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CONTENTS

Evaluating the Congestion Relief Impacts of Public Transport in Monetary Terms

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Abstract

Traffic congestion is a major urban transport problem. Efficient public transport (PT) can be one of the potential solutions to the problem of urban road traffic congestion. Public transport systems can carry a significant amount of trips during congested hours, improving overall transportation capacity, and can release the burden of excess demand on congested road networks. This paper presents a comparative assessment of international research valuing the congestion relief impacts of PT. It explores previous research valuing congestion relief impacts and examines secondary evidence demonstrating changes in mode split associated with changes in public transport. The research establishes a framework for estimating the monetary value of the congestion reduction impacts of public transport. Congestion relief impacts are valued at between 4.4 and 151.4 cents (Aus$, 2008) per marginal vehicle km of travel, with an average of 45.0 cents. Valuations are higher for circumstances with greater degrees of traffic congestion and also where both travel time and vehicle operating cost savings are considered. A simplified congestion relief valuation model is presented to estimate the congestion relief benefits of PT based on readily -available transport data. Using the average congestion valuation and mode shift evidence, the model has been applied to a number of cities to estimate the monetary value of the congestion relief impact of public transport. Overall, the analysis presents a simplified method to investigate the impact of public transport on traffic congestion.

Further research is warranted to develop a comprehensive approach for establishing a measure of the congestion relief impact of public transport.

Introduction

Road traffic congestion is a major urban transport problem (Cervero 1991; Downs 1992). Increasing demand for travel will compound the problem if appropriate solutions are not actively sought. Efficient public transport (PT) can be one of the potential solutions to the problem of urban road traffic congestion (Hyman and Mayhew 2002,;Pucher et al. 2007; Vuchic 1999).

This paper presents a comparative assessment of international research valuing the congestion relief impacts of PT. It explores previous research valuing congestion relief impacts and examines secondary evidence demonstrating changes in mode split associated with changes in public transport. The research establishes a framework for estimating the monetary value of the congestion reduction impacts of public transport. To illustrate findings, a theoretical model is presented where congestion impact evidence is applied to understand congestion relief impacts.

The paper is structured as follows. The next section ¬outlines the methodological approaches adopted in previous research concerning PT and congestion relief impacts. In Section 3, valuations of PT congestion relief benefits are summarized from Australasian, European, and North American research. Section 4 synthesizes the evidence of congestion relief benefits to establish valuations of congestion relief impacts on a common currency and single-year basis. Section 5 reviews mode shift evidence associated with car and public transport. In Section 6, a simplified congestion relief valuation model is presented, and the research findings are illustrated by estimating congestion relief impacts for a number of global cities. The concluding section summarizes the key findings of the paper and provides some suggestions for further research.

Review of Benefit Assessment Methodologies

A range of studies have examined the economic benefits of public transport congestion relief impacts. This section reviews previous research related to the economic evaluation of congestion relief associated with public transport.

A literature review of quantitative approaches for measuring and valuing public transport benefits and disbenefits was undertaken by Cambridge Systematics and

Apogee Research (1996). The review identified three main tools that are central to the assessment of public transport benefits and disbenefits:

- travel demand models
- transport cost analysis techniques
- transport sketch planning and impact spreadsheets

A report by ECONorthwest and PBQD (2002) provided practical methods in the framework of cost-benefit analysis for estimating the benefits and costs of a typical public transport project. The report noted that a public transport improvement affects the user costs of alternative modes due to the interconnected nature of the typical urban transport network. The report suggests that under congested conditions, even small changes in vehicle volumes can have significant effects on the performance of the roadway. Travel time and vehicle operating costs are affected and can be estimated as follows:

- Changes in travel time can be calculated from volume-delay relationships that are embedded in the traffic assignment element of transport planning models. These can be monetized using a standard value of time (as a percentage of standard average wage rate).
- Vehicle operating cost can be estimated from the information provided by motoring organizations (e.g., the American Automobile Association) that perform research calculating the cost of operating automobiles of various types.

Research on the economic implications of congestion was conducted by Weisbrod et al. (2001). Estimation of the economic cost savings for road users (the traditional user impacts) associated with urban roadway congestion reduction can be determined from the difference of user travel time and vehicle operating costs in base and project cases. Their methodology for estimating user travel time and vehicle operating costs can be described in the following steps:

1. Trip Data—It is first necessary to obtain zone-to-zone trips matrices to show the number of trips corresponding to each origin-destination pair of traffic analysis zones (TAZs).
2. Travel Time and Distance Data—Transport planning models typically include zone-to-zone matrices of travel distances and mean travel times. These travel time and distance data together with trip data can be used to calculate vehicles hours of travel and vehicle miles of travel.

3. The components of unit travel costs (costs of driver time and vehicle operating expenses) are obtained from standard sources. Unit cost factors are multiplied by the travel time, distance, and trip data to calculate aggregate user time and expense costs.

The Australian Transport Council (2006) suggests a method for estimating decongestion benefits using the following three elements: (1) an estimate of the quantity of road traffic removed from the road system, (2) an estimate of the change in travel speed (by using a manual approach or a computerized travel demand model), and (3) a value of travel time for car occupants. Their method for estimating decongestion benefits is essentially the same as that in the New Zealand approach (Land Transport New Zealand 2005).

Beimborn et al. (1993), in reviewing the principles and issues for public transport benefit measurement, provided a framework for benefit analysis and described measurement techniques. Their study presented public transport benefits in the form of a benefit tree by dividing the benefits into four main groups (branches) and further subdividing them within four branches:

1. Public transport as an alternative—the value of having public transport available as a possible alternative (i.e., an option value).
2. Travel by public transport—the public transport trips resulting from a shift between auto and public transport and from trips by persons who could not otherwise travel.
3. Public transport and land use—the public transport accessibility that changes property value, preserves open space, affects interaction among people, and affects the efficiency of certain public services.
4. Public transport supply—the presence of public transport as an enterprise that employs people in its operation and construction.

Their study proposed that traffic congestion relief benefits for auto users in terms of travel time savings can be estimated through an enhanced consumer surplus technique. The enhanced consumer surplus can be estimated by using appropriate travel forecasting models in which the trip distribution and model split steps are based upon roadway disutilities that are appropriate for the amount of traffic congestion. The technique measures the decrease in disutility of travel in units of time (i.e., the increase of consumer surplus) for an alternative public transport system as compared to a base system. Again, travel time savings are converted to monetary units by multiplying by the value of time.

An estimation of the congestion reduction effects of public transportation was made in a study of 85 cities (Schrank and Lomax 2005). The report determined the delay benefits by assuming the question "what if all transit riders were in the general traffic flow instead of on public transport?" The additional shifted traffic would clearly increase congestion on the road network. The size of additional roadway traffic was calculated by dividing the number of existing PT users by car occupancy factor. In the 85 North American urban areas studied, approximately 43 billion passenger-miles of travel were on public transport systems in 2003. Ridership ranged from 17 million in the small urban areas to about 2.7 billion in the very large areas. Overall, if riders did not use public transport systems, they were estimated to cause an additional roadway delay of approximately 1.1 billion hours (a 29% increase in delay) at an additional congestion cost of $18 billion (US$, 2005) (Table 1).

Table 1. Delay Increase if Public Transport (PT) Service were Eliminated - 85 Areas

			Delay reduction due to public transport		
Population group (number of areas)	**Annual average travel (millions of pax-miles)**	**Annual delay (millions of hours)**	**Delay reduction (millions of hours)**	**Percent of base delay**	**Saving (US $M)**
Very Large (13)	2,718	2,526	919	36	15,289
Large (26)	233	875	148	17	2,485
Medium (30)	58	288	27	9	444
Small (16)	17	34	2	4	25
Total (85 Areas)	**43,403**	**3,723**	**1,096**	**29**	**18,243**

Nelson et al. (2006) estimated both the total system benefit to PT users and congestion impact to motorists of PT in Washington, D.C. The study used a regional travel demand model and calculated the aggregate welfare change by reducing public transport supply to zero. The decline in traveler welfare minus the savings in operating costs was interpreted as a measure of benefits of the existing system. The study tested three scenarios: eliminating bus and rail separately, and eliminating both modes together. Based on the welfare change estimates and using the "shutting down both modes together" scenario, the study predicted motorists' congestion reduction benefits as $736 million (US$, 2000) annually.

In summary, two principal measurement approaches are adopted in the literature, those based on transport models and those from other indirect approaches. These are summarized in Table 2.

Table 2. Summary of Economic Estimation Methods for Congestion Reduction Impacts of Public Transport

Method	Description
Transport System Model	**Transport system models** are used to simulate and forecast the effects of transport facilities and services on trip generation, mode split, trip routing, travel times and travel costs. The output from the model (the travel time savings in time units) is multiplied by a value of time to quantify the benefits in monetary terms.
Indirect measurement technique	**Indirect measurement techniques** measure the effects of existing transport facilities and service through analysis of historical data/user impacts through surveys of travelers, nearby businesses, or both as well as through secondary data. As an example of the indirect measurement technique: • Increase in road traffic congestion from the cessation of public transport = (The number of passengers diverted to car / Car occupancy rate) * Average motor vehicle trip distance * Estimated road decongestion benefit. • Benefits to motorists who remain in the road system after an improved public transport system = An estimate of the quantity of road traffic removed from the road system * An estimate of changes in travel speed (a manual approach/ a survey) * A value of travel time for car occupants.

Summary of Congestion Relief Valuation Evidence

This section reviews international evidence where public transport decongestion benefits were valued to better understand the range and types of impacts studied.

Australasian Evidence

Congestion relief associated with the provision of Sydney CityRail services was quantified by investigating the cost and benefits associated with the hypothetical cessation of CityRail services (Karpouzis et al. 2007). The study used a second best alternative mode approach. This assumed that journeys would divert from rail to road (about 53% to car, about 42% to bus) and walking (about 5%). A traffic congestion relief benefit of 30.5 cents (Aus$, 2007) per car kilometer and 104.0 cents (Aus$, 2007) per bus kilometer was derived. The study estimated the total cost of additional congestion at $740.5 million p.a. (Aus$, 2007) if CityRail services were removed.

A preliminary study was conducted by Thornton (2001) for the scoping study of a very high speed train in Eastern Australia. This used a road decongestion value of 28 cents per car kilometer (Aus$, 2001) diverted to rail in metropolitan areas.

The Department of Infrastructure, Victoria, in 2005 (cited in ATC 2006) suggests a generalized unit decongestion value of 17 to 90 cents (Aus$, 2004) per vehicle-kilometer (vkm) of reduced car travel. The value covers both time and vehicle operating cost changes.

Estimates of decongestion benefits (the reduced congestion costs experienced by remaining road users due to removal of a marginal vehicle) were made by Land Transport New Zealand (2005). The average congestion cost saving was Auckland NZ$1.190/vkm and Wellington NZ $0.911/vkm. This is adjusted for induced traffic effects.

European Evidence

A procedure for assessing the road decongestion benefits arising from the reduction in car traffic was developed by the UK Department for Transport (2007). This study valued the decongestion benefit as the savings of travel time and other externalities due to the removal of a vehicle kilometer of car travel from a road. The marginal external costs for cars were considered as the decongestion benefits. Decongestion benefits were estimated for "A" (or major) Roads as 53.4 pence (UK£, 2007) per km (including travel time and vehicle operating costs) and 98.4 pence (UK£, 2007) per vkm (including travel time penalty, vehicle operating costs and other externalities such as accidents, noise, infrastructure damage, local air quality and greenhouse gases).

According to Sansom et al. (2001), the congestion benefits of "major-rail based urban public transport" per car-kilometer removed from the road network range from 12.7 to 50.8 pence per PCU-km (in 1998 prices; PCU = passenger car unit).

In his study for estimating congestion costs of Britain, Newbery (1990) used values derived from the marginal congestion cost associated with traffic speed-flow relationships. Marginal congestion cost estimates ranged from 0.26 p/PCU-km for motorways to 36.37 p/PCU-km (UK£, 1990) for urban central peak roads.

Lobe (2002) estimated the congested costs of Brussels by using STRATEC demand models. The model estimated a marginal congestion cost (i.e., the benefits of removing a marginal vehicle from the traffic stream) of 0.09 € per PCU-km (2002).

North American Evidence

Research estimating congestion reduction benefits from reduced vehicle traffic by Litman (2003, 2006) reviewed several measurement methods and proposed an "easier approach." The approach is to assign a monetary value to reduced vehicle travel, typically estimated at 10-30 cents (US$, 1996) per urban peak vehicle-mile, for calculating congestion reduction benefits. Skolnik and Schreiner (1998) used the midpoint of Litman's value (20 cents) for congestion benefit calculation of public transport.

Marginal costs of roadway use studied by FHWA (2000) reflect the changes in total costs associated with an additional increment of travel. The study estimated the congestion costs associated with an additional mile of travel on an urban interstate highway for passenger vehicles as 7.7 cents (i.e., 4.8 cents per kilometer) (US$, 2000).

The average congestion reduction benefits for 85 US cities (Schrank and Lomax 2005) can be estimated as 42.0 cents per mile /26.1 cents per km of reduced auto travel (US$, 2005) by considering 18,243 millions of congestion reduction benefits resulting from 43,403 passenger-miles of public transport travel (Table 1) (a one-to-one relationship has been assumed between auto and public transport passenger miles). Using similar assumptions, the congestion reduction benefits of $736 million (Nelson et al. 2006) for public transport in Washington, D.C., can be interpreted as 20.4 cents (US$, 2000) per km of reduced auto travel.

Synthesis of Congestion Relief Values

Table 3 presents a summary of the evidence presented above. Results have been standardized to comparable terms by adjusting for currency (to Australian dollars) and year of estimate (using Australian CPI indices). Standardized values show a considerable range. Congestion impacts per reduced car km range between 4.4 and 151.4 cents, with an average of 45.0 cents. The highest valuations are associated with "A" roads in Greater London and also for "heavy congestion" in the Melbourne, Australia, context. In both of these cases, travel time and vehicle operating cost impacts have been considered. The lower valuations of congestion relief impacts are associated with Christchurch, UK, motorways and non-major roads of small urban areas, and U.S. urban interstate highways. One possible explanation for low congestion relief benefit values for small urban areas is that they witness a relatively low volume of traffic in comparison to their big counter-

Table 3. Summary of Decongestion Benefit Rates (Values per km of Reduced Auto Travel)

City/Country	Original value/auto vehicle-km	Original year	Standardized value in Australian cents (2008 rate)*	Source	Comments
Melbourne (heavy congestion)	A¢90.0	2004	100.8	ATC 2006	Includes both travel time (TT) and vehicle operating costs (VOC) benefits
Melbourne (moderate congestion)	A¢64.0	2004	71.7	ATC 2006	
Melbourne (light congestion)	A¢17.0	2004	19.0	ATC 2006	Includes both TT and VOC benefits
Sydney	A¢30.5	2007	31.4	Karpouzis et al. 2007	Includes both TT and VOC benefits
Australian Capital Cities	A¢28.0	2001	33.9	Thornton 2001	Includes TT benefit only
Auckland	NZ¢59.5	2002	62.2	LTNZ 2005	Includes both TT and VOC benefits
Wellington	NZ¢45.6	2002	47.6	LTNZ 2005	Includes TT benefit only
Christchurch	NZ¢4.21	2002	4.4	LTNZ 2005	Includes TT benefit only
Urban conurbations (Motorways)	UK 5.7p	2002	16.2	DfT 2007	Includes both TT and VOC benefits (avg. urban peak)
Urban conurbations (A roads)	UK 53.4p	2002	151.4	DfT 2007	
Urban conurbations (Other roads)	UK 26.2p	2002	74.3	DfT 2007	Includes TT benefit only
Other urban areas (A roads)	UK 22.2p	2002	62.9	DfT 2007	Includes TT benefit only
Other urban areas (Other roads)	UK 5.6p	2002	15.9	DfT 2007	
Brussels	0.09 €	2002	17.6	Lobé 2002	
USA	US¢4.8	2000	8.0	FHWA 2000	
USA	US¢12.4	2000	21.8	Litman 2003, 2006	
USA	US¢26.1	2005	36.9	Schrank & Lomax 2005	
Washington, D.C.	US¢20.4	2000	33.9	Nelson et al. 2006	
Average			**45.0**		

*The values of other currencies were converted to Australian cents by using the average of last 5 years' exchange rate of Reserve Bank of Australia (2008) and all values were converted to 2008 terms using consumer price index of Australian Bureau of Statistics (2008).

parts and, hence, the unit congestion relief benefits are less. UK motorways and U.S. urban interstate highways have relatively high capacity compared to roads in urban central areas and, therefore, unit congestion relief benefits are small. Figure 1 illustrates the average decongestion value assuming a simple linear relationship with transit supply.

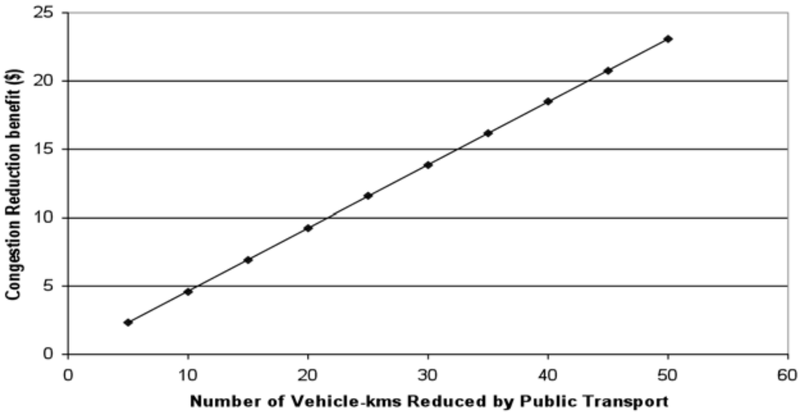

Figure 1. Congestion Reduction Benefit Resulting from Reduction of Auto Vkm Due to Public Transport

Travel Mode Shift Evidence

This section examines revealed and stated evidence where travel behavior acted to change urban traffic congestion in relation to public transport. Its aim is to establish evidence that might better inform the assessment of congestion relief impacts.

Removing Public Transport

Cases where public transport systems have been removed are examined. Van Exel and Rietveld (2001) reviewed 13 studies of PT strikes to determine nature and size of travel impacts. Their study showed that most travelers switch to the car either as driver or passenger (Table 4a). Other travelers switch to alternative modes and some trips are cancelled. Mode shift to car driving was 5 to 50 percent (average 28.6%), mode shift to car lift was 21 to 60 percent (average 29.6%), shift to other modes was 23 to 60 percent (average 39.8%), and trip suppression (stop travelling) was between 5 and 15 percent (average 10.3%).

Table 4. Evidence of Impacts of Removing Public Transport

4a. Effects of public transport strikes

Strike	Year	Spatial scale	PT modes	Trips switched to car		Trips switched to other alternatives	Trips cancelled
				Driver	Pax		
New York	1966	Urban	All	50%	17%	23%	10%
Los Angeles	1974	Regional	Bus	50%	25%	---	---
Leeds	1978	Urban	All	5%	60%	35%	15%
The Hague	1981	Urban	All	10%	25%	50%	5%
Ile-de-France	1995	Regional	All	28%	21%	51%	11%
Average				**28.6%**	**29.6%**	**39.8%**	**10.3%**

Source: HLB Decision Economics (2003)

4b. Alternative transport modes for those individuals who responded they would make the same trip via an alternative mode if public transport withdrawn

Journey purpose	Use other means of transport	Driving car	Sharing car/taxi	Walking, cycling and other
Work	48.0%	10.7%	19.2%	18.1%
Education	48.0%	10.7%	19.2%	18.1%
Healthcare	47.5%	10.5%	19.0%	18.0%
Shopping and recreation	32.7%	7.3%	13.1%	12.3%
Average		**9.8%**	**17.6%**	**16.7%**

Source: HLB Decision Economics (2003)

In a study examining the choices that public transport riders might make, HLB Decision Economics (2003) conducted a survey in Wisconsin. Each individual was asked to indicate how their travel would differ if they did not have access to public transport. The study shows that about 50 percent of public transport users would make trips via an alternative transport mode. Of these, car or taxi would be the likely new mode for about 60 percent. Table 4b summarizes the important elements of the study. The likely mode shift to car driving varied from 7 to 11 percent (average 9.8%), mode shift to car/taxi riding as passengers varied from 13 to 19 percent (average 17.6%), and walking, cycling, and other modes varied from 12 to 18 percent (average 16.7%).

These studies demonstrate a range of variation in mode change behavior if public transport is no longer supplied. Overall, mode shift for car drivers ranged from 5 to 50 percent (average 20.2%) and mode shift for car passengers ranged from 13 to 60 percent (average 24.3%) (Table 5).

Table 5. Summary of Mode Shift for Car Drivers and Passengers

Source	Mode shift (car drivers)		Mode shift (car passenger)	
	Range	*Average*	*Range*	*Average*
Exel and Rietveld (2001)	5%-50%	28.6%	21%-60%	29.6%
HLB Decision Economics (2003)	7%-11%	9.8%	13%-19%	17.6%
Average[1]		**20.2%**		**24.3%**

[1] Average of values appeared in Tables 4a and 4b

Litman (2006) noted specific subsets of those passengers who might decide to get a lift by car. One group does ridesharing (additional passengers in a vehicle that would be making a trip anyway). The other group does chauffeuring (additional auto travel specifically to carry a passenger).

Litman suggested that motorists can spend a significant amount of time chauffeuring children to school and sports activities, family members to jobs, and elderly relatives on errands. Such trips can be particularly inefficient if they require drivers to make an empty return trip. Hence, while ex-public transport users who drive a car clearly have a direct impact on congestion, those getting lifts may also impact congestion if chauffeuring acts to also increase car travel.

Overall, this analysis suggests that removing public transport can result in increased traffic congestion of about a shift of 20.2 percent (Table 5) of public transport to car driving. However, the work of Litman also suggests that ex-public transport users might also generate extra car travel in the form of chauffeuring trips. Little data are available on how many ex-PT users in this context might be involved in chauffeuring trips. For the purpose of our modelling analysis, we assumed that half of all trips transferring to a lift in a car might involve chauffeuring. Hence, on average, based on the results in Table 5, an estimate of 32.4 percent (20.2% car drivers + half of 24.3% car passengers as chauffeuring travelers) or approximately one-third of PT users might act to increase auto travel if the public transport system were removed. This interpretation should be used cautiously, as the proposed value is an average of a wide range of values from different cities of the world. A wide range of methodologies also have been applied to obtaining these values. In addition, public transport strikes manifest short-term effects. In the long term, the estimated percentage might be different because people will adjust their travel behavior to cope with the changed situation (such as trip re-timing, trip redistribution, changes of O-D pattern and travel behavior, etc.).

Improving Public Transport

This section considers evidence of mode shift associated with improvements in public transport. Anlezark et al. (1994) examined mode shift outcomes resulting from the introduction of new Transit Link (express bus services) in Adelaide, Australia. They also compiled evidence from other new public transport initiatives (Table 6a). They report that about 20 percent of users are new to public transport and of these the highest proportion are formerly car drivers. Mode shift from car drivers was from 8 to 23 percent (average 14.1%), mode shift from car passengers was from 1 to 12 percent (average 5.7%), trip generation was from 8 to 12 percent (average 9.8%), and diversion from existing public transport was between 64 and 78 percent (average 68.5%).

Table 6. Evidence of Impacts of Improving Public Transport

6a. Comparison of mode change behavior after the introduction of new public transport services

	Source of Demand				
	Mode Shift				
New Service	*Car driver*	*Car Pax*	**Generation**	**Diversion from PT**	**Redistribution**
Adelaide-Express Bus	8.4%	4.4%	8%	78%	1%
Adelaide-Obahn Busway	13.3%	5.7%	9%	67%	0%
Brisbase Cityxpress	11.6%	11.6%	12%	65%	0%
Perth Northern Railway	23.0%	1.1%	10%	64%	1%
Average	**14.1%**	**5.7%**	**9.8%**	**68.5%**	

Source: Anlezark et al. (1994)

6b. Travel market data for Australasian BRT systems

	Immediate Travel Impacts		
	Direct corridor ridership growth	*% new pax who previously drove*	*% who previously drove as a total of all riders*
Adelaide Busway	24%	40%	16%
Sydney Transitway	56% (47% new journeys)	9%	5%
Brisbane SE Busway	56% (17% new journeys)	26%	15%
Average	**11.9%**		

Source: Currie (2006)

Table 6. Evidence of Impacts of Improving Public Transport (cont'd.)

6c. Prior mode for new public transport riders- fare reduction and service improvement

Location	Prior Mode				
	Auto Driver	*Auto Passenger*	*Walk*	*Other*	*Trip Not Made*
Atlanta	42%	22%	4%	10%	22%
Los Angeles	59%	21%	0%	10%	10%
Average	**50.5%**	**21.5%**			

Source: McCollom and Pratt (2004)

A review of performance of Bus Rapid Transit (BRT) in Australasia by Currie (2006) reveals that introduction of BRT played a significant role in changing travel behavior (Table 6b). BRT passengers who were previously driving is high in Adelaide (40%). Mode shift from car drivers was from 5 to 16 percent (average 11.9%).

A number of studies have sought to understand mode shift impacts from fare reduction and service increase policies in the U.S. (McCollom and Pratt 2004). These studies show diversion from auto ranging from 64 percent of new riders in Atlanta to 80 percent of new riders in Los Angeles. The full range of previous modes of travel is shown in Table 6c. Mode shift for car drivers was from 42 to 59 percent (average 50.5%), mode shift for car passengers was from 21 to 22 percent (average 21.5%).

Again, a range of variation can be observed. Overall, mode shift for car drivers ranged from 5 to 59 percent (average 21.4%), and mode shift for car passengers ranged from 1 to 22 percent (average 11.0%) (Table 7). Passengers who change mode from car driving to transit clearly act to reduce traffic congestion. Considering the view of Litman (2006) that chauffeuring trips act to increase car travel, it might again be assumed that a travel shift from a car lift trip to transit might also reduce car travel. For the purpose of analysis, the data suggest that 26.9 percent of travelers (21.4% car drivers + half of 11.0% car passengers as chauffeuring travelers) on new public transport services might have acted to reduce road travel (Table 7). This is lower than the impact suggested for removing public transport (32.4%). A higher impact for removing transit systems compared to improving seems intuitively reasonable. Withdrawal of PT means users have no choice but to make a change in behavior. Improvements leave an element of user choice in deciding travel options and will largely depend in scale on the size of improvements being made. Figure 2 illustrates this relationship as a simple linear model based on this relationship.

Table 7. Summary of Mode Shift for Car Drivers and Passengers

Source	Mode shift (car drivers)		Mode shift (car passenger)	
	Range	*Average*	*Range*	*Average*
Anlezark et al. (1994)	8%-23%	14.1%	1%-12%	5.7%
Currie (2006)	5%-15%	11.9%	---[3]	---[3]
McCollom and Pratt (2004)	42%-59%	50.5%	21%-22%	21.5%
Average[2]		**21.4%**		**11.0%**

[1] Average of values appeared in TABLE 6 a, b and c
[2] Data unavailable

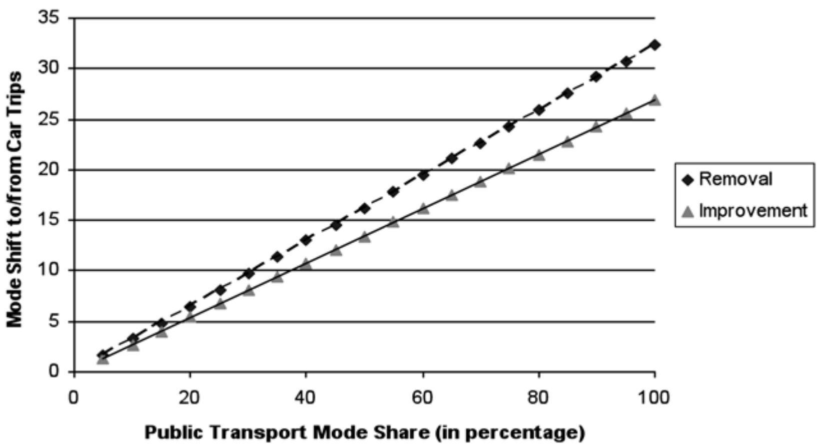

Figure 2. Relationship Between Mode Shift to/from Car and Public Transport Mode Share

Application of a Simplified Congestion Relief Valuation Model

This section models the congestion relief benefits of public transport for a number of cities by applying the evidence assembled in the previous sections. The aim is to present a simplified congestion relief valuation model and to illustrate the application of this model. The performance of public transport to relieve traffic congestion depends on many city and transport variables such as population, trip rate, mode share, average trip distance, city size and density, land use, development patterns, topography, the roadway network and public transport system, existing levels of congestion, socio-economic status of users and non-users, overall travel pattern and telecommuting, peak spreading, and so on. Each of those variables can be viewed as a dimension of a hyper-cube. If the impacts of those variables are to be considered, it is necessary to specify values for numerous combinations of those variables. Six parameters for this model are selected to demonstrate a practical method with easily available data for most cities. A simple model is proposed of the following form:

$$DCB_{PT} = P \text{ x } TR \text{ x } PT_{share} \text{ x } D \text{ x } MS \text{ x } DB \quad (1)$$

Where,

DCB_{PT} = Annual decongestion benefit of public transport in a city

P = population

TR = average trip rate (trips per person per annum)

PT_{share} = Public transport mode share

D = average trip distance

MS = Percentage of mode shift (additional auto travel for removal of PT)

DB = Unit value of decongestion benefits

The simplified congestion relief valuation model has been used to a group of cities covering a wide range of sizes throughout the world have been used. Sixty cities from "Millennium Cities Database" (Kenworthy and Laube, 2001) were selected for the analysis. The cities from developing Asian and African countries were not included in this study because the nature of transit provision and car ownership of these cities differs substantially from those of the selected cities from the developed countries. In this database, per capita annual public transport passenger-km of travel (PT_{PKT}) is available. This PT_{PKT} can be use as a combined term for TR, PT_{share} , and D of the equation 1. Thus equation 1 takes the form of equation 2.

$$DCB_{PT} = P \text{ x } PT_{PKT} \text{ x } MS \text{ x } DB \qquad (2)$$

Where,

DCB_{PT} = Annual decongestion benefit of public transport in a city (Aus$, 2008 value)

P = population

PTPKT = Per capita annual public transport passenger-km of travel

MS = Proportion of mode shift (additional auto travel for removal of PT) = 1/3

DB = Unit value of decongestion benefits = ¢45.0 (Aus$ 2008)

Modeling considers the cost impacts of removing public transport for global cities. Key parameters include:

- the mode shift impacts of removing public transport—in this case, we have assumed the average of the evidence presented in the previous section, i.e., an estimate of 32.4 percent of PT travel would end up using roads (including 20.2% car drivers + half of 24.3% car passengers as chauffeuring travelers), i.e., approximately one third of PT travelers.
- The unit value of congestion costs—in this case, we have assumed 45.0c per additional vehicle km based on the average of the analysis in Table 3.

Table 8 shows the estimated congestion relief values of public transport in millions of Australian dollars (2008). It indicates that European and developed Asian cities feature prominently in congestion relief impact of public transport. The congestion relief values of some these cites exceeds $1 billion per annum. These values certainly give insight how public transport act to relieve congestion in global cities and facilitate cross-city comparison in terms of congestion relief impact.

Table 8. Estimated Congestion Relief Benefit of Public Transport for Global Cities

City	City population (M)	PT pax-km per capita	Congestion Relief Value (M$)	Rank
Tokyo	32.34	5,605	27,192	1
Osaka	16.83	6,011	15,175	2
Moscow	10.38	7,153	11,137	3
New York	19.23	1,266	3,651	4
Hong Kong	6.31	3,675	3,478	5
Paris	11.00	1,763	2,909	6
London	7.01	2,047	2,153	7
Rome	2.65	3,805	1,512	8
Singapore	2.99	3,143	1,409	9
Madrid	5.18	1,454	1,129	10
Ruhr	7.36	987	1,090	11
Budapest	1.91	3,627	1,039	12
Berlin	3.47	1,736	903	13
Sydney	3.74	1,509	847	14
Prague	1.21	4,321	784	15
Chicago	7.52	688	776	16
Barcelona	2.78	1,764	735	17
Toronto	4.63	1,050	730	18
Stockholm	1.73	2,317	601	19
Milan	2.46	1,480	546	20
Munich	1.32	2,622	519	21
Athens	3.46	958	497	22
Montreal	3.22	993	480	23
Sapporo	1.76	1,789	472	24
Melbourne	3.14	994	468	25
San Francisco	3.84	810	466	26
Copenhagen	1.74	1,704	445	27
Los Angeles	9.08	326	444	28
Washington	3.74	781	438	29
Vienna	1.59	1,642	392	30
Hamburg	1.70	1,446	369	31
Zurich	0.79	2,503	297	32
Glasgow	2.18	884	289	33

Table 8. Estimated Congestion Relief Benefit of Public Transport for Global Cities (cont'd)

City	City population (M)	PT pax-km per capita	Congestion Relief Value (M$)	Rank
Helsinki	0.89	1,970	263	34
Brussels	0.95	1,613	230	35
Manchester	2.58	541	209	36
Oslo	0.92	1,512	209	37
Newcastle	1.13	1,167	198	38
Cracow	0.74	1,772	197	39
Brisbane	1.49	720	161	40
Atlanta	2.90	358	156	41
Amsterdam	0.83	1,136	141	42
Berne	0.30	3,114	140	43
Ottawa	0.97	851	124	44
Perth	1.24	642	119	45
Stuttgart	0.59	1,344	119	46
Frankfurt	0.65	1,167	114	47
Houston	3.92	184	108	48
Calgary	0.77	925	107	49
Dusseldorf	0.57	1,205	103	50
Lyon	1.15	550	95	51
San Diego	2.63	206	81	52
Marseille	0.80	540	65	53
Nantes	0.53	798	63	54
Denver	1.98	205	61	55
Graz	0.24	1,564	56	56
Geneva	0.40	774	46	57
Bologna	0.45	666	45	58
Vancouver	0.37	767	43	59
Phoenix	2.53	100	38	60

Conclusion

The paper has presented a comparative assessment of international research valuing the congestion relief benefits of public transport. It also has explored previous research methodologies evaluating congestion relief impacts and examined secondary evidence demonstrating changes in mode split associated with changes in public transport.

Congestion relief impacts are valued at between 4.4 and 151.4 cents (Aus$, 2008) per marginal vehicle km of travel, with an average of 45.0 cents. Valuations are higher for circumstances with greater degrees of traffic congestion and also where both travel time and vehicle operating cost savings are considered.

Mode shift evidence suggests on average some 21 percent of PT trips might be attracted to PT from car drivers (or could be returned to car driving if PT were removed). On average, around 11 to 24 percent of passengers getting a lift have been encouraged onto PT (or might return to getting a lift if PT were removed). It is estimated that approximately one third of PT travelers lead to additional car travel in the case of its removal (this mode shift value is the summation of car drivers and half of car passengers as chauffeuring travelers).

A simplified congestion relief model is presented to value the congestion relief benefits of PT based on readily available data. Using the average congestion valuation and mode shift evidence this model has been applied to a number of cities to estimate congestion relief values. A model of this type could be applied for studies at a city scale but would also be of value to localized corridor studies and smaller scale reviews evaluating infrastructure investment proposals.

A range of areas for further analysis are suggested by the research:

- A linear relationship between the unit benefit of congestion reduction and the number of users has been assumed but in reality, the unit congestion unit is expected to vary at different level of number of users.
- The values shown in this paper for the effects of PT removal/improvement are short-term in nature, and further research can be carried out to distinguish between the short-term and long-term effects.
- The paper does not consider the effects of land use change, existing levels of congestion, socio-economic status of users and non-users, overall travel pattern and telecommuting, peak spreading, and other related issues. The model in the previous section can be extended by including the effects of these variables.

In addition to the above, research in this field needs to be mindful of wider research concerning both the value of time and the value of reliability related benefits to both road users and public transport users. Value of time is a critical input to any economic assessment of congestion relief. Travel and waiting time reliability is also critically influenced by traffic congestion and is a component not directly considered in the research reported here. Clearly, research in these areas has a role in informing discussion about congestion impacts.

Overall, the analysis presents a simplified method to investigate the impact of public transport on traffic congestion. Further research is warranted to develop a comprehensive approach for establishing a measure of the congestion relief impacts of public transport.

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The Operating Characteristics of Intercity Public Van Service in Lampung, Indonesia

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Abstract

The business of providing pickup and delivery service for intercity passengers flourishes in Indonesia. In Lampung Province, it is available to popular destinations, including Jakarta, Palembang, and Bakauheni. To date, there is no detailed information regarding operating characteristics, highlighting the importance of this research for future reference. The data for analysis were collected through a series of field surveys on service frequency and passenger and driver interviews conducted at the ferry terminal of Bakauheni. Results of the analysis suggest that there are too many vehicles operating on the Bandar Lampung-Bakauheni route. The implications are that the total number of trips, the number of passengers carried, and crew income per vehicle per day are limited. The vehicle queuing and dispatching system needs to be improved to prevent passengers from waiting too long. The conclusion is that this business is profitable only if there is a good operating arrangement.

Introduction

Pickup and delivery service for intercity passengers enjoys increasing demand in Indonesia. This is due to the relatively low level of private vehicle ownership and the improved socio-economic status of the population where a higher level of transport service is demanded but cannot be met by the existing public transport services. To date, there is limited data, if any, regarding the operating characteristics of pick-up and delivery service vehicles for intercity travel (locally known as "travel vehicles").

In Bandar Lampung, the capital city of Lampung Province in western Indonesia, there are a number of small private firms offering intercity passenger service other than bus. Among the most popular destinations are Jakarta (the national capital, 200 km to the east), Palembang (the capital city of the Province of South Sumatra, 300 km to the north) and Bakauheni (a ferry crossing port linking the islands of Sumatra and Java, 100 km to the east). Being a door-to-door service, a passenger can make a telephone call to one of the service providers and be picked up and delivered to his/her final destination without the need to transfer to any other mode(s) of transport. This is what makes the travel service superior to ordinary public transport, and there is room for further improvement since customers are willing to pay more for a better level of service.

Previous research by Arifianto (2003) does not discuss sufficient details of the operating characteristics of such service, but merely conducts a cost-revenue analysis in general. This current research is expected to contribute to the transport system database in the province, as well as to improved operating conditions and level of service for the benefit of both operators and users.

Research Methodology

In Bandar Lampung, travel service companies normally have their own schedule of departure for their vehicles. Depending on the destination and the demand for that particular route, the intervals between successive departures of the same route vary from, for example, once an hour to twice within a day. These schedules are not coordinated among the service providers, so a potential customer should shop around to find the most appropriate time of departure to fit his/her need. Unfortunately, it is not unusual for an already-scheduled departure to be delayed because of lack of customer demand. For these reasons, observation of departures and arrivals was not conducted at the dispatching points scattered around the city, but concentrated in Bakauheni, an inter-island ferry terminal between Java and Sumatra, the busiest destination in terms of travel operation within the province.

Data concerning the operating characteristics of the travel vehicles were collected through a series of surveys in Bakauheni, including observation of the arrival and departure times of vehicles, departing arrangements by the port authority, and interviews with drivers and passengers. Surveyors were assigned to record vehicle registration numbers, arrival or departure times, and number of passengers carried, continuously for 24 hours for 3 days (3x24). The length of observation was specifically designed to get a sufficient number of cycle times, since from the previous research by Arifianto (2003) it was known that not all vehicles operate on a daily basis. A similar case occurs in bus operations on the route of Rajabasa-Bakauheni because there are too many buses, well over the required number (Chandradewi 2003; Tjikasan 2003).

Another team of surveyors conducted the driver and passenger interviews, which were done at a convenient time and place within the passenger terminal of the port. Interviews with passengers were intended to gather data regarding passenger characteristics such as gender, age, marital status, level of education, occupation, purpose of trip, frequency of using the travel service (per week or per month), etc., which may be useful for demand analysis. Similar interviews with drivers were administered with slightly different questions to include main occupation other than driving travel vehicle, number of working days per week, monthly take-home pay, etc. A total of 50 drivers and 50 passengers, well above the minimum target of 30 individuals each for a reliable statistical analysis, were successfully interviewed.

There were complaints that travel vehicles usually run fast, disobeying the standard procedures for safe driving and, therefore, risking passengers onboard, so an additional survey was designed to check the average travel speed of the vehicles. For this purpose, observers were located in Panjang, roughly 20 km prior to reaching the Bandar Lampung city centre, where travel vehicles start to deviate their routes due to different passenger destinations, to record vehicle registration numbers and their passing times. Since the departure times of all travel vehicles from Bakauheni were recorded by the other team of surveyors, it was possible to calculate the average travel speed between Bakauheni and the respective observation point.

Data Analysis

From the data collected during the survey, several performance indicators were computed, consisting of number of trips per vehicle per day, travel distance per vehicle per day, number of passengers carried per trip, number of passengers carried per vehicle per day, travel time, cycle time, queuing time, service headway, required number of vehicles, etc. In addition, based on the interviews and observation of the whole operation, driver and passenger characteristics, as well as the operating characteristics of the vehicles, can be clearly described. However, the main discussion in this paper is about the operating characteristics of the vehicles.

Driver Characteristics

Driver interviews revealed that most drivers (58%) are aged 31-40 years, typical of the major workforce within any community; educated to senior high school (98%); married (96%); and working as a driver as their major source of income (100%) for seven days per week (48%), with an average monthly earning of roughly Rp600-700,000.00 per month. These conditions do not differ significantly from the characteristics of drivers of other types of public transport vehicles. The fact that they fully rely on driving for a living, while the average take-home-pay is even less than the 1999 level (Rp40,000.00 per day, as discussed by Arintono 2001 and Arintono 2003), reflects severe competition and high operating inefficiency. If they had more spare time, they might spend it on other productive activities.

Passenger Characteristics

Based on the interviews with 50 travel passengers, most were male (66%), 21-30 years of age (30%), not married (68%), educated to senior high school (44%) or university graduate (42%), self-employed (32%) or employed by a private company (32%), with an average income of over Rp1,000,000.00 per month (38%). The socio-economic status of passengers is just slightly higher than that of drivers, which implies that there could be more demand if service quality improves.

Trip Characteristics

The majority of passengers use the travel service on a non-regular basis (50%), and about 36 percent travel between the origin and destination points regularly once or twice a month. In terms of the purpose of the trip, 54 percent make it for social visits, and almost all of them are more or less satisfied with the service provided. There are some complaints regarding the delivery of passengers to their final destinations, which is not in good order (22%) and the tendency of the crew to drive the vehicle too fast (20%).

Vehicle Operating Characteristics

Distinct from the other public transport vehicles in Indonesia (bus, taxi, mikrolet, and truck), which have registration plates that are yellow with black letters, travel vehicles operating in Lampung Province have special registration plates that are black with white letters, similar to private vehicles. Normally, the numbering starts with two letters (BE, the same for all vehicles registered in Lampung Province) followed by four digits and two letters, indicating the district in which a particular vehicle is registered within the province (for example, BE 2956 LA). Special for travel vehicles are the last two letters, RS, for "Ranmor Sewa" or "Hired Vehicle" to declare that they are actually public transport vehicles.

The vehicles used are usually minibuses of popular models in the country such as an Isuzu Panther, a Toyota Kijang, a Mitsubishi Kuda, or a Mitsubishi L-300. All minibuses have an 8-seat capacity except the Mitsubishi L-300, which can accommodate up to 10 adult passengers. There are 128 registered vehicles operating on this route with 171 drivers. However, during the 3x24-hour survey, only 124 vehicles were observed. Detailed information on company name, number of vehicles operated, and number of drivers is shown in Table 1.

Table 1. Travel Vehicle Distribution by Company

Company Name	No. of Vehicles	No. of Drivers
Purnagama	27	37
Wijaya Kesuma	27	37
Ananda	19	27
ASDP	9	12
Lampung Surya	13	18
Ramayana 8181	13	14
Karona	8	9
Tegas	12	17
Total	**128**	**171**

Source: Calter (2006)

In the ferry terminal of Bakauheni, each travel company has its own dispatching point alongside other companies. Therefore, there are always eight vehicles ready to depart at any time once they are fully loaded. The intending passengers do not know which of the eight vehicles will depart first. The common practice is that drivers of other vehicles of the same company (who are queuing) take the empty seats, pretending to be passengers to show that the vehicle is almost full to attract passengers since the vehicles will depart only when all seats are occupied. This dispatching arrangement causes passengers to wait for a long time since the limited number of passengers is distributed among eight vehicles, and thus the departures of all vehicles are sufficiently delayed.

The only good thing about this kind of practice is that passengers are free to select their own preferred vehicle, e.g., the new and clean vehicle with good service as recommended by their family or friends. They do not have to take the first vehicle in the queue as in the single queue system, since the vehicle may be an old and dirty one and is not recommended because of bad service.

Switching the queue system from single to multiple occurred at the Jakarta International Airport taxi operation. Previously, Blue Bird was the only taxi company that could legally carry passengers out of the airport. Later, other taxi companies demanded that the system be open to all companies with no limitations. Following this demand, the airport authority applied an open system with a single queue in which intending passengers were to take the first taxi in the queue. However, passengers had their own preferences when selecting a taxi to ride; among the locals and well-informed visitors, Blue Bird was at the top of the list. Thus, there were protests from users against the single queuing system, as many of them could not get their favorite taxi and were forced to take a taxi with a bad reputation. After many complaints through newspapers and other media, the queuing system was again altered. Since then, every taxi company has its own queue line, and passengers once again have the option to choose. Clearly, this change has benefitted both the taxi operators (for access to carry passengers out of the airport) and passengers (for retaining the freedom to choose).

The case of travel vehicles at the Bakauheni ferry terminal is slightly different. First, unlike taxis, which are exclusively-hired vehicles (passengers are groups of people who travel together for a single destination), travel passengers can be people who are not familiar with one another and have multiple destinations. For this reason, they have to wait much longer to depart until the vehicle is full (8 persons) compared to taxi (3-4 persons). Second, no travel company is significantly superior to others in terms of service quality. No matter what vehicle a passenger chooses, he/she will get more or less the same level of service as offered by other vehicles. In this respect, there is no benefit to having a multiple queue system in which passengers have to wait much longer for departure.

Some vehicles do not join the queue for two reasons: first, they are requested by the company to return to Bandar Lampung because there is no vehicle left for the next departure, and second, the driver is not patient enough to wait for a long queue. The vehicles that do not go through the queue, however, will not depart empty, but rather will carry passengers already in another vehicle of the same company (from the dispatching point). The general agreement between the drivers is that they will carry no more than four passengers, and the driver of the vehicle in the queue will receive some compensation.

While vehicles departing from Bakauheni are always fully occupied (except those departing earlier not through the queue), the same does not apply to vehicles departing from Bandar Lampung. In many cases, the vehicles have to be dispatched even when there are empty seats, because some of the passengers have been waiting too long. The driver always will try to fill up these empty seats on the way to Bakauheni, in which case the money collected from the additional passengers will go into his own pocket. This is actually against regulations, since the travel vehicle is not a "taxi," which can be for hire on the streets, but this is the normal practice. For this purpose, travel vehicle drivers search for extra passengers around Panjang, a small town located roughly 20 kilometers to the east of Bandar Lampung.

In addition to officially-registered travel vehicles (with RS letters at the end of their registration numbers), "black travel" vehicles also operate along this profitable route of Bandar Lampung-Bakauheni. Due to the similarity of the vehicles (the only difference being the RS code on the registration plate), intending passengers are not aware if they take a "black" (illegal) travel vehicle.

Logically, pickup and delivery of passengers should follow a certain order to save time and gasoline. For example, it should start from passengers farthest away from the company office, then pick up the nearer ones. But passengers cannot expect this proper procedure to prevail. In some cases, and especially for travel vehicles departing from Bakauheni, since the drivers do not record the final destination of individual passengers before starting the journey, passengers complain that they are brought round and round in the city streets without knowing their turn to be delivered to their intended address. In addition to this inconvenient experience, the drivers also ask for extra payment, citing the extra distance to be traveled. The official fare was Rp18,000.00 per passenger trip prior to the fuel price increase of October 1, 2005 (when the fare was then increased to Rp30,000.00). However, the drivers usually charged Rp25,000.00 or higher. If the passengers do not pay, they are not delivered to their destination. This is an often-heard complaint.

Number of Trips and Passengers

During the three-day period of observation, 474 trips were recorded either entering or leaving the ferry terminal of Bakauheni. As the number of operating vehicles (indicated by the registration number) was 124 units, the total number of trips per vehicle per day was 1.27. Observation on the number of passengers recorded 3,553 persons for the trips made during the three-day period, an average of 7.49 passengers per trip. This further reveals 9.5 passengers per vehicle per day, with an average load factor of 93.63 percent per trip. It is suspected that this extremely low number of passengers carried may not be able to balance vehicle operating costs, indicating that travel vehicle operation is at a loss.

Service Frequency and Headway

The pickup and delivery service at the dispatching point in Bakauheni runs 24 hours a day, 7 days a week. Travel vehicles leave the ferry terminal with minimum, maximum, and average headways of 3, 27 and 15 minutes, respectively (four departures per hour). The last vehicle leaves Bandar Lampung at about 22:00, and the first vehicle departs at 06:00. With an average travel time of two hours from Bandar Lampung to Bakauheni, there is no arrival to the ferry terminal between 00:00 (midnight) and 08:00. Meanwhile, the minimum, maximum, and average arrival headways are 2, 24 and 10 minutes, respectively (six arrivals per hour). However, these headways do not necessarily reflect passenger waiting time due to the multiple queuing system.

Cycle Time and Queue Time

From the record of the registration numbers of the arriving and departing vehicles at the ferry terminal, cycle time and queue time can be computed. Table 2 shows cycle time based on observation of either arrival or departure times.

Table 2. Cycle Time

Basis of Calculation	Cycle Time (hours)
Arrival Time	
Minimum	19.45
Average	25.34
Maximum	31.70
Departure Time	
Minimum	13.55
Average	25.92
Maximum	39.12
Grand Average	**25.63**

Queue time is defined as the difference between the arrival time of a particular vehicle at the ferry terminal and the departure time of the same vehicle from the terminal. This queue time includes break times for drivers plus waiting time at the dispatching point until the vehicle is fully loaded. Results of the analysis suggests that the actual queue time ranges from 2.67 hours (minimum) to 5.17 hours (maximum), with an average of 3.95 hours. A reasonable break time is normally considered as 10-15 percent of work time (travel time for drivers).

As discussed earlier, the average travel time between Bandar Lampung and Bakauheni is around two hours one way, plus another three hours for the pickup and delivery of passengers in the city; the total driving task is seven hours (420 minutes) per cycle. The associated reasonable break time lies between 42-63 minutes. Assuming that a 60-minute break is average, a reasonable cycle time becomes 8 hours. It is clear from this exercise that the existing cycle time (25.63 hours) and queue time (which also functions as break time for drivers, 3.95 hours) are too long, indicating inefficiency in travel vehicle operation.

Fleet Size

Normally, in public transport operation, the required fleet size is computed by dividing the cycle time by the headway. For a general public transport vehicle serving two end terminals, the cycle time is calculated based on travel time plus break time, not the observed cycle time (especially when the total number of operating vehicles are too many, resulting in an excessively long cycle time). On the other hand, the minimum headway is chosen so that the fleet size is sufficient to serve passenger demand during peak time. However, this method is not applicable to calculate the required fleet size of travel vehicles on the route of Bandar Lampung-Bakauheni since the short minimum headway does not reflect peak passenger demand. Rather, it happens because of the uncoordinated departure of the vehicles within the existing companies, meaning that some vehicles are fully loaded at almost the same time, resulting in short headway (three minutes). As such, the grand average (12.5 minutes) between headways, based on arrival time (10 minutes) and departure time (15 minutes), and the calculated cycle time (8 hours) are taken as the basis of the analysis to determine the required fleet size. The resulting figure is 43 vehicles, including 10 percent spare, well below the existing number of 128.

Proposed Improved Efficiency

The significantly higher number of operating vehicles than required results in extremely low use of every vehicle. As discussed earlier, each vehicle can make only 1.27 trips carrying 9.5 passengers per day - not even a round trip, which could be considered as the minimum expected turn over - showing that all vehicles are highly underused. This phenomenon is also evident in the other types of public transport vehicles operating within the province, as discussed in Arintono (2008) for motorcycle taxi and Arintono (2001) for mikrolet (10-14 seat capacity minibus).

To improve vehicle operating efficiency, the following arrangements are proposed:

- The queuing system should be changed from multiple to single, based on arrival time and irrespective of the company name of the vehicles. This will reduce passenger waiting time to 15 minutes maximum.
- Vehicle operations should be arranged into three shifts, where every vehicle is allocated one day "on" followed by two days "off," given that the total number of existing vehicles (128) is almost exactly three times the required number (43).

Table 3 shows several indicators of the improved efficiency if the operating fleet size were to be controlled at the reasonable level.

Table 3. Improved Efficiency in Travel Operation

Remarks	Operating Conditions	
	Existing	Proposed
Queuing system	Multiple	Single
Shift schedule (1 day on 2 days off)	Not applied	Applied
Number of vehicles	128	43
Trips/vehicle/day	1.27	3.67
Passengers/vehicle/day	9.51	27.49
Cycle time (hours)	25.63	8.00
Passenger waiting time (minutes)	Unpredictable	15 min (max)
Driver queuing time (hours)	3.95	1.00

In Table 3, the number of trips per vehicle per day and the number of passengers per vehicle per day are calculated based on the existing demand for the multiple queue system where passenger waiting time is unpredictable. If the queuing system were altered from multiple to single, the average waiting time is reduced to 15 minutes, equal to the average departure headway. This is short enough to attract additional demand for the travel service, and therefore the total number of trips and the number of passengers carried per vehicle per day will increase, which, in turn, will decrease passenger waiting time even further.

There may be reluctance from existing drivers to follow the new "on and off" system, considering that their income will be even more limited. So a persuasive effort should be made to make them aware that the new system will be to their benefit. Initially, average vehicle use (e.g., total vehicle-kilometer per vehicle per day) will remain constant with either the multiple or the single queue system, but the utilized and non-utilized hours will be more organized in the single queue system with the "on and off" arrangement. Moreover, drivers will not need to spend long waiting times at the ferry terminal, and the non-working days can be spent for more useful and productive purposes.

A problem remains in the other side of the route, in Bandar Lampung, where every company has its own dispatching points scattered around the city. Intending passengers do not know which operator to select to get to Bakauheni at certain time of the day. If, and only if, all eight travel operators can set up a central booking office and distribute the demand properly and fairly, then potential passengers will benefit much from the new system. They will not have to shop around any more, and they can be sure to be picked up and delivered to Bakauheni as scheduled.

A somewhat similar system is practiced (though not officially declared) in Palembang. There, a number of travel companies offer intercity passenger service between Palembang and Bandar Lampung. Due to low demand and an excessive number of vehicles, usually only a very few companies (if any) dispatch their vehicles with a reasonable number of passengers onboard. The solution is for them to combine passengers from many dispatch points and transport them to their destination (Bandar Lampung) using a number of vehicles based on mutual agreement among themselves. Because of this practice, passengers are sacrificed in terms of the long waiting time (while the deal is being settled), and the ordered seating arrangement becomes invalid. It suggests that these travel companies need to coordinate their services to make the whole operation more efficient. In fact, they manage to do it to a certain extent. It will improve the existing system if they set up a central booking office to be run and financed by all the parties concerned.

Regarding the switch from a multiple to a single queue system, it may be opposed by the port authority since they have interest in this travel operation, as shown by the fact that one of the registered travel companies (ASDP) is owned by the port authority. However, observation indicates that none of them is more in demand than others, suggesting that all vehicles suffer from extremely low utilization. Therefore, there is good reason to implement the single queue system with the following benefits:

- Less space required for the dispatch point and parking of vehicles in queue
- Fewer vehicles in circulation required, implying potential for other use
- Smoother circulation of passengers within the terminal building
- Impression that the port authority is applying a “level playing field” in doing business in the transport industry

Conclusions and Recommendations

The general tendency in public transport operation in Indonesia - that the number of operating vehicles exceeds the required number, leading to low operating performance, as indicated by long cycle and queue times, limited vehicle utilization, and low number of passengers carried, resulting in limited driver income - is also evidenced in travel vehicle operation.

To improve the operating environment to benefit both users and operators, the queuing system needs to be changed from a multiple-queue to a single-queue system based on vehicle arrival time and irrespective of the company affiliation of the vehicles. A shift scheduling of one day on and two days off should be applied to reduce the daily number of operating vehicles, and a central booking office should be set up in Bandar Lampung to simplify and speed up passenger booking. It is the responsibility of the operator or driver association to implement the proposed changes such that the intended improved efficiency can be achieved.

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Site Assessment Instrument for Regional Maintenance Center

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Abstract

To minimize maintenance cost and improve rural transit vehicles services, a Regional Maintenance Center (RMC) concept is being considered by Texas. Currently, rural transit vehicles are maintained and repaired by local garages, where service fees and quality of work performed often are questionable. RMCs are designed to maintain and repair rural transit vehicles within a geographical region. A cost-efficient method to create an RMC is by upgrading an existing maintenance operation. The objective of this study is to create a site assessment instrument to assist in the process of selecting potential maintenance operations that could be upgraded to an RMC. Upon interviewing various rural transportation experts and visiting the benchmark RMC in Illinois, a list of criteria crucial for a successful RMC was compiled and classified into various categories. The result of this benchmarking was used in a preliminary study of Lubbock County, Texas, and vicinity.

Introduction

Rural transit's role in transporting Americans has grown over the past years. The ridership in small urban and rural areas had seen an increase of 32 percent since 1990 (APTA 2003). In rural counties across the nation, 41 percent of small urban and rural communities have no access to transit, whereas another 25 percent of the rural population resides in regions where transit services are below average (APTA 2003); approximately 1,200 public transit systems are available, which provided about 50 percent availability in public transit (Stommes and Brown 2002).

Rural transportation services consist of various programs such as rural transit, special services for the elderly and disabled, human services, and intercity bus and rail that may service rural passengers. These programs are usually funded through Federal Transit Agency Grants Section 5310, Section 5311, and the Rural Transportation Assistance Program (RTAP).

Rural transit vehicles often require frequent maintenance and repair, as rural road conditions vary greatly and are often in less-than-satisfactory condition. In an effort to minimize the maintenance and repair cost for rural transit providers, a centralized maintenance center seems to be one solution. Throughout America, only three rural transit regional maintenance centers exist, and all are located in Illinois.

To create such regional maintenance centers, a benchmark of Illinois regional maintenance centers was performed. The requirements from all aspects including personnel, equipment, preparedness, and buildings are crucial to the success of a regional maintenance center. A site assessment instrument to study and determine the viability of maintenance locations to become an RMC was created through this study. This paper discusses the work performed and the critical reasoning behind the requirements included in the site assessment instrument. This paper is organized as follows: background information, a detail discussion of the site assessment tool, result of the preliminary study, general discussion of the study, and potential future work. The site assessment instrument developed in this study is available at *http://www.depts.ttu.edu/ieweb/research/JPTv13iss12010.pdf*.

Project Background

This study is part of a project commissioned by Texas Department of Transportation (TxDOT) to benchmark the RMC concept and study the feasibility of potentially implementing RMCs in Texas. Beruvides et al. (2009) provide a detailed explanation of the concept and benefits of an RMC for rural transit vehicles. The remainder of this section provides a brief description of RMCs. Beruvides et al. (2009) define an RMC as:

a centralized public transportation maintenance facility that provides general maintenance and services to rural transit providers:

- Provides preventive maintenance (PM), preventive inspection, major components repair, and replacement services to rural transit agencies that service within a designated radius rural transit agencies, counties, and/or districts of the maintenance facility.
- Provides maintenance and repair services beyond the scope that a local garage would provide.
- Provides services to specialized transit vehicles and equipment including but not limited to wheelchair lifts, electric, propane, and hybrid vehicles.
- Serves as a technical information center and provides technical expertise to rural transit agencies and other transit providers.
- Acts as a warranty recovery center for all parts and labor and possibly as a designated warranty center to work on authorized original equipment manufacturing (OEM) parts.
- Provides loaner vehicles to rural transit agencies if necessary.

To provide all the services listed above, the location of an RMC is critical for its successful operation. In addition, upgrading an existing maintenance facility is probably the most cost-efficient approach. Prior to upgrading, determining the most appropriate location and analyzing which of the existing facilities is most suitable for upgrade to an RMC is crucial. TxDOT is exploring if state DOTs can provide grants for the upgrade required for a maintenance facility to become an RMC. After the initial grant, an RMC should be self sustainable.

Objectives

Creating an RMC is a hefty investment in public transportation. Though the success of any RMC is not a given, an effort to eliminate candidates that are clearly not suitable to be upgraded into an RMC is necessary to minimize the risk of failure. With 36 urban transit systems (National Transit Database 2007) and 41 rural transits systems (Turnbull et al. 1999) in operation in Texas, a selection method is required to identify maintenance operations that are most appropriate for RMC operations.

As a part of the project commissioned by TxDOT, a minimum essential specification that defines the basic requirement for an RMC facility was created. Based on the minimum essential specifications developed, a site assessment instrument was created to assist the process of determining a transit maintenance facility's ability and desire to become a regional maintenance center. In addition, this site assessment instrument could be adapted in the future to be used as an evaluation technique for existing RMCs and their readiness to meet future growth demands.

Components of Site Assessment Instrument

A site assessment instrument was developed based upon five general categories: (1) Background Information/Determining Location, (2) Requirements for a Regional Maintenance Center, (3) Technical Expertise for a Regional Maintenance Center, (4) Documentation Necessary for a Regional Maintenance Center, and (5) Future Needs for a Regional Maintenance Center. A discussion on each of the categories will be provided in the following sections. Please visit *http://www.depts.ttu.edu/ieweb/research/JPTv13iss12010.pdf* for the actual site assessment instrument.

Location and Basic/Background Information

The RMC should be strategically located such that most rural transit vehicles would pass by or be in close proximity to it on a regular basis. Beruvides et al. (2009) identified the considerations for strategic RMC location as follows:

- Locate routes in close proximity to the RMC on a regular basis to facilitate vehicle repair and maintenance.
- Maximize number of rural transit agencies that could utilize and benefit from the facility.
- Minimize overlap in coverage by each RMC.
- Maximize market and population service.

The location of an RMC is the most important aspect for success because the location determines the accessibility for rural transit providers. The ideal location for an RMC will be in a hub city, where surrounding rural populations visit on a regular basis for business, medical, and leisure (shopping, sporting or cultural events etc.) purposes. The basic/background information is further divided into three categories: Facility Background, Current Operating Procedure, and Existing Facility Building Condition.

Facility Background includes the establishment date, grantee of various Federal Transit Agency grants, history of federal and state grants awarded, hours of operation, number of employees, and number of vehicles serviced. Current Operating

Procedure is further divided into two classifications: RMC and Non-RMC. Currently, there are no RMCs in Texas. The questions in this instrument for evaluating an existing RMC are intended as a validation and verification method of the instrument (i.e., benchmarking to a successful RMC, such as those in Illinois) and as a future instrument to assess the readiness of established RMCs. The common questions for both RMC and non-RMC are the advantages and disadvantages of the location, types of vehicle serviced, preventive maintenance scheduling capabilities, work scheduling capabilities, use of fleet maintenance software, and types/frequency of major repair provided/required. An existing RMC will have to provide the ratio of urban to rural populations serviced, number of counties serviced, current clients list, and vehicle information; non-RMC will have to provide the most frequent destinations of rural riders they service and the visit frequency on a weekly basis.

The last category assesses existing building conditions, which include the construction year; square footage; building material; building details such as bay doors, washing bays, parking availability, etc.; and any known major problems such as structural, plumbing, and electrical problems. The purpose of this category is to assess the current condition and efficiency of the existing maintenance process. For example, the ratio of mechanics to number of vehicles serviced could reveal the efficiency of the maintenance operations. The most frequented locations by various providers could reveal a potential RMC location that might be overlooked. The existing maintenance and work scheduling practice and the utilization of fleet maintenance software will reveal the existing administrative capabilities. An assessment of the potential investments needed in administrative training, if the facility is chosen to be an RMC, could and should be conducted.

Requirements for a Regional Maintenance Center

The category "Requirements for an RMC" consists of requirements that are not organized into other categories. This category assesses the current maintenance practices in the facility and inventories the equipment that the facility owns. As a maintenance facility for a larger transit provider, the facility should have some form of historical data on their preventive maintenance program and safety inspection procedure for all the vehicles maintained by the facility. In addition, the equipment and tools that a facility owns define the repair capabilities of the facility.

The "Existing Maintenance Practice" category consists of the preventive maintenance program and safety inspection. Potential RMC facilities to be surveyed will have to describe the current preventive maintenance program in details, which includes preventive maintenance procedures and safety inspection procedures. The existing preventive maintenance program is indicative of the transit agency's general administrative practices and will expose any potential problems if the facility were to be upgraded to an RMC. For example, an agency that does not have a sound preventive maintenance program already in place implies that the agency places lower priority on preventive maintenance. The agency's mission is thus not consistent with the mission of an RMC. Upgrading the facility might entail additional cost and effort in aligning management's approach with the RMC's mission.

An inventory of all equipment will provide the analyst an estimate on the amount of investment required for the upgrade. In addition, a list of existing equipment in the maintenance facility will reveal the types of repair that the existing facility could provide and the extent of the repair services.

Technical Expertise for a Regional Maintenance Center

One of the main functions of an RMC is to provide technical expertise to rural transit providers. With the maintenance and repair services that an RMC provides, RMC mechanics should have higher technical expertise compared to local garages. In addition, administrative personnel should have a basic understanding of the repair and maintenance procedure in order to provide high-quality customer service when interacting with rural transit providers. This section of the site assessment instrument examines the human resources capabilities, specifically, mechanics, administrative personnel, and non-technical personnel.

The general questions in this category are the availability of continuous education for employees, availability of in-house training, recommended/required professional certification, employee turnover rates, and any plan to address the turnover problem, if present. Mechanics' abilities are highly related to years of experience, as are mechanics classifications (Peters 2007). This part of the assessment also requires the transit agency to describe the classification method and number of technicians per classification being used by the facility.

Information collected enables the analyst to project the maximum capacity of a facility to handle the potential workload increases and/or projects and the number of additional mechanics and administrative personnel needed. For example, a high turnover rate implies that human resource management requires improvement. The turnover rate and existing in-house training program will reveal the potential cost to recruit and train new employees or to develop an employee retention program.

Documentation for a Regional Maintenance Center

Good documentation practices allows the transit agency to keep track of the age, condition, and maintenance requirements of each vehicle, the ability to provide sufficient documentation to recover the warranty for defective parts, assess the performance of the facility and individual employees, evaluate the workplace safety level, and conduct better inventory management. Documentation could be accomplished through written records or the use of a software package. This section of the site assessment instrument studies the documentation practices on vehicle records, warranty recovery records, performance measurement records, workplace safety records, and inventory tracking practice.

Keeping record of each vehicle and the history of all maintenance and repairs performed on the vehicle is important as this will ensure that each vehicle gets the preventive maintenance and safety inspection when necessary. This also allows the transit agency to project vehicle life, estimate potential replacements required, incorporate vehicle replacement in the annual budget, and address the possibility of obtaining federal or state grants for the replacement. Additionally, successful warranty recovery is highly dependent on documentation that an agency provides, for example, the mileage of a vehicle when a part failed and the installation date of a particular part that failed. Proper and timely documentation is crucial in the success of recovering warranty for defective parts (Van Sickel et al. 1997).

A record of all assets and inventories in the facilities provides a method to track and replenish inventories on time and thus provide good service to clients. The inventory reordering policy is highly related to documentation as well. With the performance measurement system and historical data that the maintenance facility provides, analysts can evaluate the accuracy and effectiveness of the existing performance system.

Future Needs for a Regional Maintenance Center

Any RMC is expected to expand over time with the growth of rural transit ridership. The capability to expand and grow is important in assessing the potential of each facility to become an RMC. The ideal RMC should have the capability to provide a vehicle loaner program and road call and wrecker services to rural clients. This section of the site assessment instrument explores the readiness of a facility to incorporate a vehicle loaner program, road call service, and wrecker service. General questions include any foreseeable problems or anticipated problems if vehicle loaner, road call, and wrecker services were to be incorporated into the facility, and additional equipment and vehicles that will be required to provide such services. Other questions address the risk of providing a vehicle loaner program and the cost sharing issues to provide loaner vehicles, road calls, and wrecker services.

Preliminary Study

The site assessment instrument developed in this study can be conducted in two ways: the analyst is present and conducts the interview with a representative of the maintenance facility, or the questionnaire is given to the maintenance facility to complete on their own and the analyst reviews and evaluates the completed questionnaire. In this preliminary study, analysts were present and conducted the interviews with a representative from various transit agencies. Three transit agencies in Lubbock and its vicinity were interviewed to conduct the preliminary pilot site assessment.

Citibus

Citibus owns a fully-equipped, centralized maintenance facility in downtown Lubbock, Texas. The maintenance facility is located in a 20,000 sq ft building built in 1932 and last remodeled in 1981. Citibus services 64 buses, 28 paratransit vans, 7 supervisor vans, 4 cars, 3 service trucks, and 4 trolleys. The maintenance facility consists of 10 mechanics of various classifications and experience, and a training program (apprentice program) is provided to all newly-hired mechanics. The most frequent and major repairs performed by Citibus are air conditioning and brake systems. Citibus uses iMaintTM software to manage inventory control, preventive maintenance records, and other documentation. It is estimated that with the existing number of mechanics and amount of building space available, Citibus could service up to 200 vehicles per month. If expansion is required, Citibus could purchase an adjacent building and close a side street. The initial result of the site assessment showed that Citibus would be an ideal candidate to become an RMC.

South Plains Area Rural Transportation Assistance Network (SPARTAN)

The South Plains Area Rural Transportation Assistance Network (SPARTAN) is located in Levelland and provides services for the elderly, handicapped, and general public in 11 counties: Bailey, Cochran, Garza, Hockley, Lamb, Lubbock, Lynn, Mitchell, Scurry, Terry, and Yoakum. SPARTAN has 32 vehicles, 10 of which run on propane gas. A frequent destination for SPARTAN riders is Lubbock. SPARTAN does not perform any in-house vehicle maintenance and repair, but it does perform pre-trip and post-trip inspections. The 10 propane vehicles require certified technicians to perform maintenance, with the closest certified mechanics located in Lubbock, which is 31 miles away. Major repairs on SPARTAN vehicles are related to brakes systems, wheels, and repair of propane vehicles. SPARTAN outsources the repair and maintenance to local garages or vehicle dealers. Initial site assessment showed that SPARTAN is neither ready nor suitable to be upgraded into an RMC for several reasons. SPARTAN is located in a small town, and there is not enough transit activity nor the technical expertise at this time to justify the investment. However, SPARTAN expressed interest and enthusiasm in using an RMC if one exists in the West Texas region.

Caprock Community Action Agency (Cap-Trans)

Caprock Community Action Agency (Cap-Trans) is located in Crosbyton and provides rural transportation services to six counties: Crosby, Floyd, Dickens, Hale, Motley and King. Cap-Trans provides three types of services: fixed route, dialysis route, and paratransit. Cap-Trans has 24 vehicles in service, and frequent destinations are Plainview and Lubbock for medical services. Cap-Trans does not perform any in-house maintenance and does not have a facility to perform such activities. All maintenance and repairs are outsourced to local garages. Major repairs for Cap-Trans' vehicles include propane van repair and wheelchair lifts. Cap-Trans expressed interest in using an RMC if one is established in the West Texas region.

Discussion

Upon completing the preliminary studies, several inadequacies in the site assessment instrument were addressed. The first version of the site assessment instrument consisted of 151 questions, divided into 7 sub-categories. The revised version consists of 138 questions, divided into 15 sub-categories. This reduction/reorganization of questions and sections was a result of working with rural transit providers and maintenance providers to streamline the assessment process.

The following sections discuss the revisions to the site assessment instrument, the limitations of the instrument, future work required for the site assessment instrument, and potential applications and knowledge sharing from this study.

Revisions

A major revision to the Documentation section was made after the preliminary study. The first version of the site assessment instrument grouped vehicle records practice, warranty recovery practice, inventory control, performance measurement systems, and workplace safety into one category under Documentation. While performing the preliminary site assessment, the analysts encountered problems in actually obtaining all the information required, and some information was not required for the assessment. Due to the lessons learned in applying the initial instruments, each activity that requires documentation is now addressed as a separate category.

The Future Need for an RMC section was expanded to include road call service and wrecker service, rather than grouping all the future needs into one cluster. Through the initial site assessment, one of the maintenance facilities informed the interviewer that road call service was already in use at their facility. This implied that some maintenance facilities might be well advanced in meeting RMC requirements. By including vehicle loaner program, road call, and wrecker service together, the initial site assessment instrument failed to cover all the different operating procedures and policies and, thus, this was addressed in the revision.

Limitations

This site assessment instrument was developed to assess the existing condition of a maintenance facility for suitability to convert to an RMC. Due to the nature of the design, this site assessment instrument is not recommended to be used as a routine assessment instrument, though with alterations it could be modified as a readiness assessment instrument. Used as a routine assessment instrument, the site assessment lacks the capability to track the differences or the changes over time.

To select a maintenance facility to be upgraded to an RMC or to create an RMC, the site assessment instrument alone is insufficient to ensure the successful selection of an RMC. This site assessment instrument has to be coupled with an economic analysis model that assesses the financial readiness and uncover potential financial peculiarities of any RMC candidate. Using both the site assessment instrument and the economic analysis model will ensure the selection of an RMC candidate that has the highest probability of success.

Future Work

The site assessment instrument for determination of an RMC is a part of a larger study commissioned by the Texas Department of Transportation. To successfully create an RMC for rural transit vehicles, three aspects of an RMC must be explored and studied in detail. The overall concept of RMCs was introduced and explained in detail by Beruvides et al. (2009) in this journal. This paper explores the importance of the RMC selection process and creates a site assessment instrument to assist in the selection process. The financial aspect of creating an RMC is the final and possibly most important part determining if and where an RMC should be developed. The following section will discuss future work required to complete the RMC study.

Site Assessment Instrument

The next steps for improving the site assessment instrument would be the development of a weighting scale for the various sections and a rating system with various subject matter experts. This would allow a numerical/quantitative summary score that could be applied objectively to assess a rural transit agency's capability to become a regional maintenance operation. The ideal method is to develop weights for each category and then perform a site assessment on existing RMCs (such as the ones located in Illinois) and then develop the appropriate weights based on the successful operation.

The need exists for a tool to serve as an assessment instrument of existing RMCs, such as those in Illinois. After the formal analysis using this site assessment instrument, discussions with Illinois RMC directors will be beneficial. Any shortcomings of this site assessment instrument to assess important aspects of a successful RMC could be identified and incorporated into the next revision of this instrument.

The site assessment instrument developed in this study could be modified to incorporate measurement of changes over time for routine performance evaluation. A method to chart progress over time could be incorporated into the site assessment instrument for the purpose of tracking the progress of any implementation done at the facility.

Economic Analysis for RMC

A preliminary study on the economic factors that are crucial to the success of an RMC is discussed in detail by Beruvides et al. (2008). The ultimate economic goal of an RMC is to be self-sustainable after the initial investment to commence operations. The preliminary economic modeling conducted by Beruvides et al. (2008) discussed the factors to be considered in forecasting the financial performance of RMC candidates based on workload capacity and cost factors. The economic model will consist of various modules that address different economic aspects of an RMC. The analyst could disable modules that do not apply to the situation at hand.

Workload capacity includes factors such as existing workload and surrounding rural transit agencies' existing number of vehicles and condition. These factors will then be used to forecast the maintenance demand on the RMC and capacity and personnel required to meet the demand. Cost factors include capital investment, startup cost, operating expenses, revenue for the RMC, and savings realized by rural transit agencies using the RMC. Following the forecasts on workload and costs, engineering economic analyses such as breakeven analysis, benefit-cost ratio analysis, rate of return analysis and payback period analysis, and a sensitivity analysis will be performed. Recommendations will be provided based on the site assessment instrument and the economic evaluations.

Each RMC is unique. The financial performance of one RMC maybe different from another. The initial investment for each RMC will be different as well, depending on whether the RMC is an upgrade from an existing maintenance facility or a new operation. The economic model that will be created will be a generic model that allows analysts to input information and customize the model if required.

One important question that state DOTs interested in creating an RMC will raise is defining the radius (distance) or coverage area that an RMC would serve. The economic model addresses the distance on a case-by-case basis. The type of repair required, the cost to the repair location, the distance to the closest RMC, the number of days required for repair, and loaner vehicle usage will be considered in the economic analysis, and the model will identify the alternative with the lowest cost.

Conclusions

The site assessment instrument developed in this study requires some future work and refinements. Once completed, this instrument could be used in a variety of ways, including use by other states that are interested in creating centers similar to the RMC concept. In addition, this instrument could be modified and used to assess other major transportation related facilities. Considering the increasing cost that maintenance operations are exerting on organizations (profit, non-profit, and governmental), an instrument like this could prove to be vital in managing these operations.

Illinois DOT created RMCs in response to the need for reliable maintenance and repair for rural transit agencies. Tools and instruments to select RMCs such as a site assessment tool and economic analysis model were not available at that time. This study provides a tool that could assist other state DOTs interested in the RMC concept to explore and potentially implement this maintenance concept in their state. The culmination of information that this study provides will not ensure the success of any RMC but will eliminate candidates that are not suitable and reduce the risk of such investment.

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TTSAT: A New Approach to Mapping Transit Accessibility

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Abstract

Transit agencies have never had an accurate indicator of the extent of their service area based on riders' door-to-door travel time. This is an important gap in knowledge, because travel time is one of the most important factors determining whether or not people will use public transit. This paper presents a powerful new travel time-based method to visualize and analyze transit service coverage—a computer application called the Time-Based Transit Service Area Tool (TTSAT). Unlike other service area metrics, TTSAT incorporates total trip travel time into the transit service area maps it generates. To make these travel-time estimates realistic, TTSAT integrates all segments of a complete, door-to-door transit trip into the trip time calculations. TTSAT's mapping and analysis capabilities offer numerous potential applications for planners, developers, and members of the public working to create transit-accessible communities.

Introduction

An important planning problem for transportation and land-use planners is to evaluate the geographic areas that are "served" by a community's public transit service. Most transit system service coverage analyses use very simplistic methods, such as creating a single map showing the area within a certain distance of the transit routes. This area is then considered to be the effective "service area." The method is easy to apply and visualize, but provides incomplete information. One particular limitation is that the method ignores the key value of time—some transit trips between two points on the route might take so much time as to be unrealistic for most travelers, especially for the choice riders whom many transit operators wish to attract. This paper presents a computer application called Time-Based Transit Service Area Tool (TTSAT), a new and powerful method of analyzing and visualizing transit service coverage that allows planners to incorporate travel time into their assessment of transit service coverage.

Recognizing the problems inherent in trying to assess service coverage at a system-wide level (i.e., for all possible trips on all possible routes), TTSAT instead allows users to determine how well the transit system serves trips to or from a particular location under a given set of assumptions that the user can control. One powerful feature of TTSAT is that it incorporates all segments of a complete transit trip: the user's movement from the trip origin to the transit stop, wait-time for the transit vehicle to arrive, in-vehicle time, and time spent traveling from the disembarkation stop to the user's final destination. A second key feature of TTSAT is that users can set many of the input variables according to their personal preferences. The variables that users can set include the maximum travel-time budget for the complete, door-to-door trip; the maximum acceptable time spent traveling to and from the transit stops; the speed of the travel mode used accessing the transit stops; and the average time spent waiting to board a transit vehicle.

To apply TTSAT to a designated location, a user sets values for the factors described above. TTSAT then calculates and maps the "time-based transit service area" (TTSA) for that point The TTSA is presented on a map showing all locations that a person can reach by transit from the designated location, within his/her given travel-time budget and under the other assumptions that the user has set. (Figure 3 shows a sample of what TTSA maps look like.)

TTSAT's mapping and analysis capabilities offer numerous potential applications for planners, developers, and members of the public working to create transit-accessible communities. As such, TTSAT can support many of the most important issues in contemporary urban planning practice, including smart-growth planning efforts and equity questions, such as ensuring that a community's transit-dependent residents can reach jobs and social services.

At its most basic functionality, TTSAT allows planners to analyze the level of accessibility that a pre-existing transit system provides. Planners also can customize this accessibility analysis to different types of users—someone who walks slowly versus someone who walks quickly, users with different tolerances for their total trip time, or able-bodied users who can walk some distance versus users with limited mobility who cannot walk more than a short distance. In addition to this basic functionality, TTSAT can be used to analyze the effects of changing service characteristics, such as headway times. Thus, TTSAT functions as a modeling tool as well as a descriptive tool.

This paper begins with a brief overview of existing transit service area mapping methods. Then the paper explains briefly how TTSAT operates, including the variables users can set. Next is an overview of how the computer application operates. The following section uses real-world data from the Santa Clara Transit Center in San Jose, California, to demonstrate through three scenarios how planners can use TTSAT to analyze transit service accessibility. The concluding section summarizes the main findings from the research and recommends strategies for improving TTSAT.

The Evolution of Transit Service Area Mapping Methods

A variety of different transit service area measurement methods have been used by planning analysts to measure the spatial area served by a transit system. This section reviews the evolution of different methods that planners have used and explains how TTSAT provides more useful results by adding a time-based component to its methodology.

Early efforts to measure transit system coverage conceived of the system in terms of corridors, or the immediate area along the two sides of the streets along each transit route (see Figure 1a) (Wirasinghe and Vandebona 1987; Chapleau et al. 1987). Transportation planners recognized the inaccuracy of measuring transit service area as corridors, however, since riders cannot get on and off at any point along most transit routes. In response, planners later began to measure the transit service area as a set of concentric polygons located around each transit stop (Figure 1b) (Dufourd et al. 1996; Bruno et al. 1998). In the newer approach, a significant improvement over the corridor models, the potential riders of the system are assumed to be those travelers whose trip origin and destination both lie within one of these polygons. Destinations beyond the polygons are considered too far away from the transit stops to be easily accessible to riders.

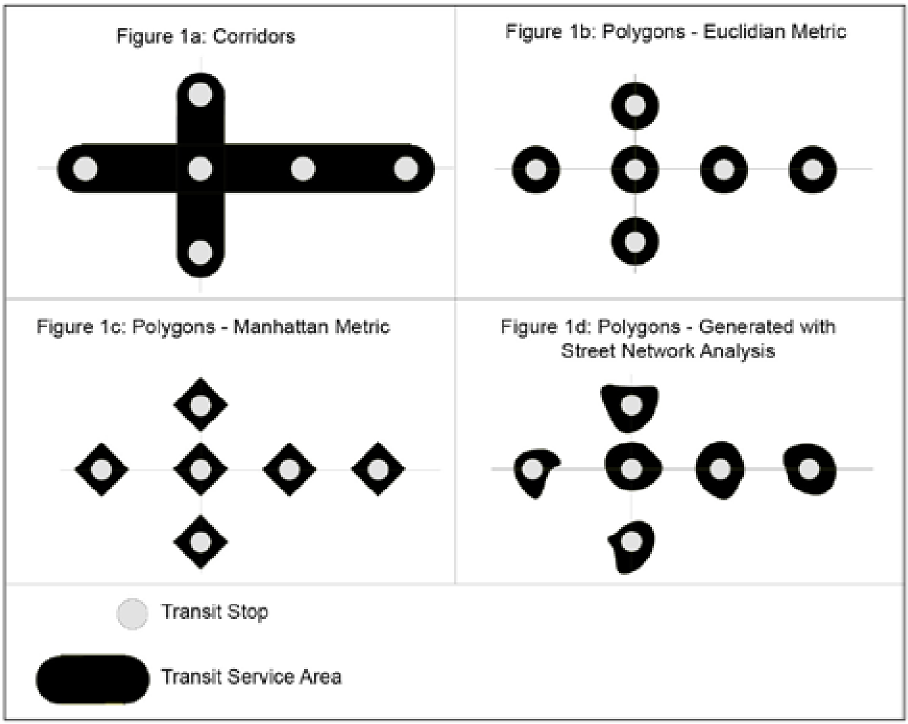

Figure 1. Four Methods to Measure Transit Service Areas

The polygons can be drawn using two different methods. The Euclidian metric encloses each stop in a circle, assuming people can walk freely from the transit stops—as the crow flies—without being blocked by buildings or other physical barriers (Figure 1b). The Manhattan metric, by contrast, attempts to simulate walking behavior more precisely by acknowledging that people are not crows who can fly over physical barriers. As a simplification, it assumes that people access transit stops by walking along a perfect street grid (of strictly eastern-western and northern-southern streets), and that the travelers will make only one right-angle turn. In the Manhattan metric, the service area drawn around a transit stop is typically a diamond (Figure 1c).

The Manhattan method still leaves much to be desired, however, since, in reality, many transit stops are not located in the middle of a perfect grid street network.

With the development of modern computer software, planners now can draw transit service areas more precisely using network analysis and GIS software (Kimpel et al. 2006). Figure 1d shows the transit service area as the locations around a transit stop that can be reached by walking a set maximum distance along the actual street network that surrounds a transit stop.

The introduction of network analysis produces much more accurate maps showing the service area around individual transit stops, but these maps stills ignore a key factor: time. The maps don't indicate whether this service area can be reached within a predetermined travel-time budget. TTSAT, by contrast, creates maps that represent the places travelers can access within a chosen travel-time budget, taking into account the time needed for all segments of a transit trip.

Figure 2 illustrates the conceptual difference between a transit service area map generated by traditional methods and the time-based transit service area generated by TTSAT. In both cases, the traveler boards the transit vehicle at stop A. The traditional methods of generating service areas produce polygons of the same area around all the stops. The TTSAT method, by contrast, shows that the more remote transit stops have smaller service area measurements, since travelers with a maximum acceptable time-budget will have less time to access destinations around the more distant stops.

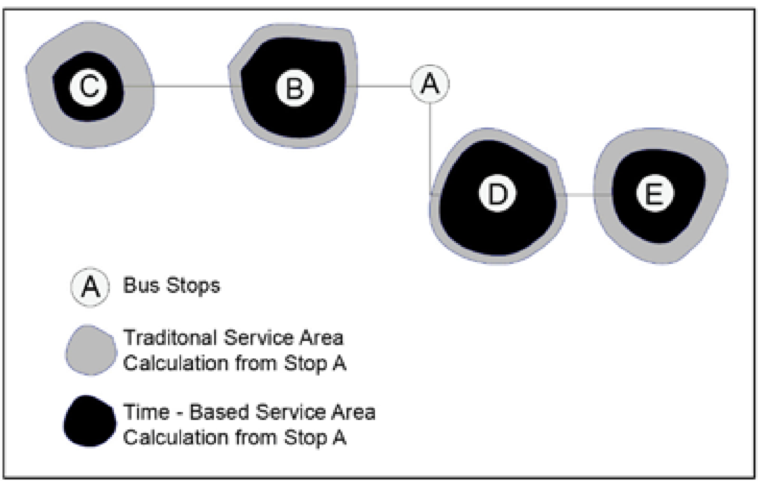

Figure 2. Transit Service Areas Generated by Traditional Methods vs. TTSAT

How TTSAT Functions: An Overview

TTSAT produces TTSA maps using a set of procedures that combine functions from both ESRI's ArcGIS suite version 9.2, for the geographical computations using a street network map, and Microsoft Access 2007, for computations related to a database containing the transit route information. This section of the paper explains the basic process through which TTSAT generates the TTSA maps. It discusses the variables the user may set and the series of six steps through which the application produces the TTSA maps.

First, the TTSAT user must set the trip origin or destination point around which the TTSA map will be created.[1] Then, the user has the option to set customized values for several variables:

- **Maximum total travel-time budget**: The maximum time passengers are willing to spend for the whole trip, including time spent traveling to the transit stop where they catch the transit vehicle, time waiting for the transit vehicle, in-vehicle time, and time spent traveling between the transit stop where they disembark and the final destination. The TTSA map will show all locations that can be reached within the maximum total travel time.
- **Maximum acceptable transit stop access time**: The maximum time passengers are willing to spend traveling from their trip origin to the transit stop where they catch the bus or train.
- **Transit stop access speed**: The speed at which passengers travel from their trip origin to the boarding stop. TTSAT uses a default speed of 2.05 miles/hour, but users can set a different speed if they walk more slowly or quickly, or if they use other travel modes, such as cycling.[2]
- **Maximum acceptable destination access time**: Similar to the acceptable transit stop access time, this is the maximum time passengers are willing to spend traveling from the transit stop where they disembark to the final trip destination.
- **Final destination access speed**: Similar to the transit stop access speed, the destination access speed is the speed at which passengers travel to their final destination after disembarking from the transit vehicle. TTSAT uses a default speed of 2.05 miles/hour.
- **Waiting-time-to-headway ratio**: This variable determines the estimated time passengers will wait for a bus or train once they arrive at the stop.

TTSAT uses a default value of 0.5, assuming that people on average wait half as long as the scheduled service frequency.

Once these variables have been set, TTSAT is ready to create the TTSA map for a given trip origin point. The application does so in six discrete steps:

1. **Find all accessible transit stops**. These are the transit stops that passengers can reach within the maximum acceptable stop access time chosen, moving at the chosen transit stop access speed.
2. **Find all accessible transit routes**. These are the bus or train routes that stop at the accessible stops identified in Step 1.
3. **Calculate the remaining available travel time at each disembarkable stop**. TTSAT calculates the remaining available travel-time budget at each stop where passengers could conceivably disembark. This time is calculated by subtracting from the maximum total travel time the following time values:
   - The time passengers spend traveling from the trip origin to the accessible transit stop where they board the bus or train.
   - The estimated time passengers spend waiting for the transit vehicle at that stop.
   - Passengers' in-vehicle time.
4. **Identify the "reachable" stops that passengers can access within the maximum total travel time**—that is, all transit stops for which the time calculated in Step 3 is greater than zero.
5. **Identify all portions of the street network that passengers can reach within the remaining available trip time**. For every reachable stop, TTSAT uses ArcGIS's network analysis function to identify the portion of the street network that passengers can reach within the remaining available travel time.
6. **Merge all reachable areas into a complete time-based transit service area (TTSA) map**. By merging all portions of the street network that can be reached within the remaining available travel time calculated in Step 5, TTSAT generates a map showing all possible locations that passengers can reach via a single transit trip from the chosen trip origin.

Applying TTSAT to the Santa Clara Transit Center

This section demonstrates how planners can use TTSAT to calculate and visualize TTSAs as part of the transit service planning process, using as an example the bus service available near the Santa Clara Transit Center (SCTC). The SCTC is an important transit hub in San Jose, California. It is served by Caltrain commuter rail, the Altamont Commuter Express rail service, Amtrak, and light rail and bus routes operated by the Santa Clara Valley Transportation Authority. To simplify the exercise, the scenarios below generate TTSA maps incorporating data only from the 11 bus lanes running nearest the SCTC.

Three scenarios are presented in this section, each illustrating a different aspect of TTSAT's ability to precisely calculate how changing the input variables leads to changes in the TTSA. For each scenario, a TTSA map is created, and the SCTC's bus accessibility is analyzed in multiple ways. One technique is simple visual inspection of the TTSA maps. In addition, bus accessibility is analyzed by calculating the number of destination bus stops a rider can access within the total travel-time budget, as well as the percentage change in the areas of the TTSAs. Each scenario concludes with a discussion of some planning implications suggested by the analysis.

Scenario 1: Variable Total Travel-Time Budgets

Figure 3 shows how the TTSA changes when travelers change their maximum travel-time budgets from 30 to 60 to 90 minutes. The scenario assumes that all other input factors remain constant—the traveler walks at a rate of 2.05 minutes on either end of the bus trip itself, the maximum acceptable walking time on either end of the in-vehicle trip is set at 15 minutes, and the waiting-time-to-headway ratio is set to 0.5.

One finding that is obvious from the map, especially from the TTSA for the 30-minute trips, is that the TTSA around reachable stops shrinks as travelers disembark at stops farther from the SCTC. This shrinkage occurs because travelers have a smaller remaining share of the total travel-time budget when they disembark farther from the SCTC. Such a result is intuitive, but TTSAT visually represents this finding in a way that viewers can easily grasp.

Figure 3 also shows that the expanding service area eventually reaches a cap. For example, the height of each horizontal strip appears to yield to a cap. This occurs because the maximum size of the service area that can be generated for any reachable bus stop is capped by the 15-minute maximum acceptable destination access time.

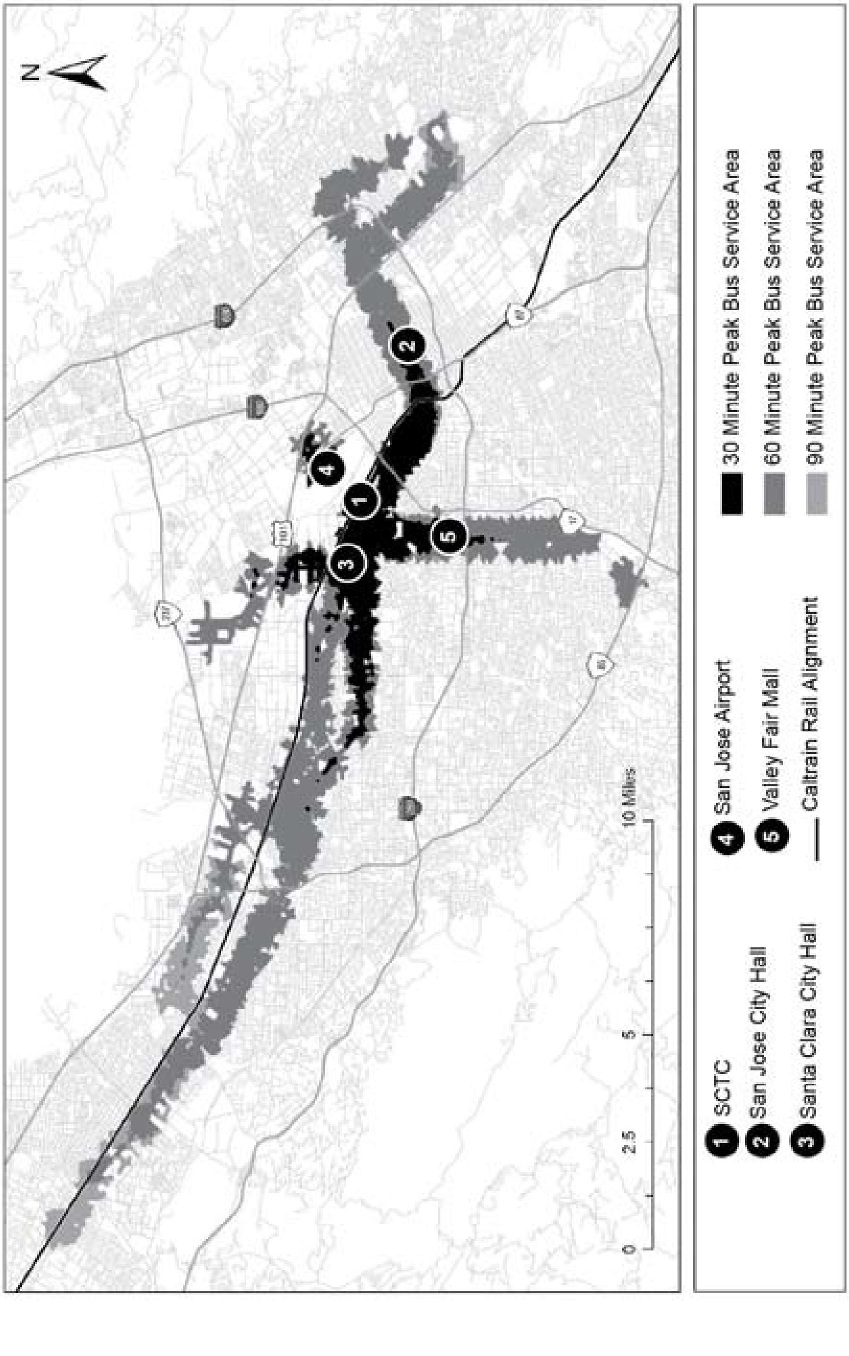

Figure 3. Thirty-, Sixty-, and Ninety-Minute Peak-Hour Bus Service Areas for the Santa Clara Transit Center

Finally, the map shows that the size of the TTSA and number of reachable destinations increases significantly as the maximum total travel time increases. The east-west strip becomes longer as the maximum total travel time increases, because now travelers have more time to spend on a bus trip from the SCTC.

Using GIS software, users can easily calculate how the area of the TTSA changes as the total travel time changes. Compared to the TTSA for the 30-minute trip, the TTSA increases by 379 percent for travelers with a 60-minute total travel-time budget and by 443 percent for travelers with a 90-minute total travel-time budget. Users can also measure the change in accessibility by counting the number of destination bus stops that travelers can reach under the different travel-time budgets. Here, the number of stops is 114 for the 30-minute trip, 280 for the 60-minute trip (a 146% increase), and 399 for the 90-minute trip (a 250% increase over the number of stops in the 30-minute trip).

Scenario 2: Changes in the Frequency of Transit Service

One of the key service variables that transit operators control is the frequency with which transit vehicles arrive at a stop, a variable also referred to as the service headway. Factors that can influence the service headway include peak and off-peak schedules (service is usually less frequent in the off-peak period), varying levels of traffic congestion (congestion that delays transit vehicles may increase the time passengers wait for the bus or train, mimicking the effect of less frequently scheduled service), or simply the decisions that operators make to increase or decrease the scheduled service frequency.

For this scenario, TTSAT assumes that passengers, on average, wait one-half the length of the service headway. Under this assumption, if vehicles come less frequently—for whatever reason—then passengers will wait longer to board the transit vehicle and will have less time remaining out of their total travel-time budget for the other segments of their trip. As a result, the TTSA shrinks when service headways increase. Figure 4 illustrates this principle by comparing the TTSA for the SCTC during peak and off-peak service, assuming a 30-minute total travel-time budget. Except for comparing peak and off-peak service, all other TTSAT variables are held constant.

Inspecting the map in Figure 4 shows that peak-hour service allows travelers to reach a considerably larger territory around the stops on one of the north-south lines. The peak-hour service along this line has considerably shorter headways than the off-peak service, generating the much larger peak-hour TTSA. However, along

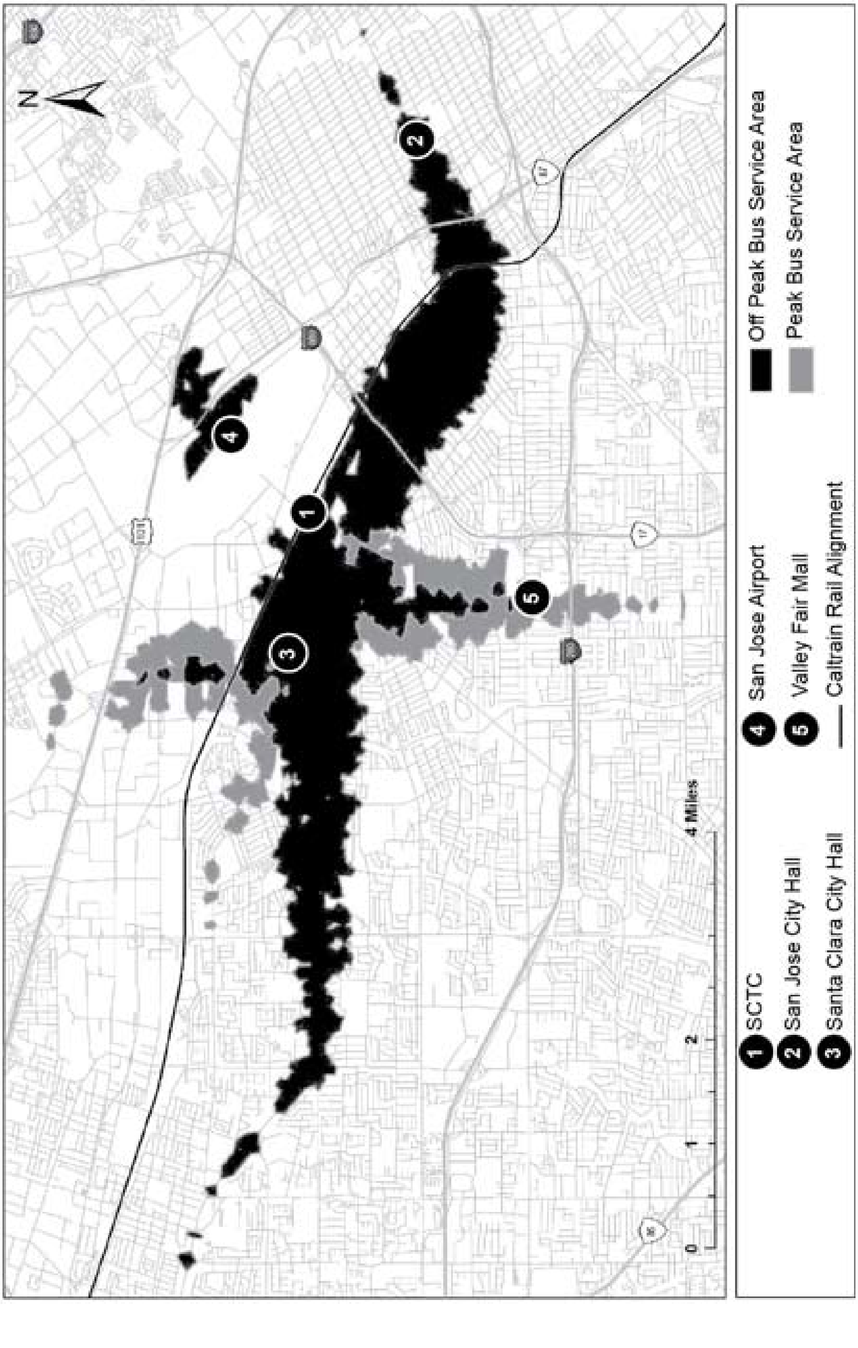

Figure 4. Thiry-Minute Peak and Off-Peak Hour Bus Service Areas for the Santa Clara Transit Center

the east-west routes, the peak-hour service is only marginally more frequent than the off-peak service, so the TTSA for the peak-hour service is only marginally bigger than the off-peak service TTSA. Looking at the entire TTSA map, the TTSA for the peak service period expands by18 percent, as compared to the TTSA during the off-peak period. The number of reachable destination stops also grows from 80 in the off-peak period to 114 during the peak period, a 42 percent increase.

Planners can use the results of modeling exercises like this one to check how much they will impact accessibility between popular origins and destinations if they change scheduled service frequencies. Using this scenario as an example, planners can inspect the TTSA map to check if the bus service provides good access to specific locations likely to attract transit riders. Figure 4 confirms that both peak-hour and off-peak bus service allow passengers to reach job-rich downtown San Jose within 30 minutes (downtown is located next to the San Jose City Hall, item number 2 on the map.) However, the Valley Fair Mall (number 5 on the map), a major regional shopping center, can be accessed in 30 minutes only during peak-hour bus service. Figure 4 shows that the mall lies slightly beyond the black area on the map, which is the 30-minute reachable area during the off-peak hours. Since many people visit shopping centers during weekends or other times that are traditionally off-peak hours for transit service, local planners might use this finding from the TTSAT analysis to support plans to add more frequent off-peak service so that patrons could have faster access to the mall on weekends.

Scenario 3: Walking vs. Biking as Transit-Access Modes

Although walking is the most common mode people use to access bus stops, bicycling is another alternative. Figure 5 shows the 60-minute bus service area of the SCTC for passengers using three different access modes:

- Walk-Only: Passengers walk on both ends of the bus ride.
- Bike-and-Walk: Passengers bike to the stop where they board the bus, park the bicycle near the bus stop, and walk from their disembarkation stop to their final destination.
- Bike-and-Bike: Passengers bicycle on both ends of the bus ride (these passengers would bring their bicycles on the bus).

For all three cases in this scenario, the maximum acceptable transit stop access time and destination access time are set at 15 minutes each, and travelers are estimated to walk at 2.05 miles per hour and to bicycle at 13.68 miles per hour.[3]

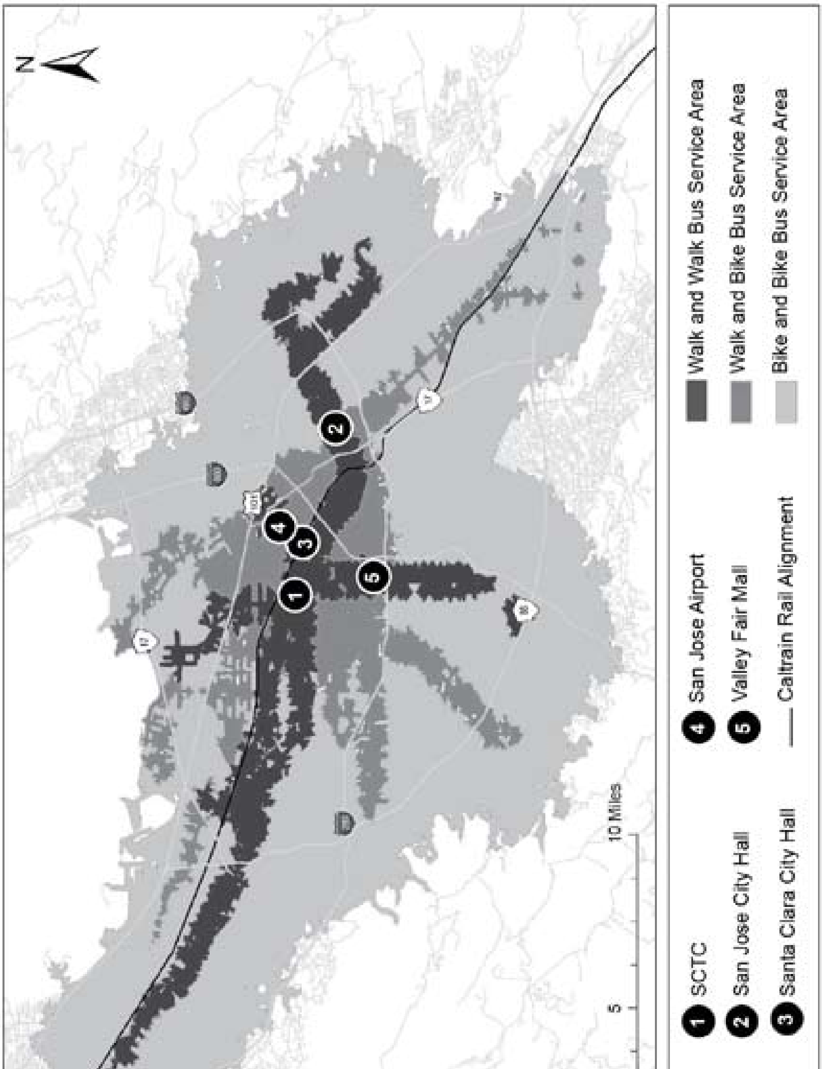

Figure 5. Sixty-Minute Peak-Hour Bus Service Areas for the Santa Clara Transit Center, by Different Access/Destination Modes

Visually inspecting Figure 5 shows that when people bicycle as an access mode, the TTSA is significantly larger than for people who walk to and from bus stops. Calculating the precise change reveals that the peak TTSA increases by 108 percent when the access mode switches from walking to bicycling. The TTSA increases even more dramatically—by 740 percent—for passengers using a bicycle at both ends of the bus trip.

The increased TTSAs are partially explained by the fact that bicycling significantly increases the number of accessible stops where travelers can catch the bus and the number of accessible routes; both factors increase the number of reachable (destination) bus stops. For travelers who walk to the stop where they wait for the bus, only 17 bus stops are accessible from the SCTC within 15 minutes, compared to 566 bus stops accessible to travelers who bicycle to a bus stop. Also, travelers who bicycle to the bus can access 11 routes, compared to the 5 routes accessible to passengers walking from the SCTC. Once passengers are on board the bus, the number of reachable disembarkation stops is 737 for those who bicycle to the bus, compared to 280 for those who walk.

The data generated from this scenario provide evidence to support the argument that transit operators and local governments should seriously consider steps to facilitate bicycle use by bus riders as a way to increase accessibility for transit patrons. Local city and county planners could install bicycle parking near transit stops, and the Santa Clara Valley Transportation Authority could provide ample and convenient bicycle racks on all the agency's buses. These relatively inexpensive steps could bring substantial increases in accessibility, as illustrated by the 740 percent jump in the size of the TTSA for the all-bike versus all-walk access modes in this scenario.

Conclusions

Summary of Main Findings

The primary goal of this research was to develop and demonstrate a new and more useful method to measure the geographic area served by a transit line or network. TTSAT is a prototype of such a tool, one that takes the approach of analyzing the transit service area for trips to and from a particular location. A key improvement of TTSAT compared to other service area measurement methods is that TTSAT incorporates time, allowing users to set the maximum acceptable trip time. Also, TTSAT integrates all segments of a complete transit trip into the trip time calculations: passengers' movement from the trip origin point to the transit stop, wait-time for the transit vehicle to arrive, in-vehicle time, and time spent traveling from the disembarkation stop to the passengers' final destinations. By incorporating all aspects of the trip, not just in-vehicle time, TTSAT produces quite realistic estimates of travel time. Finally, TTSAT users can customize the TTSA maps they generate by specifying details of passengers' expected travel behavior, such as their walking speed or the maximum time they are willing to spend going to and from the transit stops.

The second research goal was to demonstrate the types of analyses TTSAT users can perform that might improve transit and land-use planning. The scenarios presented in the previous section illustrate a sample of the types of analysis possible with TTSAT. For example, a transit planner using TTSAT can analyze how different assumptions about travelers' behavior or the frequency of transit service will change the TTSA for a particular location. This modeling capability can help transit planners and community members to identify the most useful service improvements. To give another example, applying TTSAT to the SCTC shows both visually and quantitatively the changes in bus accessibility that occur when the bus service frequency changes or when assumptions about travelers' behavior change. TTSAT users can also easily calculate the change in the number of reachable stops and the total area of the TTSAs.

Recommendations for Future Improvements to TTSAT

This paper demonstrates the basic capabilities of TTSAT as currently developed. However, the application could be improved in many ways to generate more precise results, improve the operational efficiency (and reduce the calculation time), and finally and most importantly, make the tool available to a much wider range of users. The paper concludes with four recommended improvements.

The first recommendation is to increase the precision of TTSAT's output by in-putting very precise transit route schedules and street network information. Creating accurate TTSA maps requires extremely accurate input data, both for route schedules and the underlying digitized maps. Many transit operators do not produce schedules that estimate arrival times at each stop, but only estimate arrival times at a few major stops. Planners wanting to use TTSAT for their analysis should work with their transit operators to develop the most precise possible route schedules. In addition, the TIGER/Line street network files do not produce accurate pedestrian and bicycle routes because they include only vehicle-accessible streets. If TTSAT managers use a street network map that includes pedestrian and bicycle paths, as well as streets accessible by vehicles, then TTSAT can more accurately calculate the shortest routes for people going to and from transit stops.

A second recommendation is to make TTSAT's output more precise by including more factors in the internal calculations. For example, the time travelers spend walking or biking to boarding stops could be better estimated if street-crossing behavior were included. Another method to increase precision would be to incorporate sophisticated traffic models to estimate the in-vehicle time under different traffic conditions

Third, TTSAT could be redesigned to execute its calculations more efficiently, either by recoding some of the underlying calculations or by incorporating different GIS and database applications. As currently designed, TTSAT produces maps relatively slowly. The exact time needed varies greatly, depending on the number of transit routes and the size of the geographic area under consideration, but the maps shown in this paper each took between 5 and 30 minutes to produce.

Finally, and most important of all, TTSAT should be redesigned to create a more user-friendly interface. Ideally, the application would be redesigned so that anyone could use it, including members of the public with no technical expertise. Creating an interface that anyone could use would make TTSAT useful in numerous settings. TTSAT could be used at public meetings or charrettes, allowing participants to test out how choosing different values for the variables would change accessibility. Participants could, for example, see how much service frequency would need to be increased to achieve the community's desired level of accessibility.

Ultimately, a version of TTSAT could even be included in the transit trip planning websites available to the public over the internet, such as the Transit Trip Planner available at the Metropolitan Transportation Commission's "511.org" website or Google Transit (*http://www.google.com/transit*). People moving to a new neighborhood could then use these websites to check if a potential housing unit would allow them to commute to work by transit within their personal travel constraints of time or access speed. Or, to give other example, retailers considering new locations for their businesses could check to see if it a sufficient number of customers could conveniently access those locations by transit. In the public sector, planners citing a major facility such as a hospital or job training center could check potential sites to see what geographic areas would be accessible to transit riders, using different travel time budgets and other inputs.

To obtain a report with complete details on TTSAT, contact the authors.

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Endnotes

[1] The TTSA maps show transit accessibility around a single point. The maps show an area that is both those places a transit user may access when departing from that point and all the locations from which a user can depart to access that same central point.

[2] The default walking speed is set according to recommendations from the Federal Highway Administration (2007) and Montufar et al. (2007).

[3] The bicycle speed represents the average reported speed from a survey of 5,577 bicycle commuters (Rose and Marfurt 2007).

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Commercial Vehicles in Delhi: Diesel Demand and Sulphur Emission

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Abstract

The aim of this paper is to estimate the future growth of commercial vehicles (passenger vehicles and goods vehicles) and to project the subsequent increase in diesel demand and the level of sulphur dioxide emissions in Delhi. Using an S-curve growth model on the data set of auto rickshaws, taxis, buses, and goods vehicles from 1965-66 to 2005-06, a long-term trend in the growth of commercial vehicles is projected to the year 2020-21. By 2020-21, the number of commercial vehicles is expected to increase to 0.51 million, with an increase in the share of goods vehicles and a simultaneous decrease in the share of passenger vehicles. The growth of commercial vehicles will boost the demand for diesel in 2020-21 by 68 percent, thus resulting in a three-fold increase in sulphur dioxide emissions. The conversion of goods vehicle engines from diesel to CNG (compressed natural gas) will reduce diesel demand and sulphur dioxide levels significantly. A reduction of sulphur content in diesel can further reduce sulphur dioxide emissions.

Introduction

The transportation sector is the single largest contributor to air pollution, with motor vehicles being the worst polluters apart from most energy intensive modes of transport (Delhi Pollution Control Committee, Govt. of NCT of Delhi 2003). Considering only the energy directly consumed in vehicle operation, transportation is the second largest user of commercial energy in India (Reddy et al. 2000). The energy for transportation comes primarily from petroleum products and, to a small extent, from electricity or other alternative sources. Air pollution by vehicle emissions causes the most hazardous environmental impact of the transport sector (Kathuria 2002). It is basically a product of road transport, which is the backbone of the urban transport system in most cities in India (Indian National Academy of Engineering 1996). Delhi, the capital, is spread over 1,483 sq kms with a population of 13.85 million as of the 2001 census. The transport system in Delhi is predominantly road-based, with railways catering to only about 1 percent of the local traffic. Buses are the primary mode of transport, which constitute only about 1 percent of total vehicles, whereas personal vehicles (two- and four-wheelers) account for 94 percent. The remaining five percent include goods vehicles, auto rickshaws, and taxis. Although the ratio of buses to total vehicles is far smaller than other modes, it caters to the highest percentage of the total traffic load. In comparison to other cities of India, the growth in total number of vehicles in Delhi is the largest (Planning Department, Govt. of NCT of Delhi 2007-08). This leads to higher energy consumption and air pollution. At present, Delhi has added 65.05 kilometers of mass rapid transit system (Metro rail). The expansion of this public transport system may reduce the growth of motor vehicles and, subsequently, fuel demand and air pollution (Das 2008).

The aim of this paper is to estimate the long-term trends in the growth of commercial vehicles (passenger vehicles and goods vehicles) and, subsequently based on the projected growth of vehicles, estimate the level and growth of energy demand and air pollution in Delhi. Using annual data for commercial vehicles from 1965-66 to 2005-06, the logistic and Gompertz models are appropriate for projection under the assumed saturation level. The best fit model is selected and used for projecting the level of vehicle growth on the basis of R^2 values, mean square error, and nature of the curve. These data account for four different types of commercial vehicles—auto rickshaws, taxis, buses, and goods vehicles. As a result of the growth in commercial vehicles, this paper projects the level and growth of diesel demand and sulphur dioxide emissions under different scenarios. The scenarios are business "as usual," substitution of alternative energy, and reduction of sulphur content in diesel.

The paper is organized into the following sections. In Section 2, the growth of commercial vehicles is analyed and models are developed that project this growth to the year 2020-21. Similarly, Section 3 analyzes the trend of diesel consumption and estimates the future demand under different scenarios. Sulphur dioxide emissions and future scenarios are discussed in Section 4. Section 5 provides strategies for reduction in diesel demand and sulphur dioxide emissions. The conclusion is in Section 6.

Growth of Commercial Vehicles

Trends in the Growth of Commercial Vehicles

Commercial vehicles have increased at an average rate of 7 percent per annum in Delhi (Table 1). From 1965-66 to 2005-06, the total number of motor vehicles increased more than sixty-fold, from 80 thousand to 4.8 million, while population rose about five-fold, 3.1 million to 16 million. Of total vehicles, the share of commercial vehicles is far less than personal vehicles. Commercial vehicles consist of passenger vehicles (auto rickshaw, taxi, bus) and goods vehicles. The average growth rate of goods vehicles is higher than that of passenger vehicles. In absolute terms, the number of passenger vehicles increased from 10.5 thousand to 137.8 thousand from 1965-66 to 2005-06, while goods vehicles increased from 7 thousand to 142 thousand during the same period. In the category of passenger vehicles, the share of auto rickshaws is more than that of taxis and buses. However, the average annual growth rate of buses is highest (7.6%), followed by auto rickshaws (6.6%) and taxis (4.7%). The low demand for taxis may be due to the higher cost of travel compared to auto rickshaws.

Although the growth rate of buses is highest, their share of total vehicles has gradually decreased from 1.76 percent in 1965-66 to about 1 percent in 2005-06. This is basically due to the enormous growth in the number of personal vehicles. Buses cater to 60 percent of the total traffic load, whereas personal vehicles account for 94 percent of total vehicles but cater to only 30 percent of the total traffic load (Planning Department Govt. of NCT of Delhi 2005-06). Interestingly, the period between 2000-01 and 2005-06 shows an average negative growth rate for all categories of vehicles. The negative growth rate is significantly higher in the case of passenger vehicles (-8.77%) compared to goods vehicle (-2.31%). Similarly, in the category of passenger vehicles, auto rickshaws have registered the highest negative average growth rate (-8.71%), followed by buses (-4.58%) and taxis (-2.06%). This is due to the implementation of several directives issued by the Supreme Court of India for control of vehicular pollution in the years 1998, 2000, and 2001. These directives include phasing out or banning the plying of old commercial passenger vehicles and requiring the conversion of commercial passenger vehicles to a single

Table 1. Population, Registered Number of Commercial, and Total Vehicles in Delhi

Year	Population	Auto (A)	Taxi (T)	Bus (B)	Passenger Vehicle (A+T+B)	Goods Vehicle (G)	Commercial Vehicle (A+T+B+G)	Total Vehicle
1965-66	3140214	6243	2838	1417	10498	7223	17721	80420
	(4.08)	(12.82)	(7.27)	(21.01)	(12.48)	(16.55)	(14.08)	(21.94)
1970-71	4065698	10812	4105	3266	18183	15262	33445	204078
	(4.25)	(10.06)	(4.98)	(12.98)	(9.51)	(11.83)	(10.57)	(13.72)
1975-76	5006283	16295	4996	5891	27182	26081	53263	378918
	(4.25)	(5.19)	(5.80)	(7.67)	(5.84)	(8.21)	(7.02)	(8.32)
1980-81	6220406	20920	6583	8528	36031	38072	74103	561768
	(4.41)	(10.70)	(7.25)	(13.08)	(10.63)	(11.60)	(11.08)	(13.28)
1985-86	7622810	40713	8772	14617	64102	61860	125962	1075486
	(4.15)	(11.11)	(3.41)	(6.28)	(9.07)	(12.51)	(10.79)	(13.19)
1990-91	9420644	65829	10426	19671	95926	106052	201978	1923787
	(4.15)	(4.30)	(6.46)	(8.77)	(5.49)	(5.62)	(5.55)	(7.57)
1995-96	11379236	80208	14593	29183	123984	139300	263284	2793605
	(3.85)	(2.11)	(5.09)	(6.68)	(3.57)	(2.90)	(3.21)	(4.68)
2000-01	13782976	86985	18362	41483	146830	158492	305322	3456579
	(3.09)	-(8.71)	-(2.06)	-(4.58)	-(8.77)	-(2.31)	-(5.34)	(6.91)
2005-06	16021000	73644	20693	43500	137837	141996	279833	4809010
AGR	4.1	6.6	4.7	7.6	6.5	7.8	7.1	9.9

Note: Figures in parentheses are average five years annual growth rate.
AGR: Average Annual Growth Rate
Source: Delhi Statistical Handbook (various years)

fuel mode, CNG (Transport Dept. Govt. of NCT of Delhi 2000). In spite of negative growth in the recent past, commercial vehicles have increased significantly over the years in Delhi (Table 1). In what follows, using the trend of vehicle ownership per 100 persons, forecasting models of commercial vehicle growth are developed.

Model for Forecasting of Commercial Vehicles

The growth in commercial vehicles per 100 persons over time typically follows a sigmoid or S-shaped curve. There are a number of different functional forms that can describe S-shaped curves, for example, logistic, Gompertz, Von Bertalanffy, etc. (Draper and Smith 1998). These curves forecast how and when a given growth system will reach its saturation limit. Gompertz and logistic functions are developed in reaction to Malthus' natural growth function, in which the population grows exponentially, which seems to be unrealistic because environment imposes limitations on every growth pattern. Gompertz' original work was presented at the Royal Society of London in 1825 and is described in the literature of Smith and Keyfitz (1977). However, a logistic model was applied for the first time by Verhulst, who published his research in 1838 in the journal *Correspondence Mathematique et Physique*. Almost a century later, in 1920, Pearl and Reed rediscovered the logistic model in the course of their study of the evolution of fly populations (Jarnc et al. 2005). Originally, these models were developed to describe the self-limiting growth of population. First use of these models to analyze economic growth is attributed to the French sociologist Gabriel Tarde (Tarde 1903). Tarde's idea, followed by other scholars such as Prescott (1922), obtained demand forecasts for the automobile using the Gompertz function. Although the path of these growth functions can be represented in the general S-shape fashion, different types of entities can grow different patterns. Hence, the exact form of the curves, including the slope and the asymptote, may be different for each particular growth pattern. For example, the slope may be very steep during early phases, including rapid growth, or it may be gradual, suggesting a slow and hesitant start, but all of them will level to the saturation limit. The main advantage of these models is to reach the saturation level in the long-term forecast, as most of the systems, whether natural or artificial, attain the saturation level after a certain period. The properties of the S-curve growth model are such that if the growth is quite rapid at an early phase and relatively slow when approaching the saturation level, then the Gompertz function is the best method because it attains its maximum rate of growth at an earlier phase than that of the logistic model. If, on the other hand, the diffusion process is such that growth is initially slow and relatively rapid during the maturing phases, then the logistic model is a superior forecasting method because it grows more rapidly towards the maximum level than the Gompertz model. The two frequently-used functional forms of S-curve representing different growth patterns are the logistic and the Gompertz functions (Ogut 2004; Singh 2006).

An important issue in implementation of these models is the estimation of saturation levels. A few studies have estimated the saturation level from the S-curve growth function (Singh 2000), but most of the studies provide the saturation level externally by applying a rule of thumb, e.g., one car per family (Palelink 1960), one driving member per family (Tanner 1978), per capita vehicle ownership (Button et al. 1993; Peter et al. 2003). In this paper, the seating capacity of a commercial passenger vehicle is assumed to be the saturation level. The seating capacities of auto rickshaws and taxis are 3 and 5, which implies that the saturation levels per 100 persons is assumed to be 33 and 20, respectively. However, the seating capacity of buses ranges from 11 (RTV) to 60 (high-capacity bus). Therefore, it was assumed that the saturation level for buses is 2 for 100 persons. In the case of goods vehicles, the saturation level is assumed to be 4 per 100 persons. The assumption is based on the growth-size (G-s) relationship (Pelsmacker 1990). The idea behind this approach is that at the saturation level, the relative growth rate is equal to zero. The growth of goods vehicles (G) has a linear relationship with per capita goods vehicles (s). The best fit linear function is obtained as G = -6.13 + 149.48 s, which is significant at the 95% confidence level. At the saturation limit, i.e., G = 0, this implies the number of per capita goods vehicles (s) = 0.04. Then, using the saturation level (S), models have been developed based on logistic and Gompertz distributions to forecast commercial vehicle (V) growth per 100 persons with respect to time (t) in Delhi.

Logistic Model: The change in vehicle growth with respect to time, i.e., ($\frac{dV_t}{dt}$), is proportional to the product of the level of vehicle growth at time, t i.e., (V_t), and the fraction of market untapped, i.e., ($\frac{S-V_t}{S}$), where S is the saturation limit of the growth (Das et al. 2009). The corresponding differential equation is

$$\frac{dV_t}{dt} = \frac{bV_t(S-V_t)}{S} \qquad (1)$$

where b > 0 is the proportionality constant, i.e., growth rate.

Integrating the above differential equation over interval 0 to t, the logistic function is

$$V_0 = \frac{S}{1+a} \qquad (2)$$

The parameters a and b model the location and shape of the curve, respectively. For $t = 0$, $V_0 = \frac{S}{1+a}$ is the starting level of automobile growth, and for t = very large, $V_\infty = S$ is the saturation limit. The logistic curve reaches its maximum growth rate at half of the saturation level, i.e., $V_t = S/2$, called the point of inflection of the curve, and occurs at $t = \frac{\ln a}{b}$. The logistic curve is symmetric about the point of inflection.

Gompertz Model: The change in vehicle growth with respect to time, i.e., $(\frac{dV_t}{dt})$, is proportional to the product of the present level of vehicle growth at time t, i.e., (V_t), and the logarithm of vehicle density level, i.e., $\ln(\frac{S}{V_t})$, where S is the saturation limit of the growth (Das et al. 2009). The corresponding differential equation is

$$\frac{dV_t}{dt} = bV_t \ln\left(\frac{S}{V_t}\right) \qquad (3)$$

where $b > 0$ is the proportionality constant, i.e., growth rate.

Integrating the above differential equation over interval 0 to t, the Gompertz function is

$$V_t = Se^{-ae^{-bt}} \qquad (4)$$

The parameters a and b model the location and shape of the curve, respectively. The Gompertz curve reaches its maximum growth rate at $V_t = S / e$, which is the point of inflection of the curve that occurs at $t = \frac{\ln a}{b}$. For $t = 0$, $V_0 = Se^{-a}$, is the starting level of vehicle growth, and for t = very large, $V_\infty = S$ is the saturation limit. Unlike the logistic curve, it is not symmetrical about its point of inflection.

Finally, using saturation level S and time variable t, the parameters a and b are estimated by an ordinary least squares procedure after transforming the logistic (equation [2]) and Gompertz (equation [4]) models into logarithmic form,

$$\ln\left(\frac{S}{V_t}-1\right)=\ln a-bt \tag{5}$$

$$\ln\left[\ln\left(\frac{S}{V_t}\right)\right]=\ln a-bt \tag{6}$$

where time variable t is taken as 1 for 1965-66, 2 for 1966-67, ... and 41 for 2005-06. The ordinary least squares estimation is carried out using Excel. Based on R^2 value and mean square error (MSE), the better-forecasted values are selected, where MSE is the average of square of the difference between actual and forecasted values.

Model Estimation

The estimated results of auto rickshaws, taxis, buses, and goods vehicles in both these models are shown in Table 2. Although the models have different functional forms, they have several features in common. All of them increase monotonically and have horizontal asymptotes, with one of them representing the saturation level.

As per R^2 values, the models fit the data very well. However, the R^2 value of taxis in both these models is low. All the parameters have the expected sign, and most are highly significant, as can be observed from t statistics. The highest R^2 and lowest MSE values of buses and goods vehicles are found in the Gompertz model. Similarly, the growth in auto rickshaw provides higher R^2 in the logistic model. However, taxis has same R^2 in both these modes. The properties of these models are also in Figures 1, 2, 3, and 4, respectively.

Table 2. Estimated Parameters of Logistic and Gompertz Models

Models	Parameters	Auto	Taxi	Bus	Goods Vehicle
	b	*0.0094*	*0.0066*	0.0275	0.0328
		(6.85)	*(3.83)*	(9.99)	(12.51)
Logistic	a	*107.8440*	*202.9676*	20.3391	18.2503
		(43.95)	*(110.64)*	(35.67)	(32.51)
	R^2	*0.55*	*0.28*	0.72	0.80
	MSE	*0.0317*	*0.0002*	0.0021	0.1123
	b	0.0025	0.0013	*0.0116*	*0.0139*
		(6.67)	(3.93)	*(10.02)*	*(12.60)*
Gompertz	a	4.7267	5.3200	*3.1528*	*2.9920*
		(77.15)	(223.75)	*(37.28)*	*(29.39)*
	R^2	0.54	0.28	*0.72*	*0.81*
	MSE	0.0301	0.0002	*0.0019*	*0.0276*

Note: Figures in parentheses are values of t-statistics.
Note: Italics figures are selected parameters.

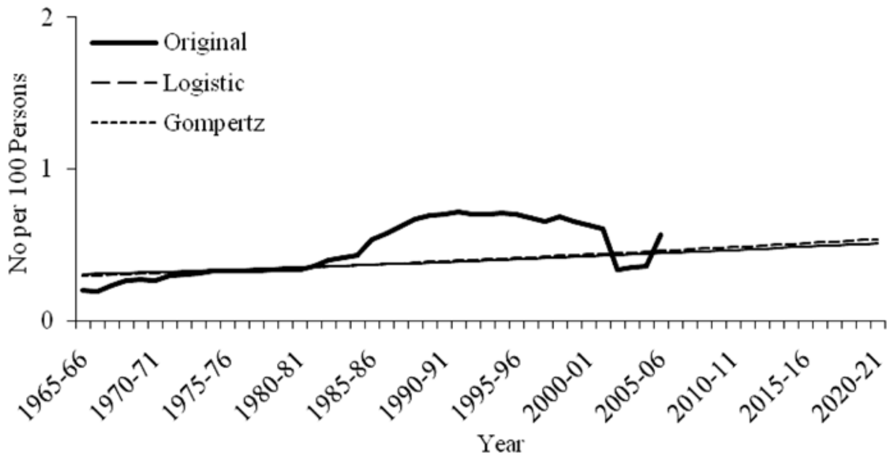

Figure 1. Auto Rickshaw Growth

In Figures 1 and 2, the original growth curve of auto rickshaws and taxis are initially slow, then increases and decreases rapidly before taking an upward direction. Therefore, the trend of the original curve seems to follow the logistic path. This decrease in growth after 2001-02 is due to the intervention of the Indian government's auto fuel policy.

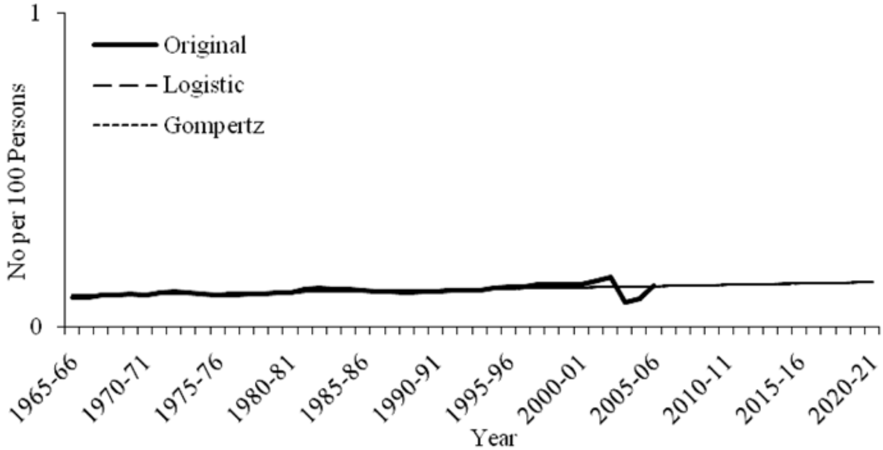

Figure 2. Taxi Growth

The slow growth of taxis make the logistic and Gompertz curves linear, by appearance, but it is really not so. Therefore, from the figure, it is difficult to identify the curve that follows the original curve.

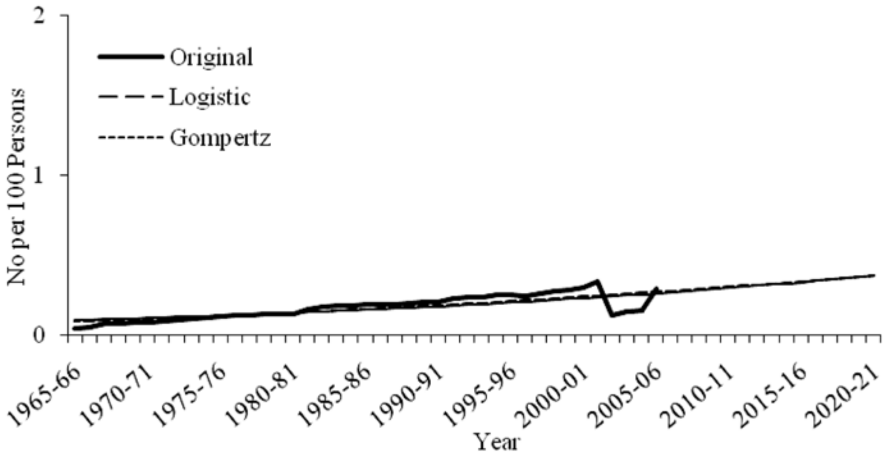

Figure 3. Bus Growth

The original growth of buses (Figure 3) and goods vehicles (Figure 4) is quite rapid at an early phase. Hence, the original growth takes the shape of the Gompertz curve.

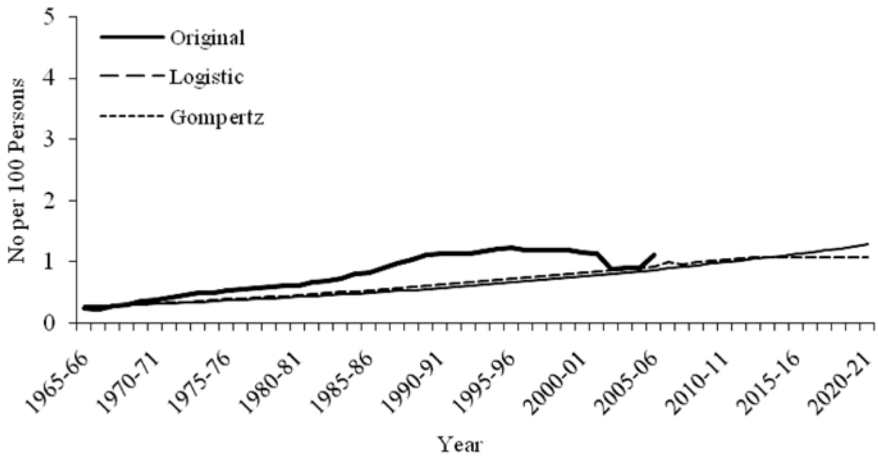

Figure 4. Goods Vehicle Growth

Therefore, as per R^2 value, MSE, and properties of the curves, the logistic model fits the data better in projecting the growth of auto rickshaws and taxis, whereas the Gompertz model fits better in projecting the growth of buses and goods vehicles. The saturation level and selected parameters a and b in Table 2 help to develop forecasting models for the growth of different motor vehicles per 100 persons as given bellow:

$$Autorickshaw_t = \frac{33}{1+107.8440e^{-0.0094t}} \quad (7)$$

$$Taxi_t = \frac{20}{1+202.9676e^{-0.0066t}} \quad (8)$$

$$Bus_t = 2e^{-3.1528e^{-0.0112t}} \quad (9)$$

$$Goodsvehicle_t = 4e^{-2.9920e^{-0.0139t}} \quad (10)$$

Growth Projection of Commercial Vehicles by 2020-21

Substituting t = 46, 51, and 56 in equations (7), (8), (9) and (10), the projected level of auto rickshaws, taxis, buses, and goods vehicles per 100 persons for the years

2010-11, 2015-16 and 2020-21 are determined. This projected level of commercial vehicles per 100 persons is converted into an absolute number by multiplying the projected population and dividing it by 100, as reported in Table 3.

Table 3. Projected Growth of Commercial Vehicles in Delhi

Year	Population	Auto Rickshaw (A)	Taxi (T)	Bus (B)	Passenger Vehicle (A+T+B)	Goods Vehicle (G)	Commercial Vehicle (A+T+B+G)
2005-06*	16,021,000	73644	20693	43500	137837	141996	279833
		(53.43)	(15.01)	(31.56)	{49.26}	{50.74}	
2010-11	18,451,000	85922	24514	56171	166607	190191	356798
		(51.57)	(14.71)	(33.71)	{46.70}	{53.30}	
2015-16	21,285,000	103838	29227	71802	204867	229106	433973
		(50.69)	(14.27)	(35.05)	{47.21}	{52.79}	
2020-21	24,485,000	125132	34749	91012	250893	263550	514443
		(49.87)	(13.85)	(36.28)	{48.77}	{51.23}	

Note: *Actual data
Note: Figures in parentheses ( ) are percentage of passenger vehicles.
Note: Figures in brackets { } are percentage of commercial vehicles.

The total number of commercial vehicles in Delhi will rise from 0.28 million in 2005-06 to 0.51 million in 2020-21. For 2005-06, the share of passenger vehicles to commercial vehicles was less than goods vehicles. However, the projected growth reflects that the share of passenger vehicles is expected to decrease rather than increase to 48.77 percent by the end of 2020-21. Similarly, in the category of passenger vehicles, the share of auto rickshaws will decrease from 53.43 percent in 2005-06 to 49.87 percent in 2020-21. The growth of taxis will be slow, and its share of passenger vehicles will be in a decreasing trend, i.e., 15.01 percent in 2005-06 to13.85 percent in 2020-21. Interestingly, the number of buses is expected to increase by more than double during the same period (43 thousand in 2005-06 to 91 thousand in 2020-21). As discussed earlier, the logistic and Gompertz models assume different distribution functions for the threshold values of motor vehicle growth. While the logistic function is based on a symmetric frequency distribution, the Gompertz model is derived from a skewed frequency distribution. The distinction has important implications for capacity planners. The results show that the rate of growth in the case of auto rickshaws and taxis is closer to symmetric, as implied by the logistic model, rather than attaining its maximum growth at an earlier phase, as the Gompertz model would suggest. Similarly, the reverse situation happens in the growth of buses and goods vehicles. The theoretical model of the logistic and Gompertz curves has been highly effective (Akoi and Yoshikawa 2002), although its empirical results are somewhat less satisfactory for a number of reasons. For example, both the logistic and Gompertz curves are characterized by constantly-declining growth rates after a certain period, but this does not always happen in a real-life situation. In spite of certain limitations, the effectiveness of these curves in theoretical studies led to their application in forecasting the growth of commercial vehicles. This future growth of commercial vehicles will help in estimating diesel demand and the level of sulphur dioxide emissions by the transport sector.

Projection of Diesel Demand

Growth Pattern in Diesel Consumption

A diesel engine differs from a petrol engine, mainly in that it relies on heat generated by compressing air in the cylinder to ignite the fuel. To generate the required heat, a diesel engine must produce higher compression than the petrol engine, making it heavier, bulkier, more expensive, and capable of being operated only at slower speeds. But it can operate on cheaper, less highly-refined fuel, which gives it an advantage in many heavy transportation and construction activities. The main users of diesel in commercial vehicles category are taxis, buses, and goods vehicles, which range from light vehicles to heavy bulldozers (Karnik 1989). To overcome some known disadvantages of petrol and diesel engines, basically due to expensive fuel and pollution, the government of Delhi substituted CNG for petrol and diesel fuel as mandatory for the public transport system in Delhi. The order was directed towards replacement of all pre-1990 autos and taxis with new vehicles using clean fuel, and the entire city bus fleet was to be steadily converted to a single fuel mode of CNG by March 31, 2001. CNG is considered to be an environmentally "clean" alternative to diesel and petrol fuels (Transport Department Govt. of NCT of Delhi 2000). Implementation of this directive helped in converting the entire bus fleet and auto rickshaws to CNG engines after 2002-03, whereas, in the case of taxis, the same was done in 2003-04 (Tables 4).

Table 4. Commercial Vehicles with CNG Engine and CNG Consumption

Type of Vehicle	2000-01	2001-02	2002-03	2003-04	2004-05
Auto Rickshaw	86985	86985	49538	52905	53656
	(22010)	(36565)	(49538)	(52905)	(53656)
Taxi	18362	20628	23145	11495	13511
	(2183)	(4569)	(9936)	(11495)	(13511)
Bus	41483	47578	18731	21962	24235
	(1982)	(6396)	(18731)	(21962)	(24235)
CNG in Tons*	43800	129575	246375	323573	336619

Source: Ministry of Petroleum & Natural Gas, Govt. of India
Note: Figures in parentheses are CNG vehicles converted from total vehicles.
Note: * 1 Kg = 1.387 litres

Since 1990-91, the average annual rate of consumption of diesel has been decreasing, while in absolute terms it decreased and attained negative growth rate after 2000-01, as shown in Table 5. The drastic fall in diesel consumption after 2001-02 is due to total conversion of commercial passenger diesel vehicles to CNG engines. At the same time, CNG consumption has increased eight-fold within five years, from 2000-01 to 2004-05, as seen in Table 4.

Table 5. Consumption of Diesel in Delhi

Years	1980-81	1985-86	1990-91	1995-96	2000-01	2004-05
Diesel (Tons)	405000	579000	798000	1198000	1301000	1272000
		(7.23)	(8.67)	(5.66)	(3.00)	-(0.16)

Source: Statistical Hand Book (various year).
Note: Figures in the parentheses are average growth rate of five years.

Diesel Demand Estimation

The demand for diesel energy is derived from the demand for diesel vehicles, which is well established by many studies (Karnik 1989; Banaszak et al. 1999). To establish a functional relationship with respect to diesel demand, it was attempted to consider the growth of diesel taxis (DT), diesel buses, and goods vehicles (DBGV) as explanatory variables. Buses and goods vehicles are combined because both contain light to heavy vehicles with proportionately the same fuel efficiency. This relationship is set up in the form of log linear multiple regressions. The forecast of diesel demand is obtained by assuming various scenarios for the future growth of the explanatory variables. Using available data from 1980-81 to 2004-05, the In *Diesel* (equation [12]) estimate the diesel demand as given below, where figures in parentheses are values of t statistics.

$$\text{In } Diesel = 4.0003 + 0.0244 \text{ x } 1\text{n}DT + 0.8443 \text{ x } 1\text{n}DBGV \qquad (12)$$

$$(3.25) \qquad\qquad (18.91)$$

$$R^2 = 0.94,\ DW = 1.61$$

From equation (12), it is observed that the estimated DW for In *Diesel* is found to be 1.61, which falls in the range of no autocorrelation, i.e., between 1.55 and 2.45 (Makridakis et al.1998). As per Klein's rule of thumb, the model is also free from multicolinearity problem (Klien 1962). Hence, the data fit well for estimating the diesel demand in Delhi. The t statistics of all the parameters in the In *Diesel* model is significant at the 95% confidence level. Similarly, R^2, the coefficient of determination of In *Diesel* model, is 0.94, indicating that all included variables account for 94 percent of the original variation in the response variable, while the remaining 6 percent represents the variation of residuals. Therefore, the determinants explaining diesel demand are highly significant. From the coefficient of determinants, it is observed that the growth of diesel buses and goods vehicles has significantly more influence on diesel demand than diesel taxis. It is also observed from In *Diesel* that the changes in the growth of a unit of diesel buses and goods vehicles change the demand of diesel by 0.84 units, provided other things remain constant. However, in the case of taxis, it is very low (0.02 units). This is basically due to the slow growth and gradual conversion of diesel taxis to CNG engines. Therefore, using diesel goods vehicles data from Table 3, the In *Diesel* model projects the demand of diesel for the years 2010-11, 2015-16, and 2020-21 under different scenarios (Figure 5).

S1 is the "as usual" scenario, which estimates the diesel demand under "as usual" growth of diesel vehicles. In this scenario, the demand for diesel will increase more than 100 percent by 2020-21, as compared to the year 2005-06. On the other hand, scenario S2 estimates the diesel demand under 5, 10, and 25 percent conversion of diesel goods vehicles to CNG engines in the years 2010-11, 2015-16, and 2020-21. The above conversion of diesel goods vehicles will reduce diesel demand by 4, 9, and 22 percent from that of the demand for diesel under S1 in the respective years.

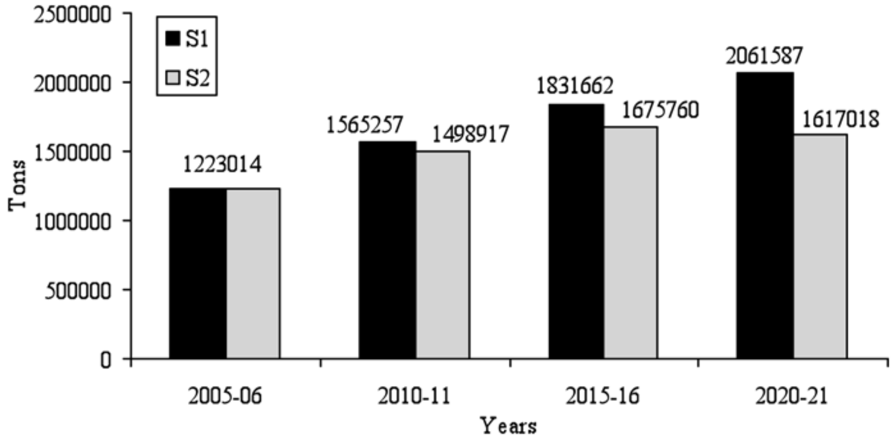

Figure 5. Projected Diesel Demand in Delhi

Projection of Sulphur Dioxide Emission

Growth Pattern in Sulphur Dioxide Emissions

Sulphur dioxide (SO_2) is one of the principal constituents of vehicular pollutants. The main source of sulphur dioxide is the combustion of sulphur contained in fuel, especially in diesel-powered vehicles. Sulphur dioxide is a colourless, soluble gas with a characteristic pungent smell, which forms sulphuric acid when combined with water. It is an irritant gas and, when inhaled, affects mucous membranes and causes oxygen deficiency in the body. Persons with asthma are badly affected by this pollutant (Rao and Rao 2001). The highest percentage of sulphur dioxide is exhausted by a diesel engine (Bose 1998; Reddy et al. 2000; Rao and Rao 2001). The period between 1990-91 and 1995-96 saw a rapid increase in the SO_2 pollutant level in the air of Delhi (Table 6). This may be due to the significant growth in diesel vehicles and diesel consumption over the last two decades, which can also be seen in Table 1 and Table 5.

Table 6. Annual Average Concentration of Sulphur Dioxide in Delhi (in µg/m3)

Year	1990-91	1995-96	2000-01	2005-06
SO_2	11.65	20.50 (17.63)	18.03 -(1.77)	8.83 -(14.19)

Source: Economic Survey Delhi, 2005-06

Note: Figures in parentheses are average five years annual growth rate.

On the other hand, the annual average SO_2 level has gradually been decreasing from 20.50 mg/m3 in 1995-96 to 8.83 mg/m3 in 2005-06 (Table 6). This could be attributed to the stringent implementation of vehicular emission norms, fuel quality upgrading, and better maintenance of engines through all possible measures. This tremendous achievement could also be linked to the conversion of commercial passenger vehicles to CNG engines (Table 4). However, during this period, goods vehicles have increased from 0.1 million to 0.14 million (Table 1), an increase of about 40 percent within a period of 15 years. From Table 5, it can be observed that diesel consumption has increased from 798 thousand tons in 1990-91 to 1,272 thousand tons in 2004-05, an increase of 62.73 percent. This has resulted in the corresponding level of SO_2 pollutants.

SO_2 Emission Estimation

The relationship between SO_2 emissions and their source, the growth of diesel vehicles, is established by linear regression model (Khare and Sharma 2002) in this section. Starting from 1990-91 to 2005-06, 16 annual observations of average SO_2 pollutant levels have been taken from the Economic Survey Delhi 2003-04 and 2005-06. The responsibility of data collection rests on the Central Pollution Control Board, which monitors air quality at various locations in Delhi. The monitoring stations are located at Ashok Vihar, Shahzadabagh, Siri Fort, Janakpuri, Nizamuddin, and Shahdara.I Initially, monitoring was for 8 hours, but was subsequently extended to 24 hours from 1994 onwards. Data for the sulphur content in diesel was taken from *www.dieselnet.com/standards/in/fuel.html*. Using data for diesel consumption (DC), diesel vehicles (DV), and sulphur content in diesel (S), the estimated SO_2 emission model is presented. (Figures in parentheses are values of t statistics.)

$$SO_2 = -15.81 + 0.000012DC + 0.000071DV + 11.85S \qquad (13)$$

$$(1.87) \qquad (2.61) \qquad (4.85)$$

$$R_2 = 0.74, DW = 1.15$$

From equation (13), it can be observed that the estimated DW for SO_2 is found to be 1.15, which falls into an inconclusive range, between 0.9 and 1.71 (Makridakis et al. 1998). As per Klein's rule of thumb, the model is also free from the multicolinearity problem (Klien 1962). The t statistics of all the explanatory variables in SO_2 models are significant at the 95% confidence level, except the variable of diesel consumption, which is significant at the 90% confidence level. Therefore, the values of the coefficients are consistent with the physical effect of the respective variables. The coefficient of the growth of diesel consumption, diesel vehicles, and sulphur content is of the expected sign in accordance with the fact that it is highly correlated with SO_2 concentration. Therefore, the growth of diesel consumption, diesel vehicles, and sulphur content in diesel are directly proportional to the growth of SO_2 concentration. This implies that the increase or decrease in SO_2 concentration depends upon the increase or decrease in the growth of diesel vehicles, diesel consumption, and sulphur content in diesel. From the coefficient of the explanatory variable in the SO_2 model, it is observed that the sulphur content in diesel influences more on SO_2 concentration than diesel consumption and diesel vehicles. Finally, the coefficient of determination R_2 for the SO_2 model is equal to 0.74 (equation [13]), indicating that all included variables account for 74 percent of the original variation in the response variable, while the remaining 26 percent represents the variation of the residuals. The diagnostic check of predictor variables suggests that the growth of diesel vehicles, diesel consumption, and sulphur content should be included, as it is capable of fitting the data satisfactorily. Using the future growth of diesel vehicles and diesel consumption from Table 3 and 4, the SO_2 model projects the future level of SO_2 pollutant for the years 2010, 2015, and 2020 under different scenarios in Delhi (Figure 6).

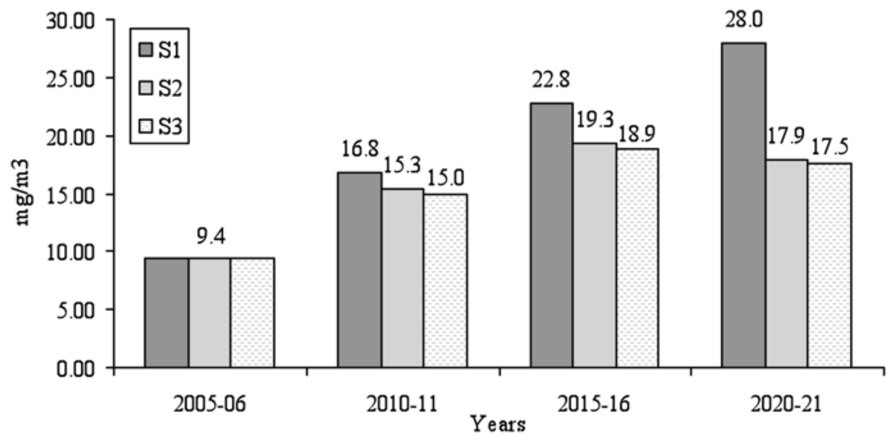

Figure 6. Projected Sulphur Dioxide Level in Delhi

S1 is the "as usual" scenario, which estimates the concentration of SO_2 pollutant under "as usual" growth of diesel vehicles, diesel consumption, and 0.035 percent of sulphur content in diesel. In this scenario, the concentration of SO_2 pollutant will increase by nearly five times by the year 2020-21 as compared to the level of 2005-06. Similarly, scenario S2 estimates the concentration of SO_2 under scenario S1 with the additional constraint of 5, 10, and 25 percent of goods vehicles converted to CNG in 2010-11, 2015-16, and 2020-21, respectively. The above percentage of conversion will reduce the concentration of SO_2 levels from 9 to 35 percent during the same period. Finally, scenario S3 estimates SO_2 levels under the S2 scenario with a reduction of sulphur content from 0.005 to 0.001 percent in diesel fuel during the period from 2010-11 to 2020-21. This reduction of sulphur content will further reduce the concentration of SO2 levels from 11 to 37 percent, as can be seen in Figure 6.

Strategies to Reduce Diesel Demand and SO_2 Emission

The transport sector is one of the fastest-growing sectors in terms of energy consumption and air pollution, not only in Delhi but also in many other cities. In this sector, the growth of commercial vehicles plays a significant role, leading to higher diesel consumption and SO_2 emission. The demand for more diesel energy for transportation leads to its scarcity and increases the cost of importing. On the other hand, SO_2 emissions in urban areas affect the health of humans, animals, and plants. Due to the depleting and polluting nature of diesel energy, reduction measures may be taken in the following manner. The rail transport system depends on electric energy in most Indian cities. Therefore, it has lower external costs than road transport in relation to energy consumption. Although rail-based transport services in Delhi are available for intra-city transportation, they play very little role in meeting the travel demand of city people. In 2005-06, Delhi opened its first phase of the Metro rail network for passenger transport. In our study, it was observed that the introduction of Metro rail has marginally reduced the use of road-based passenger vehicles on parallel routes. Considering the financial health of the government and the investment required to increase the rail (Metro) based passenger transport system, it is also evident that bus transport services in Delhi will have to play a major role in providing passenger transport services in future. Therefore, there is an urgent need for the restructuring of the bus transit system in Delhi to enhance both quantity and quality of services. There is a need for an integrated rail and road-based public transport system in Delhi, which would have the potential to attract people towards the public transport system. There should be offer of an attractive and easier way to use the public transport system, leading to the use of existing resources with improvements in the efficiency of service delivery and comfort for commuters. On the other hand, the government should encourage goods vehicles to use cleaner fuel such as CNG which, in turn, will reduce diesel demand and SO_2emissions in future. Therefore, strengthening the public transport system, especially rail, promoting cleaner fuel and improved engine technologies, and reducing sulphur content in diesel can reduce diesel demand and sulphur emissions in Delhi considerably.

Conclusion

This study estimates the future growth of commercial vehicles in the road transport sector and corresponding diesel demand and SO_2 emissions in Delhi. A simple observation of trends over the past 41 years clearly shows a significant increase in the growth of commercial vehicles. The total number of commercial vehicles will increase from 0.28 million in 2005-06 to 0.51 million in 2020-21, with almost equal shares of passenger and goods vehicles. This growth of commercial vehicles will demand 50 percent more diesel fuel in 2020-21 as compared to the year 2004-05, which leads to an increase in SO_2 levels by nearly three times. However, significant reductionswill be possible under a higher rate of conversion in diesel goods vehicles to CNG engines. Therefore, the government should encourage goods vehicles to use cleaner alternative fuel such as CNG for the reduction of diesel demand and sulphur emissions. There is a need for an integrated rail and road-based public transport system in Delhi, which will have the potential to attract people towards the public transport system.

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Determinants of Customer Satisfaction on Service Quality: A Study of Railway Platforms in India

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Abstract

Service quality has been viewed as a determinant of customer satisfaction. Different dimensions of service quality have been considered by various researchers. This study identifies components of service quality of Indian Railways at railway platforms. The study is exploratory in nature and uses factor analysis to identify the most important factors of customer satisfaction with service quality. The research methodology is empirical, and a survey of passengers (customers) was conducted. The findings reveal that five factors are considered important for determining satisfaction with railway platforms, the most important of which are refreshments and behavioral factors. Managerial and theoretical implications are drawn and discussed in the paper, and a model is proposed.

Introduction

Satisfaction from service quality is usually evaluated in terms of technical quality and functional quality (Gronroos 1984). Usually, customers do not have much information about the technical aspects of a service; therefore, functional quality becomes the major factor from which to form perceptions of service quality

(Donabedian 1980, 1982). Service quality may be defined as customer perception of how well a service meets or exceeds their expectations (Czepiel 1990). Service quality can be measured in terms of customer perception, customer expectation, customer satisfaction, and customer attitude (Sachdev and Verma 2004). Ekinci (2003) indicates that the evaluation of service quality leads to customer satisfaction. Rust and Oliver (1994) define satisfaction as the "customer fulfillment response," which is an evaluation as well as an emotion-based response to a service. This paper is an attempt to put forth the role of service quality in affecting customer satisfaction in the context of railway services, with special reference to platforms in the North Central Zone of Indian Railways.

Literature Review

Various scholars have considered different dimensions of service quality. Gronoos (1884) considers technical, functional, and reputational quality; Lehtinen and Lehtinen (1982) consider interactive, physical, and corporate quality; and Hedvall and Paltschik (1989) focus on willingness and ability to serve and the physical and psychological access to the service. In conceptualizing the basic service quality model, Parasuraman et al. (1985) identified 10 key determinants of service quality as perceived by the service provider and the consumer, namely, reliability, responsiveness, competence, access, courtesy, communication, credibility, security, understanding/knowing the customer, and tangibility to formulate a service quality framework, *SERVQUAL*. Later (in 1988), they modified the framework to five determinants: reliability, assurance, tangibles, empathy, and responsiveness, or RATER. The techniques of customer satisfaction analysis allow the critical aspects of the supplied services to be identified and customer satisfaction to be increased (Cuomo 2000).

Table 1 summarizes the findings in the literature consulted to understand various determinants of basic service quality.

Table 1. Determinants of Quality

Quality Determinants	Authors
Technical aspects, functional aspects	Gronroos (1984)
Functional aspects	Donabedian (1982, 1980) Gronroos (1984)
Customer perception, customer expectation	Czepiel (1990) Sachdev and Verma (2004) TCRP Report 100
Customer expectation, customer satisfaction and customer attitude	Sachdev and Verma (2004)

The literature review also shows that researchers have identified different factors of quality in the context of different services. Transit Cooperative Research Plan (TCRP) Report 100 (Chapter 2) defines transit quality as "the overall measured or perceived performance of transit service from the passenger's point of view." TCRP Report 88 (TCRP Report 100, Chapter 2) defines five categories of measures that wholly or partially reflect the passenger's point-of-view in transit services: (1) availability of transit service, (2) service monitoring, (3) travel time, (4) safety and security, and (5) maintenance and construction activity on passenger trips. Vanniarajan and Stephen (2008) identified the attributes that passengers use to evaluate the service quality of Indian Railways as reliability, assurance, empathy, tangibles, and responsiveness. It was found that passengers were "moderately satisfied" to "satisfied" on these dimensions. Agrawal (2008) identified employee behavior as most important determinant of customer (passenger) satisfaction with Indian Railway services.

Eboli and Mazzulla (2007) measured customer satisfaction in the context of bus service on various factors including availability of shelter and benches at bus stops, cleanliness, overcrowding, information system, safety, personnel security, helpfulness of personnel, and physical condition of bus stops. TCRP Report 100 identifies the following elements at bus stations for efficient service: shelters, waiting rooms and seating, doorways, stairways, escalators, signage and information displays, public address systems, and passenger amenities (including shelters, benches, vending machines, trash receptacles, lighting, phone booths, art, and landscaping).

In a study on Internet banking, consumers gave the highest weight to the quality of service while selecting a particular bank (Geetika et al. 2008). In another study of customer satisfaction with banking services, factors of customer satisfaction were traditional (basic) facilities, convenience, behavior of employees, and the environment of bank (Jham and Khan 2008).

J. D. Power and Associates (2008a) measured overall customer satisfaction of electric utilities through six factors: power quality and reliability, customer service, company image, billing and payment, price, and communications. J. D. Power and Associates (2008b) also measured customer satisfaction with high-speed and dial-up Internet service providers based on five factors: performance and reliability, cost of service, customer service, billing, and offerings and promotions. In another study, J. D. Power and Associates (2008c) found communication (information systems) to be a determinant of customer satisfaction for customers of utility companies.

Ribiere et al. (1999) identified customer satisfaction with hospital information systems in terms of timeliness, accuracy, and completeness. Yet another study on satisfaction with hospital services included communication with patients, competence of staff, staff demeanor, quality of the facilities, and perceived costs (Andaleeb 1998).

Customer satisfaction with full-service moving companies was measured across seven factors: transportation of belongings, loading service, unloading service, optional coverage, estimate process, packing service, and insurance/damage claims. This implies that the quality of basic facilities and other supporting facilities were used as criteria for satisfaction (J. D. Power and Associates Reports 2007).

A study on customer satisfaction from consultant services identified various factors including perceived competence of the consultant and the attitude of consultants toward the customer during the service production process (Sonne 1999).

Table 2 provides a summary of research on attributes of service quality leading to consumer satisfaction in the context of various services. The heterogeneous service contexts are taken for developing a sound theoretical base for the present research and for identifying major common attributes of service quality irrespective of the context as well as within the context.

Case Study of Indian Railways (North Central Zone)

Indian Railways is the largest rail network in Asia and the world's second largest under one management. It is a multi-gauge, multi-traction system covering 108,706 kilometers, with 6,853 stations across the length and breadth of the country. It runs 11,000 trains, of which 7,000 are passenger trains that carry 13 million passengers every day. It is the largest employer in the organized sector in India, with a workforce of 1.54 million. (*www.indianrailway.gov.in*).

For administrative purposes, Indian Railways is divided into 17 zones. The North Central Railway (NCR) is one of the 17 railway zones in India. In its present form, NCR came into existence on April 1, 2003, and comprises the reorganized Allahabad Division of Northern Railway, the Jhansi Division of Central Railway, and the new Agra Division. It is headquartered at Allahabad (Uttar Pradesh), and its network extends over a large area of North Central India, covering the states of Uttar Pradesh, Madhya Pradesh, Rajasthan, and Haryana.

Table 2. Literature Review Summary on Customer Satisfaction

Sector	Factors Identified/Considered for Customer Satisfaction	Authors
Railways	Reliability, assurance, empathy, tangibles, and responsiveness	Vanniarajan and Stephen (2008)
	Employee behavior and other factors	Agrawal (2008)
	Availability of transit service, service monitoring, travel time, safety and security, maintenance and construction	TCRP Report 88, 100
Bus transportation	Availability of shelter and benches at bus stops, cleanliness, overcrowding, information system, safety, personnel security, helpfulness of personnel, physical condition of bus stops	Eboli and Mazzulla (2007) TCRP Report 100
Tourism	Service quality	Ekinci (2003)
Full-service moving companies	Transportation of belongings, loading service, unloading service, optional coverage, estimate process, packing service, insurance/damage claims (basic facilities, other supporting facilities)	J.D. Power and Associates Reports (2007)
Gas and Electricity Suppliers	Power quality and reliability, customer service, company image, billing and payment, price, communications, information system	J.D. Power and Associates Reports (2008a, 2008c)
Internet Service Provider (ISP)	Performance and reliability, cost of service, customer service, billing, offerings and promotions	J.D. Power and Associates (2008b)
Banking	Service quality	Geetika et al. (2008)
	Basic facilities, convenience, behavior of employees, general environment	Jham and Khan (2008)
Consultancy	Behavior of employees, service quality	Sonne (1999)
Health Care	Information system in terms of timeliness, accuracy and completeness	Ribiere et al. (1999)
	Communication with patients (information system), competence of staff, staff demeanor (behavior), quality of facilities, perceived costs	Andaleeb (1998)

Indian Railways is the major mode of transport in the country for passengers as well as freight due to its large network, number of trains, and affordability. On the industry front, it is the only player; hence, a monopoly has been created (which is legal). On the market front, the majority of its customers are illiterate/semi-educated and low/middle income with no/low consciousness for quality aspects of service. According to the 2001 census survey in India, the effective literacy rate in India was 65.4 percent, so about one-third of the population is illiterate. As many as 260 million persons live below the poverty line. Railways provide them with a convenient, accessible, and affordable mode of transportation. The monopoly structure has created a typical situation where the service provider (Indian Railways) has no competition and can afford to ignore aspects such as quality of service, customer satisfaction, and product promotion. The railway is the lifeline of Indian economy and society, but it is far from healthy and satisfactory. The focus of this paper is to study and analyze the managerial aspects of services rather than to study the technical and engineering aspects of the railway.

For the purpose of analysis, the services of Indian Railways can be divided into three broad categories: ticketing, on-board services, and facilities at platforms. Tandon (2006) observes that improvements have been effected by Indian Railways to minimize ticket dispensing time through modernized passenger reservation systems using computers and the Internet at a large number of stations. He further highlights that the passengers also want efficiency, effectiveness, and politeness in service. Sharma (2006) asserts that railway enquiry counters play a pivotal role in customer satisfaction, but railway enquiry service is far from satisfactory in India. TCRP Report 100 (Chapter 7) identifies the following elements at railway stations for determining quality: space per passenger (crowding), facilities for disabled persons (ramps etc.), facilities for evacuation, security (including presence of law enforcement personnel, video cameras, and emergency call boxes), visibility, lighting, and clarity of station layout and way-finding.

Scholars have undertaken studies on various aspects of railway services, but platforms have failed to attract researcher attention. Railway platforms are an important part of the railway system. Waiting at a platform may range from 15 minutes to several hours (especially in the Indian context, where late running of trains is normal) to wait for a connecting train or due to late running of a train. A case was filed against Indian Railways highlighting the agony faced by the senior citizens and children due to delays in the arrival of trains (*http://www.igovernment.in/site/Railways-pulled-to-court-for-running-trains-late/?section=Human%20Rights/*).

There are various angles to this situation, but in this paper the premise is that passengers necessarily have to use platform services, and their agony may be mitigated by making their stay at the platforms more comfortable. Hence, a study has been attempted to determine customer (passenger) perceptions of satisfactory service quality at railway platforms.

Research Design

This research is diagnostic in nature and uses a case study method for fulfilling research objectives. The literature review clearly indicates that different variables would be important for different services for customer satisfaction. It is further seen that a study on the service quality of railway platforms and level of customer satisfaction from this service has been neglected by researchers in the Indian context. Hence, an attempt is made to study customer perception of quality of service in the context of railway platforms. A case study method is adopted and supplemented with findings of a small survey to identify the determinants of customer satisfaction with this very important public utility in the special context of India.

Objectives

The study aims to identify the factors for passenger satisfaction regarding facilities provided on platforms. Customer satisfaction has been commonly accepted as an indicator of service quality (Geetika et al. 2008; Sachdev and Verma 2004; Ekinci 2003; Czepiel 1990). However, the literature shows that there is no consensus on the determinants of service quality. Therefore, the basic objective of the study is to identify important factors determining service quality of Indian Railways platforms that lead to customer satisfaction.

Sampling and Survey

The universe in this case is defined as the entire population of the country and foreign nationals visiting India. Hence, a definite, statistically-sound sample was not feasible. Convenience sampling was used for the purpose of the survey, and a research sample was taken to measure customer perception. The survey was carried out on different days at railway platforms at Allahabad Junction. Allahabad Junction is significant for two reasons; first, it is the headquarters of the North Central Railway (NCR) and second, all trains covered under NCR pass through Allahabad Junction, along with large number of trains of Central Railway, North Eastern Railway, and other zones. There are 12 platforms at the Allahabad railway station. A team of 20 MBA students visited these platforms on different days during different hours of the day with the objective to cover passengers from all probable trains. A total of 700 passengers were contacted. This was simply a research sample and may not truly represent the entire user population; however, the test of significance has been done and shows that the sample size would not affect the results.

Research Instrument

Since the literature depicted that determinants vary with services, it was determined inadvisable to use any of the existing instruments. This made our task difficult but necessary for achieving the research objectives. An instrument was developed on the basis of the existing literature, observations, the pilot study, and expert opinion. The attributes related to service quality of Indian Railways—passenger satisfaction and passenger perception—were generated with the help of reviews and exploratory study. Interviews were conducted with passengers who travel frequently to identify the attributes for passenger (customer) satisfaction. These preliminary surveys and reviews were used to generate general variables for passenger satisfaction on railway platforms. These variables were supported with the help of the literature review. These were further refined to form a questionnaire.

The questionnaire included 16 variables to measure customer (passenger) satisfaction from service quality, including:

1. sufficiency of seating space
2. lighting
3. fans
4. drinking water and sanitation
5. clarity of announcements
6. accuracy of announcements
7. frequency of announcements
8. reservation chart display
9. affordability of refreshments
10. quality of refreshments
11. quantity of refreshments
12. security of self
13. security of luggage
14. behavior of porters
15. behavior of railway staff
16. management of parking

A fiv- point Likert scale ranging from “least satisfied” to “most satisfied” was used to measure user satisfaction level. A Likert scale was used because it allowed the researchers to quantify opinion-based items, and a scale with balanced keying (an equal number of positive and negative statements) could obviate the problem of acquiescence bias.

Analysis and Data Interpretation

Nhat and Hau (2007) identified the determinants of retail service quality using factor analysis. The same tool was used by Hsu et al. (*www.academic-papers.org*) and Agrawal (2008) to identify determinants of customer satisfaction on Internet shopping. The same method was used here to identify the factors determining customer (passenger) satisfaction. Factor analysis was done to identify the factors determining passenger satisfaction on railway platforms and to test the hypothesis formulated regarding the factors determining passenger satisfaction. Data were analyzed using SPSS 11.5 software.

The passengers were asked to rate the 16 variables on a five-point scale according to their experience. The test of validity of data was examined with the help of a Kaiser-Meyer-Ohlin (KMO) measure of sample adequacy and Barlett's test of sphericity. These two tests satisfied the validity of data for factor analysis (Table 3).

Table 3. Kaiser-Meyer-Ohlin Measure and Bartlett's Test

KMO Measure of Sampling Adequacy	.793	
Bartlett's Test of Sphericity	Approx. Chi-Square	1621.146
	df	120
	Sig.	.000

To determine the number of components, only the eigen values greater than or equal to 1 were considered (Guttman 1954; Kaiser 1960). In addition, the KMO measure and the Barlett Sphericity test were effected (Fabbris 1997). The extraction method was Principal Axis Factoring; the rotation method was Oblimin with Kaiser Normalization.

The factor analysis resulted in five factors—refreshments, behavior, information system efficiency, basic facilities, and security. These five factors were found to have eigen values greater than 1 and, hence, are significant. The reliability coefficients of these factors range from 0.6 to 0.8. The factor loading of the variables determining satisfaction in each factor, the reliability coefficient (Cronbach alpha), the eigen value, and the percent of variation explained by the factors are shown in Table 3. The most important factor determining satisfaction on railway platforms was found to be "refreshments," since the eigen value and percent of variation explained by this factor are 4.866 and 30.412, respectively. This factor consists of three variables with a reliability coefficient of 0.8627. It shows that the included variables explain this factor to the extent of 86.27. The percent variation explained by this factor is 30.4 percent.

The next two factors identified are "behavior towards passengers" and "information system efficiency." Their respective eigen values are 1.702 and 1.482. Each of these factors consists of three variables, with reliability coefficients of 0.7037 and 0.8407 each. The percent variations explained by these factors are 10.638 and 9.260, respectively.

The other two factors determining passenger satisfaction on railway platforms as identified by factor analysis are "basic facilities" and "security," with four and two variables each, respectively, and with reliability coefficients of 0.6046 and 0.8200, respectively. The percent variation explained by these factors is 8.454 and 6.425, respectively. Table 4 shows the correlation among various factors.

Table 4. Factor Loading of Variables

Factor	Variable	Factor Loading	Reliability Coefficient	Eigen Value	Percent of Variation Explained
Refreshments	Refreshments affordability Refreshments quality Refreshments quantity	0.694 0.884 0.683	0.8627 0.7037	4.866 1.702	30.412 10.638
Behavior towards passenger	Behavior of railway staff Behavior of porters Management of parking	0.650 0.785 0.412	0.8407	1.482	9.260
Information system efficiency	Clarity of announcements Accuracy of announcements Frequency of announcements Reservation chart display	0.72 0.885 0.725 0.308	0.6046	1.353	8.454
Basic facilities	Sufficiency of # of benches Lighting Fans Reservation chart display	0.637 0.460 0.561 0.301	0.8200	1.028	6.425
Security	Security of self Security of luggage	0.713 0.850	0.8200	1.028	6.425

As evident from Table 4, there is a low correlation between different factors, the maximum being 0.466 (between the factors "behavior towards passengers" and "security"). This means that all the five factors are independent, which implies that they are measuring unrelated dimensions.

Table 5. Factor Correlation Matrix

Factor	Refreshments	Behavior Towards Passengers	Information System Efficiency	Basic Facilities	Security
Refreshments	1.000	.170	.366	.327	.339
Behavior towards passengers	.170	1.000	.318	.323	.466
Information system efficiency	.366	.318	1.000	.342	.342
Basic facilities	.327	.323	.342	1.000	.341
Security	.339	.466	.342	.341	1.000

Extraction Method: Principal Axis Factoring Rotation Method: Oblimin with Kaiser Normalization

The results provide statistical evidence to support identified determinants of customer satisfaction as refreshments, safety and security, basic facilities, information system, and behavioral aspects of service quality.

1. *Refreshments*: This aspect includes the availability, quality, quantity and affordability of edibles available to passengers on railway platforms. Passengers consider refreshments as the most important aspect of satisfaction with service quality of Indian Railways.
2. *Behavioral factors*: This refers to the behavior of railway staff, porters, and parking staff outside the platform. These factors have been found to impact customer satisfaction (Sonne 1999; Agrawal 2008; Vanniarajan and Stephen 2008; Jham and Khan 2008). Behavioral factors are the second most important determinant of customer satisfaction.
3. *Information system*: This refers to announcements at the railway station, their accuracy, frequency and clarity, and reservation chart display. The information system has been identified as a determinant of customer satisfaction (Andaleeb 1998; Ribiere et al. 1999; Eboli and Mazzulla 2007; TCRP Report 100). Passengers consider the information system the third most important determinant of satisfaction with service quality.

4. *Basic facilities*: Basic facilities consist of sitting space, fans, and lighting. Basic facilities pertaining to different sectors are important determinants of customer satisfaction (Eboli and Mazzulla 2007; J.D. Power and Associates Reports 2007; TCRP Report 100). Basic facilities are the fourth most important determinant of customer satisfaction.
5. *Safety and security*: This refers to the safety and security of luggage and self, which have been identified as determinants of customer satisfaction in the transportation sector (Eboli and Mazzulla 2007; TCRP Report 100). Safety and security is the last most important determinant of customer satisfaction.

Customer Satisfaction Model

On the basis of factor analysis, a model of customer (passenger) satisfaction on railway platforms is proposed in Figure 1. In the model, customer satisfaction is the dependent variable and refreshments, information system, safety and security, behavioral aspects, and basic facilities are the independent variable.

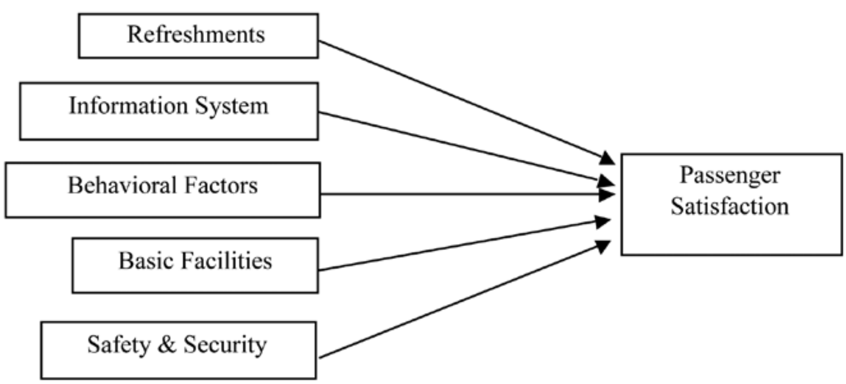

Figure 1. Research Model for Determinants of Passenger Satisfaction on Railway Platforms

This model has been derived on the basis of statistical evidence; hence, it is validated. It can be further used and developed for similar other researches.

Conclusions

Although several studies have attempted to identify factors determining overall user satisfaction with Indian Railways, railway platforms have remained a neglected aspect.

The contribution of this study is the identification of factors that determine user satisfaction with the quality of services provided on railway platforms. The study is based on empirical research. Determinants identified are availability and quality of refreshments, effectiveness of information systems, behavior of railway staff, basic amenities provided on platforms, and safety and security. Refreshments and behavioral factors are considered most important by passengers. These factors determine passenger satisfaction on railway platforms and may be different from determinants of satisfaction with Indian Railways as a whole. The study thus provides a direction for railway administration whereby areas for improving services may be identified and user (passenger) satisfaction, specifically on railway platforms, may be enhanced.

Managerial Implications

This study has identified the actual determinants of customer satisfaction with quality of service provided on railway platforms. In this respect, this paper suggests certain policy implications for Indian Railways. The proposed model of customer satisfaction may be used as a basis to plan efforts towards increasing customer satisfaction. Availability of good quality and quantity of refreshments at affordable prices is the key factor impacting customer perception of service quality. It may be due to the fact that while waiting on the platform, refreshments may help the passengers mitigate some of their miseries. By improving these food-related aspects, railway administration may increase satisfaction among passengers. In addition, other factors that passengers consider important at railway platform are behavior of staff, porters, parking staff, and quality of the information system. This implies that railway staff must be trained in such a way that their "soft" skills are enhanced. Appropriate action plans may be taken to enhance basic facilities and improve security on platforms.

The model, although designed in a specific context, may be extended to other similar services and help improve quality of life for the masses and thus increase overall satisfaction.

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