementary when their overlapping does not exceed fifty percent? Are two routes competing when their overlapped area exceeds fifty percent? Also, are two routes complementary or competing if they intersect at both ends but do not overlap in the middle? They are certainly not independent under this approach. But they are neither complementary because both ends intersect nor competing because there is not enough overlapping.

Finally, two routes are complementary in that they support each other in helping users complete a door-to-door trip that requires both routes. The approach to inter-route relationships by Peng et al. (*10*) does not fully reflect this meaning of complementary routes. The dislike of transfers by transit users is totally ignored. Instead, it only reflects an outcome of two routes being complementary. That is, increases in the alighting volume from one route lead to a higher total boarding volume on the other route at the point where the two routes intersect. That is only useful when total boarding is being modeled. In a framework where direct boarding and transfer boarding are separately modeled, this treatment of complementary routes is useless in modeling direct boarding. For forecasting purposes, however, the use of alighting to reflect complementary routes is also useless unless alighting is also modeled because otherwise data on alighting are not available for forecasting. Alighting is not modeled by *10, 17-18*.

Two routes are complementary only in terms of their inbound traffic toward their intersecting point under this recent approach to inter-route relationships. However, these same routes become competing ones in terms of their outbound traffic away from their intersecting point. A potential user at this intersecting point could use either route to get to similar movie theaters for example. While the competing effect of these two routes may not play any role in modeling transfer boarding, it can be important in modeling direct boarding.

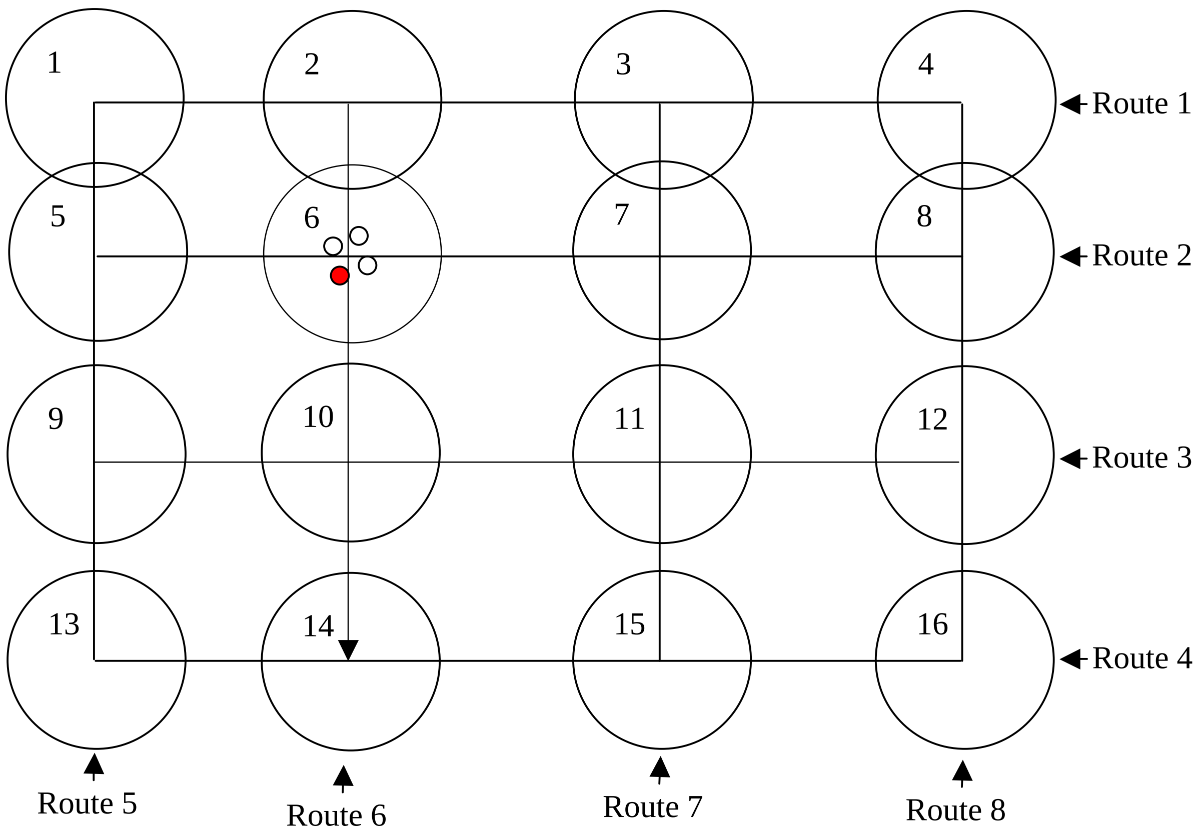
Proposed Work

Inter-relationships within a transit network occur at the stop level. At a given stop along a particular route, boarding is influenced by whether there are other stops, either along the same route or other routes, within walking distance, from which potential users can get to the same destinations or different destinations. These other stops are referred to as the neighboring stops of the subject stop. More important, boarding at this stop is influenced by the opportunities that can be reached by potential users from each of these neighboring stops. The stops accessible from the neighboring stops are referred to as the accessible stops. Among other factors, accessibility to opportunities around these accessible stops for potential activity participation can be critical in modeling and forecasting patronage at the stop level.

<u>An Example.</u> Before defining these inter-relationships and measuring these variables, consider a simple illustrative transit network of eight routes in Figure 1. The four east-west routes are numbered 1 through 4, and the four north-south routes are numbered 5 through 8. These eight routes result in sixteen nodes numbered 1 through 16 that represent geographical locations in the service area. Node 6 may be downtown and node 16 a mall in the suburb. This network has a total of sixty-four stops that are route- and direction-specific. The nature of a stop varies, depending on its location on this network. The stops at the four corner nodes, 1, 4, 13, and 16, serve either boarding or alighting but not both. At each of the other nodes at the outer boundary of the network, including 2, 3, 5, 9, 8, 12, 14, and 15, two serve both boarding and alighting; one serves boarding only; and the other serves alighting only. All four stops at each of the four nodes in the middle of the network, including 6, 7, 10, and 11, serve both boarding and alighting. Assuming that the stops at the same node share the same buffer, there are a total of sixteen

buffers. These sixteen nodes and buffers are numbered accordingly from 1 through 16. In addition, buffers do not overlap except the two buffers at the northern end of each north-south route. For ease of reference, the stops at a given node are named as *n*X, where *n* (= 1, …, 16) is the buffer number and X (= N, S, W, E) is north, south, west, or east. The four stops at node 6 are 6E, 6W, 6S, and 6N, which are indicated in Figure 1 with circles.

Figure 1. Example of a Transit Network



<u>Neighboring Stops</u>. Four sets of neighboring stops (N_0-N_3) are defined for each stop from its potential neighboring stops. For a given stop (along a particular route in a particular direction), its potential neighboring stops are other stops within its buffer or whose buffers overlap with its buffer. To illustrate, consider subject stop 6S, the southbound stop on route 6 at route 2 as indicated with a filled circle in Figure 1. It has three potential neighboring stops within its buffer (6W, 6E, and 6N), and three potential neighboring stops in buffer 2 that overlaps it (2W, 2E, and 2S). Stop 2N is not one of them because it does not serve boarding. These potential neighboring stops represent alternative points at which potential transit riders in the subject buffer may board a transit vehicle either on the subject route, in the subject direction of the subject route, or on other routes. The potential neighboring stops for a given subject stop fall into one of three groups.

One group of potential neighboring stops is those on the same route and in the same direction as the subject stop. Some of these may be upstream of and some downstream of the subject stop. For either upstream or downstream, there may be multiple stops, depending on the density of stops in the subject direction along the subject route. While all of these potential neighboring stops can influence boarding at the origin stop, only the closest upstream stop and the closest downstream stop (these are the neighboring stops) are to be included in N_1 to simplify measurement later. To illustrate, consider stop 6S again in Figure 1. Stop 2S is the only potential neighboring stop because buffer 6 overlaps buffer 2. People living in the overlapped area could choose either 6S or 2S to travel south along route 6. Stop 10S is not a potential neighboring stop because buffer 10 does not overlap buffer 6. So $N_1 = \{2S\}$.

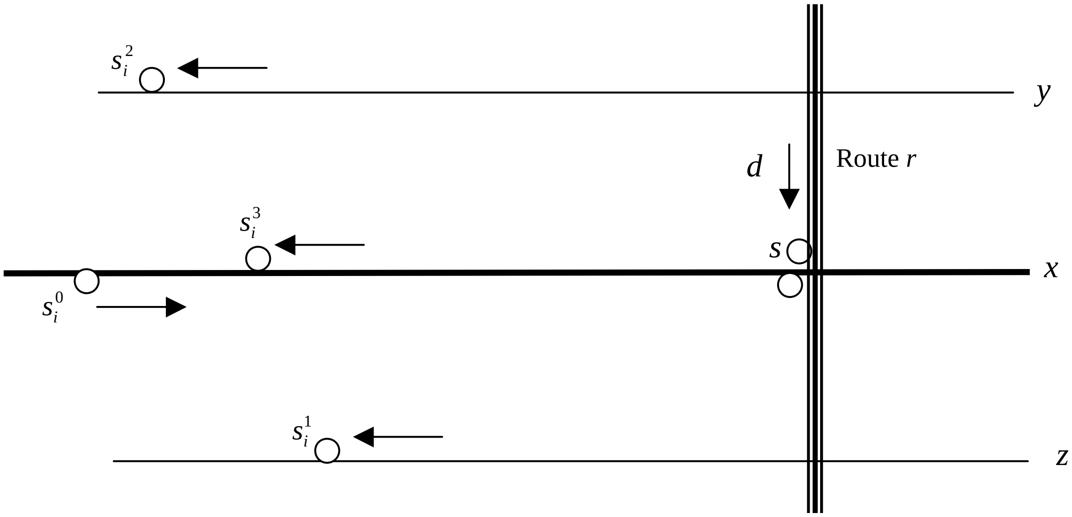
The second group of potential neighboring stops is those along the same route but in the opposite direction. There may be multiple of these potential neighboring stops. For later measurement, however, only one is required. When there are multiple ones, the one closest to the subject stop (this is the neighboring stop) is to be chosen as the N_2 neighboring stop. For stop 6S again in the above network, stop 2N is not a potential N_2 neighboring stop because it is at the end of route 6. Stop 10N is not a potential N_2 neighboring stop either because buffer 10 does not overlap buffer 6. Stop 6N is the only potential N_2 neighboring stop for stop 6S. So $N_2 = \{6N\}$.

The third group is those along other routes that are located within the subject buffer or within buffers that overlap the subject buffer. In any direction along any of these other routes, there may be multiple potential neighboring stops. Again for later computationally purposes, only one such stop from each combination of direction and route (this is a neighboring stop) is to be included in N_3. If two other routes intersect the subject route at the subject stop, for example, N_3 would have four stops in most cases. It may have fewer than four if one or both of these intersecting routes are one-way. For stop 6S in the above network, $N_3 = \{6W, 6E, 2W, 2E\}$. Stops 2W and 2E are part of N_3 neighboring stops because buffer 6 overlaps buffer 2.

Besides these three sets of neighboring stops, a forth set is defined as a subset of N_3. They are neighboring stops on other routes and are located within the subject buffer. The reason to exclude those N_3 neighboring stops located outside the subject buffer is that people alight at them would need to walk more than the radius of a buffer to transfer at the subject buffer. So $N_0 = \{6W, 6E\}$.

Accessible Stops. With the four sets of neighboring stops determined, five sets of accessible stops are defined: S_0 through S_4. Assume that stop *s* serves direction *d* along route *r*. Set S_0 includes stops that can reach any of the N_0 neighboring stops on other routes that are located within the subject buffer. Suppose that route *x* intersects route *r* at stop *s*. That is, passengers traveling along route *x* toward stop *s* can transfer to route *r* at stop *s*. Stop s_i^0 in Figure 2 along route *x* toward route *r* belongs to S_0. The purpose of S_0 is to capture passengers riding toward stop *s* through other routes. That is, S_0 represents feeders for potential transfer boarding at stop *s*.

Figure 2. Illustration of $S_0 – S_3$ Stops



S_1 includes stops downstream of stop *s* that can be reached from stop *s* through route *r* via the transit network. For example, stop s_i^1 Figure 2 along route *z* belongs to S_1. The purpose of S_1 is to capture the opportunities for potential activity participation that are accessible for a potential user who boards at stop *s* or its N_1 neighboring stops. Set S_2 includes stops in the network upstream of stop *s* through route *r* that can be reached from the N_2 neighboring stop. Stop s_i^2 in Figure 2 along route *y* belongs to S_2. S_2 captures the opportunities for potential activity participation in the opposite direction of traveling at stop *s* through the same route as boarding at stop *s*. Set S_3 includes stops that can be reached from any of the N_3 neighboring stops. Stop s_i^3 in Figure 2 along route *x* belongs to S_3. S_3 captures the opportunities for potential activity participation along other routes for people in the origin buffer. These three sets of accessible stops are used later to measure the accessibility to these opportunities for potential users in the stop *s* buffer.

In addition, set S_4 includes stops in either S_2 or S_3 that overlap stops in S_1. That is, people in the origin buffer can access some of the opportunities around each of the S_4 stops from boarding at the origin stop, or at the N_2 neighboring stop, or at any of the N_3 neighboring stops. Overlapping stops refers to stops where the buffers overlap.

III. Measuring Accessibility

Transit accessibility at the regional level has two general components. One component measures access to and egress from transit stops. The other component measures access from one stop to all other stops on the network. Access to and egress from transit stops may be measured with buffers around transit stops that are determined with air distance. More precisely, they can be measured with the buffers being determined with actual walking distance (*20*). Regional transit accessibility may be measured with one of two approaches. One approach uses zones as units of analysis and combines both components of accessibility. The other approach measures the two components separately. The proposed modeling framework takes the latter approach with air-distance buffers. This section focuses on accessibility measurement from one stop to all other stops on the network.

The standard approach to accessibility measurement is adopted (*15*). This approach adds up the weighted opportunities across all accessible stops. Commonly used opportunity measures include total population and employment. If data allow, employment components such as industrial, service, and commercial employment may be used. For any given type of opportunity measurement, one important aspect within individual buffers is to deal with overlapped buffers. Overlapped areas need to be split among overlapped buffers to avoid double-counting opportunities in modeling. Three cases are considered below where buffers overlap. The first case is overlapping among buffers in the same set of accessible stops. The second case is overlapping between the origin buffer and buffers in each set of accessible stops: S_1, S_2, or S_3. Since the number of opportunities in the origin buffer is to be used as a separate variable in modeling and forecasting as discussed later in model specification, such overlapped areas are to be split to avoid doubling counting as well. The third case is overlapping of buffers across the three sets of accessible stops: S_1, S_2, and S_3.

From a given subject stop to any accessible stop, the weight reflects the ease of travel, and is a declining function of the corresponding impedance. In this proposed framework, impedance is measured by the generalized cost of travel in minutes from one stop to another, including first-wait time, first-boarding fare, in-vehicle-time, number of transfers, transfer-wait time, transfer walk time, and transfer-boarding fare. The components other than in-vehicle time are converted into in-vehicle equivalency by using respective weights. The exponential function, $\exp(-\beta G)$, is used as the impedance function with $\beta = 0.0125$. The proposed framework uses five measures of accessibility. The first represents the transfer potential from other routes at a subject stop (P_0). The next three measures (A_1, A_2, and A_3) represent accessibility to the three sets of accessible stops, S_1 through S_3, respectively). The last measure (A_4) represents accessibility to the shared buffer areas between stops in S_4 and stops in S_1. Each measure is specific to a time period indexed with *n* because both opportunities and impedance may vary by time.

Accessibility measures have never been used in previous direct demand models. However, accessibility proxies have appeared in the literature. Variables measuring population, employment, or the presence of schools, shopping malls etc. in a route-level model partially represent the potential transit market and partially represent opportunities for potential activity participation along a route (*4*). Of course, this approach ignores opportunities along other routes that can be transferred to from the subject route. More recently, according to (*11*), Peng (*17*) includes downstream population in a segment-level model of outbound patronage model. However, Peng et al. (*10*) does not use such a variable. It is unclear whether downstream population is measured along the subject route only or along intersecting routes as well. In any case, this approach assumes that population at any point downstream represents the same potential for activity participation.

IV. Direct and Transfer Boarding

Introduction

Transit users may get to a transit stop by one of many possible access modes. The most widely used access modes are walking, using another transit route, driving or riding a car as a passenger, and biking. Boarding at a stop may be distinguished into direct versus transfer boarding by the access mode used. Transfer boarding refers to any boarding by another transit route. This definition of transfer boarding also includes those that involve some but minimum walking because the alighting stop is some distance away from the boarding stop. Direct boarding refers to any other boarding.

Previous Work

Transfer boarding in general has not been separated from direct boarding in previous research. One exception is the work Alperovich et al. (*4*) and Kemp (*6*). Alperovich et al. (*4*) formulate a simultaneous equations model of bus transit demand and supply at the route level. Demand is represented by two equations for transfer boardings and boardings without any subsequent transfers, respectively. Transfer boardings for a subject route is modeled as a function of the total patronage on the subject route, the number of interconnecting transfer routes, and a set of route-type dummy variables. Kemp (*6*) estimates the model with monthly data from San Deigo. Another exception is the work by Krechmer et al. (*19*), who use one-day on-off counts for each run in Cleveland along with on-board survey data to formulate and estimate a three-component model of boardings for route segments. One component is two transfer models with one for bus-to-bus transfers and the other for bus-to-rail transfers. Both transfer models focus on the share of passengers who would transfer. The bus-to-bus model depends solely on the sum of headways on the two involved routes, while the bus-to-rail model depends solely on the travel time from a bus segment to a rail station.

Proposed Work

The proposed framework models direct boardings separately from transfer boardings. For modeling, all stops would be divided into those that provide transfer opportunities and those that do not provide transfer opportunities. For a given stop, transfer opportunities exist when at least one stop on a different route is located within walking distance of that given stop, which is assumed to be one-eighth of a mile. Model estimation would be done in two steps. In the first step, the model for direct boardings would be estimated using data from stops without transfer opportunities. In the second step, the estimated model for direct boardings would first be applied to all stops to predict direct boardings. For those stops with transfer activities, the predicted direct boardings would be subtracted from the observed total boardings, and the difference would be used as the dependent variable for estimating the model for transfer boardings.

For forecasting purposes, the direct-boarding model would first be applied to all stops to forecast direct boarding. For any given stop along a subject route, the forecast direct boarding at all stops along other routes that feed into the subject stop is then used to measure the potential for transfers at the given stop. This potential is one of the independent variables in the transfer-boarding model. The next step would be to forecast transfer boarding at stops with transfer opportunities. Total boarding would be the sum of the two.

Direct boarding for each stop and time period is hypothesized to be a function of frequency, buffer characteristics, accessibility measures (A_1-A_4), and other stop and route characteristics. Transfer boarding also is a function of frequency, the four accessibility measures A_1-A_4, and other stop and route characteristics. The two equations differ in two ways, however. First, the buffer characteristics around the subject stop are not directly relevant to transferring users. As a result, related variables are replaced by the variable measuring transfer potential (P_0) in the transfer boarding equation. The role of P_0 is similar to the inclusion of alighting from complementary routes in modeling total boarding in the work by Peng et al. (*10*), Peng (*17*), and Pendyala and Ubaka (*18*). Second, other stop and route characteristics may differ between the two equations. For example, the presence of a park-n-ride lot may be important to direct boardings but not to transfer boardings. Similar to the treatment of opportunities in measuring accessibility, the measurement of population and employment around the origin buffer requires splitting overlapped areas to avoid double counting.

V. Application

This section presents the empirical results from applying this framework to Tri-Met, the transit agency in the Portland metropolitan area, Oregon. Tri-Met serves around 575 square miles of the urban portion of Clackamas County, Multnomah County, and Washington County. It carries more than 300,000 riders on a typical weekday, and uses over 650 buses, 100 light rails, and 7 Streetcars. Tri-Met has the highest penetration of automated passenger counters (APCs) among any medium to large transit agencies in the U.S., and has a long history of using APC and automatic vehicle location systems. Tri-Met archives a vast amount of data from these systems. Furth et al. (*21*) provide details about data collection and storage capabilities at Tri-Met.

The current application uses its archived AVL-APC data for a 6-month period from March 5, 2005 to September 3, 2005. During this period, all bus and light rail vehicles had AVL; about 75 percent of the buses and 25 percent of the light rail cars had APCs; but the streetcars did not have either AVL or APCs. Data on population and its characteristics come from the 2000 Census. Data on employment come from the Regional Land Information System Lite DVD developed by the MPO in the Portland region. This DVD also provides information on schools, malls, park-n-ride lots, etc. These land use data reflect the conditions around August 2005.

Table 1 shows the maximum log-likelihood estimation of Poisson models for both direct boarding and transfer boarding for the weekday morning peak defined as 6:00 AM to 9:00 AM. Alternative count models were also tried, but did not converge. The following highlights observations from these estimated models:

Table 1. Maximum Likelihood Estimation of Poisson Models for Weekday Morning Peaks

Groups	Variables	Direct Boarding		Transfer Boarding	
		Coefficients	t-ratio	Coefficients	t-ratio
Constant		-0.263254	-2.6	-0.151372	-3.7
Frequency		0.127912	64.4	0.111185	95.5
Buffer Characteristics	Average Household Income ($)	-0.000004	-5.2		
	Share of Immigrants	0.960558	5.1		
	Share of Blacks	1.191430	12.3		
	Share of Hispanic	0.869022	6.2		
	Share of 65+	-0.504356	-2.5		
	Share of Female	-0.452420	-2.5		
	Share of Households with Children under 18	-0.622012	-5.0		
	Population	0.000082	2.2		
Accessibility	P_0, Transfer Potential			0.000081	71.8
	A_1, Total Employment	0.000059	24.5	0.000007	3.1
	A_2+A_3-A_4, Total Employment	-0.000043	-21.3	-0.000014	-30.3
	A_4, Total Employment	0.000010	2.1	-0.000043	-21.5
Other Stop and Route Characteristics	Light Rail Station (1-0)	1.333520	29.3	1.734330	84.8
	Near a Streetcar Stop (1-0)	0.934008	7.2	-0.210465	-9.0
	On Radial Routes (1-0)	0.142510	2.7	-0.348315	-8.8
	On Express Routes (1-0)	0.610041	4.6	0.572980	11.7
	On Cross-town Routes (1-0)	-0.100293	-1.8	-0.070326	-1.7
	Number of P-n-R Lot Spaces	0.004381	34.8		
	Near a Regional Mall (1-0)			0.560974	22.5
Summary	Number of Observations	4,396		5,758	
	Restricted Log Likelihood	-27,074		-54,245	
	Log Likelihood at Convergence	-11,054		-34,625	

Notes: 1) The reader is referred to the User Guide for a transit planning software (T-BEST) that uses the conceptual framework described in this paper. This Guide is at http://tbest.org/. 2) Boardings can be predicted as an exponential function of the linear functions given in the table.

- The models fit the data well. Log-likelihood improves about 60 percent for direct boarding and about 40 percent for transfer boarding.
- Service frequency has a positive and statistically significant coefficient as expected. It appears to have a slightly larger impact on direct boarding than on transfer boarding.

- Buffer characteristics are included in the direct boarding only, as discussed in the framework. Employment and its characteristics are not included as buffer characteristics for the morning peak. The results are expected, including average annual household income, population, and shares of various population segments.
- The results on other stop and route characteristics are mostly expected, particularly for direct boarding. Holding other factors constant, for example, light rail stations have additional appeal for both direct and transfer boarding with the appeal higher for transfer boarding. Relative to circulator routes, radial and express routes attract additional direct boardings, particularly express routes, but cross-town routes do not appear to attract additional direct boardings. Stops at P-n-R lots appear to attract additional direct boardings as well. The number of spaces is used in this case because most of the P-n-R lots are well used.
- More important, the directional effect of the accessibility measures on direct and transfer boardings are as expected. Only accessibility to employment is used for the morning peak.

    - The transfer potential (P_0) has a statistically significant positive effect on transfer boardings.
    - The accessibility to downstream employment via the subject route (A_1) is positive and statistically significant for both direct and transfer boarding; however, the impact is much higher on direct than on transfer boarding.
    - The accessibility to employment at alternative destinations through the oppose direction of the subject route or through other routes has been combined (A_2+A_3-A_4), and has an expected negative and statistically significant effect on both direct and transfer boarding. Relatively, however, the effect of this combined accessibility to alternative employment is larger on direct boarding than on transfer boarding.
    - How the accessibility to employment that can be reached both via the subject stop and via other routes/stops (A_4) may impact boarding may go either way on a theoretical ground. It turns out that it has a positive effect on direct boarding but a negative effect on transfer boarding at the subject stop. In addition, the magnitude of the effects is several times higher for transfer boarding than for direct boarding.

VI. Conclusions

The paper has developed a new framework of modeling and forecasting transit patronage for service planning. It analyzes boarding at the stop level where boarding is realized in a transit network. It accounts for the inter-relationships in a transit network through a series of measures of accessibility to opportunities for potential activity participation. It models and forecasts direct boardings separately from transfer boarding. This framework has several advantages. The framework avoids the need for estimating simultaneous equations because it treats the inter-relationships in a transit network through accessibility measures that are exogenous to boardings at a subject stop. When estimated under this framework with data from one particular area, the models of direct and transfer boardings are likely to have much higher potential for transferability to other areas. Once implemented, this framework represents a flexible tool for transit planners to assess the patronage impacts of a variety of service changes to a transit network and its schedules for service planning.

While these advances create challenges to implement this framework in practice, they can be overcome with improvements in a number of areas. Detailed boarding data are required for model development, but increased penetration of automated passenger counters overcomes this data challenge. Implementing the framework requires increased computing power in determining the inter-relationships, splitting overlapped buffers, and computing the various accessibility measures, but continued improvements in the processing power of desktop personal computers help minimize the consequences of the significant computations required. To fully realize the potential of the proposed framework for transit service planning requires a friendly user interface. The most important element is to allow the user to specify a variety of service changes to be assessed, including a GIS interface through which the user can make schedule and network changes graphically.

The application to the Portland, Oregon region shows that this framework works empirically, at least for the weekday morning peak. Similar models are being developed for five other time periods, including weekday afternoon peak, weekday midday, weekday other, Saturday, and Sunday. These models along with a user-friendly interface are being implemented into a software package in Florida called Transit Boardings Estimation and Simulation Tool or T-BEST as described at www.tbest.org.

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