Transportation Network Models to Accurately Estimate Transit Level of Service

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Abstract

In models for public transit usage, the factor representing transit service often involves mostly the proximity to transit stops either using walking distance buffers around transit routes or more detailed land use information. These approaches are insufficient to examine the effect transit service has on a person's travel mode decision. In work for the Delaware Transportation Institute, factors for transit level of service were developed using ArcInfo Network Models that more realistically estimate level of service between specified origins and destinations taking into account walking distances, transfers, wait times, and park and rides. Methods discussed for travel time and distance estimates are applicable for other travel modes as well. Transit ridership models using more accurate level of service estimates are discussed.

Introduction

Transit level of service (LOS) can be described in terms of hours of service, headway, pedestrian environment (sidewalks, lights, shelters), safety, rider comfort, appearance, reliability, transfer, costs, and transit travel time, to name a few of the more common factors. Most modeling efforts are focused on generating mode split approaches that can be used in travel demand forecasting models. Most of the data employed is at an aggregate level, typically a traffic zone. LOS Measures of Effectiveness (MOEs) are typically developed such as the Persons Per Minute Served, Average Bus Headway, or total number of bus runs in a census tract. In a survey done by Cleland etal (1997) that included 14,500 surveys collected in six urban areas in Florida, transit users identified hours of service, location of routes and headways as the biggest concerns.

The literature generally supports the ability of transit systems with high-quality services to attract more users, as well as for poor services to encourage more automobile use. (Zhao pgs 2-13). Public opinion indicated increases in level of service as important factors for using transit. The availability of direct service from origin to destination, transit travel times that are not much greater than travel times by private automobile, more frequent service, and service on nights and weekends, are the types of services that are expected to encourage transit use. Those who have access to a personal vehicle are expected to weigh the benefits of taking transit relative to the convenience of driving. The use of the transit system by those who have no private vehicles and to a much larger extent those who have vehicles, does depend on the level of service. Many of the LOS factors affecting transit use however cannot be easily quantified and there is always the problem of generally not having data available. It is still difficult to formulate LOS variables in models for estimating transit share.

The approach in this project is to model the travel choice of the individual using non-aggregate data as available from the Delaware Department of Transportation (DelDOT) Household Survey. The DelDOT Household Survey has data on over 40,000 trips over the last 7 years and includes a range of socioeconomic data about respondents. The survey captured the travel mode of each trip and the trip time from the respondent. Otherwise, nothing is known about the transit service for trips. For the purposes of modeling and better understanding travel mode choice, estimates of transit service level for surveyed trips were derived. Figure 1 shows the variables that were estimated.

Figure 1
Factors Estimated to Include Level of Service in Mode Choice Models

Type of service: Direct, Indirect, No service
Trips modeled as Walk
Trip distance
Trip time by car
Total transit time
Walk time to and from bus stops at origin and destination
Ratio of transit time to reported trip time

Addressing transit service for each trip and for each individual allows a much more accurate view of information for mode choice modeling.

Trip distance is also an important factor. Whenever trip distances become shorter, there are more walking and bicycle trips across all purposes and factors. The median walk trip distance estimated for the DelDOT household data is about 0.9 mile or less, and the average bicycle distance is about a mile and a third. (As only the trip time was asked for in the DelDOT Survey, it was necessary to estimate trip distance and the estimates were least accurate for smaller trips. Actual average distances for walking and bike are expected to be a bit less.)

A factor used in many travel choice models is accessibility to transit. Often, analysts have estimated in various ways the percentage of persons that are within a particular walking distance from transit stops or other facilities. This will generally tell the number of people in aggregate that could use transit for a trip, however it usually does not take into account the destination of the trip or whether or not transit can effectively serve the trips that population wishes to make.

Considerations for Approaching Transit Level of Service

The goal then was to determine a transit level of service that could be used to model mode split. A typical way that transit service has been identified using GIS is to create a quarter mile buffer around the entire linear representation of transit routes in an area. This buffer is then overlaid on a layer that provides demographic data such as population totals, employment, households, income levels, etc to address a population that is "served by transit". Layers that are overlayed by the buffer are typically data at the Census Tract, Block Group, or Block level or some other demographic unit such as a traffic zone for which this data is available. It is generally true that once a population is within a distance of a transit stop that they may be able to get to where they are going once they access the system. But does the transit system have a stop at the destination? Does the route from origin to destination involve direct service or a few transfers? Does the transit trip involve vastly greater time than such a trip by car?   Just being near a stop does not mean necessarily that use of transit service is a realistic possibility. Most indicators of transit service used in the past do not take into account the characteristics of the transit trip offered from origin to destination.

There is also the problem of the actual accessibility of the stop. The quarter mile buffer approach typically does not take into account how passengers would actually get to the stop except in a "how the bird flies" way, does not take into account barriers between the stop and the populations, and often makes assumptions about how populations are distributed in the demographic layers being overlaid. There have been some studies that have used better methods to show access to transit. In particular, researchers have used tax parcel (property) level data and models of local road networks to determine accessibility and the populations within reach of transit. The procedure here generally is to determine more accurately what housing is actually within a certain distance of bus stops by finding housing units within certain walking distance (time) to the stop on paths taken along local roads or paths that can be identified. This is a much more sophisticated approach to determining populations within walking distance to transit stops but still doesn't address the characteristics of the entire trip.   So an identified population with certain characteristics can get to a transit stop, but is using transit actually a realistic option for a particular trip?

In earlier studies by the author it was found that about 70% of the transit ridership in suburban areas in Delaware involved use of Park and Ride facilities. Transit usage in this case has nothing to do with whether a person lives near a stop but whether the person can drive to a near Park and Ride, and then a transit trip is a viable option.

Development of a Road Network Model for Analyzing Service

This section details the construction of a road network model to estimate transit level of service for use in the modeling of mode split.   Using geographical information systems and routing software, a road network model of New Castle County was developed for analyzing accessibility, travel time by personal vehicle, travel time by transit, and travel distance.

The approach was first to develop three different networks all connected to each other:

- A walking network
- A driving network
- A transit network

For each of the above networks impedances in terms of time to cross each network section was calculated for each mode. For instance, a walking network was developed allowing for travel time along road segments at three miles per hour.   The transit network model was constructed by referencing GIS representations of transit routes from DART First State (Delaware's main transit agency) and from time schedules for each route. Time points available on the schedules were used to develop the time that transit took between each stop on each route. Representations of each route were then joined together to form the entire transit network. Connectivity between routes existed where routes shared the same stop allowing transfers to be modeled. Impedances for the driving network were based on road classifications and estimated speeds to determine the expected time to traverse each road segment by car. The New Castle County, Delaware Road Centerline file as maintained by and available through the New Castle County Department of Land Use was used as a starting point. The Centerline file has accurate representation of all roads in New Castle County (and municipalities) including highways, major and minor roads, and subdivision roads. This formed the foundation for all path building.

The walk, drive, and transit paths were all connected to each other at arc segment nodes. The GIS software used was ARC/INFO from Environmental Systems Research Institute, and network modeling extensions to this software (NETWORK) for determination of optimum path through the road network from specified origin and destination points. An optimum path is determined based on the sum of impedances of the portions of roads or transit routes or walk routes that make up the path. Using ARC/INFO's Network module and the PATH command it is possible to find the optimum/minimal path through the network based on the impedances that have been defined. Having the walk, drive, and transit paths all connected allowed the software to consider optimum paths for an entire trip using different modes. For instance, the walk to a transit stop, then to a bus stop and through the transit network and then the walk to the destination could be determined. The nearest bus stop might not be the best transit option, for instance, walking a little further to another stop might allow a transit route that would be direct to the destination and be more desirable. A drive to a Park and Ride and then a transit trip to a destination could be modeled at least in terms of trip time.

An important feature of the software that allows for the modeling to be done correctly is the ability to add a turn impedance. A turn impedance is an impedance associated with going from one segment to another, and it's primary use is to model intersections. For instance, it would take less time to make a right turn at an intersection with a yield sign than if one had to wait for a traffic light, or as another example there may be a situation where roads are connected, but a particular turn is illegal, so a turn impedance can be used to not allow path building that included the illegal turn. Turn tables were used in this project's model in two ways. During path building whenever the path went from a walk segment to a transit segment (a "turn" onto a transit segment), there was a 10 minute penalty as a way to account for waiting times and differences in headways. Leaving a transit segment to a walk segment did not involve a penalty. Going from a transit segment to another transit segment where the route designation is not the same is a transfer and a 10 minute transfer penalty was added to the path. Adding turn impedances then made sure that the paths that were determined by the computer did not unrealistically include numerous changes of route or getting off and on the bus routes without some penalty.

One other important adjustment had to be made. Since minimum path was calculated as that path with the minimum time, in some cases the computer would determine that it was quicker to take long walks (30 or 40 minutes or more) rather than take transit. As the purpose of the network modeling was primarily to develop a level of service for transit and the average walk trip was about 10 minutes, the impedances were inflated by a factor of 10 on the walking network to be able to determine a minimum transit path that involved less walking. Once the paths were determined, the walking portions of the trips were divided by 10 to get a realistic total trip time. There were still cases where trips were not served well or at all by transit but rather by a short or long (> 15 minutes) walk.

The DelDOT Household Survey has data on over 40,000 trips over the last 7 years and includes a range of socioeconomic data about respondents. The survey captured the travel mode of each trip and the trip time from the respondent and also included the location of the origin and the location of the destination of each trip. In the DelDOT Household Data, locations are coded to a Modified Grid, a commonly used demographic unit in Delaware (average size about 280 acres), a little smaller than a traffic zone. The DelTrip origins and destinations were coded to the nearest modified grid. Centroids of each modified grid were associated with the nearest node in the walking/transit network. On average, this positional uncertainty was estimated at plus or minus 5 minutes on the walk time to transit facilities. There might be extreme cases where a person could live right next to a bus stop and access times would be overestimated or the person could start from the furthest point away from the stop, underestimating the access time. Ideally, if an address were available, the origin and destination points could be specified very accurately.

With origins, destinations, and a walk and transit network specified, the optimum path algorithms can determine the least cost path, to minimize time for the trip. The best transit route is selected. Walking time to and from transit stops and transfers are well modeled and travelers do not enter the transit network at an arbitrary point in the transit network but rather to a place/route that best serves the trip. The optimum path can be displayed in the GIS, the transit route(s) involved in the trip are known, the access (walk) time is estimated, and the total transit time for the trip can be estimated. Throughout the analysis several of the paths that were derived were checked and the path and travel times by transit appeared to be reasonable.

About 70% of the suburban transit market is served by Park & Ride facilities. A full picture of transit service must include service at Park & Ride facilities. The technique was first to develop a road network that would model drive time by personal vehicle to the Park and Rides. Then the driving distance to each Park and Ride and the estimated transit time on the transit network from the Park and Ride to the destination was calculated. The process determined the optimum Park and Ride to use to minimize total door to door travel time. Park and Rides are used predominantly for the journey to work, and it was not expected that someone would drive to a Park and Ride and leave their car to go on a shopping trip for instance. A total transit trip time using Park and Rides was only estimated for the journey to work.

Some Technical Notes

Its good to note, a couple basic considerations in developing the network used that the PATH command uses. First once the walk, drive, and transit networks are joined, there can be no duplicate arc or node identifiers. Each arc must be attributed as to whether it is a walk segment, a transit route segment, or a drive segment. Transit route segments also are attributed according to what specific route they belong to (a path from a segment that is on Bus Route 1 to a segment that is on Bus Route 9 is a transit transfer, and once the optimum path is produced, you would want to know the transit routes involved.). What occurs of course when the arcs representing the transit, drive, and walk paths are collected together are segments between nodes that are identical except for the attribute associated with the kind of route and its identifier. The arc coverage should then not be subject to the CLEAN command. Once the TURNTABLE command was used to produce the entire turntable for the composite network, attributes from the arc attribute table indicating whether the arc (path, segment) was a walk, path, or specific transit route could be linked to the turn table and then used to calculate turn/transfer impedances. A turn impedance was added when going from a walk path to a transit (wait time), and one transit route to another (transfer penalty). The drive time from every trip origin to every potential Park and Ride that could be used had to be calculated and the use of a car was assumed to be at the origin side of the trip, i.e. going from transit to car was not a legal “turn” in general, and car path to transit path was not allowed (impeded) except in the Park and Ride runs. Any combination of walking or transit transfers was allowed but the “turn” impedances reflected a wait time or transfer penalty. All modified grids, (the origin and destination locations) had to be associated with a nearest node to develop the STOPS file. Cursor processing was used to go through each trip (origin – destination pair in INFO data tables to find an optimum path for each trip.

The construction of the road network models to estimate transit service involved a large effort, perhaps about 240 hours of technical staff time for data development and AML programming. Once the network data was prepared it could be used again with some update for future work. The process is very computer intensive. In a network comprised of about 30,000 arcs, optimum paths had to be generated for about 15,000 unique trips from the DelDOT Household/Travel Survey.   Running batch jobs day and night on very fast personal computers and University main frames to determine optimum paths and to process all of the information took about 150 hours computer time, though a few computers were used simultaneously on portions of the work so initial solutions were available in a couple days.

Classifying Transit Service

The results of the travel network modeling were examined and categorized based on whether the service was direct, and transit time relative to estimated drive time of service as shown below in figures 2 and 3 where "T/D" is the ratio of estimated transit trip time to drive time.

Figure 2
Park and Ride Service Categories

"G": Good service, ratio of P&R trip time to drive time <=1.5
"B: Bad Service, ratio of P&R trip time to drive time 1.5 to 2.0
"N": Not served

Figure 3
Service Classifications for Fixed Transit
(T/D = ratio of estimated transit trip time to car drive time)

Class "D": Good direct service. Direct service and T/D <= 2, and/or transit trip time less than 35 minutes.
Class "DB": Not so good direct service. Direct service and T/D > 2
Class "DP": Good fixed service and good Park and Ride Service
Class "BP": Served good by Park and Ride but otherwise not so good service or not served
Class " I": Good indirect service. Indirect service and transit time <= 35 minutes
Class "IB": Not so good indirect service. Indirect and T/D > 2
Class "B": Bad service. (direct and T/D >=4) or indirect and T/D>=4
Class "N": Not served by transit.
Class "W": Trip modeled as a 15 minute or less walk, very bad or no transit service
Class "LW: Trip modeled as a long walk > 15 min, very bad or no transit service
Class "S": Origin and destination was the same modified grid. No path developed. Many of these trips turned out to be walk trips, none were transit.

Figures 4 and 5 below show views of these service classifications versus travel mode split. When a trip is estimated as having good transit service of some kind, transit share was 4% or more. Trips where origin and destination were the same modified grid showed the highest percentages of walking trips. Direct service included shorter trips that sometimes would be done by walking. As expected, bad service and no service saw as expected very low percentage of transit trips.

Figure 4
Mode Split Versus Service Quality
DelDOT Household Survey Data 1995-2001 for New Castle County

	D	DP	DB	BP	I	IB	B	N	S	W	LW
Personal auto	*87.1*	*93.4*	*96.5*	*97*	*90.2*	*97.3*	*88.6*	*98.6*	*81.3*	*91.5*	*100*
Public Bus	*4.7*	*6.6*	*2.3*	*2.9*	*5.6*	*1.4*	*0.9*		*0.3*		
Walked	*6.5*		*0.3*	*0.1*	*3.8*	*0.3*	*8.1*	*0.2*	*16.5*	*8.5*	
Bike	*0.6*		*0.8*			*0.1*	*0.7*		*1.1*		

As there is not a large amount of transit data the classification was narrowed to three categories for mode split modeling purposes, Good service (D,BP,DP), Low service (B,DB,I,IB), and No service. Collapsing the transit service categories provides a bit clearer first view as shown in the next three tables. Level of service does seem to be a factor for populations that have no car and for those who have a car in the household.

Figure 5
Mode Split Versus Service Quality, All Trips
DelDOT Household Survey Data 1995-2001 for New Castle County

	Good	Low	No	Samegrid	Walk	Lwalk
Personal auto	90.6	96.4	98.6	81.3	91.5	100
Public Bus	4.2	1.6		.3		
Walked	4.2	1.0	0.2	16.5	8.5	
Rode Bike	0.4	0.1		1.1		

Figure 6
Mode Split Versus Service Quality
Those from Zero Car Households
DelDOT Household Survey Data 1995-2001 for New Castle County

	Good	Low	No	Samegrid	Walk	Lwalk
Personal auto	35.5	54.2	97.4	20.0	0	
Public Bus	36.7	27.8		5.0		
Walked	24.9	13.9	2.6	60.0	100	
Rode Bike		0.7		12.5		

Figure 7
Mode Split Versus Service Quality
Those from One or More Car Households
DelDOT Household Survey Data 1995-2001 for New Castle County

	Good	Low	No	Samegrid	Walk	Lwalk
Personal auto	92.8	97.5	100	84.6	91.9	100
Public Bus	2.8	0.8		.3		
Walked	3.3	0.6	0.2	16.5	8.5	
Rode Bike	0.4	0.1		1.1		

Conclusions from the mode choice modeling effort in Delaware

Not having a vehicle is the most influential factor affecting the selection of transit.
The next most important factor shown by modeling is where the trip originates or is destined for the Central Business District in Wilmington. Eighty five percent of the transit trips surveyed in the DelDOT Household Survey were trips to or from City of Wilmington zip codes. In the model constructed, level of service is significant though not the strongest factor in the model. The CBD and Wilmington in general have the highest level of transit service so there is certainly correlation between CBD and Service factors and in this type of model the influence shifts to the CBD factor rather than the good/bad service factor. When the CBD factors are removed, the service factor is shown as much more influential. In terms of modeling the CBD factors produce better models than service variables which would make sense considering the other features of Wilmington including parking costs and an urban environment.

A similar competition between factors is seen also with income and vehicle availability. When the vehicle availability factor is removed, income becomes a very influential factor (particularly low income) in the model. Vehicle availability from the models though is a more accurate predictor of transit use than income. It is not income that is the driving factor but the availability of a car (though there is a high correlation) .

A person making a work trip is 77% more likely to use transit than a person taking a trip for some other purpose. Early morning hours (5 to 7AM) see more transit trips than other times of the day. The probability of using transit increases with age up to the 65 and older category that uses transit less than any other age group.

Trip distance is the most influential factor affecting the selection of walking for a trip. Each additional tenth of a mile reduces the probability of walking by 0.3%. At ¾ of a mile the probability of walking falls to about zero. The probability of walking decreases with age, with a fairly significant drop off after the age of 30. As incomes rise the probability of walking decreases. The availability of direct transit service was an influential factor in walking trips which is thought to be a reflection of the urban environment and densities.

The model for travel as a passenger was significant but considerably less robust than the transit and walking models. A better understanding as to the factors that go into this decision is needed. Females are more than twice as likely to be passengers than men. Being a passenger is much more likely in the evening. Those 65 years and older are more likely to be passengers and the 30 to 49 year age group least likely. A person making a work trip is less likely to be a passenger. Not having a vehicle certainly increases the likelihood of being a passenger.

This project developed a methodology to quantify service for each trip by estimating trip times for each mode, and for transit whether service was direct or indirect. Accessibility to transit was estimated not just as the walking time to the nearest stop but to the stop that would best serve the intended destination. Network modeling predicted the optimum transit path. Transit time versus travel by personal auto and the type of transit service are thought of as important factors influencing travel mode choice as is indicated in the literature. The quality of service as measured in this project was a significant factor in mode choice models though overshadowed by the dominance of vehicle availability and trips to or from the Central Business District in the data. At a descriptive level, the importance of "good" service is indicated. .It was expected that a better indication of the effects of various levels of transit service for "choice riders" might be demonstrated, but the primary difficulty is always getting enough data to establish significant results.

References

A number of articles were reviewed, most of which involved models using aggregate data, such as income, population density, etc. Below are a view references to literature that has been specifically referenced or is particularly relevant.

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