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Our troubled planet can no longer afford the luxury of pursuits
Confined to an ivory tower. Scholarship has to prove its worth,
Not on its own terms, but by service to the nation and the world.
—Oscar Handlin

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A Mobility Information Management System for Rural Transportation:
A Case Study in Northwest Alabama

Michael D. Anderson
The University of Alabama in Huntsville

Abstract

This article presents the development of a Mobility Information Management System (MIMS) within a regional area. The system is designed to provide residents access to important trip information, which can assist them in making informed transportation choices. The final design of the system, demonstrated using a case study of a region in northwest Alabama, includes survey data collected from transportation providers; a database system to maintain, query, and update the information; and an Internet-based system for the public to learn about services provided. The system, after inclusion of all transportation service data, provides a convenient mechanism to educate the public on transportation services and allows transportation service agencies to better understand the services offered in the region and assist passengers in meeting their transportation needs.

Introduction

Rural public transit operators must become more than transit providers—they must become mobility managers with knowledge to assist passengers and arrange
transportation services beyond their individual system. To accomplish this goal of becoming mobility managers, providers must understand not only their system, but also the interaction of all transportation providers in their region. The heart of this effort would be an information system that contains the elements necessary to manage a trip regionwide using public and private transportation resources. This article presents the development of a MIMS system within a regional area.

At its simplest level, a MIMS is a printed compendium of accurate contact information of all transportation providers regionwide. At its grandest level, it is an Internet-based interactive system that both transportation providers and the public can access and use to chart a trip. This article focuses on the development of a methodology to compile all of this information so it may be used and understood between rural public transit operators and their private sector counterparts; and then understood and used by the public.

This article presents a description of a study area in northwest Alabama, home to 27 individual transportation service coordinators as well as an intercity bus service and a regional airport, and a methodology and design for a rural transportation MIMS. The methodology and design first focuses on what information is needed from the various transportation providers, both public and private. The next item addressed is a database designed to maintain, query, and update the transportation information. Finally, an Internet-based system for the dissemination of transportation information to the public, intended to assist individuals make informed transportation choices, is presented. The article concludes that the Internet-based MIMS provides a convenient mechanism to educate the public on transportation services and allows transportation agencies to better understand the services offered in the region.

**Case Study Area**
The case study region selected for the application of the MIMS system consisted of a five-county region in northwest Alabama (shown in Figure 1). The region represented a unique area for the development of MIMS, based on the diverse transportation system, evident through the 27 individual agencies, public and private, responsible for coordinating and/or providing transportation services, as well as intercity bus service and a regional airport. For the 27 individual agencies, there currently exists no coordinating information or technology, Advanced Public Transit System (APTS), to assist in the development of the MIMS system.
The urban center for the region is the combination of four communities, Florence, Muscle Shoals, Sheffield, and Tuscumbia, known collectively as the Shoals. The region is home to 230,230 people, with 15 percent of the population more than 65 years of age (www.census.gov). The region currently has a 7.0 percent unemployment rate and an $18,804 per capita income (http://www.shoalschamber.com/). The major regional employers include health care, government, education, meat processing, textiles, and metallurgical work (http://www.shoalschamber.com/).
Design of the MMS

The rural transportation MIMS designed for the northwest Alabama region was developed in three steps. The steps included identification of transportation information, an on-line system allowing transportation providers to enter and modify services offered, and an Internet-based dissemination system allowing the public to access information and make informed travel decisions.

Step 1. Data Collection

At the heart of any management system, transportation or otherwise, are data. Therefore, it is not surprising that the initial step in MIMS is to collect data related to transportation resources and operation. The data collection effort undertaken for the northwest Alabama region consisted initially of a written survey distributed to all agencies identified by the regional council of local governments as providing transportation services. The format and content of the mail survey was a result of a literature review of several previously used transit surveys and the U.S Department of Transportation’s Travel Survey Manual (Tooley et al. 2000; Cambridge Systematics, Inc. 1996; Transit Agency Survey Form [Montana and Colorado]. The data collection needs were divided into eight distinct categories:

1. Agency information
2. Operating schedules
3. Technology level
4. Type of service
5. Payment types
6. Qualification criteria
7. Service area
8. Fleet capabilities/demand

The first three categories relate to general agency information. The agency information data included name, address, and contact information. In general, these data are important for communications with agency personnel, but not vital for the MIMS, with the exception of the contact information, which is necessary to users who access the system to arrange transportation services. The data related to operating schedules included days of the week services are provided, hours of service, and general holiday information. The third general agency information re-
quest related to the technology level of the agency (i.e., software programs, Internet access, agency web pages, and e-mail capability). These questions were asked to determine acceptance of an Internet-based mobility system for disseminating information about transportation services.

The next three categories relate to the service structure and management practices of the agencies. Type of service data show whether the agency provided fixed-route service, demand responsive service, and if service was contracted through another agency. Questions about payment types focused on whether cash or voucher payments were accepted for service and the rates for transportation service. Qualification criteria focused on specific eligibility requirements for service (e.g., youth, elderly, disabled), as well as capabilities for providing service to specific individuals (e.g., disabled people through wheelchair-lift vehicles or elderly persons through door-to-door service with driver assistance).

The final two questions, service area and fleet capabilities/demand, focused on the operations of the transportation service provider. The service area was determined through two methods. First, a listing of the five counties and several cities and towns within the five-county region was provided with a check box on the survey for the agency to select communities where it provided service. Second, a map of the region was provided and agencies were asked to highlight all the areas in which they generally provide service. This service area data is vital for matching potential riders and transportation services. The fleet capabilities/demand questions assessed the agency's ability to transport individuals by asking for the number of buses, how many were wheelchair-lift accessible, and the number of vehicles that would allow them to meet existing needs (if they are not being met).

Preliminary results from the data collection effort indicated that the information supplied by the service providers needed to be presented on a per route basis, not as one aggregated survey per agency. The reasoning behind this was the aggregate information for a single agency might identify service in two communities within the study area; however, the agency was not necessarily offering service between the two communities. Therefore, the items collected from each agency needed to be specific to individual routes operated by the agencies, implying that a single agency could have many routes identified with unique operating schedules, qualifications, payment schedules, and service area.
Step 2. On-line System for Data Entry and Modification

The next required element of the MIMS system was on-line data entry and modification capabilities. Based on the results of the data collection effort, all the transportation providers contacted responded that there was sufficient Internet access within their agencies to allow for on-line entry and modification of the travel information. The on-line system was selected because it provided the ability to use a single database file containing the transportation services for the region in a central location that could be accessed remotely. This ability eliminated the need for each agency to maintain its own database file within the agency and allowed each agency to update the file as its service changed, without waiting for any one agency to make the changes, thus helping to ensure the data would not become obsolete. Microsoft Access was selected as the database system for the MIMS as this package was familiar to the agencies and could be interfaced through the Internet (although several other database software packages with Internet capabilities could have been used).

Originally, the database file was developed to mimic exactly the survey questionnaire distributed to the individual agencies. The eight data categories identified on the survey were replicated within an on-line system allowing new agencies wanting to enter the database to complete the information on-line and existing agencies to make changes to their information. However, as was determined during the data collection process, the entry of data needed to be adjusted to reflect individual routes, not necessarily individual agency-level information. To account for this, a system was developed that allowed the agencies to enter items unique to specific routes, without having to enter all of the basic information continually. In addition, the on-line data entry and modification system has been designed with password protection to ensure each agency is capable of altering only its specific information and to ensure the only users entering data into the system are registered agencies.

Registered agencies, upon entering the required username and password, are directed to a series of Internet pages where they can enter or modify route information for the specific type of transportation service offered. All the entry and modification screens are designed to match the dissemination screens in the system. Data entry involves a representative from the transportation agency either entering information into blank entry locations and/or through check boxes. Example screens for entering data for a special needs route and a demand response route are shown in Figures 2 and 3. For modification of existing data, the representative
from the transportation agency is shown screens similar to the blank data entry screens, but with the existing data displayed and the representative only needing to update the information.

Figure 2. Data Entry Screen for a Special Needs Route
Figure 3. Data Entry Screen for a Demand Response Route
Step 3. Internet-based Dissemination System

The dissemination of the transportation information for the region is also performed through an Internet-based system. It was decided to focus on this technology because the Internet allowed graphical selection of information and was immediately responsive to changes in the transportation service information contained in the database. This capability ensured the information would not become obsolete as long as the transportation agencies maintained their information, which is expected as transportation providers with outdated information will lose ridership. The Internet-based dissemination system was also considered favorable as access to the Internet potentially exists in residents' homes and definitely exists at public locations such as libraries, employment centers, and other community sites. For individuals lacking Internet access or transportation to public places, a common problem in poor, rural areas, the MIMS data can be disseminated by contacting administrative staff of the transit providers in the region, who have full access to the system.

Initially, a series of Internet pages were developed allowing an individual who wanted to learn about the transportation services to select the day of the week they desired transportation, any eligibility qualification classification, and the town where the service was needed. An option was included that would allow any of these, but not all three, to be entered as no concern, which excluded the option from the search requirement. The initial selection screen is shown in Figure 4 and an example of the output provided to an individual who has selected transportation services in Russellville, Alabama, is shown in Figure 5.
Figure 4. Initial Screen View of the MIMS
The initial dissemination system was modified, as with the other steps, to reflect the change in data collection from service providers to individual routes. Alterations to the MIMS included the shift from agency queries to specific route queries. The final design provided the individual interested in service two access methods: a graphical method, in which the individual selects the city of interest, and a trip purpose menu, in which the individual selects the type of trip requested. Figure 6 shows the main screen, highlighting the two access methods.
The first access method for the MIMS system is through a locality menu. For this menu, the individual is presented with an interactive map of the region from which they can choose the city where they desire transportation service. This selection will then provide all of the transportation service information available to the individual, segmented into the various types of transportation identified from the trip purpose menu. An example is shown in Figure 7 for Sheffield, Alabama.

Figure 7. Results for Sheffield, Alabama
From the information provided by the system, there are currently no home-to-work routes originating or terminating in Sheffield. However, there are four home-to-work routes within the County operated by NACOLG (Northwest Alabama Council of Local Governments), the area’s Section 5311 provider. For any of the routes available in either the City or County, there is a “show record” button available to obtain additional information. Figure 8 shows the details for one of the home-to-work routes.

Figure 8. Detailed View of a Home-to-Work Route in the System
The second access method for the MIMS is through a trip purpose menu. This menu itemizes the types of trips that an individual may select and provides a list of specific services available in the region. Types of trip purposes available to select from include:

- Home-to-work routes
- Shopping routes
- Demand response
- Special needs
- Emergency medical
- Nonemergency medical
- Intercity bus
- Regional air
- Taxi.

Upon selection of any of these menu options, the system will advance users to a screen showing a list of available services for the specific type of transportation selected as well as contact information and providers. The results for demand response transportation are shown in Figure 9. From the entire list of demand response route options, the user can then select the ID number for the appropriate route to view a more detailed listing (the ID number is located at the beginning of the line). Figure 10 shows a demand response route with enhanced detail. The dissemination screen provides sufficient information to the individual using the system to make an informed decision as to whether the services offered are capable of meeting their individual needs and agency contact information to learn more about the service or to request service.
Figure 9. Demand Response Transportation Services

Figure 10. Detailed Information for a Demand Response Route
Conclusions and Future Work
The rural transportation MIMS developed for the northwest Alabama region of Colbert, Franklin, Lauderdale, Marion, and Winston Counties provides a unique method to maintain and access transportation data. The system has been designed to be easily understood by both the transportation agencies responsible for entering and maintaining the transportation service information and the individual user who desires information on the transportation services offered in the region. The completion of the system provides a mechanism to educate the public on transportation services and allows transportation service agencies to understand all of the services available in the region and to help passengers arrange needed transportation services. Currently, the system developed for the case study area is operational and available to the public as a link from the Alabama Rural Transit Assistance Program Internet site (www.alrtap.org). The information in the system continuously evolves as new transportation providers are entering their service information and the system, itself, is being modified to include the entire State of Alabama. In addition, the possibility of establishing a statewide contact number to access MIMS system data for individuals without Internet access is to be examined. Overall, the MIMS is attempting to assist rural transit providers become mobility managers and provide a mechanism for individual travelers to obtain access to a wealth of information related to transportation services and providers.

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References


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Ridership Demand Analysis for Palestinian Intercity Public Transport

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Abstract

This article presents results of research to study the intercity bus ridership demand, assess existing services, and form a basis to predict future ridership in the Palestinian territories. This study is the first of its type in the area.

Intercity public transport between six governorates in the northern and central districts of the West Bank was examined. The relationship between public transportation demand and both operating and socioeconomic variables that influence demand was established. An on-board survey of intercity bus riders identified some of the variables that can potentially influence ridership demand. A simple linear regression equation of the ridership demand was developed using five independent variables: population of origin city, population of destination city, bus fare, percent of employees at origin city, and percent of higher education students at origin city. Ridership profiles and trip characteristics were also established.

The study results can be used to evaluate existing public transportation and forecast future intercity public transport demand. Decision-makers can use the results to improve intercity public transport services and attract more riders. Future research should be based on this simple model, include the impact of other modes on intercity de-
mand, include all governorates of the West Bank and Gaza Strip, and establish a comprehensive nationwide model.

Introduction
Public transportation plays an important role in fulfilling transport needs. Transportation planners around the world direct their research and studies toward the development of public transportation using different technologies. Research efforts focus on increasing the efficiency of the existing public transportation system using different strategies to achieve objectives. One strategy deals with the analysis and modeling of demand for travel.

Many factors—external and internal—affect public transport demand. External factors are associated with socioeconomic developments, which are not subject to control (e.g., income, car ownership, population, employment, other household characteristics). Internal factors are characteristics of the public transport system and are subject to policy decisions (e.g., public transport fares, trip length, travel time, service levels).

Background
Upon launching of the peace process between the Palestine Liberation Organization and Israel in 1993, the Palestinian National Authority (PNA) gradually resumed control over some parts of the West Bank and Gaza. During the last 35 years of occupation, the comprehensive intercity public transport system in the West Bank was partially destroyed. The role of municipalities and other transport authorities was limited in the area of transportation facilities improvements. After 1995, the PNA started several transportation development projects, including rehabilitation of road networks, transportation systems management for major cities in the West Bank and Gaza Strip, and downtown traffic management. However, there was no fund assigned to the development of the public transportation facilities at the time except by the private sector. The decision to postpone public transportation development during this period was based on several factors:

- Public transportation agencies are privately owned
- Traffic congestion on intercity roads is not a serious problem
- PNA focused on infrastructure rather than operation projects
- Most intercity roads still are not controlled by the PNA
- Some public transportation development projects need public awareness
Significance and Objective of the Study

As a result of these factors, the public transportation services needed to determine future needs and demands of riders were not recognized nor studied. Therefore, there is a need to evaluate existing public transportation in the Palestinian territories to meet expected growth in automobiles on Palestinian roads, which is expected to cause more congestion and delays.

Ridership demand analysis and modeling for public transport had been studied extensively in many developed countries. However, this study is the first of its kind in the Palestinian territories. It was designed to understand some aspects of intercity bus travel behavior and establish a simple demand model.

This study is intended to develop a simplified model of the existing intercity public transportation and forecasting ridership. In turn, the model can be used to create a framework to assist policy-makers in the decision management process of public transportation (e.g., increasing transit ridership, as recommended by Wilbur Smith Associates [2000]). Bus company owners can also use the study results to improve their services and attract new customers.

Intercity Public Transport

Two types of intercity public transport are common in the West Bank: shared taxis and buses. For all study routes, both modes are available and riders can choose between either mode.

Shared taxi is considered a paratransit service. It is privately owned and operated. The standard intercity shared taxi seating capacity is seven passengers. Services may deviate from routes and/or fixed schedule, and may pick up and drop off passengers at other than regular stops. Shared taxi is normally faster and more expensive than bus service. The majority of passengers ride at the origin terminal and take off at the end point. Therefore, it is similar to an express service.

Intercity bus service is the public transportation mode that connects between cities. Intercity bus offers fixed-fare services weekdays on a fixed route and somewhat fixed schedule. Intercity bus service is currently provided by private companies, which operate at a profit, with little or no support from the government. Trip travel time is normally longer and trip fare is cheaper than shared taxis for the same origin—destination.
Study Area
The area of study for this research was the northern and the central governorates of the West Bank. The core of the study was Nablus City, which connects the northern districts with the central and southern districts of the West Bank. In terms of population, Nablus City is the second largest city in the West Bank after Hebron. It is also considered the largest commercial center. Nablus City has the largest university in the West Bank (in terms of number of students), and it is centrally located among other cities in the West Bank. Figure 1 illustrates the location of the main cities/governorates in the West Bank.

Figure 1. Map of the West Bank and Gaza Strip
Literature Review

Historically, the analysis of factors affecting the demand for public transport goes back about 100 years. Many studies have been conducted in this field, addressing different points of view.

Bermello, Ajamil, and Partners (1997) discussed transit ridership demand in several statewide and regional studies in the United States and expressed the demand model as:

\[ \text{Ridership} = \text{Constant} \times (\text{Population})^a \times (\text{Service Frequency})^b \times (\text{Distance})^c \times (\text{Fare})^d \times \ldots \]

The study also investigated ridership demand for the Tri-Rail routes connecting the south Florida region. Tri-Rail ridership was a direct demand function of the service area demographics (population of the origin and destination stations, average population age, and income of the origin station) and route characteristics (average travel time, distance, and fare).

Al-Sahili and Taylor (1996) used the 1977 Michigan intercity bus ridership data to develop a demand model between city pairs and presented this mathematical relationship:

\[ R_{ij} = \text{(Constant)} \times (\text{Population for City } i)^a \times (\text{Population for City } j)^b \times (\text{Distance between two cities})^c \]

Moussavi et al. (1996) developed models to predict future public transportation ridership demand in rural Nebraska. Existing and historical transit operation and socioeconomic and demographic data for counties and cities in Nebraska that had rural transportation services were used to develop a series of equations for predicting future ridership demand in rural areas with or without existing public transportation services.

The results of Moussavi’s research were expected to enhance the capabilities of decision-makers at the Nebraska Department of Roads in setting priorities for meeting the public transportation needs in rural Nebraska. The general forms of equations developed in Moussavi’s study were:

\[
\begin{align*}
\text{Annual passenger} &= a_1 \times \text{VehMile} + \text{Constant} \\
\text{Annual passenger} &= a_1 \times \text{VehMile} - a_2 \times \text{AvgFare} + \text{Constant}
\end{align*}
\]
The first form was for areas that did not charge a fare while the second was for areas that did charge a fare, with $a_1$ and $a_2$ coefficients for annual vehicle miles (VehMile) and the annual average fare (AvgFare), respectively.

Most models were simple and analytical mathematical formulas based on the characteristics of surrounding communities and transit agencies. Most followed a log-linear format and few used a linear format. Factors affecting public transport demand were associated socioeconomic developments, which are not subject to control by the researchers. Internal factors, characteristics of the public transport system and subject to policy decision, were also used. The aggregate data on interdistrict travel by public transportation were used to calibrate a total demand model with influence factors.

**Methodology**

To be consistent with the general form of public transport simple demand models as depicted from the literature, statistical analysis and least square regression were used. In this research, the correlation and causation of independent and dependent variables were examined. The procedure used in this study involved examining various independent variables that can potentially influence demand. These variables were selected based on previous literature, knowledge of the area, and the survey of riders.

One of the key research steps was conducting a comprehensive on-board survey (sample size = 410) of riders on all intercity public transport study routes. The survey was designed to examine riders’ profile and trip characteristics. It was used to identify some of the primary independent variables that could influence ridership demand.

Various relationships of a log-linear format were tested; however, they did not yield reasonable or logical results. Several multiple linear regression forms were also tested and the most reasonable and logical one is presented in this article. The general form of the relationship, which describes ridership demand that was used in this research, is:

$$Y = a_0 + a_1 X_1 + a_2 X_2 + \ldots + a_r X_r$$

Correlations between the independent variables were examined. Independent variables that had high correlation were either eliminated or joined as one variable.
Data Collection

This research focused on the intercity bus services in the northern and central governorates of the West Bank, and considered the Nablus governorate as a core of this study. All city pairs with bus services in these areas were included. These cities are Jenin, Nablus, Qalqilia, Ramallah, Salfit, and Tulkarm. The cities represented the core of commercial, educational, and institutional activities in their respective governorates. Data was obtained from various sources, including:

- **The Palestinian Central Bureau of Statistics (PCBS).** The PCBS published the 1997 census, which described the population demographics and their activities in Gaza Strip and the West Bank. The PCBS also published “Transportation and Communication Statistics in the Palestinian Territories,” (1999); “Expenditure and Consumption Levels” (1999); Labor Force Survey: Main Finding (2000); and Population, Housing and Establishment Census—1997, Final Results—West Bank (1999). This research considered the year 2000 as the base year. Thus, all the collected data were based on year 2000. External variables, which were examined in the ridership demand analysis, were obtained from the above PCBS publications. These were the total population by governorate, population economical activity, auto ownership, educational level, average monthly expenditure per family (Jordanian Dinar, JD), and auto ownership.

- **Records of various public transportation agencies and bus companies.** Data records of existing intercity bus trips were collected from bus company operators and transportation agencies. These data were weekly ridership, trip length (kilometer), travel time (minutes), bus fare (New Israeli Sheqel, NIS), and average number of bus trips.

- **On-board survey (questionnaire).** An on-board questionnaire was conducted to obtain riders' input regarding travel characteristics and profiles. Data obtained from this survey included rider's employment, income, auto ownership, educational attainment, trip purpose, number of similar weekly trips, and the main reason for riding the bus.
Data Analysis
This section examines the characteristics of cities and intercity bus riders and presents the ridership model.

Characteristics of Cities and Intercity Bus Riders
The collected data for 22 city pairs indicated that Nablus and Ramallah had five bus service routes; Tulkarm, four; Jenin and Qalqilia, three; and Salit, two.

Table 1. Characteristics of Intercity Bus Services and Origin/Destination Cities

Source: Several Palestinian Central Bureau of Statistics publications (1999) and bus companies.
Nablus City had the highest number of bus trips, as well as the highest number of riders. This can be attributed to the City’s central location in the northern districts, existence of the largest university in the West Bank, and the fact that it is one of the largest commercial and business centers in the country. Table 1 shows that the highest average weekly bus trips were between Nablus and Ramallah cities (203 bus trips) and the least bus trips were between Ramallah and Salfit cities (9 bus trips).

Intercity bus ridership on a weekly basis was found to be the most reliable figure. The largest weekly ridership originated at Nablus City; the least ridership demand originated at Salfit City (see Table 1).

As shown in Table 1, the longest bus trip length (and travel time) was between Jenin and Ramallah (80 km, 90 minutes); the shortest bus trip length was between Nablus and Tulkarm (27 km, 35 minutes).

Bus fare is expected to be one of the most influential factors that affect ridership demand. As shown in Table 1, the highest bus fare was between Jenin and Ramallah (10.0 NIS); the lowest was between Nablus and Salfit (3.5 NIS).

Distribution of population by governorate showed that Nablus had the largest population (278,300) while Salfit had the smallest population (52,100), as shown in Table 2.

<table>
<thead>
<tr>
<th>Governorate</th>
<th>Population</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jenin</td>
<td>216,100</td>
<td>6.9</td>
</tr>
<tr>
<td>Tulkarm</td>
<td>142,900</td>
<td>4.5</td>
</tr>
<tr>
<td>Qalqilia</td>
<td>78,000</td>
<td>2.5</td>
</tr>
<tr>
<td>Salfit</td>
<td>52,100</td>
<td>1.7</td>
</tr>
<tr>
<td>Nablus</td>
<td>278,300</td>
<td>8.8</td>
</tr>
<tr>
<td>Ramallah</td>
<td>231,700</td>
<td>7.4</td>
</tr>
<tr>
<td><strong>Palestinian Territories</strong></td>
<td><strong>3,150,060</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>
Figure 2. Intercity Bus Rider’s Trip Purpose

Figure 3. Percent Employment by Governorate
Based on the on-board survey, the most common trip purposes were educational, mostly for a university (59.8%), and for work (30.7%) as presented in Figure 2. Figure 3 shows that Ramallah had the largest employment percent (95.4%) while Tulkarm and Qalqilia had the lowest employment percent (85.6%). Ramallah also had the highest average income/expenditure level expressed in terms of automobile ownership and family expenditure; Salfit had the lowest, as shown in Table 3.

Table 3. Average Family Expenditure and Automobile Ownership

<table>
<thead>
<tr>
<th>Governorate</th>
<th>Average Family Monthly Expenditure (JD)</th>
<th>No. of Private Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jenin</td>
<td>440</td>
<td>6190</td>
</tr>
<tr>
<td>Tulkarm</td>
<td>443</td>
<td>7044</td>
</tr>
<tr>
<td>Qalqilia</td>
<td>443</td>
<td>2336</td>
</tr>
<tr>
<td>Salfit</td>
<td>464</td>
<td>2259</td>
</tr>
<tr>
<td>Nablus</td>
<td>464</td>
<td>12028</td>
</tr>
<tr>
<td>Ramallah</td>
<td>583</td>
<td>12715</td>
</tr>
<tr>
<td>Average/Total</td>
<td>473</td>
<td>42572</td>
</tr>
</tbody>
</table>

Statistical analysis of the intercity bus service questionnaire showed that the highest two reasons that riders preferred using the bus service were the cost (45.9%) and safety and comfort (29.0%). Problems that riders faced while riding the bus included number of bus stops (29.8%), waiting time (28.7%), slowness (14.2%), walking distance to/from the bus station (9.7%), discomfort (8.1%), and other problems (9.6%), as shown in Figure 4.

**Figure 4. Bus Riders’ Problems for Riding a Bus**

**Development of the Ridership Model**

The first step in developing the mathematical relationship was the establishment of a statistical correlation matrix among the different variables included in the study. The next step of regression modeling was to find the type of function between the dependent and independent variables such as linear or log linear functions. Trials and testing the types of functions in this study showed that the best relation between the dependent and the independent variables for the studied intercity public transport was the linear format.
The selected independent variables were chosen based on their correlation and causation (logic). Initially, 14 independent variables were examined. Based on the set criteria, these variables were shorted to 5:

- Origin city population in thousands, \( D_1 \)
- Destination city population in thousands, \( D_2 \)
- Bus fare in (NIS), \( D_3 \)
- Origin city percentage of students who are attending secondary schools or universities, \( D_4 \)
- Origin city percentage of people older than 15 years who are employed, \( D_5 \)

Using the multiple linear regression analysis, the following relationship was obtained:

\[
Y = 1084.8 + 26.8 \ D_1 + 25.7 \ D_2 - 813 \ D_3 + 80.3 \ D_4 + 68.3 \ D_5
\]

The correlation coefficient, \( R^2 \), for the above equation was 0.82. The t-test and significance level statistics indicated that the variables had a good significance. Table 4 shows the values of the independent variables and the comparison between the observed and the predicted ridership demand using the above model.

The expected ridership demand for most city pairs was generally accepted, except those routes from or to Tulkarm and Salfit. Ridership from/to Tulkarm (except Tulkarm–Jenin) was underestimated. However, the overestimated ridership between Salfit and Nablus might be explained by the fact that Salfit is the smallest governorate in terms of population. Furthermore, the difference between bus fare and shared taxi fare for Nablus–Salfit trips (3.5 and 4.5 NIS, respectively) was marginal. Therefore, the incentive to use buses is low compared to other trip routes. Furthermore, the employment percentage for this governorate, reported in PCBS publications, was considered to be the same as employment for Nablus the governorate. This is obviously an overestimation for Salfit’s employment level.
Table 4. Summary of Observed and Estimated Weekly Ridership Demand

<table>
<thead>
<tr>
<th>Origin City</th>
<th>Destination City</th>
<th>$Y_o$</th>
<th>$Y_p$</th>
<th>Percent Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nablus</td>
<td>Ramallah</td>
<td>6,500</td>
<td>5,867</td>
<td>-15.0</td>
</tr>
<tr>
<td>Tulkarm</td>
<td>7,614</td>
<td>6,805</td>
<td>-10.6</td>
<td></td>
</tr>
<tr>
<td>Qalqilia</td>
<td>8,783</td>
<td>5,450</td>
<td>-12.3</td>
<td></td>
</tr>
<tr>
<td>Salfit</td>
<td>3,338</td>
<td>3,274</td>
<td>-1.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1,018</td>
<td>2,540</td>
<td>152.0</td>
</tr>
<tr>
<td>Nablus</td>
<td>Ramallah</td>
<td>8,783</td>
<td>5,509</td>
<td>-6.2</td>
</tr>
<tr>
<td>Tulkarm</td>
<td>330</td>
<td>2,849</td>
<td>703.0</td>
<td></td>
</tr>
<tr>
<td>Qalqilia</td>
<td>630</td>
<td>109</td>
<td>-3.0</td>
<td></td>
</tr>
<tr>
<td>Salfit</td>
<td>480</td>
<td>61</td>
<td>-47.9</td>
<td></td>
</tr>
<tr>
<td>Ramallah</td>
<td>Nablus</td>
<td>5,600</td>
<td>5,851</td>
<td>9.5</td>
</tr>
<tr>
<td>Jenin</td>
<td>720</td>
<td>810</td>
<td>18.1</td>
<td></td>
</tr>
<tr>
<td>Tulkarm</td>
<td>630</td>
<td>77</td>
<td>-66.3</td>
<td></td>
</tr>
<tr>
<td>Qalqilia</td>
<td>425</td>
<td>561</td>
<td>-59.8</td>
<td></td>
</tr>
<tr>
<td>Salfit</td>
<td>240</td>
<td>72</td>
<td>31.7</td>
<td></td>
</tr>
<tr>
<td>Jenin</td>
<td>Ramallah</td>
<td>820</td>
<td>906</td>
<td>29.7</td>
</tr>
<tr>
<td>Nablus</td>
<td>6,674</td>
<td>6,738</td>
<td>-12.0</td>
<td></td>
</tr>
<tr>
<td>Tulkarm</td>
<td>1,184</td>
<td>2,756</td>
<td>629.7</td>
<td></td>
</tr>
<tr>
<td>Qalqilia</td>
<td>Ramallah</td>
<td>495</td>
<td>524</td>
<td>-18.9</td>
</tr>
<tr>
<td>Salfit</td>
<td>800</td>
<td>28</td>
<td>32.7</td>
<td></td>
</tr>
</tbody>
</table>

$Y_o$ = Observed Weekly Ridership Demand
$Y_p$ = Predicted Weekly Ridership Demand
Percent Difference = (Predicted demand - Observed demand) / Observed demand
Conclusions and Recommendations

While bus ridership demand modeling has been well established in many developed countries, such efforts are nonexistent in the West Bank. Therefore, this is the first effort in analyzing existing intercity bus services and predicting future demand.

Based on the results of an intercity bus ridership analysis, ridership demand was derived from socioeconomic data and internal intercity service data using the multiple linear regression analysis.

A survey of riders, such as an on-board survey, is helpful in identifying primary variables influencing ridership. The factors that most influence intercity ridership for the study routes were origin and destination city population, percent of employees and students, and bus fare.

Riders reported that the number one reason for riding a bus was cost and the highest two problems with riding a bus were its high number of stops and waiting times. Furthermore, the overwhelming majority of trip purposes was educational and work.

It is natural that population and, thus trips, will increase in the future. Therefore, the transportation planning process should focus serious efforts on directing trips to public transportation.

This type of research cannot be feasible nor worthy as itself without the coordination with relevant authorities and decision-makers in considering the results and recommendations of this research.

Bus companies should explore providing express intercity bus service during peak periods to attract more riders such as students and employees who would like to arrive at work or classes on time.

Transportation planners and bus companies should investigate employing pricing policies to increase public transportation riders, especially daily commuters by offering weekly, monthly, or seasonal fare cards or special fares for specific groups such as students. The economic feasibility for the previous recommendations should be investigated.

Furthermore, this study was conducted with limited data and financial resources. For similar future studies, it is recommended that databases with more detailed information about trips involving other transportation modes (shared taxi and private cars) be included. It is also recommended that future research include the Gaza Strip and southern districts of West Bank.
References


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Subregional Governance of Bus Services: An Integrated Study

Xueming Chen, California State University, Northridge

Abstract

As one type of transportation governance model, subregional governance of bus services intends to improve customer responsiveness and cost effectiveness of bus service provision, with economic, political, and operational impacts.

This article compares merits and demerits of three alternatives of subregional governance: transferring bus services to local municipal operators, transferring bus services to local transportation zones, and reorganizing transit operations into bus service sectors. Los Angeles County’s Foothill Transit, is an example of a successful local transportation zone. Authorities are now in the process of creating bus service sectors. While a promising venture, the system is still in its infancy and lacks actual performance data.

Though an optimal subregional governance model fitting every circumstance does not exist, a mixed alternative balancing regional interests and local interests, and reconciling the conflicts among different governance models seems feasible.

Introduction

As an integral component of transportation governing strategies, subregional governance of bus services has become a popular planning strategy in the U.S. transit industry. For example, large and politically complicated metropolitan areas, such as New York, Los Angeles, Chicago, and San Diego, have embarked on subregionally
governing their bus services. This is not coincidental. Governance sustainability has been regarded as one of the prerequisites for achieving transportation sustainability (Schipper 2002). Yet, how to govern a particular transportation system to ensure its customer responsiveness and cost effectiveness is still debatable.

In its very essence, subregional governance represents one type of decentralized governance model, aiming at remedying flaws existing in the centralized governance model. The extent to which a decentralized or a centralized governance model is ultimately successful or not depends on many factors, including area geographic size, local political complexity, demographic characteristics of transit riders, operating characteristics of transit operators, economies of scale, and others. There is no universally applicable governance model fitting each particular circumstance.

This article describes an integrated study of subregional governance of bus services by using the Los Angeles County bus system as an empirical example. Research results reveal the existence of different trade-off options in undertaking subregional governance of bus services, and the preference of establishing a mixed alternative balancing regional interests and local interests, and reconciling conflicts among different governance models.

**Research Methodology**

A case study of subregional governance of bus services in Los Angeles County was conducted, through which economic, political, and operational impacts of this planning strategy can be assessed, and different subregional governance alternatives can be compared. The Los Angeles County case study may shed light on some of the issues associated with this planning strategy.

This article begins with a discussion of the literature review conducted to define the concept of governance, and summarize previous research findings. It then elucidates the rationale of subregional governance of bus services supported by the U.S. public transit data. Next, different alternatives and options of subregional governance of bus services as experimented in the United States are described and compared. This is followed by the case study of subregional governance of bus services in Los Angeles County, and an analysis of its key issues. The article concludes with a summary of research findings and suggested guidelines for further policy analysis related to transit service delivery systems.
Literature Review

Conceptual Definition of Governance

There is no universally agreed on definition of the concept of “governance.” Lowery (2002) shrugs off the concept of “governance” to be “one of those concepts like development or democratization that is so broad as to defy easy capture.” Nevertheless, it is still necessary to go over several key definitions to guide this study.

According to Lynn, Heinrich, and Hill (2000), “governance generally refers to the means for achieving direction, control, and coordination of wholly or partially autonomous individuals or organizations on behalf of interests to which they jointly contribute.”

Keohane and Nye (2000) define “governance” to be “the process and institutions, both formal and informal, that guide and restrain the collective activities of a group.” The nation-state is the primary instrument of domestic and global governance.

Williamson (1999) defines the concept of “governance” as “the means by which order is accomplished in a relation in which potential conflict threatens to undo or upset opportunities to realize mutual gains.”

Peters and Savoie (1995) note that “the root word for governance, and also for government, refers to steering...ability of human institutions to control their societies and their economies.” Governance has something to do with the political system, or the “state,” which is the mechanism selected to provide collective direction to society. By employing its right to issue laws, its capacity to tax and spend, and its power to use coercion legitimately, the political system can attempt to shape the society in the ways desired.

Therefore, the concept of “governance” is closely related to management, coordination, public administration, and others. The narrowly defined concept of “governance” is connotative of the “state” functions of government agencies. But, the broadly defined concept of “governance” refers to both public and private guidance and coordination.

Governance can either be centralized or decentralized in terms of its actual operating mode. Subregional governance of bus services referred to in this article represents one type of decentralized governance model, which intends to provide an alternative to the centralized governance model by rendering more responsive customer services with more local controls.
Research Findings on Subregional Governance

Lynn, Heinrich, and Hill (2000) argue that “if policy makers and public managers are to decentralize program operations and bring services closer to the people who are served, they must know how to ensure accountability and good practices across diverse service units in dispersed locations.” More specifically, how much formal control should be retained by authoritative decision-makers and how much should be delegated to subordinates and officers? How do the answers to this question vary across political and professional contexts? How can dispersed governance regimes be induced to converge on the achievement of particular policy objectives? These issues are directly relevant to the subregional governance of bus services examined in this article.

From the perspective of Deb, there are two main global trends in the restructuring of public transport. The first is to unbundle the monolithic and integrated services into more manageable and compact constituent units. The second trend is to segregate policy and planning from operational functions (Deb 2002). These two trends exactly reflect the purposes of subregional governance of bus services, under which headquarter agency will be responsible for setting policies and undertaking planning activities, whereas subordinate units will assume operational responsibilities.

Two consultant studies are directly related to this research topic: “Subregional Governance of MTA Services” prepared by Booz-Allen & Hamilton, Inc. and others in June 1998; and “Subregional Government Alternatives Study” prepared by Weslin Consulting Services in November 2000. The Booz-Allen & Hamilton report analyzes bus service divestiture priorities, stakeholder interests in divestiture, potential community impacts, cost and revenue implications, legal implications, and service delivery issues of different subregional governance alternatives. As a new task of the Southeast Bus Restructuring Study conducted for the Los Angeles County Metropolitan Transportation Authority (MTA), the Weslin Consulting report identifies six alternatives with a comparison of their advantages and disadvantages: (1) status quo; (2) MTA partnership; (3) partnership with included municipal operators; (4) joint powers agreement; (5) Southeast Community Development Corporation serves as lead agency; and (6) create a transportation zone. However, the report did not give any recommendations.
Based on the above literature review, this study unfolds a comprehensive research probing the major issues and alternatives associated with the subregional governance of bus services, using the Los Angeles County bus system as an empirical case.

Rationale of Subregional Governance of Bus Services
For bus services in a large and politically complicated geographic area, a subregional governance planning strategy will generate significant impacts as discussed below.

Economic Impact: Improve Economies of Scale
The 2000 National Transit Database (NTD) maintained by the Federal Transit Administration (FTA) includes audited cost and operational data on more than 341 North American transit service providers, which is indicative of trends and patterns of the U.S. transit industry.

As indicated in Table 1, across the 341 bus transit operators reporting on the 2000 NTD, cost per hour of service increases, on average, with the size of the peak bus fleet. This reveals the existence of diseconomies of scale in transit service provision. Cost per bus hour of service consists of such components as operations labor and services, materials and fuel, overhead, finance, security, customer relations, and others.

Table 1. Municipal Bus Transit Operating Cost per Hour by Peak Bus Fleet Size


<table>
<thead>
<tr>
<th>Peak Bus Fleet Size</th>
<th>Transit Operating Cost per Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–50</td>
<td>$57.86</td>
</tr>
<tr>
<td>51–250</td>
<td>$67.62</td>
</tr>
<tr>
<td>251–500</td>
<td>$83.48</td>
</tr>
<tr>
<td>501–1200</td>
<td>$85.40</td>
</tr>
<tr>
<td>&gt;1200</td>
<td>$97.81</td>
</tr>
</tbody>
</table>
Compared to a large transit operator, a small transit operator typically has a relatively weak union representing its contracted workers. Consequently, a small transit operator tends to have a lower bus driver wage rate. Bus driver wage rate is also affected by other factors, including the local cost of living and historical salary levels. For example, in 1997, the Los Angeles County MTA, with a bus fleet of 2,350, had a top bus driver wage rate of $19.61 per hour. In the same year, Foothill Transit in Los Angeles County, with a bus fleet of 287, had a top bus driver wage rate of as low as $12.21 per hour. Evidence suggests that a large transit operator tends to be more bureaucratic with a less efficient and a less flexible transit service delivery system, which results in a higher total operating cost. In 1997, MTA had a top systemwide cost per bus service hour of $98 per hour; Foothill Transit had a much lower top systemwide cost per bus service hour of $58 per hour (Booz-Allen & Hamilton Inc. et al. 1998).

Subregional divestiture or governance of bus services would presumably reduce bus fleet size for each new operating unit, which would improve the overall economies of scale and reduce the total systemwide bus operating cost.

Additionally, other impacts are central to this process, including the following political and operational impacts.

**Political Impact: Strengthen Local Control**

Subregional governance may increase the degree of local control over transit policy, planning, and service delivery, thus harmonizing the relationship between a regional transit operator and its local jurisdictions.

A regional transit operator would gain more political support from local jurisdictions by implementing subregional governance strategies. Local support and participation is vital to adopting regional transportation plans, implementing transportation projects, and achieving transportation sustainability.

**Operational Impact: Improve Transit Operation**

Subregional governance of bus services may better meet bus rider needs and expectations for safe, quality bus transit services at a reasonable fare.

Since the primary purpose of subregional governance is to improve local bus operations and customer satisfaction, it may have the potential risk of disrupting regional bus operations and causing inconsistent bus operating schedules, transfer connectivity, and fare media acceptance among different subregional transit operators. Therefore, regional interests and local interests should properly be bal-
anced. Only through a concerted and coordinated action among regional transit operators and subregional transit operators will the subregional governance of bus services maintain and improve the level of transit service integration, and accommodate seamless travel between and among alternative transit service providers. As a result, the overall cost of providing bus transit services would be lower, and the effectiveness of scarce resources would be enhanced.

**Alternatives of Subregional Governance of Bus Services**

There are many alternatives to subregional governance of bus services. Each alternative has advantages and disadvantages. This section introduces and evaluates three broad types of subregional governance strategies with different options, as shown in Figure 1.

**Figure 1. Subregional Governance of Bus Services Evaluation Flow Chart**
**Transfer Certain Bus Services to Existing Municipal Transit Operators**
This alternative would transfer certain bus services from a regional transit operator to several smaller municipal transit operators, as shown in Figure 2.

**Figure 2. Transfer Bus Routes from Regional Transit Operator to Municipal Transit Operators**

A couple of options may exist:

- **Option 1**: The regional transit operator only transfers local community and connector services to municipal transit operators, while retaining core regional services for itself, provided there exist three tiers of transit services: Tier 1—Regional service; Tier 2—Community service; and Tier 3—Connector service.

- **Option 2**: Municipal transit operators can freely choose bus routes of any tiers to be transferred, and the existing regional transit operator only fills in “white spaces” (i.e., operate whatever bus routes are left).

- **Option 3**: The regional transit operator transfers high-cost, low-use bus routes to municipal transit operators to improve the overall bus system efficiency and effectiveness. Some poor-performing bus routes could become good routes to be transferred.
For each option, municipal transit operators would impose certain conditions, especially funding conditions, before accepting divested bus routes from the regional transit operator. Table 2 shows the merits and demerits of each option. Option 1 is superior to both Options 2 and Option 3. In actuality, the mixed option may be chosen, under which the regional transit operator would retain core bus services while transferring some inefficient local bus routes to municipal transit operators.

Table 2. Merits and Demerits of Transferring Bus Services to Municipal Transit Operators

<table>
<thead>
<tr>
<th>Options</th>
<th>Merits</th>
<th>Demerits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option 1</td>
<td>Represents a delicate balance between maintaining regional transit service continuity and improving local transit service efficiency.</td>
<td>The boundary between regional service and local service is sometimes fuzzy.</td>
</tr>
<tr>
<td>Option 2</td>
<td>Municipal transit operators can freely choose bus routes that most benefit local communities and eliminate duplications with existing local bus routes run by the regional transit operator.</td>
<td>The regional transit operator will largely lose control over the entire bus operation. Furthermore, existing municipal transit operators wish to retain their local identity and are generally interested in services within or close to their service areas, or connecting their service areas with major trip attractors (e.g., downtown), which may disrupt regional bus services.</td>
</tr>
<tr>
<td>Option 3</td>
<td>Dramatically reduce bus operating costs and improve bus operating efficiency.</td>
<td>Existing municipal transit operators cannot afford to run those most costly bus routes without immediate funding provided by the regional large transit operator. So, there is likely a limit to the amount of bus service which can be reasonably divested under this option.</td>
</tr>
</tbody>
</table>
Transfer Certain Bus Services to Existing or New Transportation Zones

The Los Angeles County MTA stipulated the following four guiding principles for creation of a transportation zone (Los Angeles County MTA 1999):

- Improve the cost effectiveness of providing transportation services in Los Angeles County
- Increase local control of transportation services
- Increase the amount of transportation services in Los Angeles County
- Preserve other transit services in the County

As shown in Figure 3, this transportation zone alternative has two options.

- Option 1: Expand the existing transportation zone boundary and transfer some bus routes from the regional transit operator to the existing transportation zone.
- Option 2: Establish new zone(s) in the appropriate area to receive new bus routes to be transferred from the regional transit operator.

The merits and demerits of these two options are summarized in Table 3.

Figure 3. Transfer Bus Routes from Regional Transit Operator to Local Transportation Zones
Table 3. Merits and Demerits of Expanding or Establishing Transportation Zones

<table>
<thead>
<tr>
<th>Options</th>
<th>Merits</th>
<th>Demerits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option 1</td>
<td>Existing transportation zone has its track record and reputation in providing a good transit service with a lower cost. This makes it easier to convince adjacent areas to join the transportation zone. Compared to each individual transit operator, zones may better be able to take responsibility for a fairly large proportion of bus services to be transferred from the regional large transit operator, and has reasonable economies of scale.</td>
<td>Existing transportation zone expansion may be constrained by the geographic politics, thus being unable to form the regionwide subregional governance framework.</td>
</tr>
<tr>
<td>Option 2</td>
<td>Integration of several municipal transit operators to establish several new geographically based transportation zones may help form the regionwide subregional governance framework.</td>
<td>Need a consensus-building process among local municipal transit operators to form the transportation zone, which is the Joint Powers Authority (JPA). There may exist conflicts between each transit operator's interests and entire zonal interests Need to follow the complicated transportation zone application procedures.</td>
</tr>
</tbody>
</table>
Decentralize Bus Services without Divestiture while Enhancing Local Control

Both transferring bus routes to municipal transit operators and to transportation zones would carve out existing bus routes from the regional transit operator, which may potentially disrupt existing bus services. Both approaches represent a complete local micro-level control, running the potential risk of sacrificing a regional macro-level control.

To avoid this situation, a compromising alternative emerges. This alternative would reorganize and decentralize existing transportation services under the purview of the regional transit operator into different service sectors. Each service sector is a semi-autonomous unit with more local control and authority delegated from the regional transit operator. Jurisdictionally, each service sector still belongs to the regional transit operator. Under this decentralized governance model, the regional transit operator will be responsible for providing regional transit services and setting agency-wide transit operating policies, whereas service sectors will provide local connector and community transit services at their discretions, and meet local communities’ various transit demand. See Figure 4 for the conceptual framework.

Figure 4. Decentralize Bus Service Operation Through Establishing Bus Service Sectors
Therefore, this alternative only changes the intra-agency governance model without transferring bus routes out to either municipal operators or transportation zones. The evaluation of this alternative is shown in Table 4.

**Table 4. Merits and Demerits of Establishing Service Sectors**

<table>
<thead>
<tr>
<th>Options</th>
<th>Merits</th>
<th>Demerits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service Sector</td>
<td>Improve local control without losing regional control. Keep existing integrated bus service delivery system intact without divesting bus services.</td>
<td>Initial costs incurred will be higher due to hiring or reshuffling additional transit managers and staff, and setting up service sector offices. How to delegate authority to each individual service sector remains a big challenge. Cannot fundamentally solve the diseconomies of scale problems due to the same agency-wide uniform policies on bus driver wage rates, work and compensation packages, and other nonlabor cost charges.</td>
</tr>
</tbody>
</table>
Evaluation
Tables 2 through 4 suggest that each alternative has its merits and demerits, which are evaluated primarily from the standpoint of bus operation. In fact, each alternative has its distinctive community impacts, cost and revenue implications, legal implications, and operations and service delivery issues. From a pure technical standpoint, it is difficult, if not impossible, to select the best alternative of subregional governance of bus services, because many impacts are hard to be quantified.

In fact, the alternative selection process is highly political. It needs to reflect the political reality and balance competing among different transportation stakeholders. Table 5 lists some potential stakeholders who may have interests in the outcome of any subregional governance alternative selected. Under normal circumstances, a mixed alternative balancing regional interests and local interests will prevail.

Table 5. Primary Stakeholders of Subregional Governance of Bus Services

<table>
<thead>
<tr>
<th>Stakeholder Category</th>
<th>Primary Stakeholders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional transit operator</td>
<td>Bargaining units&lt;br&gt;Board of directors&lt;br&gt;Management and staff</td>
</tr>
<tr>
<td>Municipal transit operators</td>
<td>Fixed route bus operators&lt;br&gt;Transportation zones&lt;br&gt;Formula fund included operators&lt;br&gt;Private sector operators</td>
</tr>
<tr>
<td>Public</td>
<td>Bus passengers&lt;br&gt;Bus riders union&lt;br&gt;Community groups&lt;br&gt;Employers</td>
</tr>
<tr>
<td>Government agencies</td>
<td>Cities&lt;br&gt;Councils of governments&lt;br&gt;County&lt;br&gt;Joint powers authorities&lt;br&gt;State government&lt;br&gt;Federal government</td>
</tr>
</tbody>
</table>
Case Studies of Subregional Governance
This section introduces the subregional governance of bus services being undertaken in Los Angeles County, with a brief reference to the subregional governance of transit services in the other U.S. cities.

Background
In early 1998, the Los Angeles County MTA Board of Directors moved that the agency Chief Executive Officer (CEO) return to the board within 90 days with an implementation plan to divest MTA bus services into subregionally governed bus service providers, or zones.

In response to the MTA board motion, a consulting team led by Booz-Allen & Hamilton Inc. was retained by MTA to perform the technical study. The study report develops and analyzes alternative approaches for divestiture of MTA bus services into subregionally governed operations.

Alternatives of Subregional Governance of Bus Services
The Booz-Allen & Hamilton Inc. team proposed the following five alternatives:

1. Expand and leverage the role of existing transit operators.
2. Increase the geographical coverage of the existing Foothill Transit Zone.
3. Add additional local transportation zones where interest and capability to meet guideline requirements exist.
4. Subcontract appropriate individual MTA operating divisions, and provide additional local autonomy.
5. Develop subregional bus service delivery boards within the overall MTA structure to provide greater local control over bus services while maintaining some regional policy control at the MTA Board of Directors level (e.g., fares, aggregate budget).

Each alternative involves different bus service divestiture priorities, stakeholder interests, community impacts, cost and revenue implications, legal implications, and operations and service delivery issues.
Reasons Why the Original Concept of Transportation Zones Was Abandoned

Implementing the concept of transportation zones represents complete local control by carving out transportation zones from the MTA bus service area. This “draconian” approach would unnecessarily be destructive to the agency and painful for its employees. Furthermore, if MTA completely gives up control over countywide bus operation, provision of regional transit service and enforcing consent decree may be problematic. The countywide guidance, steering, and coordination of bus services among different local transit operators may be undermined, as the result of establishing transportation zones. Therefore, the original concept of transportation zones was abandoned.

Culmination of Subregional Governance: New Service Sector Plan

The MTA is currently in the process of reorganizing its countywide transit operations into five geographically semi-autonomous service sectors (i.e., San Fernando Valley/North County, San Gabriel Valley, Gateway Cities, South Bay, and Central Cities/West) in Los Angeles County. See Figure 5 for the geographic boundaries of the service sectors.

Figure 5. Bus Service Sector Boundaries in Los Angeles County
The objectives of the service sector concept are multifold (Metro Investment Report 2002):

- reduce costs while improving the quality of customer service
- respond quickly to community needs
- improve the performance and appearance of buses, and increase ridership with existing resources. As a result, the MTA can be more responsive to customers and to the community when responsibility and accountability are placed at the local level
- reorganize into service sectors to foster improvement in service quality and allow employees to be more creative in shaping and operating service

Highlights of this new service sector concept include:

- The MTA headquarter will have sole responsibility for operating such regional transit services as Metro Rail, Metro Rapid Bus, and express bus service (i.e., Tier 1 transit service).
- The countywide Tier 2 and Tier 3 transit operations (local customer service) and the designated Tier 1 transit operation will be provided by service sectors.
- Service sectors will operate as semi-independent units of the MTA with capabilities similar to a municipal operator. In addition to the staff assigned to bus operations, a service sector would have administrative and community outreach employees, service planners and schedulers, security and other support personnel.
- Utilize existing bus capacity not to exceed 500-600 buses per service sector.
- Collocate management, customer-focused, support functions at service sector operating bases within local communities served.
- Establish new relationships with reinvented MTA corporate support functions.
- Each service sector has its own general manager and council or governing board.
- Managing locally, recruiting locally also meld into the MTA’s belief that strong community involvement is essential if service sectors are to be responsive to their customers.
Table 6. Responsibilities of Headquarter and Subordinate Units

<table>
<thead>
<tr>
<th>Level of Authority</th>
<th>Responsibilities</th>
</tr>
</thead>
</table>
| MTA Board of Directors (Headquarter)| • Retaining the authority to hire the Chief Executive Officer and other board appointees;  
• Approving the agency budget and capital plan;  
• Negotiating collective bargaining agreements;  
• Setting fare and service policies;  
• Establishing and monitoring agency programs;  
• Conducting public hearings for fare changes and service changes to corporate bus lines, rapid bus, and rail service;  
• Conducting major procurements;  
• Managing construction projects, setting regional policies, and having ultimate responsibility for resolving disputes regarding agency matters;  
• Being responsible for administering all banking, investing, and debt issuance. |
| Sector Governance Council (Subordinate Unit) | • Approving the sector General Manager’s budget proposal for the Chief Executive Officer’s consideration and recommendation to the MTA Board;  
• Calling and conducting public hearings for sector bus lines;  
• Approving and evaluating sector programs;  
• Implementing service changes;  
• Reviewing and developing policy recommendations for MTA Board approval;  
• Ensuring compliance with all MTA policies and procedures and legal agreements (e.g. collective bargaining agreements, consent decree). |
On September 26, 2002, the MTA Board of Directors formally adopted the proposed policy creating the Service Sector Governance Councils. This policy stipulates the distinctive functions assumed by the MTA Board of Directors (Headquarters) and the Service Sector Governance Councils (Subordinate Units), see Table 6 for details. This distinction is very important to better understanding the subregional governance of bus services in Los Angeles County. Due to their recent inception, no performance data of five service sectors is currently available.

The Los Angeles new service sector plan of bus services has followed similar experiments in the other U.S. major cities.

For example, the New York Metropolitan Transportation Authority is comprised of a central “umbrella” agency with a 20-member board that does not operate any services and six “subsidiaries” whose boards are subsets of the members of the central board, including:

- New York City Transit operating buses and rapid transit in the New York Boroughs
- Long Island Railroad operating commuter rail from Eastern suburbs into New York City
- Metro-North Railroad operating commuter rail from Northern suburbs into New York City
- Long Island Bus operating bus services in central Long Island
- Staten Island Railway operating rapid transit rail services on Staten Island
- Bridges and Tunnels operating highway and bridge toll facilities into New York City

The Northwestern Illinois Regional Transportation Authority is also an “umbrella” agency. Its 14-member board oversees finances and budgets for Chicago area services, which are governed by three other independent boards of directors including:

- Chicago Transit Authority operating in the City and County with a 7-member board
- METRA operating commuter rail services for the region also with a 7-member board
- PACE operating bus services in the surrounding suburbs with a 12-member board
The San Diego Metropolitan Transit Development Board with a 15-member board oversees an amalgam of private and public service providers, two of which (San Diego Transit Corporation and San Diego Trolley Inc.) have separate 7-member boards.

**Summary of Findings and Guidelines for Policy Analysis**

In spite of many research efforts already made, subregional governance of bus services still has several unresolved issues worth further researching.

**Regional Governance versus Local Governance**

Whether a particular type of bus service should be regionally governed or locally governed is still disputable. Typically, the regionally significant bus routes (e.g., express bus, rapid bus) should be run by the regional transit operator. Eligible regionally significant bus routes may need to meet several criteria, such as (Los Angeles County MTA 1999):

- the line must travel between two or more subregions
- have a high percentage of passengers making longer trips
- have a high percentage of interaction with other bus routes
- have a relatively higher ridership
- have the propensity to offer relatively faster bus speeds
- have the potential for limited stop service

If the regionally significant bus routes have very poor benefit/cost ratios, should they simply be divested, restructured, or entirely eliminated? Intercommunity and local bus routes may be good candidates for subregional governance due to the nature of their local service coverage. Care must be taken to ensure that the connectivity to other regions not be impaired. Otherwise, people who travel between subregions may find their mobility worsened, and their travel times may be lengthened due to lack of adequate schedule connections with other bus service. To further strengthen regional connectivity after implementing subregional governance, uniform fare system should be implemented to integrate different transit operators and allow travelers to have smooth transfers among different bus routes.

**Most Efficient Bus Fleet Size for a Transportation Zone**

According to the 1999 Local Transportation Zone Guidelines of the Los Angeles County MTA, a transportation zone is defined as a geographically contiguous area
with at least one major trip generator and more than half of all routes to be transferred to the zone have an average transit trip length of less than five miles.

The boundary of a transportation zone is determined based on such factors as travel patterns, geographic barriers, demographic characteristics, historical/cultural factors, and political considerations.

However, given a particular set of local conditions, it is unclear what bus fleet size is most efficient for a transportation zone in terms of yielding the highest economies of scale. In developing the Los Angeles bus service sector concept, a 400- to 500-bus fleet size was assumed to be most efficient. This figure may better reflect the existing bus fleet size within each subregion of the County rather than the “optimal” bus fleet size.

**Delegation of Authority from Regional Transit Operator to each Service Sector**

It is critical to determine how much and what types of authorities should reside with the regional transit operator or reside with each service sector. How to coordinate the decentralized transit scheduling and operation process with the still centralized countywide transportation planning process remains a key issue.

Under the bus service sector concept, uniform fare policies are still set by the regional transit operator. Fare structures typically include base cash fare, transfer fare, aged and disabled fare, tokens, and passes. Due to different demographic and socioeconomic conditions among different subregions, uniform fare policies have problems. To promote geographic equity, fare policy setting is suggested to be localized as well. Poor areas should get lower fares, whereas rich areas should be charged a little more to be more equitable.

**Geographically-based Subregional Governance versus Locally-Concentrated Transit Problems**

Since most transit-dependent people live in the inner cities of metropolitan areas, will the countywide transit operation decentralization measure actually improve customer service for inner-city transit-dependent people? The answer is probably no. Instead of evenly decentralizing resources in terms of providing similar bus fleet size among five service sectors, it may be more worthwhile to shift more resources to inner-city service sectors to provide more direct transit services. Suburban travel is auto-dominated with limited transit ridership. In other words, different subregions should receive different priorities in devising subregional governance frameworks due to the uneven distribution of transit-dependent people.
Conclusions

Subregional governance of bus services is a popular planning strategy being implemented in the United States, especially in large and politically complicated metropolitan areas with diverse interests.

On the one hand, properly structured subregional governance of bus services may yield better economies of scale, enhance local control, and improve bus operations to better meet customers' ever-changing demands. But on the other hand, subregional governance of bus services may run the potential risk of causing lack of coordination among subregional transit operators in terms of having consistent bus operating schedules and fare media acceptance policies.

To improve this situation, regional bus services normally reside with the regional transit operator, and the inefficient inter-community or local bus services are transferred to the smaller transit units, in the form of divestiture or decentralization. Though bigger government is not a better government, a small-scale government is not automatically a better government, either. Therefore, the boundary line between regional bus services and local bus services should properly be drawn to determine the appropriate governance model. The uniform fare system should be established to smooth inter-route transfers and inter-agency coordination.

The subregional governance of bus services still has many unresolved research questions (e.g., the threshold between regional governance and subregional governance, most efficient bus fleet size for a transportation zone, distinction between regional governing board authority and subregional governing board authority, and consistency of subregional governance alternatives with the overall suburbanization trend in the United States). These questions still call for further research efforts which may or may not achieve consistent results.
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Developing a Decision Support System for Evaluating an Investment in Fare Collection Systems in Transit

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Abstract

This article presents the initial development of a decision support system (DSS) to assess cost impacts of upgrading or replacing a transit ticketing and fare collection (TFC) system. Assessment of these costs, typically, requires extensive calculations and involves estimation of unknown parameters such as future ridership growth rate, equipment utilization rate, and interest rate on debt financing. This DSS is developed with two categories of policy- and decision-makers in mind—transit agency managers and transit industry researchers and policy-makers.

With the aid of this DSS, a transit manager or analyst is able to specify current TFC system characteristics, select desirable options for a new TFC system, and in a matter of minutes estimate capital costs, forecast operating costs, perform net present value and payback period analyses for alternative TFC systems. This article also presents a prototype TFC DSS including a model base, database, knowledge base, and the Microsoft Excel-based graphical user interface.
Introduction

The concept of decision support systems (DSS) evolved along with the development of computer systems in the 1950s and 1960s. With the advent of inexpensive and easy-to-use personal computers in the 1980s, DSS experienced further development and gained widespread acceptance. Today, DSS are a common tool for managers and other decision-makers in most areas of business, research, and science (Shim et al. 2002).

Being one of the major sectors of the U.S. economy, transportation was among the early adapters of computer technologies. As the use of computing resources in transportation continues to grow, more and more transportation operations and planning activities benefit from the aid of DSS.

Ticketing and fare collection (TFC) systems are one of the major elements of transit infrastructure and, thus, also require comprehensive assessment. Although new fare collection technologies offer increased flexibility in revenue collection, reliability of a TFC system, and convenience to transit riders, implementation of these technologies may require substantial investment on the part of a transit agency (Lovering and Ashmore 2000).

The DSS described in this article is intended to improve the decision-making process associated with upgrading or replacing a transit TFC system. More specifically, the proposed DSS should help a decision-maker to assess capital and operating costs of alternative TFC systems. With the aid of this DSS, a transit manager should be able to specify current TFC system characteristics, select desirable options for a new TFC system, and in a matter of minutes estimate capital costs, forecast operating costs, perform net present value and payback period analyses for alternative TFC systems.

The following section presents a general description of the purpose, structure, and functions of the proposed DSS. It is followed by a detailed description of each module of the DSS. The article concludes with a discussion of a prototype TFC DSS and a step-by-step example of using this DSS in the spreadsheet environment (Buehlmann, Ragsdale, and Gfeller 2000).

General Description of the TFC DSS

The composition of the TFC DSS is similar to that of a generic DSS and consists of four modules: graphical user interface (GUI), database (DB), model base (MB), and knowledge base (KB) (Beynon, Rasmequan, and Russ 2002). The structure and functions of the TFC DSS are illustrated in Figure 1 and further discussed below.
Figure 1. Simulation-Optimization Hybrid Method
The TFC DSS is intended to aid in estimating capital costs, forecasting operating costs, performing net present value analysis, and conducting payback period analysis for alternative TFC systems. Consequently, there are two categories of policy- and decision-makers who can benefit from this DSS—transit agency managers and transit industry researchers and policy-makers.

On the transit agency level, management should find this DSS helpful in TFC budget planning, performing evaluation of TFC improvement projects, and assessment of alternative TFC technologies. The TFC DSS can provide a crude TFC budget estimate for several periods in advance based on a number of forecast variables such as ridership and TFC equipment utilization rates. It can also help in comparing cost effects of TFC improvement projects, although evaluation of such projects is likely to involve more than just a cost analysis. Finally, transit agency managers and planners can apply this DSS to assess the impact of individual TFC technologies on TFC operating costs (e.g., discontinuing the use of certain fare media such as tokens).

On the other hand, transit industry researchers and policy-makers from university transportation centers and organizations, such as the Volpe National Transportation Research Center, American Public Transit Association (APTA), and Federal Transit Administration (FTA), are also likely to find the TFC DSS useful in the following ways:

- to analyze performance of existing and new TFC technologies (as well as various combinations of these technologies) across the transit industry
- to analyze the effect of transit demand, transit mode, and other factors on costs of fare collection
- to determine trends and provide guidance in the development of fare collection systems on transit

As shown in Figure 1, the user of the TFC DSS will need to input three categories of data depending on the nature of the analysis requested. These categories of data include the current transit system performance data, current TFC system characteristics, and desired TFC system characteristics.

The current transit system performance data include transit ridership and TFC operating costs. These data are necessary to conduct various analyses on the transit agency level including TFC budget projections, evaluation of TFC improvement projects, and assessment of the impact of individual TFC technologies on TFC op-
erating costs. Current transit system performance data are not required for industry-wide TFC system analyses since these analyses rely on historic data contained in the database module.

The current TFC system characteristics data include three types of payment media utilization rates (cash, checks, and credit cards), three types of fare media utilization rates (cash, nonelectronic, and electronic), and percent of fare media sold by machine. Again, input of these data is necessary to conduct analyses on the transit agency level since the industry-wide TFC system analyses rely on the historic data contained in the database module.

The desired TFC system characteristics data are of the same format as the current TFC system characteristics data allowing the user to specify the payment and fare media utilization rates, and percent of fare media sold by machine. These data are necessary to conduct analyses on the transit agency level as well as for industry-wide TFC system analyses.

The output of the TFC DSS includes graphs and numeric results relating to estimation of capital and operating costs as well as graphs and numeric results relating to payback period and net present value analyses of alternative TFC systems.

The following sections describe each module of the proposed DSS in greater detail.

**Model Base**

The purpose of the model base module is to store mathematical equations describing relationships between variables and to execute programmatic procedures that perform various types of analyses. The mathematical models and procedures contained in this module include:

- a model describing the impact of transit demand, transit mode, and TFC technologies on TFC operating costs

- a model for calculating capital costs of alternative TFC systems

- a model for conducting payback period analysis that determines how quickly the investment in a new TFC system can be offset by reductions in operating costs associated with the new TFC system

- a model for conducting a net present value analysis that compares capital costs of a new TFC system to reductions in operating costs associated with this system over a certain period of time and takes into account discount and growth rates of the future cash flows
programmatic procedures to access spreadsheet software’s built-in tools to perform various statistical analyses

**TFC Operating Cost Model**

As reported by Plotnikov (2001), TFC operating costs (OC) are influenced by a number of factors including transit system demand, TFC and transit system technologies, labor rules, and fare policy.

\[
TFC\ OC = f(x)
\]

where:

\[
\begin{align*}
x_1 & \quad \text{is transit demand (ridership)} \\
x_2 & \quad \text{represents transit technology (mode)} \\
x_3 & \quad \text{equals TFC technology} \\
x_4 & \quad \text{is fare policy} \\
x_5 & \quad \text{represents labor rules}
\end{align*}
\]

Furthermore, Plotnikov (2001) concludes that TFC OC can be estimated based on the transit system demand, transit mode, and TFC System Technology Index (TFCSTI)—a variable that describes components of a TFC system.

\[
y_1 = b_0 + b_1x_1 + b_2x_2 + b_3x_3
\]

where:

\[
\begin{align*}
y_1 & \quad \text{equals TFC OC} \\
x_1 & \quad \text{represents transit demand (ridership)} \\
x_2 & \quad \text{is transit technology (mode)} \\
x_3 & \quad \text{equals TFCSTI}
\end{align*}
\]

Plotnikov (2001) also presents the structure of the TFCSTI. The index is a weighted sum of scores associated with TFC technology groups (TG) comprising a certain TFC system and can be computed as:

\[
TFCSTI = W_1 \cdot S_{PM} + W_2 \cdot S_{PM} + W_3 \cdot S_{EQ}
\]
where:

\[
\begin{align*}
TFC\,ST & \quad \text{is TFCSTI} \\
S_{PM} & \quad \text{represents payment media TFC TG score} \\
S_{FM} & \quad \text{equals fare media TFC TG score} \\
S_{EQ} & \quad \text{is equipment TFC TG score} \\
W_i, W_2, W_3 & \quad \text{are coefficients (weights) reflecting the relative impact of} \\
& \text{fare media, payment media, and TFC equipment on a} \\
& \text{certain aspect of a TFC system performance.}
\end{align*}
\]

As formulated by Plotnikov (2001), a TFC TG score represents the impact of a group of similar TFC technologies on a particular aspect of TFC system performance (in this case TFC OC). A TFC TG score is computed as a sum of products of utilization rates and weights associated with individual TFC technologies within their group.

\[
TFC\,TG = w_1 \cdot t_1 + w_2 \cdot t_2 + \ldots + w_i \cdot t_i \tag{4}
\]

where:

\[
\begin{align*}
TFC\,TG & \quad \text{is TFC technology group (e.g. fare media) score} \\
t_1, t_2, \ldots, t_i & \quad \text{represents technology utilization rates} \\
w_1, w_2, \ldots, w_i & \quad \text{are individual TFC technology weights}
\end{align*}
\]

Due to lack of comprehensive and uniform data on transit TFC systems in the United States, Plotnikov (2001) recommends the following variables to describe TFC systems: payment media utilization rates (expressed as percent of the total fare revenue paid with cash, checks, and credit cards), fare media utilization rates (expressed as percent of the total fare revenue collected with cash, nonelectronic fare media, and electronic fare media), and percent offare media sold by machines. Once all these variables are specified, individual technology weights, TFC TG scores, and TFC TG weights can be estimated with the aid of regression analysis.
Finally, TFC OC can be forecast based on the specified values of transit demand, transit mode, TFCSTI, and coefficients obtained from regression analysis. The transit demand is measured in unlinked passenger trips (UPT), whereas transit mode is a dummy variable that assumes a value of 0 (for motorbus mode), or 1 (for heavy rail mode).

**TFC Capital Cost Model**

The TFC Capital Cost Model is designed to facilitate the evaluation of cost impacts of investing in an electronic TFC system as opposed to continue using a nonelectronic TFC system. The model should help the user to obtain a crude estimate of investing into a new (magnetic stripe or smart card) system based on the three types of variables:

- range of TFC system capabilities desired and type of TFC equipment necessary to provide these capabilities
- quantity of the equipment required for a given system, and
- unit price of equipment selected

The general form of the capital cost model is presented in equation 5 (Booz-Allen & Hamilton, Inc. 2000).

\[
TCC = [(\epsilon UC_i \cdot q) \cdot (1 + x_{PS} + x_{IC} + x_{ESPM})]/(1 + y_c) \quad [5]
\]

where:

- **TCC** represents total capital costs
- **UC<sub>i</sub>** is the unit cost of TFC equipment <i>i</i>
- **q<sub>i</sub>** equals quantity of TFC equipment <i>i</i>
- **x<sub>PS</sub>** are nonrecurring parts and services costs expressed as percent of the equipment costs
- **x<sub>IC</sub>** are nonrecurring installation and construction costs expressed as percent of the equipment costs
- **x<sub>ESPM</sub>** equals nonrecurring engineering, software, and project management costs expressed as percent of the equipment costs
- **y<sub>c</sub>** represents contingency costs

To utilize the TFC Capital Cost Model, the user first needs to select the desired capabilities of the new TFC system through the GUI module. For example, the user may seek the capability of integrating the agency's fare collection system with other...
transit systems in the region. Next, the user accesses the KB module and specifies the TFC equipment options associated with the desired TFC system capabilities. In the previous example, the user would be required to select smart card fare media and appropriate smart card readers. For each type of TFC equipment, the user enters the quantity of the equipment needed based on the mode, size, and other characteristics of the transit systems. The KB module will assist the user by providing logical cues and ranges of values to ensure that the parameters entered are sensible. For example, the user can be advised to estimate the initial number of smart cards required based on the percentage of the number of unique transit system riders and the number of smart card readers based on the number of vehicles operated in maximum service. Finally, the user can change default values of unit costs corresponding to the equipment selected. The KB module is evoked to provide estimates of TFC equipment unit costs as well as the likely ranges for these values.

Once all types of the required TFC equipment, their quantity, and unit costs are specified, the procedure based on equation 5 is run and the user obtains an estimate of the total capital costs associated with a new TFC system. This estimate can be subsequently used to perform payback period and net present value analyses.

**Payback Period Analysis**

Although the TFC Operating Cost Model and TFC Capital Cost Models can be used separately to estimate operating and capital costs associated with different types of transit TFC systems, they can also be used together to perform payback period analysis or calculate the net present value of a certain investment project. Payback period analysis can be used to evaluate how quickly the investment into a new TFC system can be recovered based on the savings in OC associated with the use of new TFC technologies. The formula for payback period analysis is presented in equation 6 (Ross, Westerfield, and Jaffe 1996).

\[
x = \frac{TCC}{(TFC\ OC_E - TFC\ OC_N)}
\]  

[6]

where:

- \(x\) equals payback period
- \(TCC\) is total capital costs
- \(TFC\ OC_E\) represents TFC OC of the existing system
- \(TFC\ OC_N\) represents TFC OC of the new system
To perform payback period analysis, the user needs to specify all the parameters required for calculating:

- OC of the existing TFC system
- OC of the new TFC system
- capital costs of the new TFC system

**Net Present Value Analysis**

Net present value analysis shows whether the investment in a new TFC system can be recovered based on the savings in OC associated with the use of this system over a specified period of time. Unlike payback period analysis, net present value analysis takes into account the discount rate on the future cash flows as well as the potential growth rate of future cash flows. The formula for net present value analysis is presented in equation 7 (Ross, Westerfield, and Jaffe 1996).

\[
NPV = -TCC + (TFC \ OC_{ek} - TFC \ OC_{kn}) \left[ \frac{1}{(r - g)} - \frac{1}{(r - g)} \times \left( \frac{1 + g}{1 + r} \right)^T \right]
\]  

where:

- NPV is net present value
- TCC equals total capital costs
- TFC \ OC_{ek} reflects TFC OC of the existing system
- TFC \ OC_{kn} equals TFC OC of the new system
- r is the discount rate
- g is the rate of transit ridership growth
- T represents number of periods

To perform net present value analysis the user specifies all the parameters required for calculating: (a) OC of the existing TFC system, (b) OC of the new TFC system, (c) capital costs of the new TFC system, as well as the discount rate of the future cash flows and transit ridership growth rate.
**Access to Spreadsheet Software Built-in Tools**

In addition to the models described above, the model base module contains programmatic procedures that allow the user to access the spreadsheet software built-in multiple regression and optimization tools to perform regression and risk analyses. When the user runs the TFC Operating Cost model in the Microsoft Excel environment, the multiple regression tool from the Data Analysis Plus add-in component is evoked. Similarly, the user can access Excel's Solver add-in component to perform risk analysis with the TFC Capital Cost model, payback period, and NPV analyses. Then, the user can specify the objective function (e.g., total capital costs or payback period), define variable parameters (e.g., equipment unit costs), set the constraints (e.g., quantities of TFC equipment), and evaluate different investment scenarios and outcomes.

**Database**

The database (DB) of the proposed DSS consists of operational and financial data on selected transit agencies in the United States as well as data describing transit TFC systems. These data are used to assess the strength of relationship between a dependent variable (TFC OC) and a set of independent variables (transit demand, transit mode, and TFCSTI) formulated in the model base module. Based on the nature and strength of this relationship, future operating cost of a desired or existing TFC system can be forecast.

The transit operational and financial data include transit agency ID, fiscal year, transit mode, transit demand, and annual TFC OC, and can be obtained from the National Transit Database (NTD). The transit TFC system data include payment media utilization rates (expressed as percent of the total fare revenue paid with cash, checks, and credit cards), fare media utilization rates (expressed as percent of the total fare revenue collected with cash, nonelectronic fare media, and electronic fare media), and percent of fare media sold by machines. Since, currently, there is no reliable source of the specified transit TFC system data available, these data should be obtained directly from transit agencies as described by Collura and Plotnikov (2001).

Tables 1 and 2 present the initial database of the proposed DSS. They build upon the data obtained from a survey of transit agencies conducted by Plotnikov (2001) (numbers in bold typeface denote estimated values). The initial database includes data entries on 15 bus and 9 heavy rail systems for the 1993 and 1998 fiscal years. The database can be accessed, modified, and populated via the GUI module.
Table 1. Historical Database of the TFC DSS (HR Systems)

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<th>Year</th>
<th>NTD ID</th>
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<th>TFC OC</th>
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<th>PM Credit Cards</th>
<th>V M Non-Electronic</th>
<th>V M Electronic</th>
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Table 2. Historical Database of the TFC DSS (MB Systems)

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<th>TFC OC</th>
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Knowledge Base
The knowledge base (KB) of the TFC DSS consists of problem-specific rules and facts relating to a particular transit system, TFC technology, or investment scenario. Information contained in the KB can be grouped in the following categories:

- TFC equipment unit cost averages and ranges
- ridership growth and interest rate averages and ranges
- quantity of TFC equipment selection rules
- type of TFC equipment selection rules

The TFC equipment unit cost averages and ranges support the user information needs for estimating capital costs of a new TFC system. As indicated in [5], the unit cost and quantity of TFC equipment are the major determinants of the total capital costs of a TFC system. Therefore, it is important to provide the user with cost estimates that are as close to those that could be found in the marketplace as possible. In some cases, the user might already have cost quotes on selected types of TFC equipment directly from a vendor or a system integrator in which case the KB information can be used to verify the reasonableness of vendor quotes. Since the TFC equipment unit cost information is time sensitive, it will need to be updated periodically, perhaps, on a biannual basis.

Table 3 presents TFC equipment cost averages and ranges included into the KB module. These numbers are based on the estimates presented to the Greater Washington region transit operators by Booz-Allen & Hamilton, Inc. in 2000.

Another category of the KB information is the ridership growth and interest rate averages and ranges. These rates are necessary to perform net present value analysis of TFC system alternatives. As discussed above, net present value analysis shows whether the investment in a new TFC system can be recovered based on the savings in OC associated with this system over a specified period of time. It takes into account the discount rate on the future cash flows as well as the potential growth rate of future cash flows. In this analysis, the discount rate reflects the cost of borrowing capital invested into the new TFC system and would generally depend on the state of the U.S. economy. In turn, since the investment in a new TFC system is expected to be recovered based on the savings in OC associated with this system and since future TFC OC are forecast based on the future ridership, the growth
rate of future cash flows reflects potential increase or decrease in transit ridership for the given system.

Nominal interest rates (based on three-month Treasury Bills) for the United States over the last two decades varied from about 15 percent in the early 1980s to about 3 percent in early 1990s with the average about 6 to 7 percent. Therefore, the range of interest rates that the user can specify via the KB module is between 3 and 15 percent with the default value of 6 percent.

The transit system ridership data included in the database indicate that average annual ridership growth rates for heavy rail systems for the period 1993 through 1998 varied from −2.95 percent to 5.45 percent with the median value of 2.16 percent. For the motorbus systems, this statistic varied between −4.24 percent and 11.12 percent with the median value of −1.18 percent. Consequently, the range of ridership growth rates that the user can specify via the KB module is between −5.0 and 12.0 percent with the default value of 1.0 percent.
The next category of the KB information contains rules for selecting proper quantities of equipment for a new TFC system. As with the TFC equipment unit cost information, these rules should help the user calculate a gross estimate of the total capital costs associated with a new TFC system. Ultimately, equipment needs and unit costs will depend on the specific functionalities and configuration of a new TFC system as well as the vendor and specific equipment options selected. Table 4 presents allocation parameters for estimating quantities of different types of TFC equipment.

The last category of the KB information contains rules for selecting the proper type of equipment for specified TFC system capabilities. Based on these rules, the user is advised whether a magnetic stripe or a smart card TFC system is required. The TFC equipment selection rules contained in the KB are illustrated in Table 5.

Table 4. TFC Equipment Allocation Parameters

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<tr>
<th>Type of Equipment</th>
<th>Allocation Parameter</th>
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<tbody>
<tr>
<td>Magnetic stripe card (long life)</td>
<td>annual ridership</td>
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<tr>
<td>Magnetic stripe card (1 or 2 uses)</td>
<td>annual ridership</td>
</tr>
<tr>
<td>Smart card</td>
<td>annual ridership</td>
</tr>
<tr>
<td>Smart card initiation device</td>
<td>operator</td>
</tr>
<tr>
<td>Revenue collection vaults</td>
<td>operator</td>
</tr>
<tr>
<td>Mobile bins</td>
<td>operator</td>
</tr>
<tr>
<td>Money room equipment</td>
<td>operator</td>
</tr>
<tr>
<td>Initializing device</td>
<td>operator</td>
</tr>
<tr>
<td>Central data system</td>
<td>operator</td>
</tr>
<tr>
<td>Data reporting system</td>
<td>operator</td>
</tr>
<tr>
<td>Garage data system</td>
<td>operator</td>
</tr>
<tr>
<td>Ticket vending machine</td>
<td>station</td>
</tr>
<tr>
<td>Point of sale device for magnetic stripe card</td>
<td>station</td>
</tr>
<tr>
<td>Point of sale device to recharge smart card</td>
<td>station</td>
</tr>
<tr>
<td>Stand alone validator for magnetic stripe card</td>
<td>station</td>
</tr>
<tr>
<td>Stand alone validator for smart card</td>
<td>station</td>
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<tr>
<td>Bus magnetic ticket processor (stand alone)</td>
<td>vehicle</td>
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<tr>
<td>Bus smart card processor (stand alone)</td>
<td>vehicle</td>
</tr>
<tr>
<td>Hand-held device to read smart card</td>
<td>vehicle</td>
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<tr>
<td>Farebox with smart card reader</td>
<td>vehicle</td>
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<tr>
<td>Smart card reader</td>
<td>vehicle</td>
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Table 5. TFC Equipment Selection Rules

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<th>Desired Capability</th>
<th>Type of System</th>
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<td>Convenience for occasional users</td>
<td>MS, SC</td>
</tr>
<tr>
<td>Time-based pricing</td>
<td>MS, SC</td>
</tr>
<tr>
<td>Distance-based pricing</td>
<td>MS, SC</td>
</tr>
<tr>
<td>Volume discounting</td>
<td>MS, SC</td>
</tr>
<tr>
<td>Usage discounting</td>
<td>MS, SC</td>
</tr>
<tr>
<td>Intermodal transfer</td>
<td>SC</td>
</tr>
<tr>
<td>Multi-operator pricing</td>
<td>SC</td>
</tr>
<tr>
<td>Minimization of fare evasion and fraud</td>
<td>SC</td>
</tr>
<tr>
<td>Increased passenger throughput</td>
<td>SC</td>
</tr>
<tr>
<td>Increased passenger convenience</td>
<td>SC</td>
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</table>

MS - magnetic stripe system
SC - smart card system

Graphical User Interface

The GUI of the TFC DSS features five main screens: TFC DSS Front screen, OC Analysis screen, Capital Cost Analysis screen, Payback Period Analysis screen, and Net Present Value Analysis screen. These GUI screens are presented in Figures 3 through 6 and are briefly described below.

The TFC DSS Front screen (see Figure 2) is the starting point of the TFC DSS. This screen allows the user to input the current transit system performance characteristics and specify existing and desirable TFC system parameters. This screen also offers the user links to the OC Analysis, Capital Cost Analysis, Payback Period Analysis, and Net Present Value Analysis screens.

The TFC OC Analysis screen (see Figure 3) presents forecasts of the existing and new (desired) TFC system OC for the near future in tabular and graphical formats. These forecasts are based on the parameters specified in the front screen of the DSS. The OC Analysis screen also provides links to access historical databases for heavy rail and motorbus modes.
Figure 2. TFC DSS Front Screen

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<td>Current transit system performance</td>
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<tr>
<td><strong>TFC Operating Costs</strong></td>
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<tr>
<td>Ridership</td>
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<tr>
<td>Annual ridership growth rate</td>
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<tr>
<td><strong>TFC Capital Cost Calculation</strong></td>
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<td><strong>Product Period Analysis</strong></td>
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<td><strong>New Analysis</strong></td>
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<table>
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<th>Existing TFC system characteristics</th>
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<td>Payment media</td>
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<td>Checks</td>
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<tr>
<td>Credit cards</td>
</tr>
<tr>
<td>Non-electronic</td>
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<td>Percent of fare media sold by machines</td>
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<td>Cash cards</td>
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<td>Non-electronic</td>
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<td>Percent of fare media sold by machines</td>
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</table>
Figure 3. TFC OC Analysis Screen
The Capital Cost Analysis screen (see Figure 4) allows the user to select desirable TFC system capabilities, estimate nonrecurring costs as percent of total equipment costs, specify TFC system equipment options and quantities, and obtain an estimate for the total capital costs of the system.

**Figure 4. Capital Cost Analysis Screen**
The Payback Period Analysis screen (see Figure 5) facilitates presentation of the payback period analysis outcome in tabular and graphical format based on results obtained from the TFC OC and capital cost analyses.

**Figure 5. Payback Period Analysis Screen**
Finally, the Net Present Value Analysis screen (see Figure 6) shows results of the net present value analysis.

**Figure 6. Net Present Value Analysis Screen**
Summary, Conclusions, and Recommendations for Future Research

This article presents the development of a DSS to assess cost impacts of upgrading or replacing a transit TFC system. This DSS is built with two categories of policy- and decision-makers in mind—transit agency managers and transit industry researchers and policy-makers. On the transit agency level, management should find this decision support system helpful in TFC budget planning, performing evaluation of TFC improvement projects, and assessment of alternative TFC technologies. Transit industry researchers and policy-makers are also likely to find the TFC DSS useful in:

- analyzing performance of existing and new TFC technologies (as well as various combinations of these technologies) across the transit industry,
- analyzing the effect of transit demand, transit mode, and other factors on costs of fare collection, and
- determining trends and providing guidance in the development of fare collection systems on transit.

Although the major focus of this article is on a conceptual framework for financial analysis of TFC system performance, the article also provides details and specifics on the implementation of the TFC DSS in the spreadsheet software environment. To ensure the applicability of the TFC DSS as well as accuracy and precision of its forecasts, the database used in the DSS needs to be expanded and enhanced. Furthermore, it would be desirable to fine-tune the TFC DSS with reliable time-series data from individual transit agencies.
References


Gilcrease, E. 2000. Back office requirements” in Introduction to fare collection: Proceedings of the training seminar. Held in conjunction with the APTA Fare Collection Committee annual workshop in Crystal City, VA. March 19–23.


About the Authors

Parviz Ghandforoush (pghandfo@vt.edu) is professor of business information technology at Virginia Polytechnic Institute and State University. Dr. Ghandforoush has more than 25 years of research, administrative, and professional experience in information technology and management science. He has published extensively in refereed academic and professional publications in the areas of decision and optimization models, DSS in complex environments, sequencing and scheduling, staffing models, and simulation of organizational operations. Dr. Ghandforoush is director of the E-Business Systems Integration Center and managing director of the Master of Information Technology Program at Virginia Tech.

John Collura (jcollura@vt.edu) has more than 25 years of experience in transportation research and education with an emphasis on public transportation planning and management and performance evaluation and the appli-
cation of information based technologies. He also teaches courses in public transit design and operations and in public transit planning and analysis. He is a professor of civil engineering and a Transportation Fellow at the Virginia Tech Transportation Institute. Dr. Collura, a professionally registered engineer, and received his Ph.D. in civil engineering at North Carolina State University.

Valeri Plotnikov (vplotnik@vt.edu) is a research associate at the Virginia Polytechnic Institute and State University. Over the last six years, he has been actively involved in research relating to planning, design, economic, and functional evaluation of Intelligent Transportation Systems. Dr. Plotnikov is an active participant at ITS America, Smart Card Forum, Institute of Transportation Engineers (ITE), Transportation Research Board (TRB), and American Public Transportation Association (APTA) conferences and meetings.
Optimization of Travel in Bus Rapid Transit-Based Multimodal Corridors

Shahriar A. Zargari, Iran University of Science and Technology
Ata M. Khan, Carleton University

Abstract

Frequently, urban transportation infrastructure and services are operated in a suboptimal manner with respect to key policy objectives such as enhancing mobility, avoiding severe congestion, improving public transit ridership, reducing fuel consumption, and emissions. To overcome this problem, a hybrid simulation-optimization methodology was developed for identification of values of demand management variables that result in the most favorable travel condition in a multimodal corridor regarding a policy objective. This methodology was applied to a bus rapid transit-based major travel corridor in Ottawa (Canada). The travel simulation part of the model is implemented within the EMME/2 modeling framework, supported by a transitway simulation technique. The optimization part of the methodology is based on direct search method that identifies the optimal values of key demand management variables for policy responsiveness. Optimization results are presented for bus modal split, in-vehicle travel time, fuel consumption, and greenhouse gas emission.

Introduction

Improved public transit ridership is essential for avoiding severe traffic congestion and reducing fuel consumption and emissions. In urban transportation corridors, public transit services compete with the private automobile to attract and retain
choice riders. Building a rapid transit system (e.g., a bus-based system) and providing lanes on streets for the exclusive use of buses are a step in this direction. However, additional actions, such as travel demand management measures, can be taken to enhance the policy responsiveness of the corridor.

Potentially, bus fare, parking charges, and tolls on freeways can be used to divert a significant proportion of automobile users to public transit, therefore avoiding severe traffic congestion and reducing fuel consumption and emissions. While transit fare and parking charges are traditional measures used in demand modeling, charging tolls on urban freeways is an idea that is gaining momentum in North America (Smart Urban Transport 2002). In planning urban transit services, these three demand management or control variables (i.e., transit fare, parking charge, and toll) can be used to alter modal travel so as to attain policy objectives. From a methodological perspective, the challenge is to find the values of these variables that will, for example, minimize in-vehicle travel time. Likewise, it would be of interest to reduce fuel consumption and greenhouse gas (GHG) emissions.

In the current practice, sensitivity analyses are carried out by making changes to input variables and checking the result. This can be time consuming and there is no guarantee that the optimal value of the objective function can be found by trial-and-error method.

This article describes a methodology that identifies the values of demand management variables for optimizing travel in order to achieve a specified policy objective (e.g., minimization of in-vehicle travel time). The methodology is illustrated for a major corridor in the city of Ottawa (Canada) that features a bus rapid transit as well as a freeway and arterials roads.

**Methodological Framework**

A hybrid simulation-optimization methodology was developed that enables the optimization of travel in a multimodal corridor according to well-defined objectives such as reducing in-vehicle time, improving energy efficiency, reducing GHG emissions, improving air quality, etc. (Figure 1). The travel simulation model was structured by using the EMME/2 software (INRO 1999) and was calibrated for use in the Ottawa (Canada) case study. Government agencies contributed data and other information regarding the transportation network, technology factors, and origin-destination travel.
Figure 1. Simulation-Optimization Hybrid Method
To supplement the capabilities of the EMME/2 software, the following methodologies were developed for use in this research study:

- Transitway simulation technique for estimating travel time and other service quality factors (Zargari and Khan 1998)
- Energy consumption and emission macro (Zargari and Khan 2003)
- An optimization model, based on direct search method, for the identification of the optimal values of key demand management variables

Details of the optimization method are presented in this article.

A sequence of steps is required to achieve the optimal travel condition in response to a specified policy objective:

1. The objective function is to be defined that is to be optimized (e.g., minimizing in-vehicle travel time per pass-km, minimizing fuel consumption per pass-km). Each objective function requires a separate application of the methodology.

2. A set of control variables are to be defined that can potentially alter modal travel demand (e.g., public transit fare, parking charge, highway toll, etc.).

3. A realistic range of values for the control variables is to be specified. For example, the planner may want to exclude such hypothetical cases as “free transit.”

4. The travel demand model in the EMME/2 framework has to be calibrated and initialized.

5. The initial level of service factors (e.g., link level travel time/link average speed) in equilibrium condition have to be calculated by using EMME/2.

6. In a new equilibrium condition resulting from the use of specified values of control variables, corridor travel demand (i.e., person trips for each mode) and its effects (e.g., link travel time, fuel consumption, and emissions) are to be estimated.

7. The objective function is to be quantified on the basis of model outputs.

8. The best values for control variables (which are commonly known as demand management variables) are to be found by using the optimization method. This requires changing values of the control variables, estimating
travel demand and corresponding volumes on links, and estimating impacts. Following the feedback process, the equilibrium condition is attained. The outputs form the basis of the new value of the objective function. This value is compared with its previously calculated value. The design of the optimization model will signal the user to change values of control variables in order to move in the direction of the optimal magnitude of the objective function.

9. The values of control variables that result in the optimal magnitude of the objection function (e.g., minimum in-vehicle travel time per pass-km) are recommended for implementation.

**Optimization Methodology**

For the minimization of an objective function, such as fuel consumption per pass-km, a method is needed to solve the optimization problem. The direct search method, a branch of numerical search techniques, is selected for this purpose (Radin 1998, Nicholson 1971). Functions used in travel forecasting, network performance assessment, and fuel and emission estimation are nonlinear and it is difficult to compute their gradients. This makes use of analytical methods (i.e., nonlinear programming) unfeasible. The direct search method is best suited for functions that do not have a well-defined form. Computing time is not an issue given the capabilities of present generation of computers and the fact that we are dealing with a limited number of control variables (i.e., parking fee, highway toll, and transit fare). Over the years, direct search methods were developed and used successfully, mostly in the telecommunications field.

The direct search method uses the process of systematically evaluating different choices for the control variables. Figure 2 presents the concept of the direct search method. According to its design, the analyst works directly with the objective function by examining values at a series of points, in accordance with a carefully directed search across the feasible region (Radin 1998, Nicholson 1971).
The intent is to minimize a function of \( n \) variables \( f(X) \). The search procedure can be described in terms of base points and temporary positions (Nicolson 1971). The starting point is defined by the initial (i.e., minimum) values of variables specified by the analyst. This is called the first base point, denoted by:

\[
X = B^{(0)} = (b_1^{(0)}, b_2^{(0)}, \ldots, b_n^{(0)}) \tag{1}
\]

Where:

- \( B^{(0)} \) is the first base point
- \( b_1^{(0)}, b_2^{(0)}, \ldots, b_n^{(0)} \) are the initial values of variables
The objective function is estimated at \(B^{(0)}\) and its value is noted as \(f(B^{(0)})\). Then a step length \(\delta_i\) is defined for each variable \(x_i\). This is expressed in the vector \(\Delta_i\) whose \(i\)th component is \(\delta_i\) and all other components are set equal to the minimum values for each variable. The next step is to perturb or change the value of the variable according to step lengths \(+\delta_i\) or \(-\delta_i\). The change can be accepted if it leads to an improvement in the value of the objective function. Following the perturbation of each variable, the new base point \(B^{(1)}\) is reached. According to this method, local perturbations are studied first.

Following the perturbation of the variable \(x_i\) and by using the new base point \((B^{(0)} + \Delta_i - B^{(1)})\), the objective function is estimated at \(B^{(1)}\) and expressed as \(f(B^{(1)})\). If \(f(B^{(1)}) < f(B^{(0)})\), then the point \(B^{(1)}\) is called the temporary position and is designated by \(T^{(0)}_i\). Otherwise, if \(f(B^{(1)}) = f(B^{(0)})\), \(x_i\) should be estimated as \(f(B^{(0)} - \Delta_i)\) (if applicable). If it is less than \(f(B^{(0)})\), this is the temporary position. If no improvement occurs, \(B^{(0)}\) is denoted as the temporary position. Therefore, we can find \(T^{(0)}_i\) from one of the following three relations:

\[
T^{(0)}_i = \begin{cases} 
B^{(0)} + \Delta_i, & \text{if } f(B^{(0)} + \Delta_i) < f(B^{(0)}) \\
B^{(0)} - \Delta_i, & \text{if } f(B^{(0)} - \Delta_i) < f(B^{(0)} - \Delta_i) < f(B^{(0)}) \\
B^{(0)}, & \text{if } f(B^{(0)}) < \min \{f(B^{(0)} + \Delta_i), f(B^{(0)} - \Delta_i)\} 
\end{cases}
\]  

(2)

Now, instead of perturbing the next variable \(x_2\) about the original base \(B^{(0)}\), the temporary position \(T^{(0)}_2\) is used. The \(T^{(0)}_2\) will be computed as the new temporary position. In general, the \(g\)th temporary position \(T^{(0)}_g\) is obtained from \(T^{(0)}_{g-1}\) by the following equation:

\[
T^{(0)}_g = \begin{cases} 
T^{(0)}_{g-1} + \Delta_g, & \text{if } f(T^{(0)}_{g-1} + \Delta_g) < f(T^{(0)}_{g-1}) \\
T^{(0)}_{g-1} - \Delta_g, & \text{if } f(T^{(0)}_{g-1} - \Delta_g) < f(T^{(0)}_{g-1}) > f(T^{(0)}_{g-1} + \Delta_g) \\
T^{(0)}_{g-1}, & \text{if } f(T^{(0)}_{g-1}) < \min \{f(T^{(0)}_{g-1} + \Delta_g), f(T^{(0)}_{g-1} - \Delta_g)\} 
\end{cases}
\]  

(3)

This equation covers all \(g\), \((0 \leq g \leq n)\), provided that we use the convention that \(T^{(0)}_0 = B^{(0)}\).
The approach can be continued for other variables. When all the variables have been dealt with, the last temporary point, \( T_n^{(0)} \), is denoted as the second base point, \( B^{(1)} \) (i.e. \( B^{(1)} - T_n^{(0)} \)). All these moves, which determine the progression from \( B^{(0)} \) to \( B^{(1)} \), suggest a pattern of movement. Next, it can be assumed that the pattern may continue and we start the search for the next temporary position not around \( B^{(1)} \) but at a point \( 2(B^{(1)} - B^{(0)}) \) away from \( B^{(0)} \). Therefore, \( T_0^{(1)} \) can be found as:

\[
T_0^{(1)} = B^{(0)} + 2(B^{(1)} - B^{(0)}) = 2B^{(1)} - B^{(0)} \tag{4}
\]

This means that we are progressing from \( B^{(0)} \) to \( B^{(1)} \) to \( T_0^{(1)} \).

A local search is now required around \( T_0^{(1)} \). The equations for finding \( T_g^{(1)} \) for \( g = 1, \ldots, n \) are the same as those for \( T_n^{(0)} \) with superscript 1 instead of zero. If the final temporary position, \( T_n^{(1)} \), improves the value of the objective function at \( B^{(1)} \), this becomes the new base point.

\[
B^{(2)} = T_n^{(1)} \quad \text{if} \quad f(T_n^{(1)}) < f(B^{(1)}) \tag{5}
\]

If this condition is met, we can take a further “double step” away from \( B^{(1)} \) and go beyond \( B^{(2)} \). Thus, we can find the temporary position \( T_0^{(2)} \) and carry out new exploratory searches around it:

\[
T_0^{(2)} = 2B^{(2)} - B^{(1)} \tag{6}
\]

If this move turns out to be a false move, we have to go back to the previous base point. After continuing this procedure, if there is no improvement, the step length should be changed to a smaller step length than the initial step lengths. The whole procedure should be repeated until the required accuracy is obtained.

An algorithm was developed to formalize the use of the direct search method and it was integrated as a part of the methodological framework shown in Figure 1. Alternatively, direct search algorithms included in the optimization toolbox for use with MATLAB could be considered (Math Works Inc. 2000).
Case Study
The methodology was applied to a major multimodal travel corridor in Ottawa (Canada) for the P.M. peak period. In Ottawa, three major travel corridors connect satellite urban centers with the central business district (CBD) (Figure 3). These corridors feature high volume routes for automobile travel and bus rapid transit service based on the transitway technology (Regional Municipality of Ottawa-Carleton 1997, Nisar and Khan 1992). The eastern corridor was selected as the case study area. The travel demand, infrastructure, and other factors correspond to year 2011. A major highway (i.e., the Queensway), which is a part of the corridor, can be converted into an electronic toll route.

Given Ottawa's multinucleated land-use pattern and the high quality transportation infrastructure already in place, the objective of the research study was to determine the best values of highway tolls, parking charges in the CBD, and public transit fare in order to minimize a specified objective function.

To be helpful in planning demand management strategies, the future year 2011 was used. Since the intent was to make highway tolls a part of demand management measures and recognizing the fact that it takes time to implement this measure, the 2011 horizon was a logical choice. Another reason was the completion of the public transit infrastructure.

The following objective functions were investigated:

- \textit{Minimum in-vehicle time/pass-km}. This objective function reflects the policy objective of enhancing mobility by improving average travel speed.

- \textit{Minimum fuel consumption/minimum GHG emissions}. Given that the GHG emissions are a direct function of fuel consumption, no separate runs were required.

- Minimum air quality pollutants.

A specific combination of a toll charge, parking charge, and transit fare defined as a base point in the direct search method serves as a scenario for demand management. These are the important price variables that can potentially be influenced by urban transportation policy-makers. Prices are expressed in 1999 dollars. The breadth of scenarios tested can be appreciated by examining the range of values of the inputs. For example, average parking charge varies from $2.10 to $7.70 and toll varies from 0 cents to 14 cents/km. A realistic range of bus fares is used, keeping in
Figure 3. Study Area
mind the very heavy government subsidy implications for free transit or offering service at extremely low fare levels.

Travel demand for 2011 was estimated by using the EMME/2 framework and associated models. The focus is on three price types of variables, given that these can be influenced by transportation authorities. All other variables in the demand model are held constant. For the initial scenario, minimum but realistic values of control variables (i.e., parking charges, bus fare, and tolls) were used. Parking charges reflect a weighted average of all types of long-term as well as short-term parking fees paid in central Ottawa. Likewise, bus fare is the weighted average of all types of bus pass and cash fares. Since in the base case, there are no tolls on the highway, toll charge is set at zero. In the application of the optimization method, reasonably refined step lengths for changing the values of variables were used.

The order of presentation of control variable values reflects the operational aspects of the methodology. The sequence of their presentation can be appreciated by looking at the parking charge variable. It starts with $2.10 (lowest value) and gradually increases to the maximum value of $7.70 (in 1999 dollars). From there on, it takes values as required in conjunction with other control variable values. The pattern of other control variables is driven by the values of the parking charge variable.

Owing to space limitation, air quality pollutants are not covered in this article. A brief introduction to calculation of GHG emissions is provided here. As a result of fuel consumption by internal combustion engines, in addition to other emissions, the following notable GHG emissions are produced: carbon dioxide (CO₂), methane (CH₄), and nitrogen oxide (N₂O). The magnitude of these emissions per liter of fuel varies by type of fuel, engine, and emission control technologies. To find the CO₂ equivalent of these gases, equivalency factors are used which reflect their relative long-term greenhouse effect. The equivalency factors are: 1 for CO₂, 21, CH₄, and 310, N₂O (Khan 1999). On the basis of fuel consumed/pass-km, GHG emissions/liter of fuel, and the CO₂ equivalency factors, GHG emissions were computed on a pass-km basis.
Results
Selected inputs and outputs for different applications of the optimization methodology noted earlier are presented as 23 scenarios (Tables 1 and 2).

Table 1.
Modal Split, In-Vehicle Travel Time: 2011 PM Peak Period

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Parking Charge (S/day)</th>
<th>Bus Fare (S/trip)</th>
<th>Toll (Cents/Km)</th>
<th>Modal Split (%)</th>
<th>In-vehicle Travel Time (Sec/pass-km)</th>
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<tbody>
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Notes:  
(1) All dollars are in 1999 constant $.  
(2) Very little variation in in-vehicle times reflects the absence of severe congestion and the performance of bus rapid transit vis-à-vis automobile travel facilities.
Table 2.
Modal Split, Fuel Consumption, and GHG Gas Emissions:
2011 PM Peak Period

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Parking Charge ($/day)</th>
<th>Bus Fare ($/trip)</th>
<th>Toll (Cents/Km)</th>
<th>Modal Split (%)</th>
<th>Fuel Consumption (ml/pass-km)</th>
<th>GHG Emissions (gm/pass-km)</th>
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</table>

Most impacts (i.e., outputs) show much variation. For example, modal share for bus ranges from 34.5 percent to 51.7 percent. Fuel consumption (in milliliters/pass-km) varies from 36.4 to 60.5 ml/pass-km. On the other hand, the in-vehicle travel time (sec/pass-km) shows very small variation in spite of a very high diversion from automobile to bus. These figures suggest that there is an absence of severe congestion in the case study corridor. Also, the bus rapid transit is competi-
tive with high quality automobile travel facilities in terms of in-vehicle travel time. Should this methodology be applied to a highly congested urban area, the in-vehicle travel time may show a different pattern.

Although door-to-door travel time is not reported in this article due to space limitation, a brief comment is offered for the benefit of the interested reader. While the in-vehicle travel times for bus and automobile are comparable, as expected, total (door-to-door) travel time for bus is higher than for the automobile. The out-of-vehicle time components are responsible for this situation.

In relative terms, Scenario 11 is the best for minimizing in-vehicle travel time/pass-km. However, as compared to this scenario, Scenario 14 would result in 14 percent saving in fuel consumption (on a mlitre/pass-km basis) and 13.9 percent reduction in GHG emissions (in gm/pass-km). On the other hand, an increase of about 0.4 percent in in-vehicle travel time (sec/pass-km) occurs (Tables 1 and 2).

As shown in Table 2, Scenario 14 appeared to be the choice as a starting point for further search on control variables that maximize bus ridership and minimize fuel consumption and GHG emissions on a per pass-km basis. Based on selected ranges of values of the variables and step lengths, the direct search procedure was used to develop new scenarios. Scenario 23 was created. Although it shows a marginal increase in bus modal split (a 0.2% gain), the fuel consumption and GHG emissions increase. The reason is that, as compared to Scenario 14, doubling the toll charge in Scenario 23 shifts car traffic from freeway to parallel arterials and results in congested operations. Therefore, Scenario 14 is accepted as the optimal demand management scenario for public transit patronage, fuel consumption and GHG emissions. This scenario represents highly favorable conditions for public transit and yet there would not be hardship for users of other modes. It is also the optimal scenario for minimizing air quality pollutants.

The results shown in Tables 1 and 2 suggest that the demand management instruments used in this research (i.e., bus fare, parking charge, and highway tolls) have a high effect on P.M. peak period bus modal split (34.5% under Scenario 1 to 51.7% under scenario 23). Also, there are significant differences between scenarios in terms of fuel and emissions. Furthermore, it is logical to see that the best values of variables for minimizing fuel consumption and GHG emissions occur when public transit modal split is high.
As compared to scenario 1 (based on minimum values of control variables), Scenario 14 results in 39.8 percent fuel savings (m.litre/pass-km) and 39.6 percent reduction in GHG emissions (g/pass-km).

Thus, in this case study, on the basis of in-vehicle travel time, fuel consumption, GHG emissions, and air quality pollutants as objective functions, scenario 14 can be accepted as the best.

**Implementation Issues**

Urban area policy-makers have to agree on policy objective (or objectives) to be achieved. In most Canadian urban regions, favoring public transit over private automobile use for peak travel in high-density traffic areas is a well-accepted principle. Also, a high priority is being accorded to minimizing fuel consumption and emissions. An objective function favorable to energy, environment, and therefore to public transit is realistic. However, it would be beneficial for planners to see the results of minimizing in-vehicle travel time and to compare these with the public transit priority policy. In general, following the identification of the best scenarios that correspond to various objective functions, multiobjective evaluation methods can be used for the selection of the most preferred scenario.

For practical implementation of demand management instruments, it is necessary to define one set of optimal values of variables for application throughout the urban region. This can be achieved by simulating overall urban level travel and the identification of the optimal scenario. On the other hand, if major corridors are studied independently, their results can be compared and a common set of answers obtained for the various corridors can be used.

Another implementation issue is the transit authority option for a fare level that is different than the “optimal” fare. In such a case, the weighted average fare to be charged can be held fixed and values of other variables can be found from the optimization process.

It is logical to question the mechanism for implementing parking charges when the output from the optimization methodology is a “weighted average” parking charge. The answer to this question is that the proportion of each type of parking (i.e., long-term contracts and short-term parking charges) has to be estimated and then an attempt can be made to influence parking charges of each type (e.g., through special taxes).
Conclusions

Conceptual and methodological contributions are described in this article. These include (a) the concept of the optimal use of a multimodal corridor and the development of an optimization methodology to accomplish this objective, and (b) methodological capability to find the values of the demand management variables for the optimal use of travel corridors in response to a policy objective.

The results of the corridor travel optimization case study are logical and provide insight into the role of demand management instruments. It is clear that there is a role for highway tolls in conjunction with other demand management variables.

Highly significant gains in transit modal share and reduction in fuel consumption and emissions can be achieved as a result of implementing the optimal values of demand management variables.

For the case study corridor, there is a very small difference between the lowest in-vehicle time achievable (Scenario 11) and its value under a scenario highly favorable to public transit, energy efficiency and GHG emission reduction. This implies that in a multimodal travel corridor, bus rapid transit can compete with automobile in attracting choice riders and offering slightly improved in-vehicle travel times. Additionally, bus rapid transit can assist in reducing corridor-level fuel consumption and emissions.

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