An Optimization Model to Investigate Transit Equity between Original and Relocated Areas in Urban Revitalization Projects

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ABSTRACT

In urban revitalization projects, transit-captive populations are generally displaced from the inner urban core and moved out to outer-urban areas. Since such areas may not have the same level of transit service and availability, the displaced individuals often find it difficult to commute to the urban core for work resulting in forced auto dependency. While there has been growing awareness about transit oriented development in recent years, this inequity in transit service in the old and new areas should be addressed within the Environmental Justice (EJ) framework. In this paper we discuss the EJ issues resulting from displacement of low-income populations from inner urban core to outer-urban areas. Using a case study example of an urban revitalization project from Baltimore, we develop an optimization model to minimize the total out-of-pocket cost of the transit riders in the relocated area, which should, in turn maximize the transit ridership by providing the desired commuting flexibility. The relocated area is divided in different socio-economic zones with varying preferences for work-based trips. A household survey was conducted to obtain data on people's willingness to pay for transit service with varying preferences for work-based trips. The results show that abundance of affordable transit facilities and stops based on the socioeconomic characteristics and population distribution may improve transit coverage and ridership. In future works, the transit routes and stops can be optimized based on the socioeconomic characteristics and population distribution of the relocated region.

Key-words: urban revitalization, transit service coverage, transit ridership, optimization, environmental justice.

INTRODUCTION

In urban revitalization projects, transit-captive populations are often displaced from the inner urban core and moved out to lesser transit accessible outer-urban areas. The Environmental Justice (EJ) initiatives entail, among other things, transit equity among different sectors of population. Since the displaced individuals generally enjoy easy accessibility to transit systems (such as buses, subways, and metros) in the inner urban core, they often find it difficult to commute to work when displaced and moved out to outer-urban areas. These people are generally a transit-captive population being that’s being displaced, with some falling in the low-income category. This paper seeks to investigate the issue of transit inequity in the context of EJ initiatives by studying a recently completed urban revitalization project in Baltimore. Based on a closer scrutiny of the socio-economic characteristics of the displaced population in the relocated area, an optimization model is developed to minimize the total out-of-pocket cost of the potential transit riders in the relocated area, which should, in turn maximize the transit ridership by providing the desired commuting flexibility.

Environmental Justice and Transportation Equity

Every major investment or regulatory decision has social distributional effects (Miller 2005). Equity in transportation means the equal opportunity for each person to participate in social activities by varied travel modes (Ahmed et al. 2007). Costs are typically paid by those that benefit and transportation benefits are not denied to certain demographic populations. Whether
by public or private transportation different travelers should have the opportunity to have accessibility for personal purposes. Transportation equity can also be furthered divided into two broad categories: (1) horizontal where the concern relies on the distributive impacts between individuals and groups in need and (2) vertical where the concern is focused between individuals and groups that differ in income and social class. There is no single way to evaluate transportation equity. Instead evaluation depends largely on socioeconomic and demographic characteristics of an area and how they are measured. Table 1 characterizes the evaluation methods (Litman 2005).

### TABLE 1 Equity Variables in Transportation

<table>
<thead>
<tr>
<th>Equity Type</th>
<th>Categories</th>
<th>Impacts</th>
<th>Measurement Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>Demographics</td>
<td>Price or fare structure</td>
<td>Per capita</td>
</tr>
<tr>
<td>Vertical</td>
<td>Income</td>
<td>Tax burdens</td>
<td>Per vehicle mile or kilometer</td>
</tr>
<tr>
<td></td>
<td>Geographic location</td>
<td>Transportation service quality</td>
<td>Per vehicle mile or kilometer</td>
</tr>
<tr>
<td></td>
<td>Ability</td>
<td>External costs (risk, EJ issues)</td>
<td>Per trip</td>
</tr>
<tr>
<td></td>
<td>Mode</td>
<td>Economic opportunity</td>
<td>Per peak period trip</td>
</tr>
<tr>
<td></td>
<td>Vehicle Type</td>
<td>Industry Employment</td>
<td>Per dollar paid in fare or tax</td>
</tr>
<tr>
<td></td>
<td>Industry</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trip type</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All of the factors listed above can affect a transportation equity analysis. However, with each evaluation, tradeoffs are achieved between objectives. This is apparent for transit planners as they must allocate resources between special needs people, bus services for disadvantaged as well as commuter services where roadway level of service and traffic problems can have an impact on timing.

In urban transportation planning, little has been done to include objectives pertaining to social justice, driving the debate that transportation planners typically equate quantitative data to dollar figures. Most transportation related expenses constitute a significant portion of household income and, mostly a large portion of the incomes of low-income households (Deka 2004). Much of what has been done focuses on transportation research for physical infrastructures such as bridges, roads, and operations where testing facilities and research centers spend vast amounts of money on an annual basis (Falit-Baiamonte 2000) while most of the planning has focused on benefits to modes such as cars and rapid transit systems (Zhicai et al. 2008) due to higher speed and longer distance links that save time, but do little to include or offer benefits to the poor. The results of many projects should be evaluated to measure the distributive effects of equity. These measures can simply consider whether effects would or would not result from the transportation system change.

Although it is important to raise concerns for all environmental justice issues, the issues that are relevant in transportation planning are health and human safety that focuses on air, water, and noise quality, hazardous cargo, economic development that focuses on land prices, property values, business development/renovation, and societal impacts (Forkenbrook and Sheeley 2004). Since its inception, the United States Department of Transportation (USDOT)
and the Federal Highway Administration (FHWA) have worked with state and local agencies to identify tasks and practices that make environmental justice a part of the transportation planning process. According to Hartell (2006), three main issues in conducting an EJ assessment such as defining a study area, defining the reference area, and determining the threshold are necessary. The way in which these issues are defined can affect how EJ assessments are conducted from region to region (Hartell 2006).

Historically, low-income communities have been targets of displacements in transportation planning and urban revitalization projects (Coray Davis and Jha 2011) (C. Davis and Jha 2009) (Jones, Irizarry, and Jha 2008) (Jones and Jha 2010). The case of building and expanding highways in low-income areas has been evident since 1959 (FHWA 2000), when a 10-mile expressway was to be built in Durham, North Carolina. The expressway would connect Interstate 85 with Interstate 40 in Durham County serving a severely congested area of Durham, as it would pass through a mixture of industrial, railroad, and older residential land-uses. In 1970, half of the expressway was built and the remaining portion was to be constructed, but required right-of-way acquisition for it to run through a small African-American neighborhood known as Crest Street. The Crest Street community existed for over 100 years and was considered to be a low-income area and later expanded into a semi-urban neighborhood. The project called for relocating residents from the neighborhood to new areas in other parts of Durham. Tensions began to escalate over this debate, but the highway was eventually built and crossed directly through the neighborhood, significantly proving inequitable.

Other notable EJ analysis has been reported by Chakraborty (2006) where an index was developed to evaluate proposed transportation improvement projects in Volusia County, Florida (Chakraborty 2006). The focus of Chakraborty’s study was to primarily minimizing high and adverse health and human environmental effects on minority and low-income populations. A screening tool was used to gather specific data on low-income individuals as well as race and ethnicities. The indices included two road projects and concluded that one of the projects would result in a disproportionate affect on racial minorities and low-income populations. Maantay and Maroko, (2009) studied flood hazards in New York City and concluded that no minority populations are disproportionately represented within 100-year flood plains, but that same could not be said when analyzing several of New York’s boroughs (Maantay and Maroko 2009). Marshall et al (2006), in their study on air pollution in California’s South Coast Air Basin concluded that the air pollution was higher for non-whites and for individuals in low-income households than for the population of the area as a whole (Marshall et al. 2006). Non-whites and low-income households were found to be in close proximity to emissions sources than the average person. A Geographic Information System (GIS) Hot Spot Analysis of major highway corridors in the Boston, Massachusetts area showed that high rates of diesel full matter was being emitted at the borders of EJ neighborhoods (McEntee and Ogneva-Himmelberger 2008).

From the above examples, it is obvious that inequity in transportation service among various population sectors is quite likely and should be carefully investigated. The studies also bring light to the relationship between equity and risk (55) from a min/max perspective. Risk and equity are important criteria in determining site selection. Complex issues could also arise in transportation planning, urban revitalization, and transportation service delivery process, which may include: (1) need for a balancing act between benefits to users of the facility and effects on other community residents, (2) need for a balancing act among numerous effects (some positive,
some negative) and interactions, (3) varying degrees of effects among population groups within the community in terms of mixes of effects, and (4) people vary in their preferences and opinions, so that what is acceptable or even desirable to some may be unacceptable to others (Forkenbrock and Sheeley 2004). As a result, various tradeoffs must be evaluated to present results that are feasible for all interested parties.

As noted above, the objective of this research is to investigate the transit equity issues in displaced communities in urban revitalization projects. People who depend on transit typically travel fewer miles than their automobile counterparts. The employment opportunities for transit captive riders in the relocation areas are generally limited due to the lack of adequate transit service coverage. An optimization method is therefore, developed for maximizing transit service coverage in the relocation area where transit accessibility is less than that available in the original area.

LITERATURE REVIEW

Transit service coverage in urban relocation areas can have potential impacts on the accessibility of economically marginalized households. A number of past studies quantified transit service by using normative measures such as travel time, travel cost, change in family income, or destinations reached (Robert Cervero and Day 2008), (Olaru, Smith, and Taplin 2011). In the relocation areas vehicle ownership rates of individuals are very low, and many individuals in this category are captive riders. Transit service in these areas needs to consider the accessibility to destinations in both peak and off peak hours as many jobs start during the off peak hours (Thakuriah [Vonu] et al. 2006). Often transit service demand is modeled only for the peak hours. Transit demand often competes with the existing highway service. Layout of transit (combination of bus and rail) routes and stops in the relocation areas should be interfaced with the existing highway infrastructure (Lee and Vuchic 2005) (Ibeas et al. 2010).

Modeling transit service planning is a complex decision making process involving multiple objectives and constraints, uncertainties, non-quantifiable factors, large capital expenditures and long term commitments (Gendreau, Laporte, and Mesa 1995) (S. Samanta and Jha 2006) (Jha, Schonfeld, and Samanta 2007) (Sutapa Samanta and Jha 2011). The process is shared by several players such as planners, engineers, users, environmentalists and other interest groups. To achieve a coherent and scientific distribution of transit lines and stops requires modeling of the user needs, (travel behavior) and the availability of resources (decision maker’s budget) in a sequential manner to optimally design the transit system in the urban relocation areas.

Ridership estimation models are frequently studied in public transit and have been reviewed multiple times (Kain and Liu 1999) (Abdel-Aty 2001) (Wang and Skinner 1984) (Horowitz 1984) (Taylor et al. 2004) (Ben-Akiva and Morikawa 2002). Not surprisingly, these studies are framed for transit agency related questions and purposes. Thompson and Brown (2006) group ridership determination factors into two categories from a transit agency perspective: external and internal. External factors include population, economic conditions, auto ownership levels, and urban density; all factors over which agency managers have no control. Internal factors, in contrast, allow transit agency managers exercise to some control. They include the amount of service the agency provides, the reliability of service, service amenities,
and fare (Thompson and Brown 2006). Taylor et al. (2009) show that understanding the influence of these factors is important to transportation system investments, pricing, timing, and deployment of transit services (Taylor et al. 2009).

Studies on the influence of external factors on ridership have employed a variety of methodological approaches, including case studies, interviews and surveys, statistical analyses of characteristics of a transit district or region, and cross-sectional statistical analyses. These studies find that transit ridership varies depending upon a number of factors, such as (i) regional geography (e.g. total population, population density, total employment, employment density, geographic land area, and regional location)(Ong and Blumenberg 1998) (Kuby, Barranda, and Upchurch 2004) (Hsiao et al. 1997) (Wu and Murray 2005) (Zhao et al. 1997) (Polzin, Pendyala, and Navari 2002) (Peng and Dueker 1995), (ii) metropolitan economy (e.g. median household income) (Ingram 1998) (Cohn and Canada 1999a) (Frisken 1991) (Thompson and Brown 2006) (Fujii and Hartshorni 1995) (Yoh, Haas, and Taylor 2003) (Hirsch et al. 2000) (Kyte, Stoner, and Cryer 1988) (R. Cervero et al. 1993), (iii) population characteristics (e.g. percent of captive and choice riders, or household with zero cars)(Cohn and Canada 1999b) (Polzin, Chu, and Rey 2000) (Ewing 2008) (Davies 1976), and (iv) auto/highway system characteristics (specifically non-transit/non-single occupancy vehicle trips, including commuting via carpools) (R. Cervero 2007)(Lisco 1968) (Holtzclaw, Council, and Systems 1994) (Taylor and Fink 2002) (Gómez-Ibáñez and Fauth 1980).

While the above literature helps in listing potential explanatory variables in a statistical analysis of ridership and to test outcomes of transit agency decisions, it has several limitations. First, the use of transit ridership estimation models are limited as they are either too cumbersome to build and operate, or unavailable outside of large metropolitan areas, or are overlooked. They are also limited to one or two transit modes at a time and consider other services and variation in critical factors such as land-use as exogenous to the model. Second, the internal/external separation of factors in the literature usually is framed from a transit agency perspective and is not directly translatable to, say, a state agency. A number of factors, such as urban densities, that are external to a transit agency may indeed be within the sphere of influence of the state. However, it requires prudent planning strategies to design frequency, fare, and level of service for an attractive public transportation system for the relocation areas.

To address transit ridership questions from the perspective of higher-level agencies, there is a need to 1) consider transit interdependencies with a broader range of transportation services and regional urban form characteristics; and 2) reframe the methodology to focus upon providing service to transit relocation areas.

MODEL FORMULATION
In order to investigate and capture the inequity in transit service between the old and new areas in urban revitalization projects, a comprehensive comparison of the socioeconomic characteristics of both areas must be made. Transit oriented planning and development (12) of the new area must be carried out. Failure to undertake transit oriented planning may result in reduced transit service coverage in the relocated area.
Assuming that the land-use planning, zoning, and development of the relocated area has already occurred and people have moved to the new area, the transit equity can still be achieved by maximizing the transit ridership, subject to given transit availability, accessibility, and people's willingness to pay for the transit service. In order to achieve this objective, we develop an optimization formulation to minimize the total out-of-pocket cost of the potential transit riders in the relocated area, which should, in turn maximize the transit ridership by providing the desired commuting flexibility. The formulation is given as:

\[
\begin{align*}
\text{Minimize } Z(x) &= \sum_i \sum_j c_{ij} x_{ij} \\
\text{subject to: } \sum_i x_{ij} &\leq \sum_i T_{ij} \\
\sum_j x_{ij} &\leq \sum_j T_{ij} \\
c_{ij} &\geq 0, \forall i, j \\
x_{ij}, T_{ij} &\geq 0 \text{ and integer}
\end{align*}
\]

In Eq. (1), \(x_{ij}\) represents an individual transit rider who wants to travel to work (assumed to be a fixed location, such as an inner urban core or a central business district) from the \(i^{th}\) segment at the \(j^{th}\) time-period; \(i=\)segments of the relocation area based on socio-economic characteristics (assumed to be 1,.., 4 in the case study example presented in the next section); \(j=\)time-window of travel (four time windows are assumed in tour analysis, am peak, midday, pm peak, night, as described in the next section).

Equation (1) minimizes the total out-of-pocket cost for outward trip (assuming same cost structure for return trips), Eqs. (2a&b) indicate that total transit riders cannot exceed those residing in the relocation area, and Eqs. (2c&d) are non-negativity and integer constraints.

CASE STUDY EXAMPLE

In order to investigate the transit equity issue in urban revitalization projects, we study a recently completed project in Baltimore, whereby residents have been relocated for the implementation of a new mixed-use development located in the city’s Middle East neighborhood. This project is part of a larger revitalization effort within the East Baltimore area (see, Fig. 1). In addition to the Middle East urban renewal plan the proposed revitalization consists of four additional urban renewal plans – Broadway East, Oliver, Johnston Square and Gay Street – that “collectively
with Middle East make up the East Baltimore Revitalization Area.” (xx). The revitalization area is located in the city’s inner core represented by census tracts 80800 and 704000 on Fig. 1. The relocation area is represented by census tracts 260102 and 270401 in Fig. 1.

**Relocation Neighborhood Data**

Figure 2 shows the population distribution in the relocation area. Approximately 50% of the households moved to one of the following six neighborhoods: Cedonia/Frankford, Belair/Edison, Hamilton, Madison/East End, Jonestown/Old Town, and Patterson Park in Baltimore, Maryland. Census tract 260102 is within the Cedonia/Frankford neighborhood, and tract 270401 is within the Hamilton neighborhood (xx).

**Socioeconomic Characteristics of the Relocated Area**

**Demographics**

U.S. Census 2000 total population for tract 260102 was 5,083; for tract 270401 it was 4,986. The percentage of the population sampled for our analysis was 13.9% for tract 260102, and 10.5% for tract 270401. Racial distribution for tract 260102 was as follows: black 63%; white 32%; two or more races 3%; Asian 1%; other 1%. Racial distribution for tract 270401 was as follows: black 37%; white 57%; Asian 4%; two or more races 1%; other 1% (xx).

**Median Income and Rent**

Median household income for 1999 for census tract 260102 was $42,684; for census tract 270401 it was $36,795. The average of the income for the two relocation tracts represents an increase of 170% over that for the two tracts represented in the Phase One area (the area from which residents were moved). Median gross rents were $566 for tract 260102 and $540 for tract 270401, 30% higher than the average for the Phase One area rents (xx).
FIGURE 1 Map of Baltimore City with selected tracts outlined in red.

Census Tracts 808.00 and 704.00 are within revitalization area

Census Tracts 260102 and 270402 are relocation areas
FIGURE 2. Map of the Relocated Area
Mode of Transportation to Work
The census data showed that the population in the relocation areas studied used vehicular transportation as their main transportation mode of travel to work. Census figures for tract 260102 showed that 1,768 people (in the sample of 2,070 persons) reported using a car, truck or van. Of those, 1,330 drove alone and 438 carpooled. Only 189 reported using public transportation as a means to get to work. Forty-six walked, 22 used other means, and 45 worked at home.

Census tract 270401 showed similar data. Of 2,177 people in the sample, 1,788 reported using a car, truck or van to get to work. Of those, 1,427 drove alone and 361 carpooled. Only 249 used public transportation (mainly the bus); 6 walked, 43 used other means and 32 worked at home (Figure 3) (xx).

Vehicle Availability
The vehicle availability for the relocation area is shown in Table 2. The census data for tract 260102 showed that for owner-occupied households, most had at least one vehicle available. Of 1,584 households in the sample, 726 had one vehicle available and only 162 had no vehicle available to them. Renter-occupied households had fewer vehicles available: of 257 households in the sample, 103 had no vehicle available; 107 had one vehicle; 38 households had two vehicles and 9 had three vehicles available.

Census tract 27040’s data showed that out of a sample of 1,431 owner-occupied households, 608 had one vehicle; 102 households had no vehicle available. Of 524 renter-occupied households, 332 had one vehicle available and 135 had no vehicle available (2). Table 1 shows all vehicle availability for the two census tracts.

Neighborhood Physiography
Figure 4 shows land use surrounding the relocation tracts, which are outlined in black. These areas show more low-density residential areas than the Phase One area. Commercial development aligns along arterial roads, along which the bus lines run. The low-density residential neighborhoods are designed with more curving, irregular and dead-end roads, and are
therefore-less suited to public transit than to the automobile. The city/county boundary line is visible to the east of the two census tracts.

**TABLE 2 Vehicle Availability for Relocation Areas**

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Census Tract 260102</th>
<th>Census Tract 270401</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Owner Occupied</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No vehicle available</td>
<td>162</td>
<td>102</td>
</tr>
<tr>
<td>1 vehicle available</td>
<td>726</td>
<td>608</td>
</tr>
<tr>
<td>2 vehicles available</td>
<td>492</td>
<td>541</td>
</tr>
<tr>
<td>3 vehicles available</td>
<td>158</td>
<td>148</td>
</tr>
<tr>
<td>4 vehicles available</td>
<td>46</td>
<td>32</td>
</tr>
<tr>
<td><strong>Total Owner occupied:</strong></td>
<td><strong>1584</strong></td>
<td><strong>1431</strong></td>
</tr>
</tbody>
</table>

| **Renter Occupied**      |                    |                      |
| No vehicle available     | 103                 | 135                  |
| 1 vehicle available      | 107                 | 332                  |
| 2 vehicles available     | 38                  | 57                   |
| 3 vehicles available     | 9                   | 0                    |
| **Total Renter occupied:**| **257**             | **524**              |
| **Grand Total:**         | **1841**            | **1955**             |
Population Density
Figure 5 shows population density for the relocation areas for 2000. The blocks of census tracts 260102 and 270401 are outlined in black. In contrast to the Phase One area, with population density of about 20-50 persons per acre, the areas surrounding the relocation tracts show lower population densities; the dominant density is 0-21 persons. This map also shows the lack of a defined grid pattern, in contrast to that of the revitalization area.

FIGURE 5 Population density for relocation areas (outlined in black) in 2000.

APPLICATION OF THE OPTIMIZATION MODEL

The relocation area has a total of 19 bus transit lines in the two census tracts as shown in Figures 6 and 7. In census tract 260102 there are 11 transit bus lines and 81 stops within half mile, compared with 19 bus lines and 253 stops for the Phase One (original) area. The transit lines run along the periphery of the tract, as many of the neighborhood roads do not accommodate buses. Figure 5 shows the tract with lines and stops within a half-mile radius.

Mapping of transit lines and stops within a half mile radius of census tract 270401 show a similar pattern of peripheral roads along which the transit lines are located. There are eight bus lines and 109 stops located within a half-mile radius of the tract (see Figure 6). Baltimore Route 19 Carney –Downtown, and Baltimore Route 36 Northern Parkway & York Rd – Univ. of MD TC
are two of the bus routes that will be analyzed in our study for maximizing transit service coverage.

FIGURE 6 Transit lines and stops within 0.5 mile radius of tract 260102.

FIGURE 7 Transit lines and stops within .5 mile radius of tract 270401
**Baltimore Route 19**

**Carney - Downtown**

The area covering this route is divided into 5 segments and 5 different time zones based on the trip pattern of the population residing within 0.5 mile radius. The unit out-of-pocket cost were obtained by performing a sample household survey in the relocated communities. The total potential ridership from various segments and at different times are shown in Table 3 below:

<table>
<thead>
<tr>
<th>Segment and Time of Day</th>
<th>Ridership</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segment 1</td>
<td>2913</td>
</tr>
<tr>
<td>Segment 2</td>
<td>5108</td>
</tr>
<tr>
<td>Segment 3</td>
<td>482</td>
</tr>
<tr>
<td>Segment 4</td>
<td>17</td>
</tr>
<tr>
<td>Am Peak</td>
<td>2014</td>
</tr>
<tr>
<td>Midday</td>
<td>2787</td>
</tr>
<tr>
<td>PM Peak</td>
<td>2146</td>
</tr>
<tr>
<td>Night</td>
<td>1573</td>
</tr>
</tbody>
</table>

The objective function can be represented as:

Minimize

$$2.35x_{11} + 1.22x_{12} + 0.83x_{13} + 2.30x_{14} + 0.60x_{21} + 1.01x_{22} + .90x_{23} + 1.65x_{24} + 2.66x_{31} + 2.60x_{32} + 3.14x_{33} + 2.14x_{34} + 7.31x_{41} + 3.00x_{44}$$

subject to:

1. $x_{11} + x_{21} + x_{31} + x_{41} \geq 2,014$ (4a) Passengers at AM Peak
2. $x_{12} + x_{22} + x_{32} \geq 2,787$ (4b) Passengers at Midday
3. $x_{13} + x_{23} + x_{33} \geq 2,146$ (4c) Passengers PM Peak
4. $x_{14} + x_{24} + x_{34} + x_{44} \geq 1,573$ (4d) Passengers at Night
5. $x_{11} + x_{12} + x_{13} + x_{14} \leq 2,913$ (4e) Passengers from segment 1
6. $x_{21} + x_{22} + x_{23} + x_{24} \leq 5,108$ (4f) Passengers from segment 2
7. $x_{31} + x_{32} + x_{33} + x_{34} \leq 482$ (4g) Passengers from segment 3
8. $x_{41} + x_{44} \leq 17$ (4h) Passengers form segment 4
9. $x_{ij} \geq 0$ and integer $\forall i,j$ (4i) Non-negativity constraint

The above optimization problem was solved using the commercial LINDO software. The optimal solution is given below:
The optimal ridership is compared against unit out-of-pocket cost and presented in Table 4 below. The results show an optimal distribution of potential transit riders from various zones at different times that ensure minimum total out-of-pocket cost. The optimal ridership values were plotted on a logarithmic axis against unit out-of-pocket costs as shown in Figure 9.

TABLE 4. Route 19 Unit Out-Of-Pocket Cost and Optimal Ridership

<table>
<thead>
<tr>
<th>Zone-Time of day</th>
<th>Unit out-of-pocket cost</th>
<th>Optimal Ridership*</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>2.35</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>1.22</td>
<td>20267</td>
</tr>
<tr>
<td>13</td>
<td>0.83</td>
<td>887</td>
</tr>
<tr>
<td>14</td>
<td>2.3</td>
<td>1</td>
</tr>
<tr>
<td>21</td>
<td>0.6</td>
<td>2014</td>
</tr>
<tr>
<td>22</td>
<td>1.01</td>
<td>761</td>
</tr>
<tr>
<td>23</td>
<td>0.9</td>
<td>1260</td>
</tr>
<tr>
<td>24</td>
<td>1.65</td>
<td>1573</td>
</tr>
<tr>
<td>31</td>
<td>2.66</td>
<td>1</td>
</tr>
<tr>
<td>32</td>
<td>2.6</td>
<td>1</td>
</tr>
<tr>
<td>33</td>
<td>3.14</td>
<td>1</td>
</tr>
<tr>
<td>34</td>
<td>2.14</td>
<td>1</td>
</tr>
<tr>
<td>41</td>
<td>7.31</td>
<td>1</td>
</tr>
<tr>
<td>44</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

*Note: for logarithmic plotting the zero values are changed to 1
FIGURE 9. Optimal Ridership vs. Unit Out-of-Pocket Cost for Route 19

Route 36
Northern Parkway & York Road – Univ. MD TC

The area covering this route is divided into 3 segments and 5 different time zones based on the trip pattern of the population residing within 0.5 mile radius. The unit out-of-pocket cost were obtained by performing a sample household survey in the relocated communities. The total potential ridership from various segments and at different times are shown in Table 5 below:

<table>
<thead>
<tr>
<th>TABLE 5. Route 36 Total Ridership from Different Zone and Time of Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segment and Time of Day</td>
</tr>
<tr>
<td>Segment 1</td>
</tr>
<tr>
<td>Segment 2</td>
</tr>
<tr>
<td>Segment 3</td>
</tr>
<tr>
<td>Am Peak</td>
</tr>
<tr>
<td>Midday</td>
</tr>
<tr>
<td>PM Peak</td>
</tr>
<tr>
<td>Night</td>
</tr>
</tbody>
</table>

The objective function can be represented as:

Minimize:

\[ 3.69x_{11} + 1.0x_{12} + 1.13x_{13} + 2.44x_{14} + 1.50x_{21} + 1.2x_{22} + 2.89x_{23} + 1.69x_{24} + 1.37x_{31} \\
+ 0.94x_{32} + 1.85x_{33} + +1.12x_{34} \]
subject to:
\[ x_{11} + x_{21} + x_{31} \geq 973 \]  \hspace{1cm} (7a) \hspace{1cm} \text{Passengers at AM Peak}
\[ x_{12} + x_{22} + x_{32} \geq 1,675 \]  \hspace{1cm} (7b) \hspace{1cm} \text{Passengers at Midday}
\[ x_{13} + x_{23} + x_{33} \geq 1,052 \]  \hspace{1cm} (7c) \hspace{1cm} \text{Passengers PM Peak}
\[ x_{14} + x_{24} + x_{34} \geq 919 \]  \hspace{1cm} (7d) \hspace{1cm} \text{Passengers at Night}
\[ x_{11} + x_{12} + x_{13} + x_{14} \geq 1,612 \]  \hspace{1cm} (7e) \hspace{1cm} \text{Passengers from segment 1}
\[ x_{21} + x_{22} + x_{23} + x_{24} \geq 1,486 \]  \hspace{1cm} (7f) \hspace{1cm} \text{Passengers from segment 2}
\[ x_{31} + x_{32} + x_{33} + x_{34} \geq 1,512 \]  \hspace{1cm} (7g) \hspace{1cm} \text{Passengers from segment 3}
\[ x_{ij} \geq 0 \text{ and integer } \forall i,j \]  \hspace{1cm} (7h) \hspace{1cm} \text{Non-negativity constraint}

The above optimization problem was solved using the commercial LINDO software. The optimal solution is given below:

\[
\begin{bmatrix}
  x_{11}^* \\
  x_{12}^* \\
  x_{13}^* \\
  x_{14}^* \\
  x_{21}^* \\
  x_{22}^* \\
  x_{23}^* \\
  x_{24}^* \\
  x_{31}^* \\
  x_{32}^* \\
  x_{33}^* \\
  x_{34}^*
\end{bmatrix}
= 
\begin{bmatrix}
  0 \\
  569 \\
  1052 \\
  0 \\
  973 \\
  0 \\
  0 \\
  513 \\
  0 \\
  1106 \\
  0 \\
  0
\end{bmatrix}
\]  \hspace{1cm} (8)

The optimal ridership is compared against unit out-of-pocket cost and presented in Table 6 below. The results show an optimal distribution of potential transit riders from various zones at different times that ensure minimum total out-of-pocket cost. The optimal ridership values were plotted on a logarithmic axis against unit out-of-pocket costs as shown in Figure 10.
TABLE 6. Route 36 Unit Out-Of-Pocket Cost and Optimal Ridership

<table>
<thead>
<tr>
<th>Zone-Time of day</th>
<th>Unit out-of-pocket cost</th>
<th>Optimal Ridership</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>2.35</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>1.22</td>
<td>20267</td>
</tr>
<tr>
<td>13</td>
<td>0.83</td>
<td>887</td>
</tr>
<tr>
<td>14</td>
<td>2.3</td>
<td>1</td>
</tr>
<tr>
<td>21</td>
<td>0.6</td>
<td>2014</td>
</tr>
<tr>
<td>22</td>
<td>1.01</td>
<td>761</td>
</tr>
<tr>
<td>23</td>
<td>0.9</td>
<td>1260</td>
</tr>
<tr>
<td>24</td>
<td>1.65</td>
<td>1573</td>
</tr>
<tr>
<td>31</td>
<td>2.66</td>
<td>1</td>
</tr>
<tr>
<td>32</td>
<td>2.6</td>
<td>1</td>
</tr>
<tr>
<td>33</td>
<td>3.14</td>
<td>1</td>
</tr>
<tr>
<td>34</td>
<td>2.14</td>
<td>1</td>
</tr>
</tbody>
</table>

*Note: for logarithmic plotting the zero values are changed to 1

FIGURE 10. Optimal Ridership vs. Unit Out-of-Pocket Cost for Route 36

RESULTS AND DISCUSSION

The optimal solutions for the two transit routes studied above reveal some interesting findings. First, for route 19 it is observed that the transit ridership is highest for segment 2 at midday. This seems reasonable since an inspection of Table 3 reveals that the ridership at midday in Segment 2 is the highest. An inspection of Figure 9 reveals that while in general, the ridership drops with
increasing unit out-of-pocket cost there does not seem to be a consistent relationship between unit out-of-pocket cost and optimal ridership since there are other factors that influence ridership, such as the varying demand for travel at different times for different purposes, based on people's varying preferences and requirements.

For route 36, the optimal ridership is highest for zone 1 at midday (see, Table 5). Also, unit out-of-pocket cost is highest for segment 3 at evening peak. In general, optimal ridership is higher as unit out-of-pocket cost drops (Figure 10).

The results from the above studies do indicate that using transit within the revitalized area presents a more equitable solution for transit riders when compared with total out-of-pocket cost.

CONCLUSIONS AND FUTURE WORK

In this paper, we investigated the transit equity between old and new areas due to relocation associated with urban revitalization projects. We also developed an optimization model to maximize ridership subject to different commuting preferences and unit out-of-pocket costs. One key conclusion, as is obvious from the comparison of old and new areas, is that there does exist transit inequity between old and new areas in urban revitalization projects. This issue needs to be carefully investigated and adequate transit coverage needs to be provided in the relocation areas. With each evaluation, tradeoffs are to be analyzed between objectives. Since the neighborhood physiography of the relocated area is a key factor affecting transit route accessibility, a careful study to meet the transit demand intertwined with the socioeconomic characteristics of the relocated area needs to be performed. Census tracts offer and good indication of determining socioeconomic characteristics. A Geographic Information System (GIS) can also be used in combination with census data to determine specific areas for analysis. The developed model, with accurate and specific data for each area in question, could assist planners in understanding the interrelationships among local urban communities, facilitating more scientific and equitable planning for public transportation projects.

In future works, an optimization model that determines optimal transit routes and stops for prevailing demand, subject to given neighborhood physiography can be developed. Moreover, study of additional case studies of urban revitalization projects may reveal a consistent pattern in transit inequity, which may require this issue to be carefully studied in the planning stages of the urban revitalization projects.

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References


