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Impacts of Express Bus Service on Passenger Demand

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Abstract

The Region of Waterloo, Ontario, is a rapidly-growing metropolitan area approximately 100 km west of Toronto. In 2005, the Region's transit operator, Grand River Transit, introduced an express bus service, known as iXpress, along the central north-south corridor of the Region. This paper explores the impact of the iXpress service on transit user costs and passenger attraction. We employ a methodology to quantify the generalized cost (including waiting time, in-vehicle and transfer times) of transit trips between key destinations in the Region before and after the implementation of iXpress. We also develop a methodology to identify those customers who benefit from the reduced cost of the iXpress. Finally, we present the change in ridership (boardings) in the corridor pre- and post-implementation. From these demand and cost data, we compute transit elasticity of demand with respect to generalized cost.

Introduction

The Region of Waterloo,[1] located approximately 100 km west of Toronto in southern Ontario, comprises three cities—Kitchener, Waterloo and Cambridge—and four rural townships. The Region has a population of approximately 500,000 but is expected to reach 730,000 by 2031 (Region of Waterloo 2003.) Commensurate job growth is also predicted. In response to these growth pressures, the Region of Waterloo (2003) developed a Regional Growth Management Strategy (RGMS) to manage the locations of new homes and jobs and to provide suitable transportation alternatives. A principle component of the RGMS is a balanced transportation system that promotes multimodal travel options and leads to intensified land uses. One major investment in the Region's Grand River Transit (GRT) has been the introduction of an express bus service, known as iXpress, connecting major activity centers along the region's central north-south corridor.

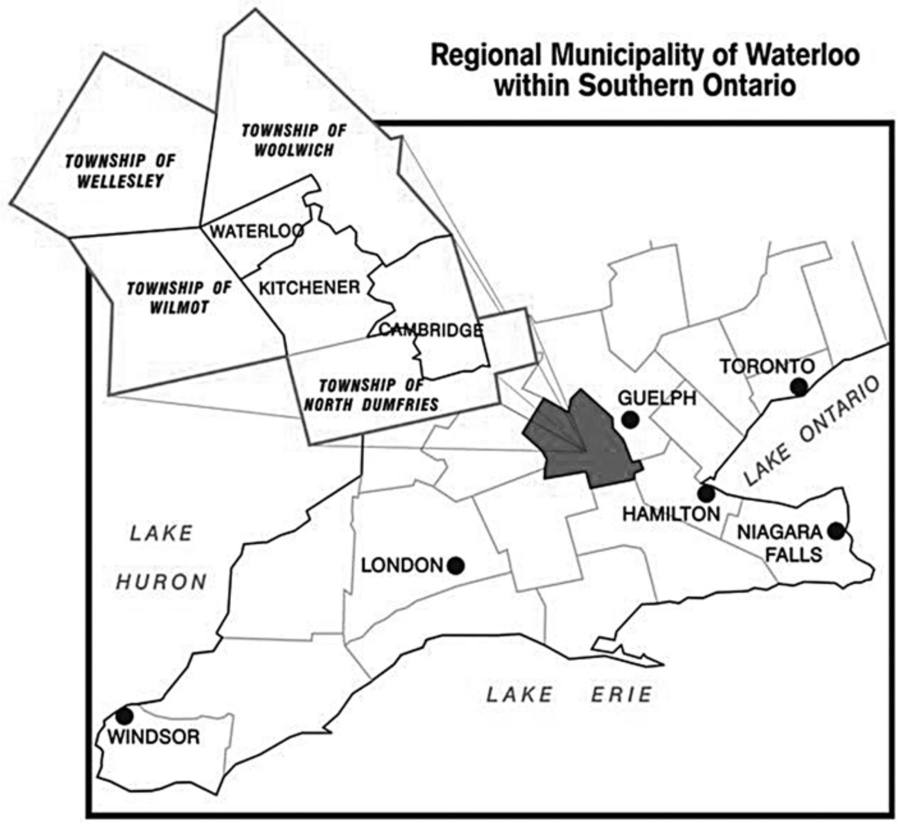


Figure 1. Location and Composition of the Regional Municipality of Waterloo in Southern Ontario

This paper develops and applies a methodology to analyze the impacts of the iXpress on travel costs and ridership in an existing transit corridor. We compute the differences in generalized costs (including waiting time, in-vehicle time, and transfer time) for travel between major activity centers in the Region before and after the introduction of iXpress. We define and apply a methodology to identify transit customers who benefit from the introduction of the iXpress service. We also present the number of boardings in a service corridor that took place pre- and post-implementation of the iXpress service. Based on the reduction in generalized cost and increase in ridership, we compute the elasticity of transit demand with respect to generalized cost.

The remainder of the paper is structured as follows. The following section presents a literature review of generalized cost formulations and elasticity models for analyzing transit demand. In the third section, further detail is provided on the Region of Waterloo and the iXpress service. Section four presents the methodology used in computing generalized costs and applies that method to the case study. Elasticities are presented. In section five, the results of elasticity computations are analyzed and the shortcomings of elasticity models are presented. Section six presents conclusions and suggestions for further research.

Literature Review

The concept of utility theory suggests that consumers choose an alternative that possesses a set of characteristics that maximizes the benefit derived by the consumer (Lancaster 1966). Transportation studies often assume that travelers derive no utility from the trip itself, but rather travel to achieve other goals (i.e., work, shopping, education etc.) Thus, travel consumers are modeled not as utility maximizers, but instead as disutility (or generalized cost) minimizers. Disutility of transit travel has the following components (Kittelson and Associates 2003): access time to transit service, waiting time, in-vehicle time, transfer times (where applicable), egress times, and fares. Typically, the relative contribution to overall disutility of these individual attributes is expressed by a weighted, linear sum of the attributes (Ortuzar and Williamson 2001). For example, most studies suggest that passengers perceive waiting time and transfer time to be more onerous than in-vehicle travel times.

Utility theory has long been used in mode choice models to predict transit ridership. When choosing between competing modes (typically transit and auto), a traveler's propensity to choose a given mode is a function of the relative generalized costs, or disutility, of the competing modes. Often, logit or probit models are used to compute the probability of choosing a mode amongst a set of candidate modes based on a comparison of their generalized costs (Ben Akiva and Leman 1985). These models often are employed at the regional level as part of travel forecasting work.

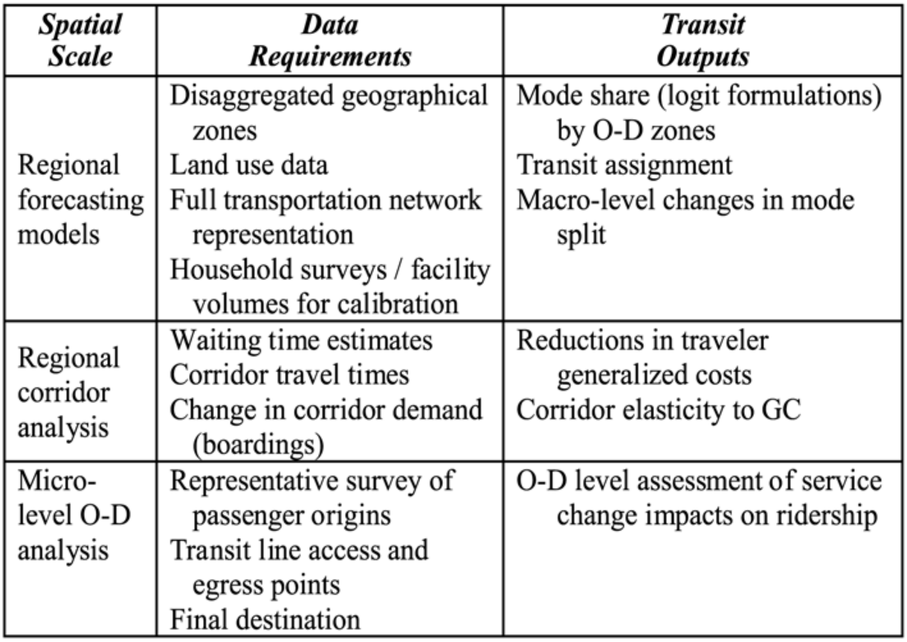
Utility models have been employed to assess the impacts of potential changes in transit services on transit ridership in regional corridors. Examples of this type of study include Kopp et al. (2006) in Chicago and Casello (2007) in Philadelphia. The benefits of corridor-level analysis are that it allows for a more detailed representation of transit costs than is possible when working at a regional level and requires significantly less data and computational effort. As such, corridor-level analysis may be feasible for transit agencies to complete in-house, thereby reducing reliance on consultants or external travel models.

The output of corridor level analysis may also be elasticities of demand with respect to generalized cost that may be assumed to be valid within the study area. The use of elasticities to predict changes in travel habits has been studied extensively. A comprehensive reference list of such studies is presented by Taylor and Miller (2003). In the same paper, the authors present a two stage, least-squares regression that considers the ridership impacts of non-transportation variables (geography, economy, and population) as well as transport variables (auto ownership, fuel prices, transit supply and cost). Their results are consistent with most other studies—that transit supply (positively correlated) and fares (negatively correlated) are both statistically significant predictors of transit ridership, which explain much (in their case, 95%) of the variation in ridership.

In the current application, the generalized cost, or disutility, of travel is computed without and with the iXpress service. The change in disutility is correlated to changes in ridership through standard elasticity models. Litman (2004) defines short- and long-term elasticities and presents the findings for various inputs (fares, auto costs, income, etc.), modes, and locations. A more sophisticated summary of previous studies is presented by Holmgren (2007), who utilizes a meta-analysis method to draw conclusions about the importance of functional form, data inclusion, data types, and environmental factors on predicted elasticities. Holmgren also presents observed ranges of several demand elasticities (price, supply, income, auto ownership, and fuel prices). Balcombe et al. (2004) present elasticities for various components of generalized costs using UK examples.

Ideally, the travel patterns of individual transit customers could be surveyed and recorded, and changes in behavior in response to changes in transit services could be evaluated on an individual origin-destination basis. This would require extensive data collection that would only be feasible if fully automated, perhaps through smart card fare collection technology. In the absence of smart cards, we suggest that corridor level analysis provides an appropriate balance between data requirements and the robustness of the ridership projections. The potential levels of transit analysis are shown in Table 1.

Table 1. Possible Levels of Analysis for Predicting Changes in Ridership as a Result of Transit Service Change



Spatial Scale	*Data Requirements*	*Transit Outputs*
Regional forecasting models	Disaggregated geographical zones Land use data Full transportation network representation Household surveys / facility volumes for calibration	Mode share (logit formulations) by O-D zones Transit assignment Macro-level changes in mode split
Regional corridor analysis	Waiting time estimates Corridor travel times Change in corridor demand (boardings)	Reductions in traveler generalized costs Corridor elasticity to GC
Micro-level O-D analysis	Representative survey of passenger origins Transit line access and egress points Final destination	O-D level assessment of service change impacts on ridership

The current paper builds upon the existing literature in several ways. First, the paper develops and implements a method to analyze comprehensively the change in travel parameters as a result of the proposed transit service upgrades. Second, the paper applies utility theory to compute the changes in generalized costs for trips made between major activity centers. The changes in generalized cost are then compared to observed changes in ridership to compute mid-run elasticities for a specific case. The calculated elasticities are compared to previously published results.

The Region of Waterloo and iXpress service

Waterloo Region is one of the most diverse and dynamic economic regions in Canada. The area extending from Toronto in the east, Niagara Falls in the south, and the Region of Waterloo in the west is known as the Greater Golden Horseshoe

(GGH). The GGH is often referred to as the economic engine of Ontario. The entire GGH is experiencing strong development pressures. The Province of Ontario has produced a strategic plan known as "Places to Grow," which intends to steer development to targeted built-up areas. The Region of Waterloo is one of these areas.

The Region itself is a significant contributor to the national economy, with an annual estimated regional GDP of over $16 billion (CDN) derived from a strong mix of agricultural, manufacturing, and service sector employment. A major challenge for the Region in light of the projected growth is to accommodate increased housing and employment lands without diminishing the value of local agricultural activities. Moreover, the Region currently experiences very little congestion. The intention of Regional planners is to develop a balanced, multi-modal transportation system that will both facilitate future travel demands and positively influence land uses (achieve intensification). The iXpress service is a major step towards balanced transportation alternatives in the Region.

iXpress Service

The iXpress is a limited-stop, express service that travels between Waterloo, Kitchener, and Cambridge. The alignment, shown in Figure 2, is approximately 33 km in length and consists of 13 stops. Along the route are four downtowns (two in Cambridge), two universities, office complexes, major hospitals, and regional shopping centers. When the iXpress service commenced in September 2005, it operated between 06:45 and 19:00 Monday through Friday, with 15-minute headways during the morning and afternoon peak periods and 30-minute headways during the midday. In the fall of 2007, weekday service was extended to 05:40 and 23:00; Saturday and Sunday services were introduced. The iXpress service is provided using standard 40-foot Nova low-floor buses that are differentiated from buses servicing local routes by unique exterior branding.

Prior to 1999, transit service was operated by two independent providers—one serving Kitchener and Waterloo, the other serving Cambridge. In 2000, the system was unified under a single operator, the Region of Waterloo, which created Grand River Transit. Despite unifying operations, the previous route structure remained. Prior to the introduction of iXpress, no single-seat connections were provided between Cambridge and points north of Fairview Mall; all trips between Cambridge and central Kitchener and Waterloo required a transfer.

In addition to providing regional connectivity, the introduction of iXpress supplemented a local transit route (Route 7) within Kitchener and Waterloo, between

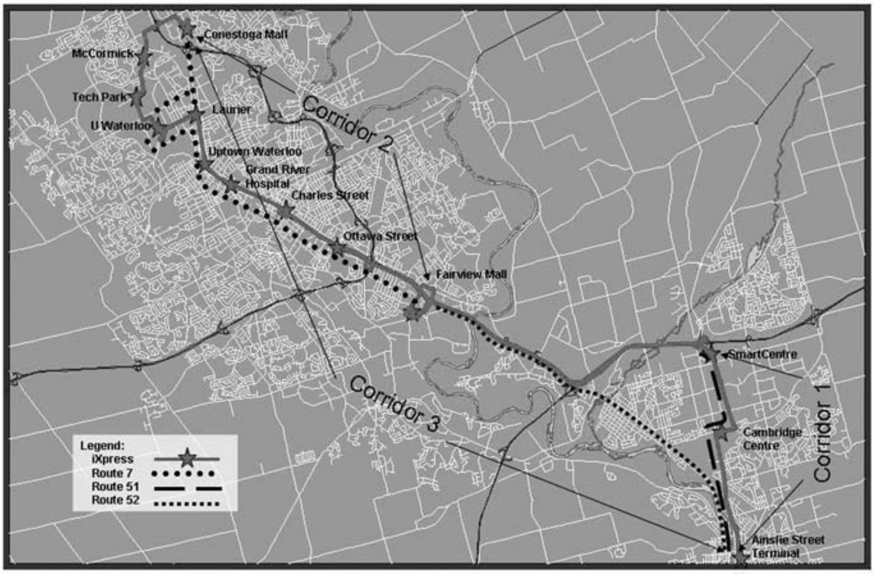


Figure 2. iXpress and Local Routes Connecting Activity Centers in Cambridge, Kitchener and Waterloo

the Fairview and Conestoga Mall iXpress stops. Route 7 is operated with three northern branches—two terminating at the University of Waterloo and one terminating at Conestoga Mall. During peak periods, Route 7 headways on the common section are approximately 5 minutes and 15 minutes for each branch. Note that no direct (single-seat) service is provided by Route 7 from the University of Waterloo to Conestoga Mall. iXpress also supplements two local routes in Cambridge. Route 51 connects three activity centers—the Ainslie, Cambridge Center and Hespler terminals along Hespler Road, a major commercial artery in the Region. Route 52 connects the Ainslie terminal and Fairview Mall via King St. in Cambridge and Highway 8 in Kitchener.

The next sections demonstrate a methodology to quantify the benefits and beneficiaries as a result of the implementation of iXpress.

Methodology

The goals of this paper are to demonstrate a method to analyze the impacts of express bus service on transit users' costs, to identify those users who benefit from these reduced costs, and finally to correlate changes in cost to ridership gains. To estimate the reductions in user costs, we quantify the changes in travel costs for three travel patterns:

1. The corridor between Ainslie St. Terminal and Smartcentres, where the iXpress supplements Route 51. This represents travel between activity centers within the city of Cambridge.
2. Trips between Ainslie Terminal, Fairview Mall, and all points along the Route 7 alignments. This represents travel between one Cambridge activity center and many activity centers in Kitchener and Waterloo.
3. The corridor between Fairview Mall and Conestoga Mall, including the University of Waterloo, but not Tech Park or McCormick because local service was not previously provided to those stops. This quantifies the improvement as a result of iXpress in the existing Route 7 corridor.

In our case, the introduction of express service affects passengers in the following ways:

- For the travel patterns considered, iXpress operates on the same alignment as local service so that the access and egress times for express service are the same as the local service. We therefore eliminate access and egress time from our generalized cost computations.
- iXpress may increase or decrease passenger waiting times, depending on the frequency of the existing local service in the corridor and the specific origin and destination of the traveler (see section on waiting times, below).
- iXpress reduces in-vehicle times because there are fewer stops than on local service.
- iXpress connects origin-destination pairs directly, eliminating the need for passenger transfers.

Waiting times, in-vehicle times and transfer times are analyzed in detail in the following sections.

Waiting Times

In calculating passenger waiting times, we make the following assumptions. First, we assume that wait time is correlated to service frequency as follows. For short headways, less than or equal to 10 minutes, we assume random passenger arrivals and an average wait time of ½ the headway. For headways greater than 10 minutes, we assume passengers consult schedules, but still allow slightly longer wait times.

Mathematically, we apply the following continuous functions to compute wait times:

$$WT = \begin{bmatrix} \dfrac{h}{2} & h \leq 10 \\ 10 - 5e^{\left(1-\frac{h}{10}\right)} & h > 10 \end{bmatrix} \qquad \text{Eq. 1}$$

where: WT is the waiting time in minutes

h is the headway in minutes.

For headways greater than 10 minutes, Equation 1 predicts a wait time that increases as headways increase, but moves asymptotically to a maximum wait time of 10 minutes. This model is very similar to that found empirically by Lam and Morall (1982), as shown in Figure 3. Sensitivity to this waiting time formulation is explored in subsequent sections.

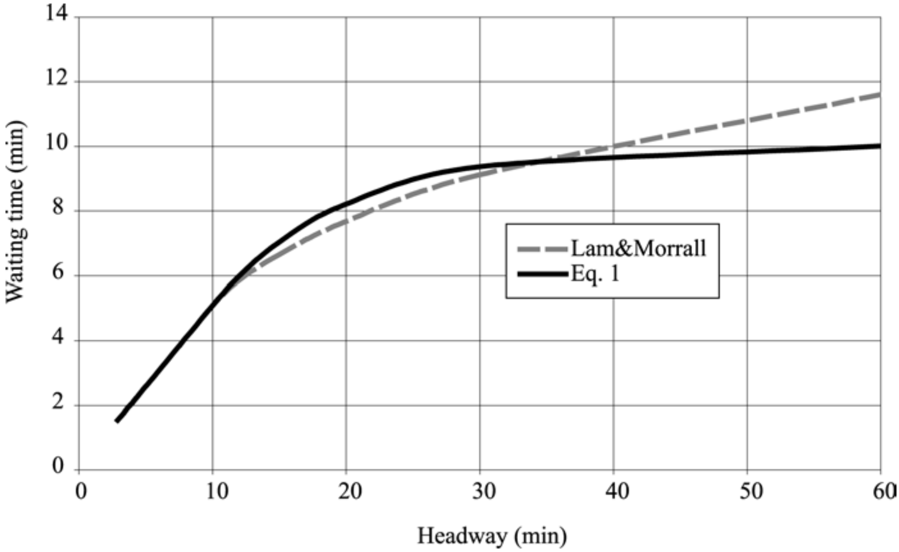


Figure 3. Comparison of Predicting Waiting Times by Lam and Morrall and Eq. 1

In considering traveler behavior, we are faced with three alternatives. We may assume that customers prefer single-seat rides (trips without transfers) and, therefore, extend their wait time for iXpress to avoid a transfer. Alternatively, we may assume that customers minimize their wait times by boarding the first arriving vehicle regardless if a transfer is necessary. The third alternative, which we apply in our method, is the assumption that transit customers choose the lowest generalized cost alternative of the previous two choices. This is consistent with oft-cited user equilibrium condition.

Travel Time Analysis

Because of its limited stops, iXpress has significantly shorter travel time compared to local routes that serve the same alignment. We compute the difference in inter-station travel times for trips completed by local routes (7, 51, and 52) and trips completed by iXpress in each of the travel corridors. Note that this analysis considers only the difference in in-vehicle time; transfer times are considered separately in the next section.

Transfer Times

The method developed by Vuchic (2005) to estimate average transfer times between two lines with headways h_1 and h_2, as presented in Equation 2, is used.

$$E(TT) = \min\left\{\frac{h_1}{2}, \frac{h_2}{2}\right\} \qquad \text{Eq. 2}$$

Where:

E(TT)	expected (average) transfer time, min
h_1	time headway of originating line, min
h_2	time headway of destination line, min

Using Equation 2, we compute the transfer times necessary for local trips that include routes 51 and 7 (transfers at Fairview Mall) and between branches of Route 7 (transfers at Laurier). No transfers are required for trips on the iXpress.

Computing Generalized Cost

Having computed the changes in each cost component (waiting, in-vehicle and transfer times), generalized costs for travel between all O-D pairs is calculated. The generalized cost, *GC*, is calculated as shown in Equation 3.

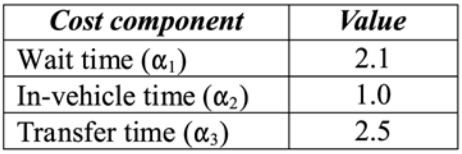
$$GC^i_{OD} = \left(\alpha_1 WT + \alpha_2 IVTT + \alpha_3 TT\right)\frac{VOT}{60} + fare \qquad \text{Eq. 3}$$

Where:

GC	generalized cost for travel from origin O to destination D via route i, \$
α_i	relative weight of cost component i
WT	waiting time, min
$INVT$	in-vehicle travel time, min
TT	transfer time, min
VOT	value of time, \$/hr
fare	Transit fare, \$

Passengers perceive the passage of time differently for each portion of their trip (i.e., wait time at the stop, in-vehicle time, and transfer time). Because we have no local information on the relative weights of the cost components, we utilize the mean values presented in Kittelson et al. (2003, p. 3-20), as shown in Table 2.

Table 2. Relative Weights of Cost Components Used in Generalized Cost Calculations



Cost component	*Value*
Wait time (α_1)	2.1
In-vehicle time (α_2)	1.0
Transfer time (α_3)	2.5

Many wide-ranging estimates exist for value of travel time in the literature. We use a simple estimate of value of time, \$8 per hour. Because our analysis involves percent reductions in travel costs, our findings are largely insensitive to the value of time assumption. The GRT pre-paid fare is \$1.40.

We are primarily concerned with the reduction in generalized costs for passengers after the implementation of the iXpress service. As such, we define the reduction in generalized cost, ΔGC as:

$$\Delta GC_{OD} = GC_{OD}^{L} - \min\left[GC_{OD}^{L}, GC_{OD}^{X}\right] \qquad \text{Eq. 4}$$

Where: GC^L is the generalized cost from O to D via local service, $

GC^X is the generalized cost from O to D via iXpress service, $

As noted above, this method assumes that passengers choose the lowest-cost alternative. In the cases where local service is less expensive than iXpress, then we see a zero reduction in generalized cost.

Finally, we compute the percent change in generalized cost as shown in Equation 5:

$$\Delta GC^{L-X}(\%) = \frac{\Delta GC_{OD}}{GC_{OD}^{L}} 100 \qquad \text{Eq. 5}$$

Corridor 1 Analysis

In Corridor 1, existing Route 51 service with a frequency of two buses per hour is supplemented by four iXpress runs per hour. The iXpress also has shorter travel times, saving five minutes between Ainslie Terminal and Cambridge Centre and an additional six minutes between Cambridge Centre and Smartcentres. Neither route requires a transfer. The steps in computing the change in generalized cost are summarized in Table 3.

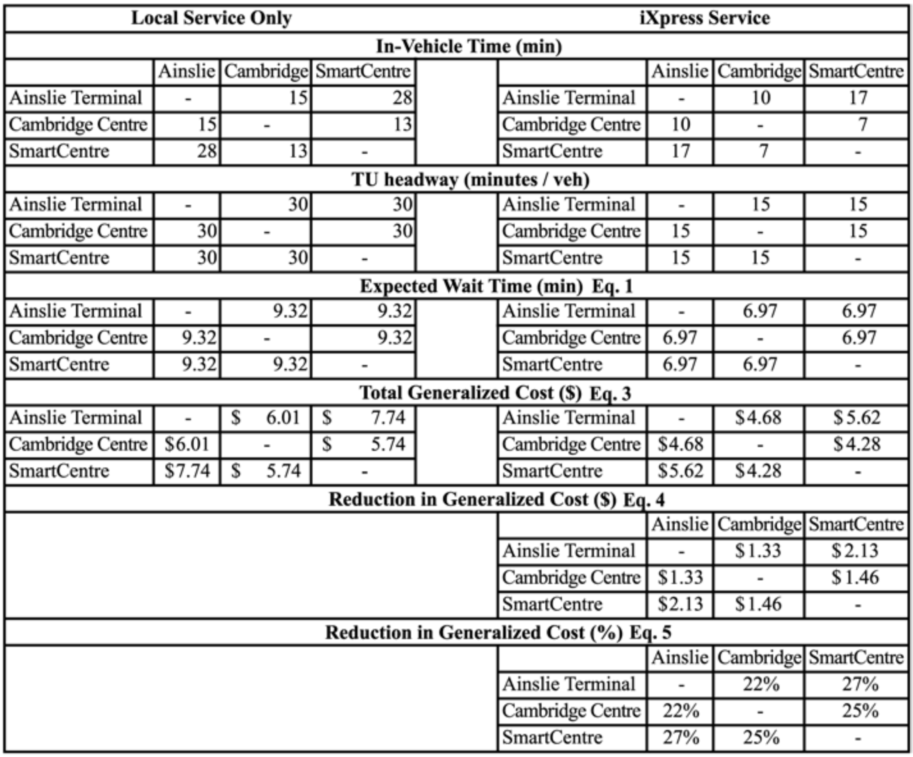
Because of the reduced in-vehicle and waiting times, the introduction of iXpress reduces generalized costs between these origin-destination pairs by between 22 and 27 percent.

Corridor 2 Analysis

In Corridor 2, iXpress connects origin-destination pairs that were previously served by Route 7 with high frequency service. As a result, many of the main line station pairs remain best served by local service. Naturally, as the distance traveled increases, the benefits of higher speeds on iXpress offset longer waiting times, and benefits are derived for iXpress trips. For the University of Waterloo, iXpress introduces higher-frequency, direct connections in both the north and southbound directions. Significant reductions in generalized costs are experienced for trips beginning from or destined for the University.

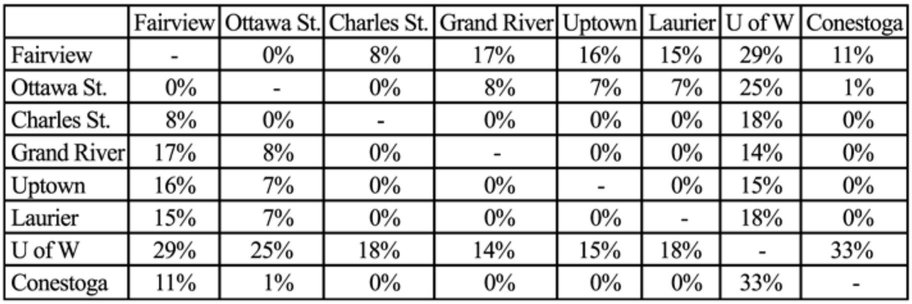
Using the same methodology presented in the Corridor 1 analysis, we compute the reductions in generalized costs as a result of iXpress between origin-destination pairs in Corridor 2. These are shown in Table 4.

Table 3. Full Methodology for Computing Reduction in Generalized Cost as a Result of iXpress Service



Local Service Only				iXpress Service			
In-Vehicle Time (min)							
	Ainslie	Cambridge	SmartCentre		Ainslie	Cambridge	SmartCentre
Ainslie Terminal	-	15	28	Ainslie Terminal	-	10	17
Cambridge Centre	15	-	13	Cambridge Centre	10	-	7
SmartCentre	28	13	-	SmartCentre	17	7	-
TU headway (minutes / veh)							
Ainslie Terminal	-	30	30	Ainslie Terminal	-	15	15
Cambridge Centre	30	-	30	Cambridge Centre	15	-	15
SmartCentre	30	30	-	SmartCentre	15	15	-
Expected Wait Time (min) Eq. 1							
Ainslie Terminal	-	9.32	9.32	Ainslie Terminal	-	6.97	6.97
Cambridge Centre	9.32	-	9.32	Cambridge Centre	6.97	-	6.97
SmartCentre	9.32	9.32	-	SmartCentre	6.97	6.97	-
Total Generalized Cost ($) Eq. 3							
Ainslie Terminal	-	$ 6.01	$ 7.74	Ainslie Terminal	-	$4.68	$5.62
Cambridge Centre	$6.01	-	$ 5.74	Cambridge Centre	$4.68	-	$4.28
SmartCentre	$7.74	$ 5.74	-	SmartCentre	$5.62	$4.28	-
Reduction in Generalized Cost ($) Eq. 4							
					Ainslie	Cambridge	SmartCentre
				Ainslie Terminal	-	$1.33	$2.13
				Cambridge Centre	$1.33	-	$1.46
				SmartCentre	$2.13	$1.46	-
Reduction in Generalized Cost (%) Eq. 5							
					Ainslie	Cambridge	SmartCentre
				Ainslie Terminal	-	22%	27%
				Cambridge Centre	22%	-	25%
				SmartCentre	27%	25%	-

Table 4. Percent Reductions in Generalized Costs for O-D Pairs in Corridor 2



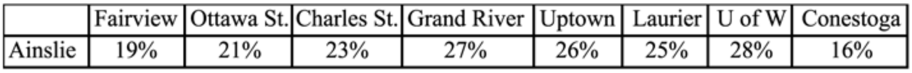
	Fairview	Ottawa St.	Charles St.	Grand River	Uptown	Laurier	U of W	Conestoga
Fairview	-	0%	8%	17%	16%	15%	29%	11%
Ottawa St.	0%	-	0%	8%	7%	7%	25%	1%
Charles St.	8%	0%	-	0%	0%	0%	18%	0%
Grand River	17%	8%	0%	-	0%	0%	14%	0%
Uptown	16%	7%	0%	0%	-	0%	15%	0%
Laurier	15%	7%	0%	0%	0%	-	18%	0%
U of W	29%	25%	18%	14%	15%	18%	-	33%
Conestoga	11%	1%	0%	0%	0%	0%	33%	-

The range of travel cost savings for this corridor is 0 percent (where the local service remains the lowest cost option) to 33 percent for travel between Conestoga and the University of Waterloo.

Corridor 3 Analysis

In the Corridor 3 analysis, we attempt to identify the cost savings between Ainslie Terminal and northern activity centers. This analysis is a measure of the regional connectivity improvements as a result of iXpress. Table 5 shows the cost reductions. For simplicity, only the reductions in cost from Ainslie Terminal to all northern stops are shown; the cost savings are symmetric.

Table 5. Percent Reduction in Generalized Costs for Trips Originating from the Ainslie St. Terminal (Corridor 3)



	Fairview	Ottawa St.	Charles St.	Grand River	Uptown	Laurier	U of W	Conestoga
Ainslie	19%	21%	23%	27%	26%	25%	28%	16%

The range of cost savings in this case is between 16 and 28 percent.

Identifying Transit Customers Who Benefit from iXpress

To identify those customers who benefit from the introduction of iXpress, we consider those transit riders who travel in Corridor 2. As shown in Figure 3, there are four trip types that involve some travel through the corridor:

1. Type I: a trip that both begins and ends in the corridor (O_1, D_1)
2. Type II: a trip that begins outside the corridor on a local route, L_1, but ends in the corridor (O_2, D_1) via a transfer
3. Type III: a trip that begins in the corridor but ends outside the corridor (O_1, D_2) via a transfer to a local route, L_2
4. Type IV: a trip that begins outside the corridor on a local route, L_1, transfers for travel through the corridor, then transfers to a local route, L_2, to reach the destination (O_2, D_2)

Prior to the introduction of iXpress, all trips through the corridor involved only Route 7. After the introduction of iXpress, each of these trips may involve a transfer to either iXpress or to Route 7, whichever involves the lowest generalized cost. The benefits derived as a result of iXpress differs for each of these trip types. Table 6 quantifies these benefits.

In each case, the potential generalized cost saving is the same—the reduction associated with the iXpress compared to the Route 7 service. The percent reduction, however, varies for each trip type. For those trips that involve transfer to and/or from local service, the time savings along the central corridor represents a smaller percentage of total trip time. This is indicated by the increasing denominator in the third column of Table 6.

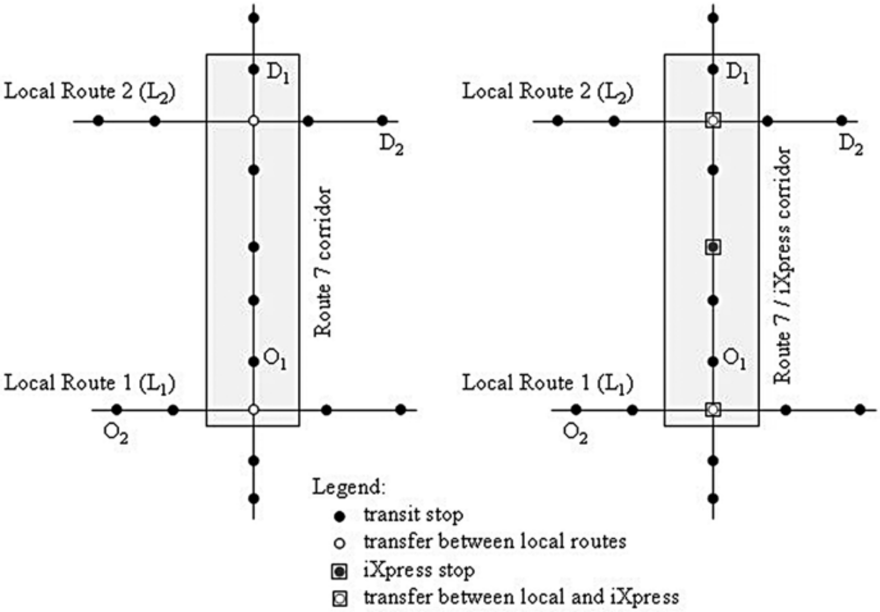


Figure 4. Identifying the Trip Patterns Influenced by the Introduction of iXpress

Table 6. Reductions in Generalized Cost (Total and %) for Each Trip Type

Trip Designation	*Trip*	*Cost Reduction*	*% Reduction*
I	$O_1 D_1$	$\Delta GC^{7\text{-}X}$	$\frac{\Delta GC^{7\text{-}X}}{GC^{7}}$
II	$O_2 D_1$	$\Delta GC^{7\text{-}X}$	$\frac{\Delta GC^{7\text{-}X}}{GC^{L1} + GC^{7}}$
III	$O_1 D_2$	$\Delta GC^{7\text{-}X}$	$\frac{\Delta GC^{7\text{-}X}}{GC^{7} + GC^{L2}}$
IV	$O_2 D_2$	$\Delta GC^{7\text{-}X}$	$\frac{\Delta GC^{7\text{-}X}}{GC^{L1} + GC^{7} + GC^{L2}}$

Correlating Changes in Generalized Cost to Ridership Gains

A common economic tool to predict changes in demand as a result of changes in price is to compute elasticity of demand with respect to price. Mathematically, elasticity, *E*, is defined as:

$$E = \frac{\Delta D}{\Delta P} = \frac{\Delta Boardings}{\Delta GC} \qquad \text{Eq. 6}$$

Where: ΔD is the change in demand, %

ΔP is the change in price, %

In our case, we have computed the change in generalized cost for trips between individual origin-destination pairs. As noted in the literature review, ideally these changes in O-D costs could be compared to changes in ridership between O-D pairs. However, due to data limitations, only the change in corridor demand is known. Therefore, to compute elasticities, we utilize these changes in O-D costs to compute a corridor-wide change in generalized cost.

From ridership surveys (Region of Waterloo 2005), the percentage of total trips between each O-D pair is known. Therefore, to compute a corridor-wide elasticity, we calculate a weighted average of reduced generalized costs within the corridor based on travel patterns. Mathematically, this average is given by:

$$\overline{\Delta GC} = \sum_{O} \sum_{D} T_{OD} \cdot \Delta GC_{OD} \qquad \text{Eq. 7}$$

Where: ΔGC is the weighted average of generalized cost savings, $

T_{OD} is the observed percentage of transit trips from origin to destination

The percentages of trips between origin destination pairs are given in Table 7. From Equation 7, we compute a weighted average generalized cost reduction of 14.1 percent.

This calculation provides the average benefits accrued for travel within the corridor. As noted in the previous section, not all travelers realize this full benefit. Those who make trip type I accrue the full benefit. For trip types II, III and IV, a lesser benefit is realized as a percentage of total trip cost.

Table 7. Percentage of Travel Between All O-D Pairs

	Fairview	*Ottawa*	*Charles St.*	*Grand River*	*Uptown*	*Laurier*	*U of W*	*Conestoga*
Fairview	-	0.0%	9.1%	2.0%	2.2%	2.2%	6.1%	2.5%
Ottawa	0.0%	-	0.0%	0.0%	0.0%	0.0%	0.3%	0.3%
Charles St.	10.3%	0.3%	-	1.4%	3.7%	3.4%	7.8%	1.9%
Grand River	1.7%	0.2%	1.7%	-	0.0%	0.0%	2.4%	0.3%
Uptown	0.8%	0.0%	0.8%	0.0%	-	0.5%	1.4%	0.0%
Laurier	2.9%	0.2%	2.4%	0.2%	0.5%	-	0.7%	0.5%
U of W	4.4%	0.2%	4.7%	0.5%	1.2%	1.0%	-	4.4%
Conestoga	3.0%	0.0%	1.7%	0.7%	0.5%	1.0%	6.1%	-

To estimate the benefits realized by travelers making trip types II - IV, we make the following assumption. We assume that the travel cost on each local section is equal to the travel cost in the corridor. Mathematically, we assume:

$$GC^{L1} = GC^{L2} = GC^{7} \qquad \text{Eq. 8}$$

This results in trip types II and III experiencing one half the generalized cost reduction and trip type IV experiencing one third the cost reduction.

Again, from travel surveys, we know the percentage of trip makers through the corridor that makes trips of each type. We can then weigh the number of trip takers by their expected reduction in generalized cost to compute a final, corridor-wide reduction in generalized costs. These calculations are shown in Table 8.

Table 8. Computing Corridor-Wide Reduction in Generalized Cost

Trip type	*Number of trip makers (%)*	*Reduction in generalized cost (%)*	*Weighted reduction (%GC)*
I	40.2	14.1	5.7
II	22.7	7.0	1.6
III	21.6	7.0	1.5
IV	15.5	4.7	0.7
Corridor-wide, weighted average reduction in GC			9.5

Thus, the introduction of the iXpress service in the corridor reduced cost by an average of 9.5 percent.

Finally, to compute elasticity, we calculate the percent change in demand through the corridor. Prior to the introduction of iXpress, there were 15,941 boardings in the Route 7 corridor. When boardings were counted in the corridor after iXpress, there were 16,528 boardings on Route 7 and 2,701 boardings on iXpress, for a total of 19,229.

In the time between the two counts, GRT system ridership grew by 7 percent system wide. To account for this growth, we compute the difference in actual boardings (19,229) to expected boardings (15,941*1.07=17,057) assuming ridership on Route 7 grew at the system average. This calculation results in a net growth of 2,172 boardings, or 12.7 percent.

The elasticity of demand with respect to generalized cost can be computed using equation 6, with ΔD = 12.7% and ΔP = 9.5%. The elasticity, E, is then equal to -1.3.

Understanding Model Results

Other researchers (as summarized by Litman and Balcombe et al.) typically observed absolute values of short-term elasticities for quality of service, quantity of supply, and price in the range of 0.5 to 0.7, and long-term in the range of 0.7 to 1.1. The elasticity observed in this research (which can be considered short- to mid-term) is -1.3, which is inconsistent with the previous findings. We suggest that this surprisingly large value is a result of computing the elasticity of ridership with respect to the composite generalized cost. As noted above, in our case, the introduction of the iXpress results in decreased waiting time, shortened in-vehicle time, and fewer transfers. The results of previous research (Balcombe et al. 2004) suggests a mean elasticity value for ridership with respect to passenger waiting time of -0.64; the same research reports a mean value of elasticity of ridership with respect to in-vehicle time of -0.5. No study was found to directly compute the elasticity for ridership with respect to transfer times.

Consider the following example. If waiting time were reduced by 10 percent, using an elasticity value of -0.64, ridership is expected to increase by 6.4 percent. Subsequently, if in-vehicle travel time were reduced by 10 percent, ridership is expected to increase by an additional 5.0 percent. The total increase is calculated as 1.064*1.05 or 1.117 or 11.7 percent. Using our generalized cost representation and assuming no transfer, if both in-vehicle time and waiting time were reduced by 10 percent (as in the previous case), then the generalized cost would be reduced by 10 percent. From our elasticity finding of -1.3, we would expect an increase in ridership of 13 percent, which is consistent with previous findings.

Sensitivity Analysis

In assigning the relative weights of travel disutility (equation 3), we assumed the average value presented by Kittelson et al. Further, we assumed a standard value of time of $8.00 per hour. To assess the sensitivity of our findings to these assumed values, we present the following analysis. We recomputed the percent reduction in generalized cost in the corridor while varying each of the assumptions from a minimum of 0.5 times the initial value to a maximum of 1.5 times the initial value. For example, in the initial analysis, we assume waiting time is considered 2.1 times as onerous as in-vehicle time. To test the sensitivity, we compute the reductions in generalized costs if waiting time ranged from 1.05 times to 3.15 times as onerous as in-vehicle time. Similarly, we test values for transfer time that range from 1.25 to 3.75. Finally, we compute percent reductions in generalized travel costs for ranges of value of time from $4.00 to $12.00. The results are shown in Figure 5.

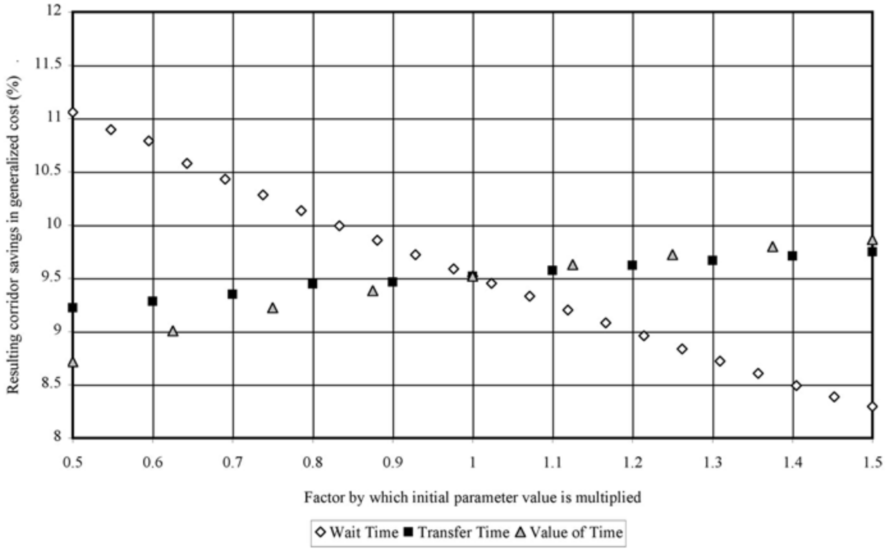


Figure 5. Sensitivity of Generalized Cost Reductions to Parameter Assumptions

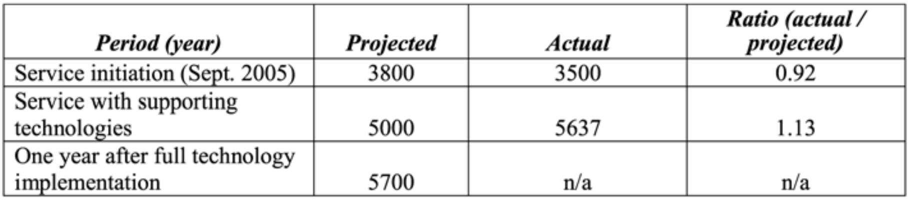
When all the initial parameters are multiplied by 1.00, the reductions in generalized cost equal the result presented in the previous section, approximately 9.5 percent. In analyzing each parameter, it is noted that the reductions in generalized costs are most sensitive to the relative weight for waiting time. If we reduce the relative importance of waiting time in calculating generalized cost, then travelers in the corridor experience savings of 11.1 percent. If we increase the importance of waiting time, then the benefits accrued from iXpress are reduced to approximately 8.3 percent in the corridor. This is logical as the introduction of iXpress has the least impact on waiting times in this corridor.

Varying the importance of transfer times has little effect on the net benefits associated with iXpress, with the generalized costs savings varying from 9.2- 9.8 percent. Obviously, as transfer times become relatively more important, generalized costs savings increase. Similarly, the magnitude of corridor savings increases with increased of value of time, but only marginally. If we assume travelers have very low value of time, then the travel cost savings falls from the initial value of 9.5 percent to approximately 8.7 percent. Under the assumption of high value of time, $12.00 per hour, then the travel cost savings increase to 9.8 percent.

iXpress Service Performance and Upgrade Plans

During the planning of iXpress, Grand River Transit forecasted ridership projections for several periods: immediately after service initiation, at the time when all supporting technologies for iXpress had been implemented, and one year after this full implementation. These BRT technologies include transit signal priority (TSP) along its corridor, AVLS to support real time arrival information at all locations, a web-based trip planner, and an interactive voice response (IVR) system to provide passenger information. At the time of the most recent data collection, several delays had precluded the full implementation of these technologies. Table 9 summarizes how ridership (average weekday boardings) forecasts compare with actual ridership.

Table 9. Projected and Actual Ridership Values



Period (year)	*Projected*	*Actual*	*Ratio (actual / projected)*
Service initiation (Sept. 2005)	3800	3500	0.92
Service with supporting technologies	5000	5637	1.13
One year after full technology implementation	5700	n/a	n/a

Based on the success of the iXpress, the Region has undertaken an Environmental Assessment to determine the feasibility and optimal design of an upgraded, rapid transit system which will be operated on longitudinally separated right of way. The process is ongoing, with final approval slated for 2009.

Conclusions

This paper presents a methodology to assess the impacts of express bus service in areas with existing transit service. The method presented is based on utility theory, the traditional model used in mode choice models. However, the application in this case is done for individual origin-destination pairs in three corridors such that micro-level generalized cost components (waiting time, in-vehicle time, and transfer times) can be readily computed before and after the introduction of the express service. We find cost savings for individual O-D pairs that range from 0% (local service remaining the best option) to as high as 33 percent.

Next, using survey data that provide travel volumes between O-D pairs, we aggregate the O-D cost savings to a corridor-wide average travel cost savings for the highest ridership area. We calculate an average travel cost savings of approximately 9.5 percent for all riders as a result of the iXpress. The benefits of computing this corridor-wide cost reduction is that corridor elasticity can now be computed based only on the changes of boardings in the corridor, rather than a change in O-D volumes. When combined with an increase in demand in the corridor of 12.3 percent, this cost reduction suggests an observed elasticity of demand with respect to price of 1.3.

Finally, we test the sensitivity of our travel cost savings to the assumed weights of waiting time and transfer time, as well as value of travel time. All of these variables display the expected relationships: travel costs savings decrease as waiting time becomes more important (because the express service contributes little to waiting time savings); travel costs savings increase with transfer times becoming more important, and with increasing value of time. The magnitude of each of these changes suggests that the model is largely insensitive to these parameter values.

Endnotes

[1] Many Canadian metropolitan areas have so-called Regional governments that, in essence, act as a bridge between Provincial and municipal governance. The Regional Municipality of Waterloo has legal responsibility to develop a Regional Official Plan which is consistent with the Province in its strategic planning goals, and sets the objectives for municipal plans. The Region also operates Grand River Transit, the region's transit service.

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Users' Perceptive Evaluation of Bus Arrival Time Deviations in Stochastic Networks

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Abstract

This work is a report on research concerning transit service characteristics as seen from the users' point of view. Users of two separate bus lines, operating in a shared/common urban infrastructure, were interviewed at bus stops about their perception concerning headways of bus lines operation. An analysis was made regarding deviations between actual and scheduled bus arrival headway. Further statistical analysis was carried out to check factors giving rise to different perceptions. The operation of each bus line was registered, and corresponding service characteristics were compared with those perceived by the users. Based on these results, a model for bus line headways was proposed, incorporating the perception of deviations by the users. In conclusion, a reliable service, meaning smaller deviations, is more appreciated by the public than any service of shorter headways and less reliability.

Introduction

In recent studies regarding travel time and reliability, it has been found that travelers are not only interested in saving travel time but also in reducing travel time variability. Their attitudes and "choice of way and route" strongly depend on this perception. Variability causes uncertainty, as they do not know arrival time at the destination. Thus, variability is considered by travelers as an additional cost. Research is rather limited on demand-and-supply variation effects on travel time reliability in an uncertain environment. For example, a recent report was examined how individual travelers with different risk-taking attitudes responded to such changes (Chen et al. 2001). Route choice models that were originally proposed were based on the assumption that all travelers are aware of the travel times of a certain network (deterministic models [Beckmann et al. 1956] as well as stochastic models [Daganzo amd Sheffi 1977; Fisk 1980; Sheffi and Powell 1982]). However, both categories of models tend to disregard network uncertainty (stochasticity) and assume that the network is deterministic, an assumption that is not true, especially during rush hours.

This paper, based on a recent university study (Daskalakis 2002), focuses on how passengers perceive reliability of bus line operation, and models the relationship between bus line operation characteristics and this perceived measure of reliability.

Travel Time Perception and Evaluation by Passengers

Travel time is a natural measure of the effectiveness of a bus service. The purpose of bus service is to transport people to their destination with safety and convenience, offering easy access and providing service information. However, most people rate travel speed and, consequently, travel time above all quality characteristics (Chen et al. 2002). This time often varies considerably, primarily during rush hours in everyday commuting.

Waiting time deviation is an indicator of how passengers experience the operation of a bus line, while waiting at the same stop, around the same period of the day, when headway schedules are the same. Studies concerning time cost have shown that passengers would rather wait than pay for a more frequent service, though not for long (Hess et al. 2003). Bus operators aim at offering services that best suit passenger needs. Does this mean they have to provide more frequent bus schedules, which is something evidently expensive, or is there any other way of keeping passengers sufficiently satisfied while waiting for the bus? The answer should be regular bus transportation, leading to an increased quality of service.

Collection and Analysis of Data

To acquire data that would assist in this evaluation of user perception of bus schedule variability, a survey was conducted downtown Athens, Greece. Frequencies of bus lines were registered on site and were compared to the original scheduled frequencies by OASA (Athens Urban Transportation Organization).

Two lines were selected: line A and line B (originally code named "A14" and "730"), linking central Athens to western suburban districts. The survey was carried out from May to June (on usual weekdays, primarily Tuesdays and Thursdays) from 07:00 to 17:00, covering both morning and afternoon commuting. More specifically, the time period 07:00- 09:30 was chosen to cover traveling to work from the suburbs to central Athens. This period was called the inbound direction "I." The period 13:45-16:45 was chosen primarily for passengers returning to their homes, following the outbound ("O") direction. It is noted that, during the days and the times of the interviews, weather conditions were normal, no major events affected the usual operation of bus lines, and the interviewed passengers were chosen randomly. These two bus lines are operated by ETHEL (an OASA partner, responsible for operating thermal buses). Both are radial-shaped, linking the commercial center of Athens with suburban districts and run along signalized arterials (see Tables 1 and 2). By the time of the research, schedule information was not posted at bus stops. Passengers had to find out the scheduled bus line frequency usually by asking bus drivers. For survey needs, such data were derived from original scheduling timetables of OASA.

Table 1. Characteristics of the Surveyed Bus Lines

	Line A		**Line B**	
	Inbound (I)	*Outbound (O)*	*Inbound (I)*	*Outbound (O)*
Route length (m)	7631	7270	7555	7097
No. of stops	27	26	25	26
Average length between stops (m)	293	280	302	273
Scheduled round trip time (min)	85		80	

Source: Athens Urban Transportation Organization

Table 2. Scheduled and Observed (Mean) Bus Headways

Line	**A**		**B**	
Direction	*I*	*O*	*I*	*O*
Scheduled time (min)	7.9	6.9	17.0	16.0
Mean observed time (min)	8.2	7.7	21.0	16.6

Basic questions asked were the following:

1) How often do you use this particular bus line (weekdays)? (daily—4+ days a week, 2-3 times a week, 1-2 times a month, less than once a month)
2) In your opinion, what is the usual delay? (no delay, considerable, much, too much) (i.e., magnitude of the delay)
3) In your usual schedule, how long would you be willing to wait for the bus? (0, 5, 15, 20, 20+ min)
4) From your experience, how long (in minutes) is the usual bus latency? (0, 5, 15, 20, 20+ min)
5) How long do you usually wait at the bus stop before concluding that the bus is late? (0, 5, 15, 20, 20+ min)
6) How long (in minutes) would you be prepared to wait for the bus? (0, 5, 15, 20, 20+ min)
7) You arrive at the bus stop. When would you decide that your schedule has been seriously affected? (0, 5, 15, 20, 20+ min)
8) What is the purpose of the particular trip? (work, returning home, education, shopping, recreation, other)
9) After how long (in minutes) would you consider the delay unjustified?
10) Suppose that the exact arrival time is indicated at the bus stop. How would you describe a bus delay of

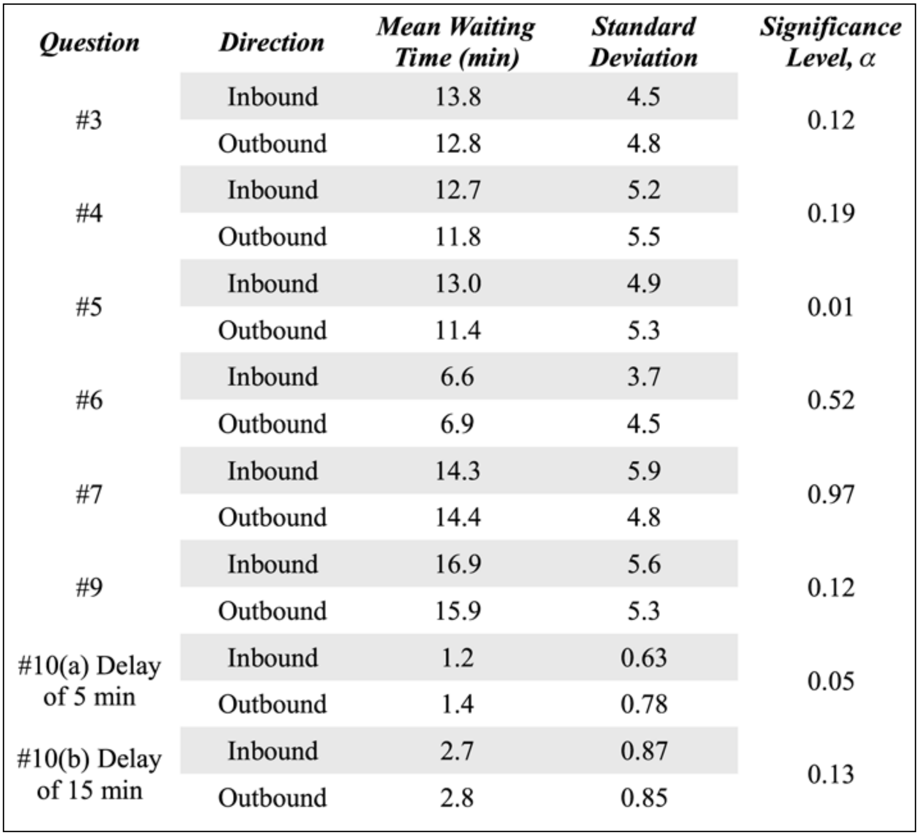
    a) 5 minutes? (short, average, long, unacceptable)
    b) 10 minutes? (short, average, long, unacceptable)

A total of 300 valid questionnaires were collected. The resulting data were subjected to a series of statistical tests and analysis.

T-tests were conducted for each travelling direction with regard to different expressions of waiting time perception, as addressed in questions 3, 4, 5, 6, 7, 9 and 10. Table 3 shows the statistical results for the means, standard deviations and the significance levels for the null hypothesis H_0 of equal means.

No assumption of equal means, except that for question 5, was found to be statistically significant with a confidence coefficient in excess of $(1\text{-}\alpha)_5 = 95\%$, since all t-statistics were over 0.05. Homogeneity of variance test was performed by calculating Levene's statistic to verify the assumption of homogeneity of variance

Table 3. Statistical Results (t-test)



Question	*Direction*	*Mean Waiting Time (min)*	*Standard Deviation*	*Significance Level, α*
#3	Inbound	13.8	4.5	0.12
	Outbound	12.8	4.8	
#4	Inbound	12.7	5.2	0.19
	Outbound	11.8	5.5	
#5	Inbound	13.0	4.9	0.01
	Outbound	11.4	5.3	
#6	Inbound	6.6	3.7	0.52
	Outbound	6.9	4.5	
#7	Inbound	14.3	5.9	0.97
	Outbound	14.4	4.8	
#9	Inbound	16.9	5.6	0.12
	Outbound	15.9	5.3	
#10(a) Delay of 5 min	Inbound	1.2	0.63	0.05
	Outbound	1.4	0.78	
#10(b) Delay of 15 min	Inbound	2.7	0.87	0.13
	Outbound	2.8	0.85	

that would certify the performance of further tests, such as ANOVA and Discriminate Analysis. Levene's test is an alternative to Bartlett test (Bartlett 1937), testing also observations originating from populations showing the same variance that depend heavily on the assumption that these observations refer to normal distributions. Since in our case is that no such evidence exists, Levene's test was considered as preferable.

Regarding questions 6 and 10, the test confirmed heteroscedasticity with confidence coefficient $(1\text{-}\alpha)_{6,10}$ = 99.8%. That is, the hypothesis that waiting time (as specified in questions 6 and 10) is of equal levels of variance for both directions "I" and "O" is not accepted. Consequently, the answers to questions 6 and 10 do not explain the same proportion of the variance by direction.

Results of the t-tests for the rest of the questions 3, 4, 5, 6, 7 and 9 did not indicate significant differences concerning the means of the given answers for a confidence coefficient $(1\text{-}\alpha)_{3,4,6,7,9} > 90\%$, and no definite conclusion may be drawn about the effect on the answers of any of the two directions. In question 10, for a waiting time of 5 minutes, the mean value of the answers given by the passengers of direction "O" is greater than that of direction "I" with a confidence coefficient of $(1\text{-}\alpha)_{10} = 95\%$. It should be noted that the ordinal scale of question 10 was transformed to a numerical, using the following convention: small = 1, medium = 2, large = 3, unacceptable = 4.

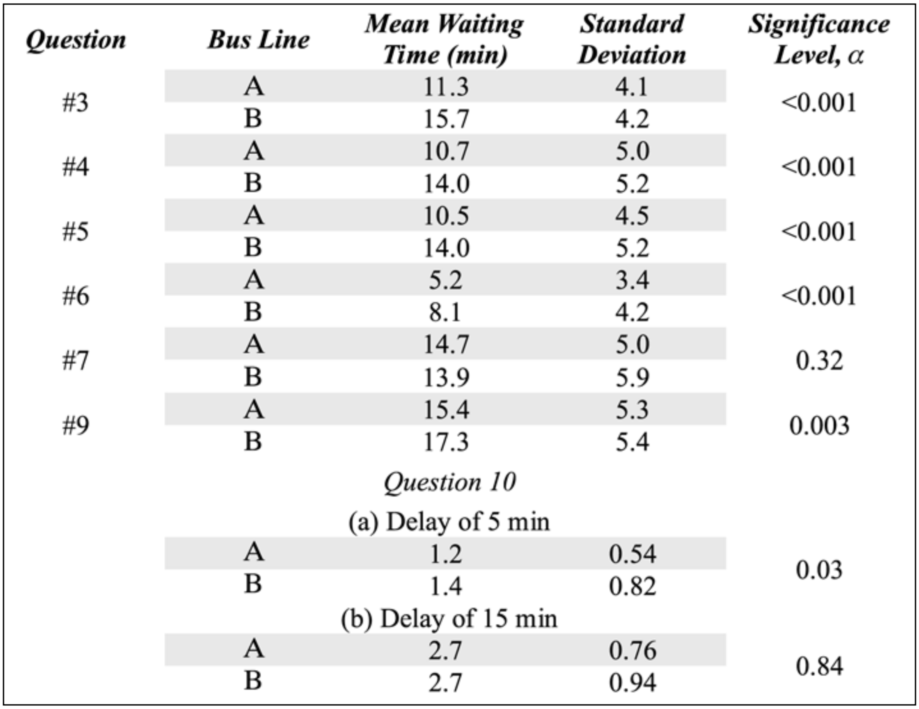
Similar tests were performed for each line separately, combining the two directions. Relevant results are shown in Table 4. All the differences of the means for the two bus lines, except that of question 7, are statistically significant with a confidence coefficient $(1\text{-}\ \alpha)_{3,4,5,6,9,10(5)} > 95\%$. In questions 5, 6 and 10, Levene's test gives $\alpha < 0.05$, which reveals heteroscedasticity. That is, the null hypothesis that the variable (waiting time as specified in questions 5, 6 and 10) has equal levels for both bus lines A and B does not hold and the variance cannot be explained at the same degree.

There is also a direct correspondence between the answers given by passengers to questions 3, 4 and 9 and the type of bus line. In particular, passengers of bus line A stated at the above questions significantly (with a confidence coefficient $(1\text{-}\alpha)_{3,4,9} > 99\%$) shorter mean time.

The mean (waiting time) based on the samples answering questions 5 and 6 for bus line A is shorter than waiting time of bus line B. However, existence of heteroscedasticity in the sample does not allow concluding that the type of bus line is a significant factor. In question 10 (a), mean waiting time in the case of bus line B is longer than that of line A, indicating less tolerance by the users as long as waiting is concerned. In question 7, bus line type does not affect the answers.

In contrast to passengers of line B, passengers of line A spend everyday shorter waiting time at the bus stop. It appears from the answers, that passengers perceive scheduled headway of each bus line rather accurately, even if they do not have direct information about it. They evaluate the degree of schedule adherence and adapt their own trip schedule to the mean headway for each line. The time they are prepared to wait at the bus stop is not related to the mean headway of the bus line. Deviations between actual bus lines operation and scheduled headways create problems and affect their activities. In cases where these activities require

Table 4. Combined (Inbound-Outbound) Statistical Results (t-test)



Question	*Bus Line*	*Mean Waiting Time (min)*	*Standard Deviation*	*Significance Level, α*
#3	A	11.3	4.1	<0.001
	B	15.7	4.2	
#4	A	10.7	5.0	<0.001
	B	14.0	5.2	
#5	A	10.5	4.5	<0.001
	B	14.0	5.2	
#6	A	5.2	3.4	<0.001
	B	8.1	4.2	
#7	A	14.7	5.0	0.32
	B	13.9	5.9	
#9	A	15.4	5.3	0.003
	B	17.3	5.4	
		Question 10		
		(a) Delay of 5 min		
	A	1.2	0.54	0.03
	B	1.4	0.82	
		(b) Delay of 15 min		
	A	2.7	0.76	0.84
	B	2.7	0.94	

a precise schedule, passengers begin to consider alternative bus lines, taxi service, a combination both, or even walking.

Usually, after carrying out a test of statistical importance, it is desirable to know which factor contributed to the results. In our case, we pay special attention to the differences between the answers. Analysis can, of course, be limited to the simple t-tests, in order to compare all possible pairs of the sample means. However, such a procedure would depend on chance.

Post hoc comparison techniques, on the other hand, take into account specifically the fact that more than two sample means may be examined. Post hoc stands for the logical error of believing that temporal succession implies a relation. These post hoc comparisons were made using Scheffé's and Duncan's tests. Scheffé's test performs simultaneous joint comparisons in pairs for all possible combinations of means in pairs using the F sampling distribution. This test is considered to be "conservative" (Clarke and Cooke 1998); therefore, its usage helps to find out significant (at a level **a** = 0.05) errors occurring in multiple comparisons.

At the same time, there is a chance that important differences, possibly existing, may not occur. To limit this possibility, a more tolerant test (Duncan) is performed. Duncan's test makes comparisons in pairs using a stepwise order of comparison, setting a protection level for the rate of error regarding the collection of data sets, rather than rate of error for individual tests.

Tests mentioned above made it clear that a significant factor differentiating the answers is the headway of each bus line. To find a quantitative expression (function) of that differentiation, Discriminant Analysis was used. This type of analysis describes the differentiating features from observing known populations and tries to find "discriminants" of which numerical values are such that the observations (responses) are as distinct as possible (Fisher 1936).

Responses to questions 3, 4, 5, 6 and 9 were treated as quantitative variables. Analysis indicates that 57-74 percent of the answers at the basis of bus lines A and B with confidence coefficient of $(1\text{-}\alpha)_{3,4,5,6,9} > 95\%$. Wilk's Lambda found to be ranging between 0.78 and 0.88, depending on the type of question. Wilk's Lambda ($\in[0,1]$) is a multivariate test of significance, sometimes called the U-statistic, with values close to 0 indicating that the group means are different and values close to 1 indicating the group means are not different.

The most felicitous analysis was found to be the one referring to question 3 ("In your usual schedule, how long do you estimate you will be willing to wait for the bus?"), in which the discriminant percentage of the questions was 74 percent, with Wilk's Lambda 0.78 with a confidence coefficient of $(1\text{-}\alpha)_3 > 99\%$. The linear discriminant function for each of the two bus lines was:

$$\text{Bus line A: } y_{3,A} = -4.415 + 0.661x \tag{1}$$

$$\text{Bus line B: } y_{3,B} = -7.878 + 0.918x \tag{2}$$

where: y is the classification variable of bus line

x is answer to the question no.3, in minutes

For a specific x, the larger of the two classification variables $y_{3,A}$, $y_{3,B}$ classifies the user to the one or the other bus line. The discriminant line is made up by the parts of the two functions that give higher scores before and after the point of intersection (dashed line, Figure 1). The two lines intersect at a point with an abscissa equal to 13.45 min. Thus, a user whose response is less than 13.45, is more likely to use line A. Users of line A, compared to those of line B, spend less of their time at the bus stop. This indicates that the users of the more frequent line A perceive their waiting time through the assumption that line A has a higher headway. Passengers of line B, on the contrary have a better perception of the actual headway of the particular line.

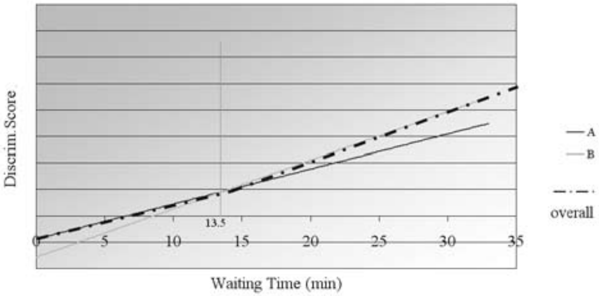


Figure 1. Bus Line A & B Discriminant Functions

Results of previous test-controls are summarized as follows:

- Passengers of both lines in the outbound direction, that is, those mainly returning home in the afternoon, answered that they are less tolerant compared to answers given to the same question while making the morning inbound trip. For passengers returning home, the reliability of service is evaluated (perceived) as more important than is in the inbound trip.
- Headway analysis showed a large degree of schedule deviation (up to 90% –95%). This implies about ±7.5 minutes for line A and ±16.5 minutes for B (extreme negative signs indicate a bunching). Passengers perceived average times of: 10.7 and 14 minutes, respectively. Passengers of the most frequent line (A) perceive greater delays than actual ones, while passengers of the less frequent line (B) perceive smaller schedule deviations than actual ones. This phenomenon is known as "time drag," in which waiting time seems longer than it actually is (Moreau 1992). A possible explanation for this would be that the perception of time from an unreliable bus service follows a logarithmic trend (i.e. during the first waiting minutes, time "runs" faster).

Model Proposal and Development

To investigate further the claim of the logarithmic-like relationship as suggested in the previous chapter, the following simple calculations were undertaken. The basic relationship is expressed as follows:

$$T_i = k_i H_i^L \tag{3}$$

where: $\mathrm{T_i}$: the users' perception of deviation as stated in the interview for bus line i.

$\mathrm{H_i}$: headway of bus line i

k_i : coefficient of proportion, independent of the bus line's headway, related to bus line i user's characteristic, the purpose of traveling, the frequency of bus usage, travel time, etc.

L : unknown numerical variable

For bus line A, eq(3) becomes: $T_A = k_A H_A^L$ and for bus line B, eq(3) becomes: $T_B = k_B H_B^L$

In our case, users of bus lines A and B have similar characteristics (purpose of travelling, frequency of bus usage, etc) and this means $k_A = k_B$

$$\begin{aligned} & k_A = k_B \Rightarrow \frac{T_A}{H_A^L} = \frac{T_B}{H_B^L} \Rightarrow \frac{T_A}{T_B} = \frac{H_A^L}{H_B^L} \Rightarrow \left(\frac{T_A}{T_B}\right) = \left(\frac{H_A}{H_B}\right)^L \Rightarrow \\ & \Rightarrow \ln\left(\frac{T_A}{T_B}\right) = \ln\left(\frac{H_A}{H_B}\right)^L \Rightarrow \ln\left(\frac{T_A}{T_B}\right) = L * \ln\left(\frac{H_A}{H_B}\right) \Rightarrow \\ & \Rightarrow L = \frac{\ln\left(\frac{T_A}{T_B}\right)}{\ln\left(\frac{H_A}{H_B}\right)} \end{aligned} \tag{4}$$

Observed $\mathrm{H_A}$=7.68min and $\mathrm{H_B}$=17.65min. $\mathrm{T_A}$ and $\mathrm{T_B}$ can be derived from the answers collected in the survey and refer to the perception of schedule deviation of bus lines A and B, respectively.

By substituting in (4) H_A, H_B and the values given in question no.3 (Table 4), i.e. T_A=11.27 and T_B=15.66:

$$L = \frac{\ln\left(\frac{11.27}{15.66}\right)}{\ln\left(\frac{7.68}{17.65}\right)} = \frac{\ln(0.719)}{\ln(0.435)} = \frac{-0.33}{-0.83} = 0.4 \Rightarrow L = {}^{2}\!/_{5} \tag{5}$$

And finally:

$$T=kH^{2/5} \qquad \text{T, H in min} \tag{6}$$

The above model was iteratively fitted to the survey responses, i.e. the values of the responses to those questions that combine on the same basis, passenger perception with actual bus line performance. These are questions no. 3,4 and 5 (Table 4). Coefficient of proportion k for passengers of bus lines A and B is then derived as the minimum square root error solution to (6), using the survey data for each pair of $T^{quest\ no.(3),(4),(5)}_{(A),(B)}$ and $H_{(A),(B)}$.

The resultant form of the model is then:

$$\mathrm{T(H)} = 4.7\mathrm{H}^{2/5} \qquad \text{T, H in min} \tag{7}$$

The rate of T vs. H, r(h) derives from:

$$\mathrm{T(H)} = 4.7\mathrm{H}^{2/5} \Rightarrow \frac{\partial \mathrm{T(H)}}{\partial \mathrm{H}} = 4.7\frac{2}{5}\mathrm{H}^{\frac{2}{5}-1} \Rightarrow$$

$$\Rightarrow r(\mathrm{H}) = 1.88\mathrm{H}^{(-\frac{3}{5})} \tag{8}$$

H in min, r in $\min^{(-3/5)}$

where: r(H) is a decaying function of H, signifying the diminishing impact of a headway increase on the perception of schedule deviation.

The plotted results of the (7) and (8) are shown in Figure 2.

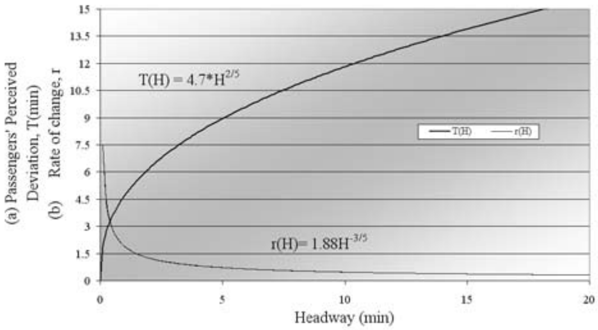


Figure 2. Perceived Deviation and its Rate of Change vs. Headway

(Factors 4.7, 1.88 concern users of specific bus lines A & B as described above)

Conclusions

Bus line users traveling in stochastic transportation networks, having little knowledge of the exact schedule timetables, usually base their travel decisions on the empirical perception of time in order to organize their own time schedules. The perception of the mean waiting time and its variances determines how service reliability is evaluated by the user and, subsequently, the user's attitude towards the way of traveling. Knowing the way passengers perceive schedule deviations and the resultant variations of their waiting time would help the management of transportation in achieving operational effectiveness. Having interviewed passengers waiting at bus stops, it was verified that a (the) significant factor related to the perception of waiting time deviations was the headway, yet not linearly.

On the basis of the proposed model, deviation is perceived as a function of the headway H raised to the number of 2/5. The curve expressing the relation between perceived deviation (leading to the so-called "time drag") and headway has a logarithmic shape, while the curve expressing the rate of the perception of deviation has that of a negative exponential. The greater the headway, the greater deviation the users perceive, but at a diminishing rate. So, if an operator wishes to upgrade the quality of those services related to passenger waiting time, it is important to keep bus lines even with greater headways reliable and then try to achieve shorter headways. Once a bus line with shorter headway is in operation, it should be strictly reliable, as passengers become indignant about unreliability of bus lines with shorter headways.

Limitations and Future Work

Natural limitations in this research concern the basic sample of only two specific bus lines, the fact that bus operators may have incorporated some manual headway control into schedules—a thing unknown to us, and that passengers had no credible source available of information about bus line scheduled operations. By implementing intelligent transport systems such as real-time information at bus stops and automatic headway control methods, new and challenging conditions appear in transportation environment.

Suggestions for further investigation on the subject could involve research on different types of bus lines and networks, such as peripheral instead of radical bus lines or bus lines using exclusive lanes. The question of how reliable (in quantitative terms) a service should be before it is made more frequent, regarding cost and benefits of alternative operational strategies, is also another interesting direction of research.

Acknowledgment

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Impact of High Occupancy Vehicle (HOV) Lane Incentives for Hybrids in Virginia

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Abstract

This paper examines the impact of Virginia's policy of exempting hybrid-electric vehicles from minimum occupancy requirements on state HOV lanes. Virginia registration statistics are used to compile hybrid market shares on a county level to compare the impact of HOV lane access to other socioeconomic variables. The HOV incentive is shown to have a significant impact in Northern Virginia, but not in the Hampton Roads area. The paper also addresses the criticisms and potential unintended consequences of the incentive policy, including whether it has impacted the "green" image of the hybrid in Virginia.

Introduction

This article examines the impact of HOV lane exemption policies for hybrid-electric vehicles, focusing primarily on the state of Virginia. Sales and general interest in Hybrid Electric Vehicles (HEVs) has risen steadily in recent years in response to rising fuel costs and increased concern about pollution and greenhouse gas emissions. Hybrid vehicles utilize the same gasoline fuel infrastructure as conventional Internal Combustion Engine (ICE) vehicles, yet represent a distinct technology improvement that can provide greater fuel economy and reduced emissions for equivalent vehicle performance by recapturing energy normally lost during break-ing (U.S. Department of Energy 2007). As an energy efficiency technology, HEVs also address positive externalities associated with resource management, the environment, and energy security, which are not taken into account by the market (Jaffe and Stavins 1994). In addition, HEVs face barriers to diffusion that are common to many new cost-saving technologies, such as high initial unit costs, lack of knowledge by potential adopters, high discount rates for future cost savings, and low consumer risk tolerance (Jaffe and Stavins 1994; Stoneman and Diederen 1994; Argote and Epple 1990). To account for these externalities and barriers to adoption, the U.S. Federal Government and many state governments have offered a variety of incentives and privileges to consumers who purchase hybrids and alternative fuel vehicles (U.S. Department of Energy 2007), one of the most notable being an exemptions from minimum vehicle occupancy requirements in High Occupancy Vehicle (HOV) carpool lanes. This privilege can result in considerable time savings for commuters who purchase hybrids.

Where HOV lanes exist and have sufficient excess capacity, allowing hybrids or alternative fuel vehicles on HOV lanes with a single occupant provides a means of promoting adoption with almost no direct marginal costs to taxpayers, other than the cost of publicizing, administering, and enforcing the program. Virginia was the first state to adopt this policy, starting in 2000, and since 2005 several other states, including Florida, Georgia, Utah, New York, New Jersey, California and Arizona, have allowed hybrids on at least some of the state's HOV lanes (U.S. Department of Energy 2007). Due to its seven-year history of allowing hybrids on HOV lanes, Virginia provides an excellent case study of the impact of HOV incentive policies for hybrids and may provide insights for other jurisdictions considering similar policy incentives. To that end, this paper examines the background of Virginia's HOV lane incentive and its impact on local adoption patterns. It compares the impact of Virginia's HOV lane policy to other potential determinants of hybrid vehicle adoption, including income, environmentalism, and commuting characteristics. Additionally, it looks at the potential for unintended consequences of the policy and whether there is evidence that HOV incentives have led to a backlash against the "green" image of hybrids in Virginia.

This paper builds on previous research into the determinants of hybrid vehicle adoption. Kahn (2007) found that environmentalism (as indicated by Green Party affiliation) was associated with hybrid ownership, based on regression analysis of census track-level data in six California cities. Heffner et al. (2005) conducted detailed interviews with households in Northern California that own HEVs and determined that both anticipated cost savings and the "green image" of hybrids influence purchase decisions. McManus and Berman (2005) analyzed the results of an online survey taken by 532 hybrid owners and 933 potential owners who visited the HEV information website HybridCars.com. Their report identified the desire to save money on gas and reduce pollution as significant motivating factors for purchasing a hybrid among both sets of respondents. A 2004 marketing survey by ChangeWave Research concluded that hybrid owners tend to be in the highest income demographics and are more sensitive to gas prices than environmental benefits in purchasing their vehicles (ChangeWave Research 2005).

Several more recent studies on hybrid vehicle adoption that also examine the impact of government incentives have been conducted using sales and registration data for U.S. states. Diamond (2008) conducted cross-sectional regressions of annual state market share for top-selling hybrid models using RL Polk registration data. The analysis found that average gasoline prices, income, miles traveled, and environmentalism were all positively related to market share, but that the presence or values of monetary incentives at the state level was generally weak or insignificant compared to these other factors. Gallagher and Muehlegger (2008) analyzed actual sales transaction data provided by JD Power and found a more significant impact from state incentives. However, both studies noted that sales tax waivers tended to be more significant than income tax credits, and that Virginia's HOV incentive appeared to have significantly impacted market share. This paper further contributes to the literature on incentive policies for hybrids by examining the impact of Virginia's HOV policy at the local level. It makes use of market share calculations for individual Virginia cities and counties to explore how the impact of the HOV incentive on hybrid adoption varied among different jurisdictions within the state, taking into account local variations in other factors such as income, environmentalism, and commuting habits.

Virginia HOV System Background

Virginia's incentive policy stems from a law predating the introduction of hybrids, which authorized the HOV lane exemption for a variety of alternative fuel vehicles. When hybrids were first introduced in the U.S. in 2000, the state Department of Motor Vehicles—under pressure from consumers and lawmakers—allowed hybrids (which run on gasoline and are therefore not technically alternative fuel vehicles) to also qualify for the program (Morrison and Counts 2005). Access to HOV lanes is controlled by issuing hybrids and other alternative fuel vehicles a "special clean fuel" license plate, which can be seen by police enforcing HOV rules. These plates provide single-occupant access to HOV lanes in two major areas: Northern Virginia, which boarders Washington, DC, and the Hampton Roads area, which includes Newport News, Norfolk, Chesapeake, and Virginia Beach. The Northern Virginia HOV lanes include three major highways—along Interstate Route 66 (I-66), the Dulles Toll Road (VA 267) and Interstate Route 95/395 (I-95/395).[1] The law authorizing the exemption originally contained a two-year sunset clause, but until 2006 it was renewed for two additional years each time it had been set to expire. In 2006, lawmakers renewed the exemption for only one additional year, but ended single-occupant access for hybrids purchased after June 30, 2006, on the I- 95/395 HOV lanes in response to concerns about overcrowding. In 2007 and 2008, the law was extended only on an annual basis; it is currently set to expire on June 30, 2009 (Virginia Department of Transportation 2008).

The map in Figure 1 shows the general locations of the Hampton Roads and Northern Virginia HOV networks. The map in Figure 2 shows the highways that make up the Northern Virginia HOV network.

On VA 267 and Interstate 66 (outside of I-495), HOV lanes consist of the left-most highway lane in each direction and are not physically separated from the rest of the highway. During the morning rush hours, these lanes are restricted to HOV-2 (two or more occupants required) in the inbound direction, switching to HOV-2 outbound during the evening rush hour. Along I-66 between I-495 and the Washington, DC border, the entire highway is restricted to HOV-2 inbound in the morning (with non-HOV traffic permitted outbound only), and HOV-2 only for all outbound traffic in the afternoon (with non-HOV traffic permitted inbound). The most extensive HOV lane network is the 27-mile segment along Interstate I-95/395. The I-95/395 HOV lanes consist of a reversible two-lane segment that is separated from the main highway with limited access points, open to inbound (northbound towards Washington, DC) traffic in the morning and outbound traffic in the evening. Traffic is restricted to HOV-3 (three or more passengers required) during the morning and evening rush hours. Of these three HOV systems, the I-95/395 HOV lanes handle the most traffic and offer the most significant percentage time savings (approximately 50%) compared to non-HOV traffic (Morrison and Counts 2005). Hampton Roads has HOV lanes on several of the main highways, but time savings and traffic volume on the HOV network are much lower than in Northern Virginia (The Marketing Source 2002).

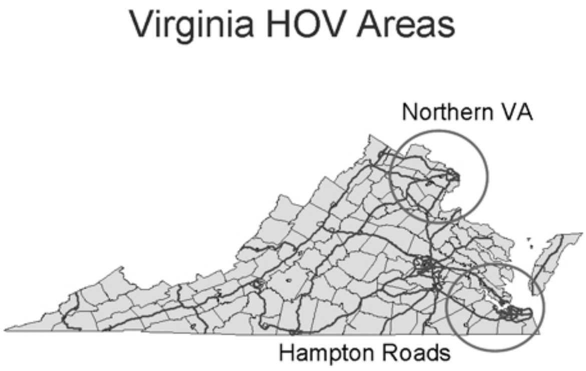


Figure 1. Virginia HOV lanes

Figure 2. Northern Virginia HOV Lanes

Criticism and Unintended Consequences

Since its inception, Virginia's HOV exemption rule for hybrids has been the subject of considerable debate. Originally, the practice was in violation of Federal highway regulations for HOV lanes on interstate highways, which mandated that HOV lanes were only for high occupancy vehicles (Federal Highway Adminsitration 2005). This debate was ended by the Energy Policy Act of 2005, which authorized states to allow HOV exemptions for hybrids and other clean fuel vehicles. However, critics in newspaper editorials, opinion pieces, and internet discussion boards point out that the incentive policy runs counter to other policies designed to promote energy efficient practices such as carpooling and the use of mass transit (Ginsberg 2006). Some of the most vehement criticism of hybrid HOV drivers is found on discussion boards devoted to carpooling and ridesharing. One such message board, Slug-Line.com, contains over 2,800 mostly negative postings in 88 separate threads devoted to hybrids in the HOV lanes, with topics such as "hybrid hate," "anti-hybrid road rage," and "tired of choking on hybrid fumes."[2]

One common complaint by critics is that single-occupant hybrid commuters in HOV lanes actually consume more gasoline per mile, on average, than carpoolers in less efficient vehicles with two or three passengers (Kuehnel 2006). By this criterion, hybrids would have to achieve a fuel economy of over 60 mpg to justify access to the HOV lanes that normally require two vehicle occupants, based on an average fuel economy of 29.5 mpg for passenger automobiles in 2006 (National Highway Transit Safety Administration 2006). This comparison may be partially valid, but the broader environmental impact of the policy is more difficult to determine and depends both on the percentage of hybrid drivers who would have commuted alone in the non-HOV lanes otherwise and the extent to which solo hybrid commuters also use their hybrids for non-commuting trips on evenings and weekends in place of less fuel efficient vehicles. Virginia has not conducted sufficient survey research to determine whether hybrid ownership has directly impacted carpooling or mass transit ridership in Virginia. However, a 2005 Virginia Department of Transportation Study concluded that hybrids accounted for 19 percent of traffic on the I-95 HOV corridor during the morning rush hour, and that this additional traffic had pushed the HOV lanes beyond their design capacity (Morrison and Counts 2005). It is likely that such increased congestion in the HOV lanes would serve as a disincentive to carpooling.

There is also an equity issue, since the HOV exemption policy favors those who not only can afford to buy a new car but can also pay the incremental premium to purchase a hybrid model over an equivalent gasoline-only model. While the availability of more affordable used hybrids should increase over time, Virginia Department of Motor Vehicles (DMV) records in May 2007 indicated that used vehicles still accounted for less than 15 percent of the total number of hybrids titled.

The combination of HOV lane overcrowding and backlash by carpoolers could potentially promote a more negative image of hybrid owners in Virginia, as compared to a generally positive image of hybrid owners in other parts of the country as environmentally-conscious consumers. To the extent that this phenomenon occurs, it may serve as a disincentive to consumers in the Northern Virginia area who do not desire HOV lane access but might otherwise have considered a hybrid for the positive environmental or "green" image it connotes.

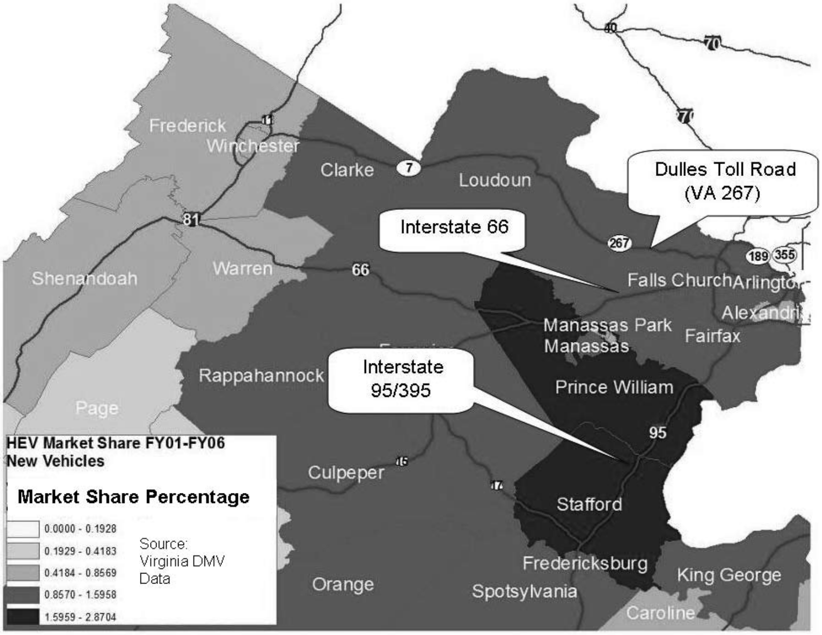
The remainder of this paper addresses several basic research questions that arise from Virginia's experience with its HOV lane incentive. First, it explores whether the HOV incentive has been effective in promoting adoption of hybrids in Northern Virginia and Hampton Roads and how the effect of the policy compares to other socioeconomic factors. Second, it explores whether there is evidence that the policy has tarnished the "green" image of the hybrid in Virginia.

Geographical Analysis of Virginia Adoption Patterns

Statistics on new hybrid market share (new hybrids as a percentage of all new vehicles registered) for all Virginia counties and independent cities were used to test the impact of HOV lane policies in promoting adoption compared to other factors. The Virginia DMV provided basic data on every hybrid registered in the state as of May 31, 2007, including the automobile make, model, model year, original title date, and garaged jurisdiction (county or independent city).[3] Using this database, the numbers of new and used hybrid vehicles titled in each county and independent city were calculated each year for Virginia Fiscal Years[4] 2001 through 2006 (FY01-06) and for the first three quarters of FY07. The DMV also provided a separate data set with the total number of new and used vehicles titled each fiscal year for each jurisdiction, which allowed the calculation of market share. The decision to analyze market share by fiscal year was driven primarily by the way that the DMV provided the data on total numbers of vehicles titled for each jurisdiction. However, the use of fiscal year was also convenient because it corresponded nicely with the change in the HOV policy for I-95/395 starting on July 1, 2006.

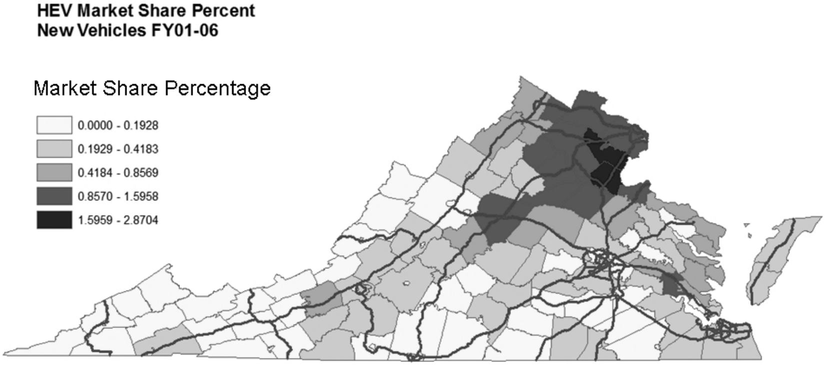
Figures 3 and 4 show the relative market share (given as a percentage) of new hybrids among counties in Northern Virginia and in the entire state, respectively, from FY01-06.

Figures 3 and 4 illustrate the dramatic difference in market share between counties adjacent to the Northern Virginia HOV lanes from those in the rest of the state. Stafford County, which includes the southern terminus of the I-95 HOV lanes, had the highest market share in the state for each individual year and for the combined period from FY01 through FY06. In FY06 (the year before the I-95/395 exemption ended), almost 6 percent of all new car registrations for Stafford County were for hybrid vehicles. Presumably, the high hybrid market shares in Northern Virginia



Source: Virginia DMV Data

Figure 3. Hybrid (HEV) Market Share Percentages in Northern Virginia, FY01-06



Source: Virginia DMV Data

Figure 4. Hybrid (HEV) Market Share Percentages in Virginia Counties, FY01-06

are directly related to the time-savings value of the HOV exemption for commuters in these counties. The impressive market share in the Northern Virginia HOV corridors is in sharp contrast to lackluster market share in the remainder of the state. Despite the apparent impact of the HOV incentive policy in Northern Virginia, there is little graphical evidence that the policy impacted market share in the Hampton Roads area. This apparent discrepancy will be discussed further in the following sections.

It is important to note that the market share is based on new hybrids as a percentage of new vehicles, so this comparison already takes into account the fact that consumers in more affluent counties or cities are more likely to purchase new cars (versus used cars) than in less affluent jurisdictions. Figure 5 shows a geographical representation of market share percentages after correcting for income (dividing the market share by median county income), illustrating that the high market share for hybrids along the I-95/395 and I-66 HOV corridors is not strictly a function of higher consumer income in Northern Virginia.

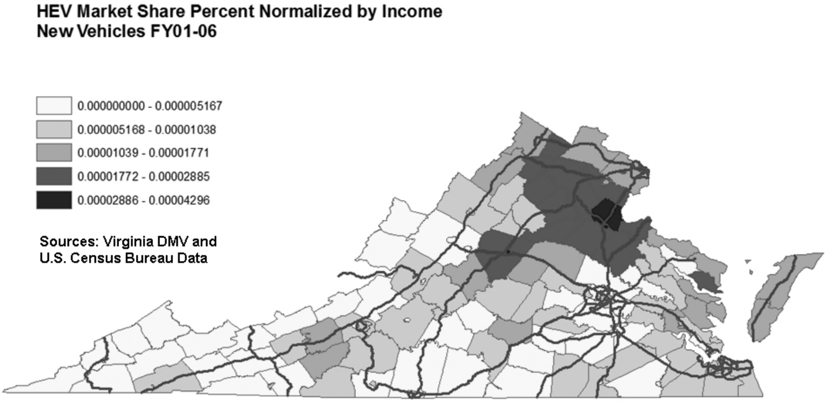


Figure 5. Hybrid (HEV) Market Share Normalized by Income, FY01-06

Another indication of the impact of the I-95/395 HOV exemption is the change in hybrid sales patterns in Northern Virginia after the exemption ended for hybrids purchased after June 30, 2006. Market share for the first nine months of FY07 dropped dramatically in Stafford and Prince William counties compared to FY06. The relative ratios of FY07 to FY06 sales in Virginia counties and cities are shown in Figure 6.

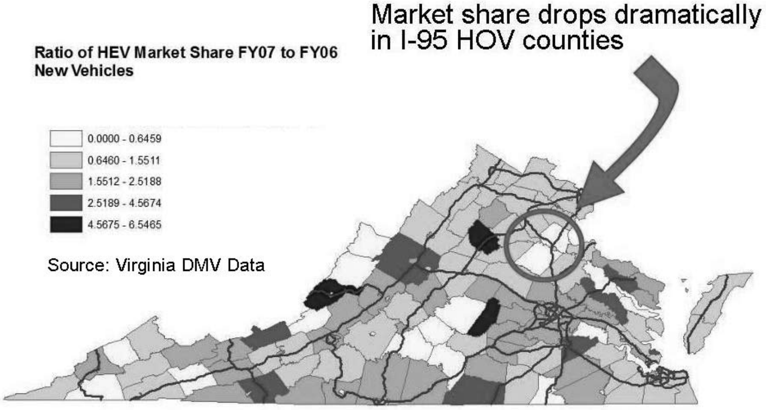


Figure 6. Ratios of FY07 to FY06 Hybrid (HEV) Sales

Regression Analysis of Virginia Cities and Counties

The significance of the HOV lane incentive compared to other socioeconomic determinants was explored further via cross-sectional regressions of annual market share of Virginia counties and independent cities. The basis for this cross-sectional methodology is described in Diamond (2008), where it is used to test for the significance of incentives using state aggregate market share. The significance of the presence of or close proximity to an HOV lane was tested, along with several other demographic variables for each county or city, using the following model specification:

$$s_h = \alpha + \beta_1 Income + \beta_2 HOV_{NOVA} + \beta_3 HOV_{HR} + \beta_4 Green\_Vote + \beta_5 Commute\_Time + \varepsilon$$

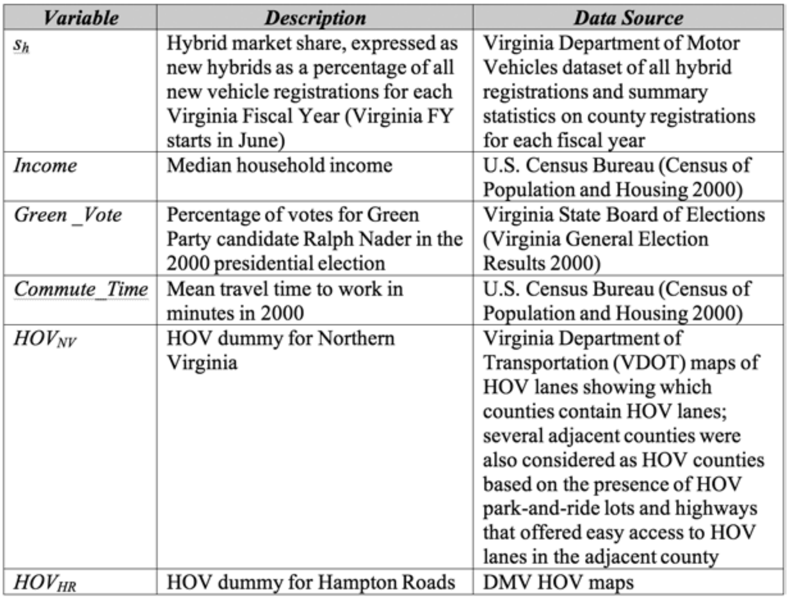
This specification is extremely basic due to the limited amount of control data available at the local level. The percentage of votes for Green Party presidential candidate Ralph Nader in the 2000 presidential election was chosen as a proxy for environmentalism in the absence of a more direct local proxy such as the Green Planning Capacity Index used by Diamond (2008) or per-capita Sierra Club memberships used by Gallagher and Muehlegger (2008). However, the choice of Green Party votes is consistent with Kahn (2007), who uses Green Party registration percentages as a proxy for environmentalism. Because Virginia does not track individual party membership, actual election results were used instead.[5]

Mean commute time served as a proxy for relative commute distance, under the assumption that a further commute would provide a greater incentive to purchase a more fuel-efficient vehicle. Actual survey data on commute distance was not available at the county and city level for Virginia. While commute time proved significant in the regression, congestion may artificially inflate commute time for a given distance in urban areas.

Average gas prices proved significant at predicting hybrid market share at the state levels in previous studies (Diamond 2008; Gallagher and Muehlegger 2008), but it was difficult to incorporate gas prices into the Virginia analysis. Detailed historical average gas prices at the Virginia county and city levels were not readily available, although several services, such as Gasbuddy.com and VAgasprices.com, provide daily price data from a selection of gas stations within each locality. A county-level plot of daily gasoline prices from Gasbuddy.com on June 6, 2007, showed that average county gas prices varied between $2.82 and $3.11, with a standard deviation of only 4.5 cents per gallon (Gasbuddy 2007). However, variations between individual stations in the same county were almost as much as variations between county averages. In one attempt to use the June 6 county gas prices as a control, prices were statistically significant in some years, but with a negligible (and, in some cases, negative) effect.[6]

Table 1 provides a description of the variables and data sources.

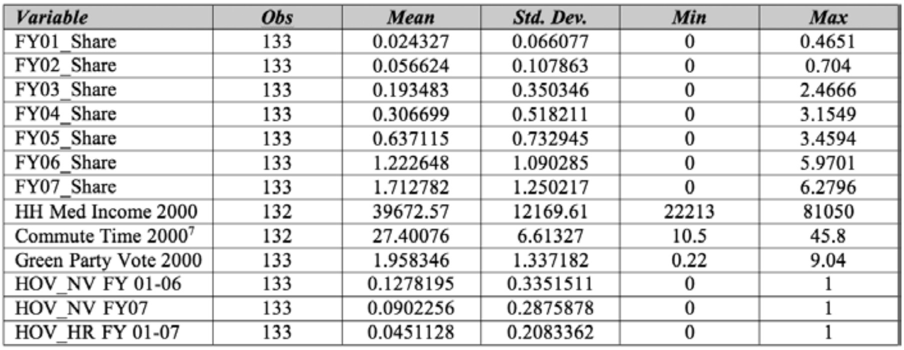
Table 1. Description of Variables for Virginia Hybrid Analysis



Variable	*Description*	*Data Source*
s_h	Hybrid market share, expressed as new hybrids as a percentage of all new vehicle registrations for each Virginia Fiscal Year (Virginia FY starts in June)	Virginia Department of Motor Vehicles dataset of all hybrid registrations and summary statistics on county registrations for each fiscal year
Income	Median household income	U.S. Census Bureau (Census of Population and Housing 2000)
Green _Vote	Percentage of votes for Green Party candidate Ralph Nader in the 2000 presidential election	Virginia State Board of Elections (Virginia General Election Results 2000)
Commute_Time	Mean travel time to work in minutes in 2000	U.S. Census Bureau (Census of Population and Housing 2000)
HOV_{NV}	HOV dummy for Northern Virginia	Virginia Department of Transportation (VDOT) maps of HOV lanes showing which counties contain HOV lanes; several adjacent counties were also considered as HOV counties based on the presence of HOV park-and-ride lots and highways that offered easy access to HOV lanes in the adjacent county
HOV_{HR}	HOV dummy for Hampton Roads	DMV HOV maps

Table 2 provides a summary of the data used for each variable.

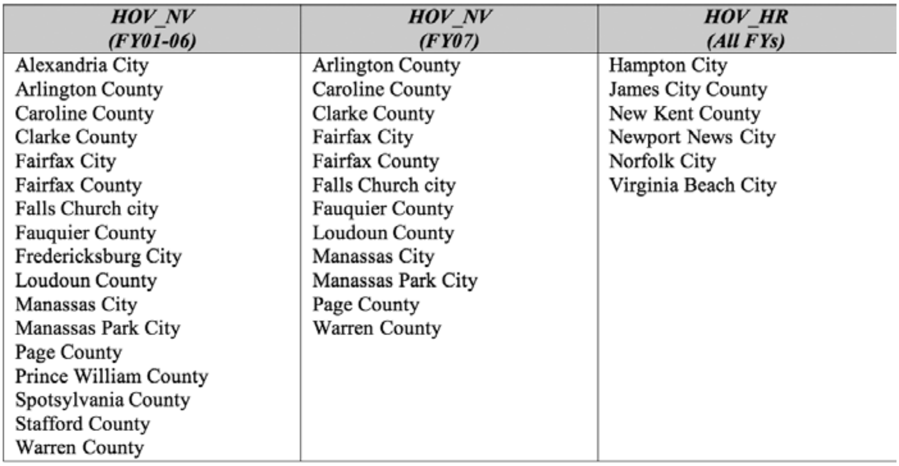
Table 2. Summary of Variables for Virginia Hybrid Analysis



Variable	*Obs*	*Mean*	*Std. Dev.*	*Min*	*Max*
FY01_Share	133	0.024327	0.066077	0	0.4651
FY02_Share	133	0.056624	0.107863	0	0.704
FY03_Share	133	0.193483	0.350346	0	2.4666
FY04_Share	133	0.306699	0.518211	0	3.1549
FY05_Share	133	0.637115	0.732945	0	3.4594
FY06_Share	133	1.222648	1.090285	0	5.9701
FY07_Share	133	1.712782	1.250217	0	6.2796
HH Med Income 2000	132	39672.57	12169.61	22213	81050
Commute Time 2000[7]	132	27.40076	6.61327	10.5	45.8
Green Party Vote 2000	133	1.958346	1.337182	0.22	9.04
HOV_NV FY 01-06	133	0.1278195	0.3351511	0	1
HOV_NV FY07	133	0.0902256	0.2875878	0	1
HOV_HR FY 01-07	133	0.0451128	0.2083362	0	1

In FY07, the HOV dummy variable for Northern Virginia was adjusted to remove counties containing or adjacent to the I-95/395 HOV lanes, where new hybrids were no longer entitled to single-occupant HOV lane access. Table 3 lists the counties represented by the HOV dummy variables.

Table 3. Virginia HOV Counties and Cities[7]



HOV_NV (FY01-06)	*HOV_NV (FY07)*	*HOV_HR (All FYs)*
Alexandria City	Arlington County	Hampton City
Arlington County	Caroline County	James City County
Caroline County	Clarke County	New Kent County
Clarke County	Fairfax City	Newport News City
Fairfax City	Fairfax County	Norfolk City
Fairfax County	Falls Church city	Virginia Beach City
Falls Church city	Fauquier County	
Fauquier County	Loudoun County	
Fredericksburg City	Manassas City	
Loudoun County	Manassas Park City	
Manassas City	Page County	
Manassas Park City	Warren County	
Page County		
Prince William County		
Spotsylvania County		
Stafford County		
Warren County		

The regression was performed using an Ordinary Least Squares (OLS) specification. A Breusch-Pagan/Cook-Weisberg test for heteroskedasticity in STATA indicated significant heteroskedasticity problems for jurisdictions with higher marketshare.

The presence of multiple zero values in the dependent market share variables (indicating jurisdictions that had no hybrids titled for that fiscal year) precluded the use of a log or Box-Cox transformation to reduce the effect. Instead, the results include heteroskedasticity-robust standard errors generated in STATA for the OLS regression. Table 4 lists regression results for each fiscal year.

Median household income, Green Party voting percentage, and mean commute time were statistically significant in explaining hybrid market share for all years except FY01. Of these three variables, Green Party voting percentage and household income had the strongest effects, with Beta coefficients increasing steadily each year from FY02 through FY06. In FY06, one standard deviation changes in Green Party voting percentage and household income were associated with .40 and .33 standard deviation changes, respectively, in new hybrid market share. In Northern Virginia, the HOV lane incentive was significant at the $p < .001$ level from FY02 to FY06, with Beta values between .3 and .5 for each year. After the incentive ended on I-95/395 in FY07, the presence of the HOV lane incentive on I-66 and VA-267 remains significant, although the Beta value dropped substantially, to .17. In Hampton Roads, there was no statistically significant relationship between HOV lane incentives and new hybrid registration for any year, which is consistent with the results of the geographic plot analysis in the previous section.

The strength and significance of Green Party voting percentage as a predictor of market share from FY05 onward also suggests that any "hybrid backlash" that may have occurred in Northern Virginia was not strong enough to erase the positive environmental image of the hybrid statewide. To further examine whether this theorized backlash actually occurred in Northern Virginia, regressions of market share versus income, commute time, and Green Party voting percentage were performed only for the 17 counties in Northern Virginia that were impacted by the HOV lane incentive (where the original HOV_NV dummy variable was equal to 1). Green Party voting percentage was insignificant until FY04, when it bordered on significance with Beta values greater than .5. In FY07, after the elimination of the incentive for new hybrids on I-95/395, it became significant with a Beta value of .71. Thus, the trends in significance and strength of effect for the environmentalism proxy in Northern Virginia from FY04-FY07 are fairly consistent with the trends statewide from the original regression. A detailed results table for Northern Virginia is omitted.

Table 4. Regression Results

Dependent Variable = Hybrid Market Share	***FY01***	***FY02***	***FY03***	***FY04***	***FY05***	***FY06***	***FY07***
Independent Variables	Coef. (Robust SE) Beta	Coef. (Robust SE) Beta	Coef. (Robust SE) Beta	Coef. (Robust SE) Beta	Coef. (Robust SE) Beta	Coef. (Robust SE) Beta	Coef. (Robust SE) Beta
Med HH Income 2000	-1.51e-07 (5.07e-07) -0.028	1.38e-06 * (6.15e-07) 0.156	5.66e-06 * (2.51e-06) 0.196	8.85e-06* (3.63e-06) .207	1.92e-05 *** (4.60e-06) .318	2.92e-5 *** (5.50e-06) .325	3.03e-05 *** (7.10e-06) .294
Green Party Vote 2000	.00600 (.00577) 0.121	.0118 * (.0061) 0.148	.0667 *** (.0167) 0.255	.103*** (.024) .265	.194 *** (.040) .355	.322 *** (.0430) .396	.566 *** (.067) .606
Commute Time 2000	.000694 (.00162) 0.069	.00232 * (.00119) 0.142	.00886 ** (.00331) 0.167	.0118* (.0050) .150	.0136 * (.0058) .122	.0179 * (.0083) .108	.0180 + (.0111) .095
HOV_NV	.0236 (.0247) 0.120	.162 *** (.038) 0.504	.456 *** (.136) 0.437	.724 *** (.203) .468	.722 *** (.219) .331	1.19 *** (.28) .366	.745 * (.265) .172
HOV_HR	-.00163 (.0129) 0.120	-.00747 (.01400) -0.014	-.0153 (.0519) -0.009	.0779 (.0558) .031	.106 (.117) .030	.021 (.187) .004	-.00271 (.20187) -.0005
N	132	132	132	132	132	132	132
R-squared	.037	.511	.547	.597	0.609	.670	.658
Root MSE	.066	.077	.241	.336	.468	.609	.751
Significance: *** P < .001, ** P < .01, * P < .05, + P <.1							

Conclusions

The geographic and regression analyses of hybrid registration patterns in Northern Virginia and Hampton Roads suggests that HOV lane incentive policies can significantly impact the adoption of hybrids by consumers, but only under specific circumstances. The geographic analysis shows that hybrid market share was highest along the I-95/395 corridor—where HOV lanes offer the greatest time savings for commuters—but less dramatic on I-66 and VA-267. Likewise, the Beta value for the Northern Virginia HOV dummy in the regression dropped sharply after the I-95/395 corridor was excluded in FY07.

Surprisingly, the HOV incentive appears to have had no significant impact on hybrid vehicle market share in the Hampton Roads area. This may be due to a number of factors, but is most likely due to the nature of the local highway and HOV lane systems. While HOV lanes provide some degree of time savings in the Hampton Roads area, the overall traffic congestion and time saved are much less than on Northern Virginia highways. A 2002 study on attitudes about HOV lanes in the Hampton Roads area indicated that only 59 percent of Peninsula (Newport News and Hampton) and 76 percent of Southside (Norfolk and Virginia Beach) commuters felt that HOV lanes allowed commuters to reach their destinations faster than non-HOV lanes, compared to an almost universal appreciation of potential HOV time savings among Northern Virginia commuters (The Marketing Source 2002). Average distance traveled in the Hampton Roads HOV lanes was only 15 miles, compared to 25 mile HOV commutes in Northern Virginia, and much of the traffic congestion in Hampton Roads is actually the result of several narrow bridges and tunnels (none of which have HOV lanes) that connect neighboring counties. Additionally, the mean commute time for Hampton Roads HOV counties is significantly less than for Northern Virginia HOV counties—24.8 minutes versus 33.3 minutes—providing less of an incentive for adopting any time savings measure in the first place (U.S.Census Bureau 2000).

The significance of control variables for income, Green Party votes, and commute time is consistent with the theory and previous findings that individuals who have higher incomes and longer commutes and are more environmentally conscious are more likely to become early adopters of new vehicle efficiency technologies, *ceteris paribus*. In the case of HOV lane incentives, the effect of income may be amplified because the value of the time savings from HOV access is proportional to the value or utility that individuals place on their time. Therefore, individuals who earn more per hour might be likely to place a greater value on the incentive.

The fact that Green Party voting percentage was the strongest and most significant predictor of market share from FY05 onward statewide and still significant in Northern Virginia (based on the separate Northern Virginia regressions), particularly in FY07, also suggests that any "hybrid backlash" that may have occurred did not erase the positive environmental image of the hybrid.

Even before FY07, the relative effect of Northern Virginia HOV lane access on market share had begun to decrease compared to other factors, perhaps in anticipation of the incentive's eventual expiration. The Beta values for the Northern Virginia HOV incentive peaked in FY04 then dropped each of the following years. Conversely, the Beta values for the coefficient of the household income variable increased from .21 in FY04 to .32 in FY05 and remained steady through FY07, while the Beta values for the Green Party voting percentage variable continued to increase, reaching a value of .61 by FY07.

The main findings of this research are that 1) Virginia's HOV lane incentive appears to have had a significant impact on hybrid vehicle adoption in Northern Virginia, but not in Hampton Roads; 2) the impacts of HOV incentive policies in general appear to be very sensitive to local conditions and the potential for time savings on a particular HOV corridor; and 3) the presence of the HOV incentive did not appear to diminish the impact of other factors—particularly environmental consciousness—on adoption of hybrid vehicles. While this paper looked specifically at Virginia, it is reasonable that evaluations of incentive policies in other states would highlight similar trade-offs between effectiveness, equity and unintended consequences.

Other states have already incorporated limitations into their own HOV policies. California limited the total number of solo HOV access permits to 85,000 to prevent overcrowding, although there is still anecdotal evidence that the policy has resulted in HOV lane congestion and sharply inflated prices that dealers charged for hybrids as the state neared the limit on permits (McKenzie 2007). Utah offers single passenger express lane access to all drivers willing to pay a $500 per year fee, but charges hybrid owners only $50 for the fee (U.S. Department of Energy 2007). While this may address the equity issue and help prevent any hybrid image backlash, it may also dampen the perceived utility of the incentive by explicitly limiting its value to $450 per year. Other states have qualified HOV and other incentives with minimum gas mileage standards or periodic impact reviews.

Finally, an important consideration of the HOV exemption policy, compared to "one-time" incentives such as rebates or credits, is that it creates a small but extremely vocal group of "entrenched stakeholders"—hybrid owners—who have a significant personal stake in continuing the policy and are likely to fight strongly against any attempt to discontinue it by lawmakers or state agencies. Although this concern is common to all incentives that offer a continuing benefit over time, HOV access—more so than monetary incentives—may also influences residents' long-term decisions on where they live and work, encouraging choices that cannot be easily undone. Thus, the unique nature of the HOV incentive and the debate that the policy has caused in Virginia should give pause to other states considering similar programs. At the very least, policymakers would be wise to include feedback and data collection requirements into incentive legislation to help assess and manage the impact of incentive policies.

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Endnotes

[1] I-95 becomes I-395 between the I-495 Beltway and the Washington, DC border.

[2] The term "slug line" refers to the anonymous ridesharing lines that form at several HOV park-and-ride lots in Northern Virginia. During rush hour, single drivers pick up anonymous passengers, known as "slugs," to gain access to the HOV lanes.

[3] The data set excluded vehicles that were purchased in Virginia but removed from the state prior to May 2007. This may under-report the market share values slightly, but it is assumed that this trend affects all counties equally and does not affect the comparisons of market share between counties.

[4] The Virginia fiscal year runs from July 1 through June 30.

[5] The 2000 presidential election was chosen because of the strong Green Party showing (2.2% statewide) compared to other years.

[6] The negative gas price effect may be due to zone pricing strategies used by gasoline distributors set prices based in a manner that optimizes profits in specific geographic regions (Bayles 2001). While specific pricing strategies are held as trade secrets, prices are generally based on factors affecting demand such as commuting patterns and income. In the outlying Northern Virginia HOV counties where commuters have the choice of solo commuting, carpooling, or rail transport, prices may be kept lower to encourage automobile commuting and maintain demand. Since these suburban areas include the counties that benefit most from the HOV privileges, the zone pricing system may result in a spurious inverse correlation between gas prices and hybrid sales.

[7] Commute time was not provided for Alleghany County.

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Project NPV, Positive Externalities, Social Cost-Benefit Analysis—The Kansas City Light Rail Project

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Abstract

The Heartland Light Rail project represents Kansas City's biggest infrastructural investment in decades. The ballot initiative for the light rail project was voted down three times until it was finally approved in November 2006. Using best estimates of construction costs, operating expenses and federal funding, I estimate the net present value (NPV) of the project to be negative $343 million. From a standard NPV perspective the Kansas City light rail transit (LRT) system is unlikely to break even. However, if the negative externalities of auto travel and the positive externalities associated with light rail are properly accounted for in a comprehensive social cost-benefit framework, investment in the Kansas City LRT system becomes an increasingly feasible option.

Introduction

In November 2006, after several previous failed attempts, voters in Kansas City approved a measure for the construction of a light rail transit (LRT) system that would be partly financed by a 3/8-cent sales tax for 25 years. According to the official ballot language, the plan proposes the construction of a new $1 billion, 27-mile Heartland Light Rail system. The plan also proposes enlarging the light rail system's service area by employing a green fleet of 60 electric shuttles that would provide connecting transit service to nearby job and shopping centers.

Kansas City and Transportation

During the 1990s, Kansas City embarked on a widespread strategic planning initiative. A key recommendation of the initiative involved the city's transportation system. Federal Highway Administration (FHWA) data indicated that the poor quality of Kansas City roads imposed annual vehicle operation costs of $651 on Kansas City drivers[1]—the highest in the nation's major cities outside California. Data from the 2003 national Consumer Expenditure Survey indicated that among major metropolitan areas, Kansas City residents spent about 20 percent of their budget on transportation—the fifth highest in the nation. Kansas City offers no real alternatives to driving and, with continued growth, transportation is projected to become even more time-consuming and costly. As a result, a key recommendation of the planning initiative was for the development of a light rail transit system to "enhance the movement of people, to protect clean air, and to protect the natural environment … and the promotion of more clustered development along transit corridors."[2]

Kansas City is actually composed of two cities—Kansas City, Missouri and Kansas City, Kansas. Kansas City, Missouri is, by itself, the largest city in Missouri. The combined population of the greater Kansas City metropolitan area is close to 2 million. Once known primarily for agriculture and manufacturing, Kansas City today has a diversified economic base composed of telecommunications, banking, finance, and service-based industries. Kansas City is also a transportation hub and a major national distribution center. Transportation is, therefore, central to the continued development of Kansas City.

Notwithstanding the importance of transportation for Kansas City's economic development, recent investment in transportation infrastructure in Kansas City has been poor. In a study conducted by the Mid-America Regional Council (MARC), a regional public policy research organization located in Kansas City, Kansas City ranked at the bottom of a group of peer cities in terms of public transportation financing. The only public transit offered by the city is bus services. But even this service is underinvested; in fact, Kansas City would have to double its bus services to reach the average of its peer cities.

Due to the extensive highway projects implemented in Kansas City during the 1970s and 1980s, Kansas City possesses the most freeway lane miles per capita of all large urbanized areas in the United States and the fourth highest total roadway miles per person.[3] Even though Kansas City ranks high in the number of roadway miles per person, its roads are in worse condition than national and peer city averages. The Road Information Program's (TRIP's) *2004 Bumpy Roads Ahead* report found that Kansas City's "poor" pavement conditions significantly exceeded national averages, and Kansas City had a smaller percentage of roads classified as "good." In addition, overall pavement conditions have notably deteriorated since 2000.

Transportation by automobile is, by far, the preferred mode of transportation in Kansas City, and recent studies indicate that reliance on automobiles is continuing to grow. More than 93 percent of all trips are by automobile, of which 83 percent are single-occupancy trips and 10 percent are carpool trips. About 4 percent work from home, 1 percent walk to work, and public transit accounts for the remaining 1 percent.

The extensive roadway system in Kansas City offsets the excessive reliance on automobiles; thus, congestion is not a major problem. However, there is significant congestion during peak periods, and nearly all studies are in agreement that congestion is growing. The *2001 Travel Time Study* conducted by MARC found that congested travel as a percentage of peak vehicle miles traveled increased from 5 percent in 1982 to 32 percent in 2002. However, this still compares very favorably to other urban areas in which congested travel increased far more substantially, from 24 percent in 1982 to 65 percent in 2002. The low-density urban form of Kansas City means that travel distances in Kansas City are longer. The average vehicle miles of travel (VMT) per person in Kansas City was 28.65, whereas the average for metropolitan areas of similar size was 24.04 VMT per person each day.[4] However, the relatively lower congestion in Kansas City results in greater travel speeds and shorter travel times. The MARC *2001 Travel Time Study* found that even though average travel speeds steadily increased, "there are several routes where congestion is an increasing problem. This is evident in that there is a large percentage of routes and segments with delay … and several of the most highly traveled routes in the region have significantly more delay than in previous studies." A similar study by the Missouri Department of Transportation found that of the 10 most heavily-congested sections of the urban Missouri interstate highways, 7 are located in Kansas City.[5]

The Heartland Rail System

Planning for the Kansas City LRT system began in the 1990s. The Technology Work Team considered six technology options—improved bus service, bus rapid transit with dedicated guideway (such as in Ottawa or Curitiba), electrified bus rapid transit (as in Lille, France or Mexico City), electrified street car, monorail and light rail—and settled on light rail as the preferred technology with electric bus transit as a second option.

The Heartland Rail system would serve some of Kansas City's densest residential neighborhoods in the mid- and south-town areas. The proposed system alignment runs through downtown Kansas City, serving an employment corridor with 250,000 jobs. The primary market that would be served by the proposed light rail system is work trips though strong connections to cultural and shopping centers would result in a strong secondary market. During peak weekday morning and evening periods, service is proposed to be provided every 12 minutes.

Capital Costs, Operating Costs, and Funding for the Heartland Light Rail Project

The Heartland Rail system, as proposed, would constitute one of the biggest infrastructural investments in Kansas City history. Detailed estimates of capital costs, cash inflows, and cash outflows for the project is provided in the Central Business Corridor (CBC) Transit Plan. The essential features of the project and the underlying project assumptions of the CBC Transit plan are summarized in Table 1.

The CBC plan assumes that the project would be funded by three major sources. Federal funding of $593 million was assumed to cover 60.50 percent of the capital costs of the project. A 3/8-cent sales tax for 25 years was assumed to generate $29 million in the first year and a total of $878 million over the 25-year tax period. The project would also be funded by a $195 million, 19-year, 7.70 percent bond issue, which would result in interest payments of $19.87 million annually. The funding for the project would become effective on April 1, 2009.

The Financial Economics of the Heartland Light Rail System—Project Analysis

While detailed estimates of capital costs, cash inflows, and cash outflows over the 25-year life of the light rail system are provided in the Central Business Corridor (CBC) Transit Plan, there is no attempt to provide an economic or financial analysis of the project. The project inflow and outflow estimates provided by the CBC plan over the 25-year life of the project are shown in Table 2.

Table 1. Project Assumptions

Project Life	25 years
• Capital Period	8 years (Year 1 – Year 8)
• Operating Period	17 years (Year 9 – Year 25)
Estimated (Inflation Adjusted) Capital Costs	$981
Base Estimate of Annual Operating/Maintenance Costs	$15.20 million
Annual Growth in Operating/Maintenance Cost	4%
Annual Operating/Maintenance Cost in Year 9	$20.80 million
(\$15.20 x $[1 + .04]^8$ = \$20.80)	
Total Operation and Maintenance Cost (Years 9 - 25)	$493
Federal Capital Funding Percentage	60.50%
Secondary Funds Base Assumption	$1.50 million
(Annual Growth Rate 1.80%)	
Base Estimate from Sales Taxes	$29 million
Estimated Annual Growth in Taxes	1.80%
Tax Period	25 years
Bond Issue	$195 million
Bond Repayment Period	19 years
Bond Interest Rate	7.50%
Annual Bond Interest Payment	
	$19.87 million
($195 million issue, Effective rate of 7.70%, 19 years)	
Base Estimate of Fare Revenue (Year 9 of project)	$6.11 million
Annual Growth Rate in Fare Revenues	1.80%

Table 2. Project Cost and Revenue Flows (in millions): Estimates Based on CBC Study

YEAR	CAPITAL COSTS	OPERATION & MAINTENANCE	BOND PAYMENT	TOTAL CAPITAL OUTFLOWS	BOND SALES	FEDERAL FUNDS	SECONDARY FUNDS	OTHER FUNDING	SALES TAX REVENUES	FARE BOX REVENUES	INTEREST EARNED	TOTAL CAPITAL INFLOWS
1	$2.22			$2.22		$3.50	$0.38		$7.25			$11.13
2	$11.57			$11.57		$16.00	$1.53		$29.51		$0.27	$47.31
3	$9.62			$9.62		$95.58	$1.55		$30.02		$1.26	$128.41
4	$55.89			$55.89		$95.58	$1.58		$30.55		$2.42	$130.13
5	$97.16			$97.16		$95.58	$1.61		$31.08			$128.27
6	$281.88			$281.88		$95.58	$1.64	$12.00	$31.63			$140.85
7	$293.16		$19.87	$313.03	$195.00	$95.58	$1.66	$12.21	$32.18			$336.63
8	$229.75		$19.87	$249.62		$95.58	$1.69		$32.74			$130.01
9		$20.80	$19.87	$40.67			$1.72		$33.32	$6.11		$41.15
10		$21.63	$19.87	$41.50			$1.75		$33.90	$6.22	$1.61	$43.48
11		$22.50	$19.87	$42.37			$1.78		$34.49	$6.33	$1.71	$44.31
12		$23.40	$19.87	$43.27			$1.82		$35.10	$6.44	$1.81	$45.17
13		$24.34	$19.87	$44.21			$1.85		$35.71	$6.55	$1.90	$46.01
14		$25.31	$19.87	$45.18			$1.88		$36.34	$6.67	$1.99	$46.88
15		$26.32	$19.87	$46.19			$1.91		$36.97	$6.78	$2.07	$47.73
16		$27.37	$19.87	$47.24			$1.95		$37.62	$6.90	$2.15	$48.62
17		$28.47	$19.87	$48.34			$1.98		$38.28	$7.02	$2.22	$49.50
18		$29.61	$19.87	$49.48			$2.01		$38.95	$7.14	$2.28	$50.38
19		$30.79	$19.87	$50.66			$2.05		$39.63	$7.27	$2.32	$51.27
20		$32.02	$19.87	$51.89			$2.09		$40.32	$7.40	$2.35	$52.16
21		$33.31	$19.87	$53.18			$2.12		$41.03	$7.53	$2.37	$53.05
22		$34.64	$19.87	$54.51			$2.16		$41.75	$7.66		$51.57
23		$36.02	$19.87	$55.89			$2.20		$42.48	$7.79		$52.47
24		$37.46	$19.87	$57.33			$2.24		$43.22	$7.93		$53.39
25		$38.96	$19.87	$58.83			$2.27		$43.98	$8.07		$54.32
TOTAL	**$981**	**$493**	**$378**	**$1,852**	**$195**	**$593**	**$45**	**$24**	**$878**	**$120**	**$29**	**$1,884**

Notes: Total Capital Outflows = Capital Costs + Operation & Maintenance + Bond Payment
Total Capital Inflows = Bond Sales + Federal Funds + Secondary Funds + Other Funding + Sales Tax Revenues + Fare Box Revenues + Interest Earned

A good starting point for financial analysis is to compute the NPV of the Kansas City LRT project. For long-term capital projects, the Federal Transit Authority (FTA) recommends using a project discount rate of 7 percent.[6] Using this as the applicable discount rate, the NPV of the project based on the CBC Transit Plan estimates turn out to be about $70 million. However, this NPV value is based on preliminary estimates provided in the CBC Transit Plan and needs to be readjusted in the light of recent developments and other factors such as inflationary effects. The most significant revisions to the preliminary estimates are:

- The CBC Transit Plan estimates are based on operating cost assumptions of $20.80 million. More realistic estimates suggest that operating costs would probably be in the range of $25-$30 million annually. The mid-point of this range is used here with the assumption (as in the CBC study) that operating costs escalate annually at 4 percent.
- The CBC Transit Plan revenue estimates are based on a ½-cent sales tax assumption. The actual amount approved by Kansas City voters was 3/8 cents. (Thus, actual sales tax revenues earmarked for the project are 25 percent lower.) The lower estimate suggests that a 3/8-cent sales tax would generate sales tax revenues of $23 million annually. The CBC estimates were revised to reflect the lower sales tax with the assumption (as in the CBC study) that sales tax revenues increase by 1.75 percent annually.

The revised estimates are shown in Table 3. The NPV of the project based on the net cash flows of the project turn out to be -$53.31 million, while the Internal Rate of Return (IRR) is 10.58 percent[7]—a clear signal that the project has some inherent problems.

What is clear from an analysis of the cash flow stream is that the project is heavily-dependent on federal funding. Ironically, the only periods in which the project has any positive cash flow stream are the initial years—the periods when one would expect the project to run deficits because of high capital costs. This is due to the fairly high values assumed for federal funding. While capital costs reach a peak in years 6-8, a bond issue in Year 7 partially offsets some of these capital costs, resulting in a net inflow in Year 7.

The most instructive aspect of the financial analysis is the non-self sustaining nature of the project in the operating phase covering years 9-25. *Net cash flows in the operating phase of the project are negative in every year of the project.* In principle, the operating phase is somewhat less subject to uncertainty since the

Table 3. Project Cost and Revenue Flows (in millions): Revised Estimates Based on CBC Study

YEAR	CAPITAL COSTS	OPERATION & MAINTENANCE	BOND PAYMENT	TOTAL CAPITAL OUTFLOWS	BOND SALES	FEDERAL FUNDS	SECONDARY FUNDS	OTHER FUNDING	SALES TAX REVENUES	FARE BOX REVENUES	TOTAL CAPITAL INFLOWS	NET CASH FLOW	PV's Discounted at 7% p.a.
1	$2.22			$2.22		$3.50	$0.38		$23.00		$26.88	$24.66	$23.05
2	$11.57			$11.57		$16.00	$1.53		$23.40		$40.93	$29.36	$25.65
3	$9.62			$9.62		$95.58	$1.55		$23.81		$120.94	$111.32	$90.87
4	$55.89			$55.89		$95.58	$1.58		$24.23		$121.39	$65.50	$49.97
5	$97.16			$97.16		$95.58	$1.61		$24.65		$121.84	$24.68	$17.60
6	$281.88			$281.88		$95.58	$1.64	$12.00	$25.08		$134.30	-$147.58	-$98.34
7	$293.16		$19.87	$313.03	$195.00	$95.58	$1.66	$12.21	$25.52		$329.97	$16.94	$10.55
8	$229.75		$19.87	$249.62		$95.58	$1.69		$25.97		$123.24	-$126.38	-$73.55
9		$27.50	$19.87	$47.37			$1.72		$26.42	$6.11	$34.25	-$13.12	-$7.13
10		$28.60	$19.87	$48.47			$1.75		$26.89	$6.22	$34.86	-$13.61	-$6.92
11		$29.74	$19.87	$49.61			$1.78		$27.36	$6.33	$35.47	-$14.15	-$6.72
12		$30.93	$19.87	$50.80			$1.82		$27.84	$6.44	$36.10	-$14.71	-$6.53
13		$32.17	$19.87	$52.04			$1.85		$28.32	$6.55	$36.72	-$15.32	-$6.36
14		$33.46	$19.87	$53.33			$1.88		$28.82	$6.67	$37.37	-$15.96	-$6.19
15		$34.80	$19.87	$54.67			$1.91		$29.32	$6.78	$38.01	-$16.65	-$6.04
16		$36.19	$19.87	$56.06			$1.95		$29.84	$6.90	$38.69	-$17.37	-$5.88
17		$37.64	$19.87	$57.51			$1.98		$30.36	$7.02	$39.36	-$18.15	-$5.74
18		$39.14	$19.87	$59.01			$2.01		$30.89	$7.14	$40.04	-$18.97	-$5.61
19		$40.71	$19.87	$60.58			$2.05		$31.43	$7.27	$40.75	-$19.83	-$5.48
20		$42.33	$19.87	$62.20			$2.09		$31.98	$7.40	$41.47	-$20.73	-$5.36
21		$44.03	$19.87	$63.90			$2.12		$32.54	$7.53	$42.19	-$21.71	-$5.24
22		$45.79	$19.87	$65.66			$2.16		$33.11	$7.66	$42.93	-$22.73	-$5.13
23		$47.62	$19.87	$67.49			$2.20		$33.69	$7.79	$43.68	-$23.81	-$5.02
24		$49.53	$19.87	$69.40			$2.24		$34.28	$7.93	$44.45	-$24.95	-$4.92
25		$51.51	$19.87	$71.38			$2.27		$34.88	$8.07	$45.22	-$26.16	-$4.82
TOTAL	**$981.25**	**$651.68**	**$377.53**	**$2,010.46**	**$195**	**$592.98**	**$45.42**	**$24.21**	**$713.63**	**$119.81**	**$1,691.05**		**-$53.31**

Notes: Total Capital Outflows = Capital Costs + Operation & Maintenance + Bond Payment
Total Capital Inflows = Bond Sales + Federal Funds + Secondary Funds + Other Funding + Sales Tax Revenues + Fare Box Revenues
Net Cash flow = Total Capital Inflows - Capital Outflows

major uncertainty in infrastructural projects tends to center around the substantial initial investment costs. Four major factors determine the economic viability of the Heartland Light Rail project in the operating phase of the project: operating and maintenance costs, bond interest payments, sales tax revenues, and fare box revenues. The effect of each of these variables are analyzed below.

Operating and Maintenance Costs

The budgeted value for operating and maintenance cost in the first year of the K.C. Light Rail project is $20.80 million. A more realistic estimate, taking into account factors such as cost escalation and inflation, is $25-$30 million. Using a mid-range estimate of operating costs, the NPV of the project, as pointed out earlier, turns out to be negative. Now, suppose one were to give the operating costs of the project more latitude. What is the lowest value that one could assume for base operating costs and still end up with a positive value for NPV? Holding everything else constant, the effect on NPV for different base year operating and maintenance cost assumptions is reported below.[8]

Table 4. Project Sensitivity to Base Year Operating & Maintenance Cost Assumptions

Operating & Maintenance Cost (millions)	*NPV (millions)*
$27.50 (Base Estimate)	**-$53.31**
$25	-$34.72
$24	-$27.28
$23	-$19.85
$22	-$12.40
$21	-$4.97
$20.33	$0

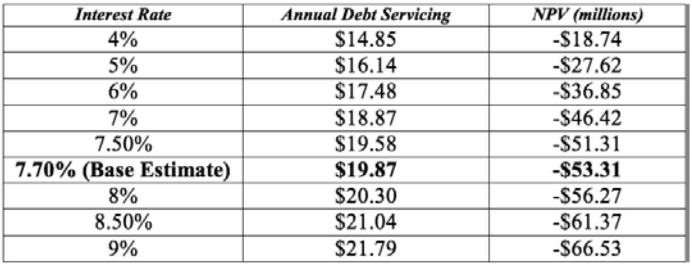
Thus, operating and maintenance costs would have to be lower than $20.33 million at inception of project operation for NPV to be positive. Given that the current estimate is $25 million, it seems unlikely that operating and maintenance costs could go as low as $20.33 million. In addition, if the annual percentage increase in operating costs were higher than 4 percent, the resulting NPV's would be even more unfavorable.

Bond Interest Payments

The base estimates are based on partial funding of the Heartland Light Rail Project through a $195 million, 7.70 percent effective rate, 19-year bond issue in Year 7 of the project. This results in interest obligations of $19.87 million over 19 years. How low would interest obligations have to be to result in a break-even NPV?

The effective interest rate assumed for the Heartland Light Rail bond issue is 7.70 percent. Of course, future interest rates are unknown, but, based on Kansas City's current credit rating, an interest rate of 7.70 percent seems reasonable and perhaps even on the higher side. In 2007, Kansas City issued $138 million of general obligation "GO series 2007A" bonds at a rate of 4.60 percent. All three credit rating agencies—Standard and Poor's, Moody's, and Fitch Ratings—affirmed their belief in the City's financial strength. In Table 5, a19-year bond issue of $195 million is assumed, and the effect of different interest rates and debt servicing levels on project NPV is computed.

Table 5. Project Sensitivity to Interest Cost Assumptions



Interest Rate	*Annual Debt Servicing*	*NPV (millions)*
4%	$14.85	-$18.74
5%	$16.14	-$27.62
6%	$17.48	-$36.85
7%	$18.87	-$46.42
7.50%	$19.58	-$51.31
7.70% (Base Estimate)	**$19.87**	**-$53.31**
8%	$20.30	-$56.27
8.50%	$21.04	-$61.37
9%	$21.79	-$66.53

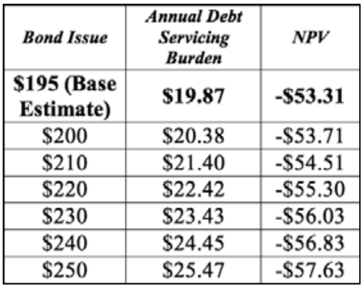
Note: The above is based on a $195 million, 19-year bond issue.

It is clear from the sensitivity analysis above that even if long-term interest rates were to decline to a historical low of 4 percent, the resulting savings in debt servicing costs is insufficient to result in a non-negative NPV. Since long-term interest rates have historically been around 7.50 percent, it is improbable for much savings to be realized from a decline in annual debt servicing costs alone.

Suppose we were to consider two other options—increasing the size of the bond issue or increasing the maturity of the issue. It is important to recognize that size, maturity, and annual payments are all simultaneously determined, so that changing any one variable affects the value of at least one of the other variables. Now suppose that the size of the issue was increased from $195 million to some higher value while maturity of the issue is kept constant. What effect would this have on the NPV of the project? The results are reported in Table 6.

Clearly, increasing the size of the bond issue worsens the NPV of the project. This is due to the fact that while a larger bond issue increases the cash inflow in Year 7, it also results in higher debt servicing burdens in the outer years of the project. In fact, a lower issue size may be the answer, but there may be constraints about running unacceptably high levels of deficits in the initial years of the project.

Table 6. Project Sensitivity to Bond Issue Size



Bond Issue	*Annual Debt Servicing Burden*	*NPV*
$195 (Base Estimate)	**$19.87**	**-$53.31**
$200	$20.38	-$53.71
$210	$21.40	-$54.51
$220	$22.42	-$55.30
$230	$23.43	-$56.03
$240	$24.45	-$56.83
$250	$25.47	-$57.63

Note: The above assumes an effective funding cost of 7.70 percent and a maturity of 19 years.

Would increasing the maturity of the bond issue and consequently reducing the annual debt servicing burden improve the NPV of the project? Suppose the size of the issue and interest rate remained at $195 million and 7.70 percent, but the maturity of the issue was increased from 19 to 25 years. The annual debt servicing burden in this case would decrease from $19.87 million to $17.80 million over the life of the project, and NPV would improve from the base case NPV of -$53.31 million to -$45 million.

At an extreme, imagine that Kansas City could issue a perpetual bond. Suppose the issue size is $195 million and the interest rate is 7.70 percent. In this case, the annuity payments would decline from the base case estimate of $19.87 million per annum to perpetual annuity payments of $15.02 million ($195m x .0770). This is the lowest-possible annual debt servicing burden attainable by increasing bond maturity. However, this would still result in a negative NPV.

The bottom line is this: Declining interest rates and consequently a lower debt burden would improve NPV, but even at very low interest rates the project does not break even. Other solutions, such as increasing the size of the bond issue or increasing the maturity of the bond issue, are either not helpful or do not impact the NPV in any substantive manner.

Sales Tax Revenues

Initial estimates suggested a ½-cent sales tax earmarked for the Heartland Light Rail project. Anti-tax sentiment is, however, very strong in Kansas City, and the final amount approved for the light rail project by Kansas City voters was a 3/8-cent tax for 25 years. The possibility for increasing the sales tax rate is remote;

the ballot language is very specific, and no significant changes can be made without submitting any changes to a vote. Thus, increasing sales tax revenues to provide additional funding for the project seems unlikely.

Fare Box Revenues

The CBC Transit Plan assumes that fare box revenues in the first operational year of the project (Year 9) will be around $6.11 million and increase roughly at the rate of 1.76 percent annually. Demand estimates of ridership are not provided in the CBC Study, but one can extrapolate from the above value.

Assume a one-way fare price of $3. At a single trip cost of $3, the number of passenger boardings required to generate $6.11 million is about 2.036 million per year or 8,146 weekday boardings ([$6.11 million] / [$3 x 250 working days]). Assume for simplicity that 100 percent of the rides are generated by daily round trip commuters. This implies that the number of round trips assumed in the CBC study is 4,073 round-trips per working day. Thus, at a one-way trip price of $3, the fare box revenue projections will be fulfilled if there are 4,073 daily round-trip commuters per working day. At a lower fare price of $2 per one-way trip, it can similarly be determined that the required number of daily round trip commuters is 6,110.

Are the estimates for the number of riders above feasible? One way to answer this question is to look at the usage for current modes of transportation in Kansas City. Data from 2005 compiled by the U.S. Census Bureau on "Commuting to Work" indicates that, of the 914,000 daily commuters in the greater Kansas City metro area, an overwhelming number (800,0000 or 88%) drove alone; 80,731 (9%) carpooled, and 9,767 (1.07%) used public transportation. Clearly, public transportation is not a preferred transportation mode in Kansas City. However, the assumed number of daily commuters in the CBC study (4,073)—even given the disappointing number of current daily public transit users—seems low. The proposed Kansas City light rail system would serve a route corridor estimated to contain 250,000 workers. If 1.63 percent of these workers would choose to use light rail, the ridership estimates in the CBC study would be fulfilled.

Ridership estimates are invariably subject to varying degrees of error. Suppose the problem is looked at somewhat differently and a related question is asked. Holding everything else constant, what is the lowest estimate of fare box revenues that would result in a break even NPV? The model suggests that fare box revenues of $14.47 million in the first year of the project (or more than twice the revenue assumed in the CBC Study) would result in a break-even NPV. Annual fare box revenues of \$14.47 million implies 14,470 round-trips per working day ([\$14.47 million] / [\$4 round-trip cost x 250 days]). In fact, if the one-way trip cost was increased to \$2.50 from \$2, the required number of round-trips per day would be even lower, at 11,576.[9] While options relating to sales tax revenues, bond funding, maturity of the bond issue, etc., do not seem to hold much promise, estimates for ridership in Kansas City seem to hold more promise. The reason for this is counterintuitive: the very fact that regions like Kansas City are so poorly served by public transportation constitutes an advantage in the sense that a good public transit system has a great deal of potential and much room to grow.

How likely are the ridership estimates above? Does light rail hold promise for Kansas City? In this regard, the experience of St. Louis, Missouri may be instructive. In fact, if one wanted to use a reference city to draw a comparison with Kansas City, it would be difficult to come up with a better example than St. Louis. Besides being geographically proximate, both cities share strong cultural ties. St. Louis uses a light rail system called MetroLink, which consists of two lines that carry an average of 49,287 people each weekday. In 2006, a second line (Shrewsbury Line) opened for operation and within seven months reached ridership targets that were predicted to be reached eight years later. The *St. Louis Dispatch* (March 22, 2007) reported that "average weekday boardings vary month to month but were up 30,500 in January over the same month last year…. In four of the months since the line's inauguration in August, average weekday ridership surpassed 63,000—a number that transportation planners thought would not be reached until 2015." The *St. Louis Dispatch* argued that commuters, fed up with high gasoline prices and congested roadways, were finally beginning to consider public transportation as a serious alternative in the Midwest. If the experience of St. Louis is anything to go by, public transit's time may have finally arrived in Kansas City.

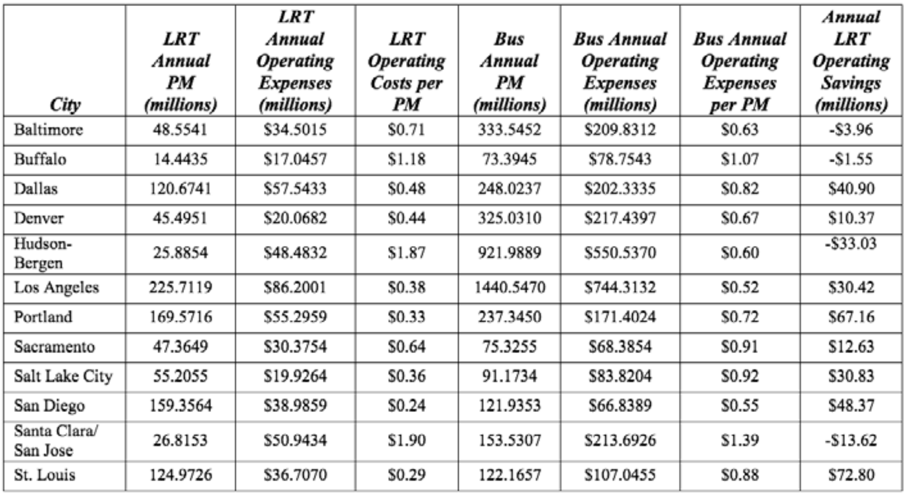
Operating Costs, Capital Costs and Federal Funding for the Heartland Light Rail Project

This section analyzes three aspects of the Heartland Light Rail project that are subject to a considerable degree of uncertainty—operating costs, capital costs, and federal funding—and then attempts to use the experience of other U.S. cities to construct realistic cost and funding estimates for the Heartland Light Rail Project.

Operating Costs

Most criticism of light rail transit systems center around the high capital and operating costs of LRT systems as compared to bus systems. Table 7 compares operating costs for LRT and bus systems in 12 cities and then computes the operational cost savings from using a LRT system.

Table 7. Comparison of Operating Expenses per Passenger Mile (PM) for LRT versus Bus Systems in Selected Cities (2003)

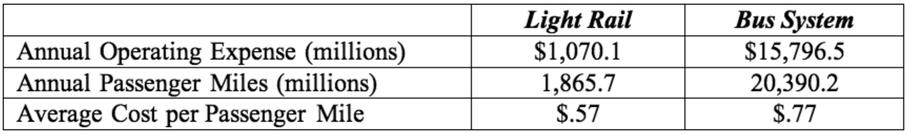


City	*LRT Annual PM (millions)*	*LRT Annual Operating Expenses (millions)*	*LRT Operating Costs per PM*	*Bus Annual PM (millions)*	*Bus Annual Operating Expenses (millions)*	*Bus Annual Operating Expenses per PM*	*Annual LRT Operating Savings (millions)*
Baltimore	48.5541	$34.5015	$0.71	333.5452	$209.8312	$0.63	-$3.96
Buffalo	14.4435	$17.0457	$1.18	73.3945	$78.7543	$1.07	-$1.55
Dallas	120.6741	$57.5433	$0.48	248.0237	$202.3335	$0.82	$40.90
Denver	45.4951	$20.0682	$0.44	325.0310	$217.4397	$0.67	$10.37
Hudson-Bergen	25.8854	$48.4832	$1.87	921.9889	$550.5370	$0.60	-$33.03
Los Angeles	225.7119	$86.2001	$0.38	1440.5470	$744.3132	$0.52	$30.42
Portland	169.5716	$55.2959	$0.33	237.3450	$171.4024	$0.72	$67.16
Sacramento	47.3649	$30.3754	$0.64	75.3255	$68.3854	$0.91	$12.63
Salt Lake City	55.2055	$19.9264	$0.36	91.1734	$83.8204	$0.92	$30.83
San Diego	159.3564	$38.9859	$0.24	121.9353	$66.8389	$0.55	$48.37
Santa Clara/ San Jose	26.8153	$50.9434	$1.90	153.5307	$213.6926	$1.39	-$13.62
St. Louis	124.9726	$36.7070	$0.29	122.1657	$107.0455	$0.88	$72.80

Source: These values are derived from Table 12 (Transit Operating Expenses by Mode, Type of Service and Function) and Table 19 (Transit Operating Statistics: Service Supplied and Consumed) of the National Transit Database (NTB) 2003 figures. Annual LRT Operating Savings is computed by considering the cost advantage of LRT over bus systems and then multiplying the result by the number of annual LRT passenger miles. Note that negative figures imply that LRT is more expensive than the bus system in that city. Values do not add up exactly because of rounding.[10]

Clearly, LRT systems in most cities result in lower operating costs than bus systems.[11] The results reported above can be reinforced by looking at the most recent data available from the National Transit Database on annual operating costs for LRT and bus systems for the U.S. as a whole.

Table 8. Comparison of Operating Expenses for Light Rail and Bus Systems in the U.S.



	Light Rail	*Bus System*
Annual Operating Expense (millions)	$1,070.1	$15,796.5
Annual Passenger Miles (millions)	1,865.7	20,390.2
Average Cost per Passenger Mile	$.57	$.77

Source: See 2006 National Transit Profile, National Transit Database.

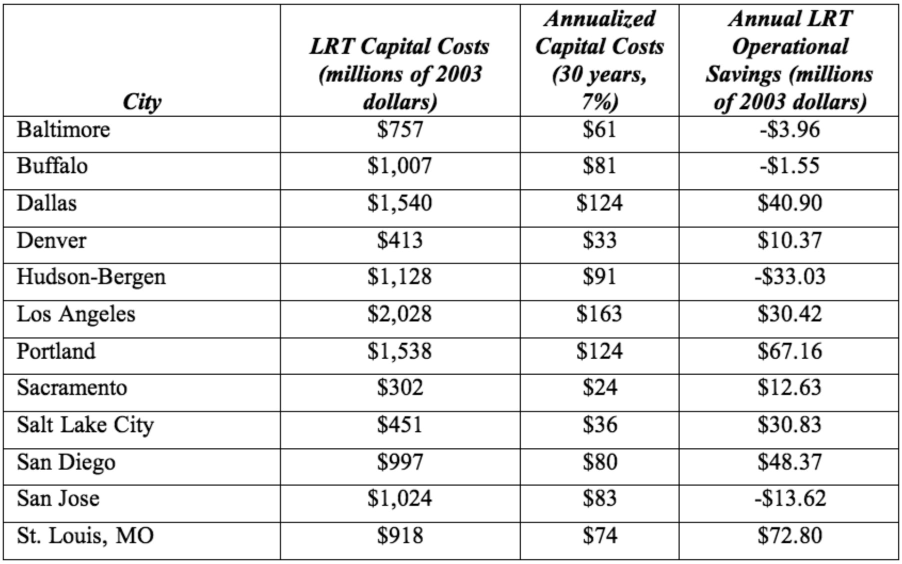
An approximation of the operational cost benefit of LRT systems over bus systems for the U.S. as a whole can be calculated thus. Since operating cost per LRT passenger mile is $.20 cheaper than bus systems, and LRT accounted for 1,865.7 million passenger miles, the annual cost savings from LRT systems for the U.S. as a whole in 2006 was about $373 million.

The bottom line is that operating costs are not a reasonable basis on which to criticize LRT systems. The empirical evidence is reasonably clear that operating expenses for LRT systems are lower than bus systems. Based on this experience, it can reasonably be concluded that, over the long run, operating expenses of the Heartland Light Rail would probably be lower than bus operating costs.

Capital Costs

Even though operating costs of LRT systems are, on average, lower than bus systems, the capital costs of light rail systems are another matter. Data on construction costs of light rail systems are not easily available. A recent paper by Baum-Snow and Kahn (2005) uses a variety of sources to provide an estimate of construction costs for major rail transit projects.[12] The data reveal wide variations in construction costs, depending on the type of construction (see Table 9). The least-expensive lines are typically those that are built on the surface either as upgrades of existing railroad lines or on city streets. At the other extreme are bored tunnel lines, which can cost more than $300 million per mile. For instance, Seattle's new LRT system is expected to cost $179 million per mile, while at the other extreme the LRT systems in Baltimore, Sacramento, and Salt Lake City cost less than $20 million per mile. Since most of these systems were built at different points in time, it is difficult to directly compare capital costs. Table 9 reports capital costs for major LRT projects in 2003 dollars[13] to facilitate comparison with the LRT and bus operating cost data reported in Table 7. These capital costs are then amortized over 30 years at 7 percent per annum and reported in the third column of the table.[14] Utilizing data from Table 7, the last column reports the annual

Table 9. Estimated Light Rail Capital Costs



City	LRT Capital Costs (millions of 2003 dollars)	Annualized Capital Costs (30 years, 7%)	Annual LRT Operational Savings (millions of 2003 dollars)
Baltimore	$757	$61	-$3.96
Buffalo	$1,007	$81	-$1.55
Dallas	$1,540	$124	$40.90
Denver	$413	$33	$10.37
Hudson-Bergen	$1,128	$91	-$33.03
Los Angeles	$2,028	$163	$30.42
Portland	$1,538	$124	$67.16
Sacramento	$302	$24	$12.63
Salt Lake City	$451	$36	$30.83
San Diego	$997	$80	$48.37
San Jose	$1,024	$83	-$13.62
St. Louis, MO	$918	$74	$72.80

Note: The last column is derived from Table 7.

operational cost savings from using an LRT system. In comparing columns 3 and 4, it is evident that, in every case, the amortized annual capital cost of LRT systems are invariably higher than the operational cost savings generated by LRT systems.

Since operational savings of LRT systems do not cover their capital costs, a common argument is to expand bus service as a more feasible alternative to investing in capital intensive light rail projects. A recent paper by Thompson and Matoff (2003) analyzes bus systems in selected cities and comes to the conclusion that "regions that choose to improve their public transit systems based on express buses do not escape making heavy capital expenditures"(p. 311). Thompson and Matoff also point out that arguments based on "saving" money on capital investment projects and routing those savings to expanding bus services seem fallacious. They point out that:

The region that made the smallest capital investment in its transit system—Columbus—severely reduced the amount of service that it provided per capita. If the position of the critics were correct, Columbus, by not "wasting" funds on capital investment, should have had large resources left over to greatly expand its bus service; obviously, that has not happened.... It is clear that transit agencies that have pursued development of multidestinational networks that include rail for trunk lines have been able to generate significant ridership without sacrificing effectiveness, efficiency or equity. (p. 311).

As pointed out earlier, the wide variations in capital costs of LRT systems arise primarily from the type of construction as well as factors like right of way acquisition costs. If one considers only projects since 2000 (and ignores an outlier such as Seattle), the approximate average construction costs per mile of an LRT system is about $35 million per mile. A base estimate for the Heartland Light Rail project, then, is $945 million ($35 million per mile x 27 miles). This value is, in fact, the same as that assumed in the Kansas City light rail ballot initiative. If one makes allowances for cost escalations and inflation, a reasonable capital cost estimate for the Heartland Light Rail project is about $1 billion. This value is used in the subsequent sensitivity analysis.

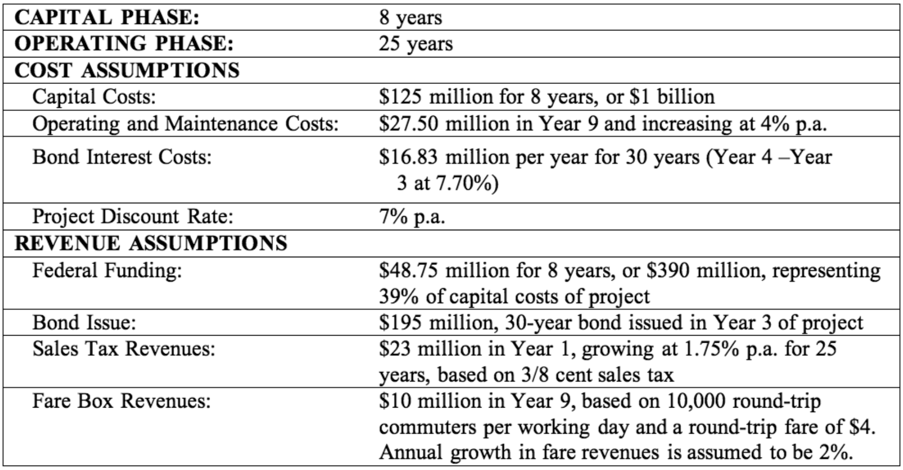
Federal Funding

Even though the dollar value of federal capital funds assistance to transit agencies has been increasing over the last decade, the percentage contributed by federal agencies has been generally falling. The percentage of federal funding assumed in the Central Business Corridor Transit Study is 60 percent. This is an unrealistically high percentage that is out of line with the realities of current federal capital funding. The most recent data from the National Transit Database suggests that the current level of federal assistance is about 39 percent. This is used as a base value for federal assistance in the subsequent analysis.

In light of the above, previous values assumed in the Central Business Corridor plan are readjusted to reflect the current realities of capital costs and federal funding. In addition, the operating phase of the project is adjusted to be 25 years rather than the 17 years assumed in the Central Business Corridor study. The revised capital/operating phase, cost, and revenue assumptions are reported in Table 10.

The NPV based on these results is not encouraging. The Heartland Light Rail project consistently runs a loss in almost every year, with the result that the project NPV is about -$343 million. (See the last column of Table 11 for the discounted project cash flow estimates). Given that capital and operating costs are not subject to a decrease, the only way that the project would be viable is if fare box revenues were to increase dramatically. What would fare revenues need to be for the project to break even? The financial model indicates that fare box revenues would have to be $52.27 million in the first year of the project with ridership increasing at 2 percent p.a. over the 25-year operating phase of the project. At a single-trip fare

Table 10. Revised Project Cost/Revenue Assumptions



CAPITAL PHASE:	8 years
OPERATING PHASE:	25 years
COST ASSUMPTIONS	
Capital Costs:	$125 million for 8 years, or $1 billion
Operating and Maintenance Costs:	$27.50 million in Year 9 and increasing at 4% p.a.
Bond Interest Costs:	$16.83 million per year for 30 years (Year 4 –Year 3 at 7.70%)
Project Discount Rate:	7% p.a.
REVENUE ASSUMPTIONS	
Federal Funding:	$48.75 million for 8 years, or $390 million, representing 39% of capital costs of project
Bond Issue:	$195 million, 30-year bond issued in Year 3 of project
Sales Tax Revenues:	$23 million in Year 1, growing at 1.75% p.a. for 25 years, based on 3/8 cent sales tax
Fare Box Revenues:	$10 million in Year 9, based on 10,000 round-trip commuters per working day and a round-trip fare of $4. Annual growth in fare revenues is assumed to be 2%.

of $2.50, with a fare revenue of $52.27 million, implies 20.908 million annual passenger boardings, or 41,816 weekday round-trip boardings. This level of ridership is not unattainable. The most recent data available from the St. Louis Metrolink system indicate that, over the annual period from July 2006 to June 2007, the Metrolink system accommodated 16.885 million or 33,772 round-trip weekday boardings[15]—an increase of 43 percent over the previous year. Moreover, the Kansas City transit corridor contains 250,000 jobs and an estimated population of about 300,000 within ½ to ¾ miles of the transit corridor.[16] If these two factors are anything to go by, a weekday ridership that would eventually result in a project breakeven for the Kansas City LRT system is not out of the question.

Table 11. Project Cost and Revenue Flows (in millions): Final Estimates

YEAR	CAPITAL COSTS	OPERATION & MAINTENANCE	BOND PAYMENT	TOTAL CAPITAL OUTFLOWS	BOND SALES	FEDERAL FUNDS	TAX REVENUE	FARE BOX REVENUE	TOTAL CAPITAL INFLOWS	NET CASH FLOW	PV of CF's Discounted at 7% p.a.
1	$125.00			$125.00		$48.75	$23.00		$71.75	-$53.25	-$49.77
2	$125.00			$125.00		$48.75	$23.40		$72.15	-$52.85	-$46.16
3	$125.00			$125.00	$195.00	$48.75	$23.81		$267.56	$142.56	$116.37
4	$125.00		$16.83	$141.83		$48.75	$24.23		$72.98	-$68.85	-$52.53
5	$125.00		$16.83	$141.83		$48.75	$24.65		$73.40	-$68.43	-$48.79
6	$125.00		$16.83	$141.83		$48.75	$25.08		$73.83	-$68.00	-$45.31
7	$125.00		$16.83	$141.83		$48.75	$25.52		$74.27	-$67.56	-$42.07
8	$125.00		$16.83	$141.83		$48.75	$25.97		$74.72	-$67.11	-$39.06
9		$27.50	$16.83	$44.33			$26.42	$10.00	$36.42	-$7.91	-$4.30
10		$28.60	$16.83	$45.43			$26.89	$10.20	$37.09	-$8.34	-$4.24
11		$29.74	$16.83	$46.57			$27.36	$10.40	$37.76	-$8.81	-$4.19
12		$30.93	$16.83	$47.76			$27.84	$10.61	$38.45	-$9.32	-$4.14
13		$32.17	$16.83	$49.00			$28.32	$10.82	$39.15	-$9.85	-$4.09
14		$33.46	$16.83	$50.29			$28.82	$11.04	$39.86	-$10.43	-$4.04
15		$34.80	$16.83	$51.63			$29.32	$11.26	$40.58	-$11.04	-$4.00
16		$36.19	$16.83	$53.02			$29.84	$11.49	$41.32	-$11.70	-$3.96
17		$37.64	$16.83	$54.47			$30.36	$11.72	$42.07	-$12.39	-$3.92
18		$39.14	$16.83	$55.97			$30.89	$11.95	$42.84	-$13.13	-$3.88
19		$40.71	$16.83	$57.54			$31.43	$12.19	$43.62	-$13.92	-$3.85
20		$42.33	$16.83	$59.16			$31.98	$12.43	$44.41	-$14.75	-$3.81
21		$44.03	$16.83	$60.86			$32.54	$12.68	$45.22	-$15.64	-$3.78
22		$45.79	$16.83	$62.62			$33.11	$12.94	$46.05	-$16.57	-$3.74
23		$47.62	$16.83	$64.45			$33.69	$13.19	$46.88	-$17.57	-$3.71
24		$49.53	$16.83	$66.36			$34.28	$13.46	$47.74	-$18.62	-$3.67
25		$51.51	$16.83	$68.34			$34.88	$13.73	$48.61	-$19.73	-$3.64
26		$53.57	$16.83	$70.40				$14.00	$14.00	-$56.39	-$9.71
27		$55.71	$16.83	$72.54				$14.28	$14.28	-$58.26	-$9.38

Table 11. Project Cost and Revenue Flows (in millions): Final Estimates—cont'd.

YEAR	CAPITAL COSTS	OPERATION & MAINTENANCE	BOND PAYMENT	TOTAL CAPITAL OUTFLOWS	BOND SALES	FEDERAL FUNDS	TAX REVENUE	FARE BOX REVENUE	TOTAL CAPITAL INFLOWS	NET CASH FLOW	PV of CF's Discounted at 7% p.a.
28		$57.94	$16.83	$74.77				$14.57	$14.57	-$60.20	-$9.05
29		$60.26	$16.83	$77.09				$14.86	$14.86	-$62.23	-$8.75
30		$62.67	$16.83	$79.50				$15.16	$15.16	-$64.34	-$8.45
31		$65.17	$16.83	$82.00				$15.46	$15.46	-$66.54	-$8.17
32		$67.78	$16.83	$84.61				$15.77	$15.77	-$68.84	-$7.90
33		$70.49	$16.83	$87.32				$16.08	$16.08	-$71.24	-$7.64
TOTAL	**$1,000**	**$1,145**	**$505**	**$2,650**	**$195**	**$390**	**$714**	**$320**	**$1,618.93**		**-$343.31**

Note: For definition of Total Capital Outflows, Total Capital Inflows, and Net Cash Flow, see notes for Table 3.

Social Cost-Benefit Analysis of the Heartland Light Rail Project

An important aspect to recognize about financial analysis is that, even though financial analysis of projects is invariably useful, the finances involved in a project essentially represent transfer payments between different economic entities—e.g., from federal taxpayers to local economies or from one group of tax payers to another. A more comprehensive analysis should take into account the economic/social costs and benefits generated by infrastructural projects. The previous section implied that daily round trip ridership of the Heartland Light Rail project would have to be about 42,000 for the project to break even. Suppose the actual level of ridership falls far short of this level? Could the project still be justified based on other social benefit/social cost arguments?

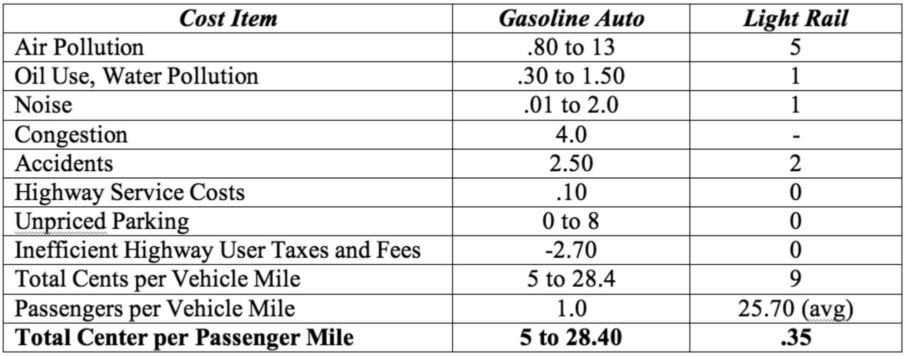
There is a logical reason for the inability of most mass transit systems to be profitable. After a century of massive government investment in roads and highways, the cost of motor vehicle transportation is subsidized to such an extent that public transit systems find it impossible to raise fares by enough to be operationally self-sufficient. Vuchic (1999)[17] referring to a study by the U.S. Office of Technology Assessment (OTA) estimates that car drivers pay only about 60 percent of the total costs of their travel while the other 40 percent (highway construction costs, maintenance costs, etc.) is subsidized by different levels of government. Other implicit costs, such as free parking, are subsidized by employers, store owners, schools, etc., while various social and environmental costs are absorbed by society. It is, thus, hardly surprising that public transit systems are unable to compete against motor vehicle transportation. Henry and Dobbs (2005, p.3)[18] make a similar argument:

> The competing roadway-based transportation systems ... have been structured to minimize motorists' out-of-pocket costs. The high costs of private motor vehicle travel are covered by a largely unobtrusive umbrella of public and private subsidization as well as the transfer of "external costs" (like accidents and air pollution) to the general public.... Against this heavily subsidized, government promoted competition, public transport operators find it impossible to charge fares high enough to secure "profitable" operation."

An estimate of the costs of auto transportation should, therefore, take into account the externalities imposed by auto traffic such as congestion, accidents, pollution, time delays, etc. Several studies provide estimates of the total cost of motor vehicle use. Among the most comprehensive are those by Delucchi (1996), Small (1997), Small (1999), Delucchi (1997),[19] and Delucchi (2000). While the

1996 and 1997 studies by Delucchi provide estimates of the total cost of all motor vehicle usage, Delucchi (2000) breaks down the external costs of motor vehicle usage into costs for different transportation modes. Table 12 includes Delucchi's estimates of the external costs of the two primary competing modes considered in this section—auto transportation and light rail transportation.[20]

Table 12. External Costs of Passenger Transportation Modes (cents per vehicle mile)

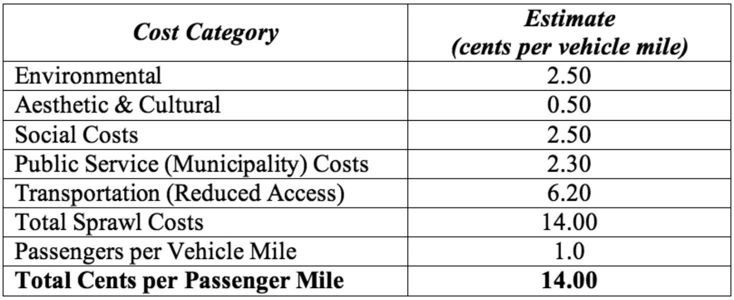


Cost Item	*Gasoline Auto*	*Light Rail*
Air Pollution	.80 to 13	5
Oil Use, Water Pollution	.30 to 1.50	1
Noise	.01 to 2.0	1
Congestion	4.0	-
Accidents	2.50	2
Highway Service Costs	.10	0
Unpriced Parking	0 to 8	0
Inefficient Highway User Taxes and Fees	-2.70	0
Total Cents per Vehicle Mile	5 to 28.4	9
Passengers per Vehicle Mile	1.0	25.70 (avg)
Total Center per Passenger Mile	**5 to 28.40**	**.35**

The possible range of external costs per passenger mile for autos is 5 to 28 cents, or a mid-point cost estimate of 11.70 cents. If one subtracts the external cost of .35 cents for light rail from this figure, the result (approximately 11 cents) constitutes an estimate of the external cost benefit provided by light rail over auto transportation. To this figure of 11 cents per passenger mile we need to add other positive externalities provided by LRT that were not explicitly valued in the Delucchi study. These include land use impact, preservation of wetlands, land erosion control, emission reduction benefits, conservation of non-renewable resources, rising property values around rail corridors, revitalization of transit corridors, enhanced mobility for the transit dependent, etc. In the current situation of rising gasoline prices, these positive externalities are likely to be considerable.

Quantifying the social benefits that arise from light rail is not easy. While operating and capital costs of light rail are explicit and thus easily quantified, many of the social benefits conferred by light rail are implicit and therefore easily ignored in policy debates. The problem of overlapping benefits and double counting involved in quantifying external benefits adds to the uncertainty surrounding such estimates. However, such social benefits could, in fact, be considerable. The following examples from the literature provide some notion of the dollar values attributed to these externalities.[21] McPhearson et al. (1997) estimate that increasing tree cover by 10 percent saves annual heating and cooling costs by $50 to $90 per dwelling. They also estimate the NPV of a single tree to be $402. Riddel (2001) estimates that as a result of 15,000 acres of open space, housing prices in Boulder, Colorado increased an average of $10,000 for median-priced homes. Roe, Irwin and Morrow-Jones (2004) found that a 10 percent increase in the amount of farmland led to a rise in housing prices of $394 for lower priced homes and about $1,100 for higher priced homes. Kiker and Hodges (2002) estimated the economic benefits of natural lands in Northeast Florida at $2.6 billion per year. A subsequent study by Kroeger (2005) extended the Kiker and Hodges' work to other types of benefits and arrived at an even higher value of $3.2 billion per year.[22] Table 13 summarizes the cost estimates provided by various studies on land use impact effects:[23]

Table 13. Land Use Impact of Auto Travel



Cost Category	***Estimate (cents per vehicle mile)***
Environmental	2.50
Aesthetic & Cultural	0.50
Social Costs	2.50
Public Service (Municipality) Costs	2.30
Transportation (Reduced Access)	6.20
Total Sprawl Costs	14.00
Passengers per Vehicle Mile	1.0
Total Cents per Passenger Mile	**14.00**

The land use impact estimates in Table 13 are subject to a substantial degree of uncertainty. Some of the effects reported above may be double counted; other effects are ignored since they simply cannot be easily quantified. The most significant of the non-quantified effects is the effect of light rail transit on property values. Suppose for the time being we ignore this effect. The fundamental political issue then centers on whether the "subsidy" to rail transit (the negative NPV of $343 million that was computed in the earlier section) could be offset by the implicit positive externalities conferred by the LRT system. How large would these externality benefits need to be? A negative NPV of $343 million over 33 years discounted at 7 percent p.a. implies that the LRT system would have to confer annual benefits of $26.89 million every year for 33 years for the project to break even. Are savings of such magnitude feasible?

The external cost estimates above imply that a conservative estimate of the net external cost savings from light rail over auto transport is about 11 cents per passenger mile. The land use impact savings from LRT adds another 14 cents, for a total of 25 cents. Since there is almost certainly some element of double counting between Delucchi's estimates and the land use impact effects reported in Table 13, assume that the land use impact effect is not 14 cents but only half as much, or 7 cents. This results in a net external cost savings of 18 cents per passenger mile. Given that the average driver's round-trip work commute is about 30 miles per day in Kansas City,[24] this implies that annual external cost savings would be $26.89 million if the number of cars would decrease by 19,919 per workday ($.18/mile x 30 miles/day x 250 days/year x 19,919 cars).[25] In other words, if 19,919 cars were taken off the roads because of a travel mode shift from auto travel to light rail transit, the Heartland Light Rail project would be justifiable based on the savings in external costs alone.

The external cost savings of 18 cents per mile is one possible estimate of external costs. A larger estimate of external costs is provided in a comprehensive study conducted by the Victoria Transport Policy Institute (VTPI) on the externalities imposed by motor vehicle travel. The VTPI study considers 20 different cost categories separated into internal and external costs, including such external costs as parking, congestion, land value, transport diversity, pollution, noise, barrier effects, waste, etc.,and estimates such external costs[26] at 59 cents per vehicle mile, more than three times the 18 cents in external cost savings considered earlier. This implies that the required decrease in the number of cars is even lower at 6,077 cars per work day to generate the equal annuity amount of $26.89 million ($.59/mile x 30 miles/day x 250 days/year x 6,077 cars).[27]

It should be noted that the external cost estimates used above do not take into consideration the effect that light rail would have on property values. The Central Business Corridor Transit Plan estimates that the Heartland light rail project would stimulate new investment of more than U$ 1 billion, increase employment by about 13,000 and provide new annual taxes of about U$17 million.[28] If these property impact estimates are even marginally correct, it is then quite probable that the substantial overhead costs involved in light rail would essentially pay for itself through its externality effects.

Conclusion

The Heartland Light Rail project represents Kansas City's biggest infrastructural investment in decades. The ballot initiative for the light rail project was voted down three times until it was finally approved in November 2006. The very fact that the light rail project idea was so resilient in the face of strenuous opposition provides some evidence that LRT may be an idea whose time has finally arrived in Kansas City.

A strict financial analysis of the project is not encouraging. Using best estimates of construction costs, operating expenses and federal funding, the NPV of the project is estimated to be negative $343 million. However, if one were to include the annual savings in external costs from lower auto travel, the Kansas City light rail project becomes an increasingly attractive option.

Since light rail projects involve substantial public funding a debate on their costs and benefits appropriately belongs in the domain of public policy. A major problem, however, in rationally evaluating the merits of such projects is that the public dialogue is often complicated by studies that make their case by either considering only costs that are explicit or ignoring non-monetized, implicit social benefits. The truth seems to be that if evaluated on a strict financial basis alone, light rail systems are unlikely to be completely self-sufficient. However, if light rail losses are not of such a magnitude that the project is completely unfeasible, it is very probable that social benefits could still render such projects worthwhile.

Acknowledgements

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Endnotes

[1] The Road Information Program (TRIP), "Rough Ride in the City: Metro Areas with the Roughest Rides and Strategies to Make our Roads Smoother," October 2006.

[2] "Central Business Corridor Transit Plan," Final Report, April 27, 2001.

[3] These data are from the 2003 Highway Statistics published by the Federal Highway Administration (FHWA).

[4] See the Texas Transportation Institute's 2004 Urban Mobility Study.

[5] See Chart 3 (page 16) of The Road Information Program (TRIP), "Rough Ride in the City: Metro Areas with the Roughest Rides and Strategies to Make our Roads Smoother," October 2006.

[6] Typically, a project's cost of capital should be computed as a weighted average cost of capital (WACC) where the weights are the proportions of debt and equity and the costs pertain to the cost of debt and cost of equity. The cost of equity is typically determined using the Capital Asset Pricing Model (CAPM). This method of estimating WACC is inapplicable for publicly funded projects since no equity is issued. An approximate cost of capital for the Kansas City LRT project can be determined thus. The cost of capital of a project is linked to the risk of the underlying assets supporting the project. In 2007, Kansas City issued General Obligation (GO) bonds at a yield of 4.60%. Assuming that the LRT project is more risky than Kansas City's asset base, we can add a "premium" over the yield of Kansas City GO bonds. Adding a premium of 200 basis points or 2% results in the assumed project cost of capital of 7%. For a detailed discussion of project valuation see Chapter 19 of *Principles of Corporate Finance*, "Financing and Valuation," Brealey, Myers and Allen (2006).

[7] Note that the project is non-normal—that is, negative cash flows occur during the life of the project. In such situations, the IRR criterion can be misleading. In the subsequent analysis, the IRR values are not reported for this reason.

[8] I continue to assume that operating costs will increase by 4% p.a. from the base year estimate of operating and maintenance costs.

[9] Given that the American Public Transportation Association has estimated that the total cost of riding public transportation (including transfers, parking, etc.) at a base fare of $2.50 is $2454/year versus estimated driving costs for midsize cars of $8,580/year, public transportation seems a bargain. However, whether the public perceives it this way, especially in auto dependent areas like Kansas City, remains to be seen.

[10] Some of these values are also reported in Toole (2005), "Does Light Rail Pay for Itself?" (see www.ti.org/vaupdate57.html). I follow a similar logic to that in the article in determining operational cost savings for light rail. The sample set of cities reported in the table is limited to those cities for which construction costs for light rail are available. This is to facilitate a comparison of operational cost with capital costs. See a subsequent section of this paper.

[11] An important part of the reason is that since light rail systems serve the densest transit corridors, operational costs for light rail generally tend to be lesser than low passenger density serving bus systems.

[12] See Table 1 of Baum-Snow and Kahn (2005). Data for LRT capital costs in some major cities is unfortunately not available. For instance, data on capital costs for both D.C. and Chicago's rail transit system are unavailable.

[13] Construction cost data from the Baum-Snow and Kahn (2005) paper is converted into 2003 dollars and reported in Toole (2005), "Does Light Rail Pay for Itself?" (see www.ti.org/vaupdate57.html).

[14] The average life span of rail hardware is 30 years. The amortization rate of 7% is prescribed by the Federal Transit Administration (FTA) for amortizing capital costs. See Toole (2005).

[15] "Metro System Ridership" numbers reported on www.metrostlouis.org

[16] This estimate is contained in the Kansas City Long Range Transportation Plan, Figure 5-7, pp. 5-13. See also Exhibits 1 and 2 that depict the spatial and demographic characteristics of the primary transit corridor.

[17] Vuchic, *Transportation for Livable Cities*, Center for Urban Policy Research, Rutgers University, December 1999.

[18] Henry and Dobbs, "Why St. Louis's MetroLink Light Railway is a Mobility Bargain," May 2005. Available on www.lightrailnow.org

[19] Delucchi (1997) is a comprehensive study of the total social cost of motor vehicle use based on 20 reports published by the UC Institute of Transportation Studies, Davis. Delucchi (1996) provides a summary of the 1997 study.

[20] The estimates here are extracted from page 12 of Delucchi (2000). In the actual table provided by Delucchi, there is an estimate of government subsidies for light rail which increases the total external cost of light rail. I ignore this subsidy for light rail since my focus here is to ask the question, Are the positive externalities provided by light rail sufficient to offset the cost disadvantages arising from the high capital cost of the Heartland LRT System?

[21] See Banzhaf and Jawahar (2005) for a comprehensive introduction to this literature.

[22] The underlying research in both these papers contributed to a provision passed by the Florida legislature in 2005. The provision encourages local governments to require a full cost accounting analysis for any proposed new development.

[23] See Litman (2007), Table 5.14-13, p. 5.14-21.

[24] U.S. Census Bureau data indicate that the mean travel time to work in Missouri is about 23 minutes. At 40 mph, this indicates an average one-way commute of about 15 miles.

[25] This calculation assumes one passenger per car. In addition to these external costs, TRIP estimates that the poor condition of roads in Kansas City imposes an additional operational cost per automobile of $651 per year.

[26] Victoria Transport Policy Institute, *Transportation Cost and Benefit Analysis*, May 2007 (available on www.vtpi.org). See Table 6-6 on pp. 6-10.

[27] In addition to these external costs, TRIP estimates that the poor condition of roads in Kansas City impose an additional operational cost per automobile of $651 per year.

[28] See Appendix B of the Central Business Corridor Transit Plan, Final Report.

[29] See Castelazo and Garrett (2004)'s "Light Rail: Boon or Boondogle," which invokes the "give them a Toyota Prius instead" argument. A response to this study is contained in Henry and Dobbs (2005), "Why St. Louis's Metro Link Railway in a Mobility Bargain."

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An Unconventional Design for Bus U-Turns at Signalized Intersections

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Abstract

This paper addresses an unconventional design for accommodating bus U-turns at signalized intersections based on a case study in Miami, Florida. Field data were collected at the study site, including traffic volumes, traffic conflicts, pedestrian/bicyclist activities, signal phase sequence, headway of buses, and radii of bus U-turns. A detailed operational analysis was performed at the signalized intersection using Synchro. The results of the operational analysis indicate that implementation of the unconventional bus U-turn design at the signalized intersection will not cause major operational problems when the total entering volume is less than 4,000 vehicles per hour. To address the safety concerns at the study intersection, both crash analysis and conflict analysis were conducted. A review of accident data for the subject intersection indicates that accidents related to the bus U-turn occur infrequently. The eight-hour conflicts analysis showed that very few conflicts were caused by bus U-turn movements.

Introduction

Many studies about the operational and safety effects of U-turns at unsignalized and signalized intersections have been conducted. Past research results show that there is no evidence to prove that U-turns at medians or signalized intersections present major safety or operational problems (Potts et al. 2004, Carter et al. 2005, Zhou et al. 2002). However, few studies have been found to deal with heavy vehicle U-turns. There is typically inadequate geometry for a bus to make a U-turn from the exclusive left-turn lane at most signalized intersections. This paper addresses an unconventional design for accommodating a bus U-turn at a signalized intersection based on a case study in Miami, Florida.

Background

Miami-Dade Transit (MDT) was requested by the City of Sunny Isles Beach to evaluate the safety of buses on Routes E and S that make a U-turn at the intersection of Collins Avenue (SR A1A) and Galahad Dade Boulevard (193rd Street). Presently, both of these routes require northbound buses to make U-turns at the subject intersection, then return southward along Collins Avenue before continuing on to the Aventura Mall.

Purpose

The purpose of this analysis is to provide policy makers with an objective assessment of the traffic operations and safety of the current routing at the subject intersection. In addition, this study indicates under what traffic conditions the unconventional design for bus U-turn may cause traffic congestion and safety problems.

Existing Conditions

A site review was conducted to assess the existing operational and design characteristics of the intersection on December 14 and 15, 2004. The study intersection is located at Collins Avenue (SR A1A) and Galahad Dade Boulevard (193rd Street). The major roadway direction is north-south bound on SR A1A, which is a four-lane, divided arterial with a speed limit of 35 mph. The minor roadway direction is east-west bound on 193rd Street. The east side of the intersection is the entrance to a residential condominium, Ocean One. The west side of 193rd Street is a private two-lane street that provides access to OceanView. An unconventional U-turn lane for bus was installed before the residential condominium was built in 2001. Figure 1 shows the intersection layout at the subject intersection.

Figure. 1 Intersection Layout at the Subject Intersection

At the intersection, the northbound buses that will be making the U-turn are channelized and separated to the right of the adjacent through-traffic by a striped separator of approximately six feet. The traffic signals for the bus U-turn and the northbound left-turns are optically programmed signal heads, which restrict the visibility of these indications in adjacent lanes. This helps to keep northbound through-traffic on Collins from being confused by the conflicting indication for the bus U-turn.

Data Collection

Field data were collected on December 14 and 15, 2004. A video camera was used to record traffic operations at the intersection from the top of Marco Polo Ramada Plaza Beach Resort, located approximately 1,000 feet south of the intersection. A total of eight hours of videotape was recorded, including two AM peak hours, two PM peak hours, two noon hours, and two non-peak hours.

Traffic data were obtained from the videotapes. While reviewing the videotapes, researchers tracked each vehicle movement at the intersection, especially the bus U-turn movements. The following information was recorded:

- eight-hour turning movement counts
- traffic conflicts
- pedestrian/bicyclist activities
- signal phase sequences
- headways of buses
- radii of bus U-turns

Crash data for the subject intersection were provided by the Florida Department of Transportation, District 6 Traffic Operations Office. The crash data were pulled for three years, from 2001 to 2003. The system timing data for the subject intersection were obtained from Miami-Dade County.

Additionally, the data collection phase involved a meeting with representatives from the City of Sunny Isles Beach to assess their concerns about the bus U-turn at this intersection. The expressed concerns are summarized as follows:

- U-turning of buses across the intersection is an unusual and unexpected maneuver; this could cause confusion for unfamiliar motorists (tourists and visitors).
- U-turning of buses causes congestion at the intersection.
- U-turn maneuvers cause traffic safety concerns.
- U-turning buses create a possible hazard for people standing on the southwest corner of the intersection due to the tracking of the U-turning buses.
- Exhaust fumes from the buses pollute the area of Ocean One.
- Buses waiting in the bus lane block the visibility of bicyclists and pedestrians, especially for northbound traffic turning right (across the bus lane) into the Ocean One condominium entrance.

The City has suggested that Miami-Dade Transit consider relocating the U-turn for routes E and S up to Hallandale Beach Boulevard, approximately 3 miles to the north.

Operational Analysis

The subject intersection currently operates at an acceptable level of service (LOS) based on the eight-hour field observation on a typical weekday. The intersection geometry, traffic volumes, and signal timing data were collected for a detailed analysis. Synchro 6.0 software was used to perform the capacity and LOS analyses for four different time periods: AM peak hours (7:00-9:00 AM), noon peak hours (11:00 AM-1:00 PM), PM peak hours (4:00-6:00 PM), and non-peak hours. Synchro is a complete software package for modeling and optimizing traffic signal timings and implements the methods of the 2000 *Highway Capacity Manual* (HCM), Chapter 16, "Signalized Intersections". It provides an easy-to-use solution for single intersection capacity analysis and timing optimization. Synchro defaults to calculate the percentile delay, which is different from the HCM's average control delay. Synchro's output also provides the average control delay based on the HCM methods.

The HCM's average control delays from Synchro's output are summarized in Table 1. As listed in Table 1, the overall intersection currently operates at LOS "A" during the AM peak hours and noon time, and at LOS "B" during the afternoon and PM peak hours. Bus U-turn volume is approximately 15 buses per hour for both peak and non-peak hours. The bus headway is about four minutes for buses making a U-turn at the intersection. The average control delay of U-turning buses is approximately 53 seconds per vehicle. The LOS of bus U-turns is "D." The through-traffic on SR A1A operates at LOS "A" or "B". The left-turn and right-turn vehicles from the minor road operate at an acceptable LOS "D." The analysis results show that the bus U-turn does not cause major operational problems at the intersection. This is because the overall intersection is currently operating at level of service "A" or "B," and no individual lane group is worse than LOS D.

To determine under what volume conditions adding a bus U-turn will significantly increase the overall delay at the intersection, additional operational analyses were conducted by gradually increasing the traffic volumes at the intersection. All approaches received the same percentage increase, except the bus U-turn volume. Figure 2 shows the impact of increasing the bus volumes and total volumes entering the intersections. Four curves were developed for bus volumes: 0, 10, 20, and 30 buses per hour. According to the *Highway Capacity Manual*, the LOS of the intersection is "E" when the average delay is greater than 55 seconds per vehicle. Figure 2 indicates the intersection operates at LOS "E" when the bus volume and total volume entering the intersection are (30, 4500), (20, 5000), (10, 5375), and (0, 6375).

Table 1. Level of Service (LOS) at the Study Intersection

Intersection SR A1A @ 193rd St.		Northbound			Southbound	Eastbound		Westbound		Total
		LT	TH/RT	U-turn	TH/RT	LT	RT	LT	RT	
PM Peak	Delay (sec./veh)	23.8	5.4	53	13.7	51.4	9.1	43.9	43.9	11.6
	LOS	C	A	D	B	D	A	D	D	B
AM Peak	Delay (sec./veh)	6.3	4.6	52.9	8.9	50.1	7.6	37.6	37.6	8.6
	LOS	A	A	D	A	D	A	D	D	A
Noon Peak	Delay (sec./veh)	7.0	4.0	52.9	8.8	51.1	9	48.1	48.1	8.7
	LOS	A	A	D	A	D	A	D	D	A
Non Peak	Delay (sec./veh)	18.3	5.0	52.9	10.9	51.6	9	41.5	41.5	10
	LOS	B	A	D	B	D	A	D	D	B

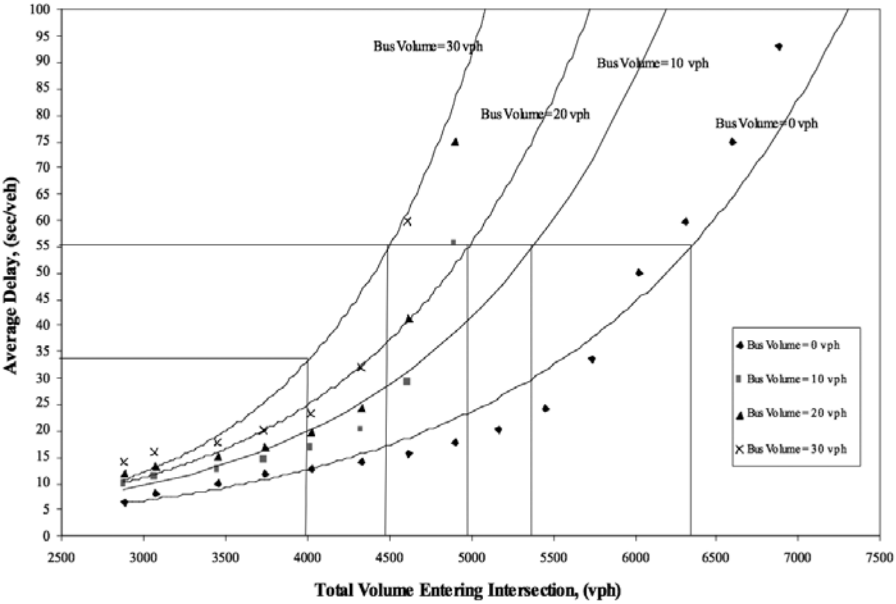


Figure 2. Impact of Bus Volumes on the Intersection Delays

This implies that an increase in bus volume from 0 to 10 buses per hour could reduce capacity by 16 percent, an increase in bus volume from 10 to 20 buses per hour could reduce an additional 7 percent, and an increase in bus volume from 20 to 30 buses per hour would reduce capacity by another 10 percent. Figure 2 also suggests that the intersection always operates at LOS "C" or better when the total volume entering the intersection is less than 4,000 vehicles per hour and bus U-turn volume is no more than 30 buses per hour.

Safety Analysis

Both crash analysis and conflict analysis were conducted to evaluate the safety of the subject intersection. Data collected include three-year crash data and eight-hour videotape for traffic conflicts. Researchers paid special attention to the crashes and conflicts caused by U-turning buses. Both crash frequency and crash rates are used for crash analysis, and the number of conflicts and conflict rates were computed for conflicts analysis. The percentage of crashes and conflicts related to bus U-turns were used to indicate the impacts of bus U-turns on the intersection safety.

Crash Analysis

Crash data at the subject intersection were collected for a three-year period (2001 to 2003). The total number of recorded crashes was approximately 27 in the three-year period, an average of 9 crashes per year. This number is relatively low when compared to the high crash intersection with over 15 crashes per year in the county. Five of the crashes were bus-related. All five were property-damage-only crashes. There were two bus-related accidents in 2001 and 2002, and one accident related to bus U-turns in 2003. The accidents involving the bus were caused mainly by careless driving or the ignoring of the traffic signal by the other drivers.

Figures 3, 4, and 5 illustrate the percentages of each type of crash in the years 2001, 2002, and 2003, respectively. Figure 6 shows the percentage of each type of crash in the three-year period. Approximately 64 percent of the total crashes were rear-end and sideswipe, especially on southbound SR A1A. These two types of crashes are caused by the unexpected left turns from southbound SR A1A and the blockage problem on the right-turn-only lane by the bus stop approximately 200 feet away from the intersection on southbound SR A1A.

It is interesting that the total number of crashes has dropped from 13 in 2001 to 5 in 2003. The corresponding crash rates also were significantly reduced, from 1.32 to 0.50 (accidents per million entering vehicles) from 2001 to 2003. The number of injuries also has dropped from 6 to 1 from 2001 to 2003. This implies that the intersection safety has improved in the last few years. Figures 7 and 8 illustrate the trend of crash frequency and crash rates from 2001 to 2003.

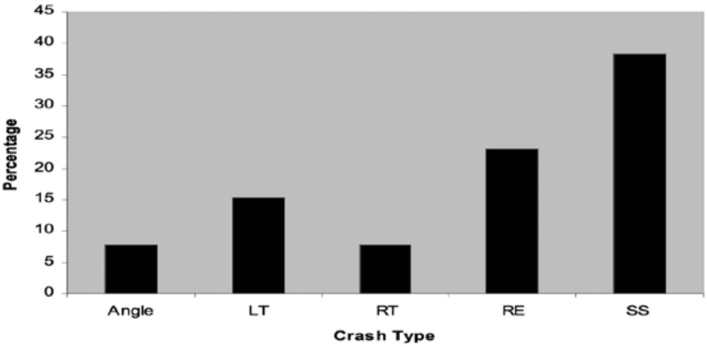


Figure 3. Distribution of Crash Type in 2001

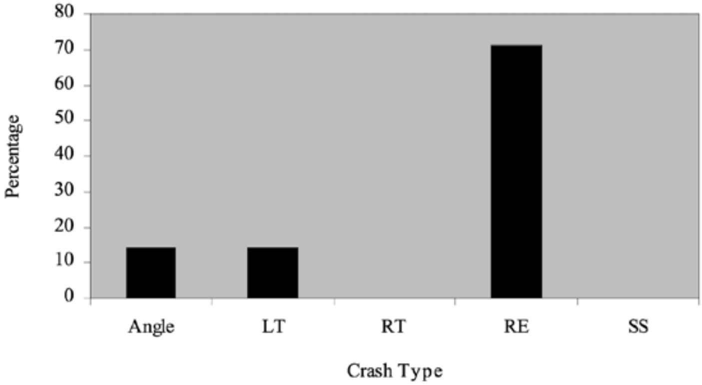


Figure 4. Distribution of Crash Type in 2002

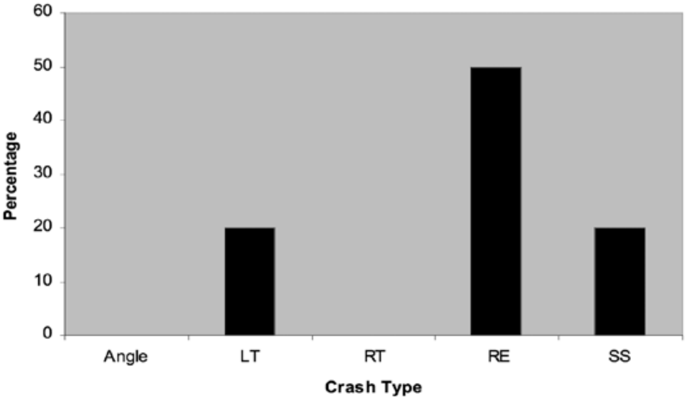


Figure 5. Distribution of Crash Type in 2003

Legend: LT=left turn, RT=right turn, RE=rear end, SS=side swipe

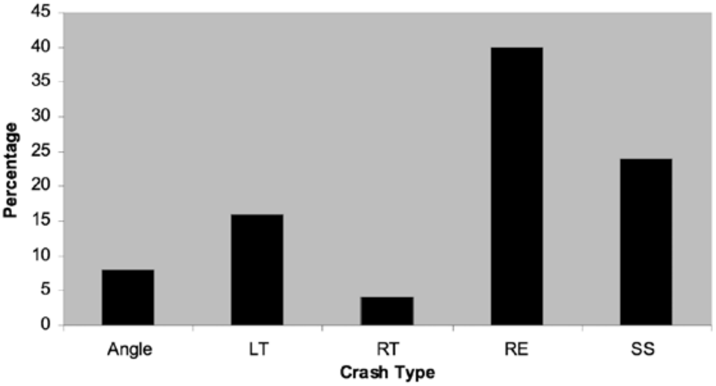


Figure 6. Distribution of Crash Type, 2001 - 2003

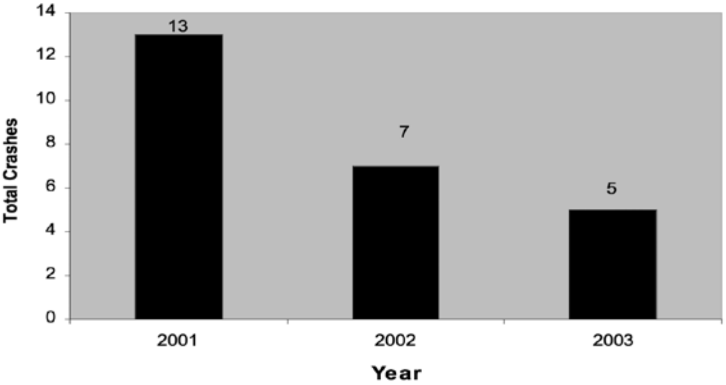


Figure 7. Change of Crash Frequency, 2001 - 2003

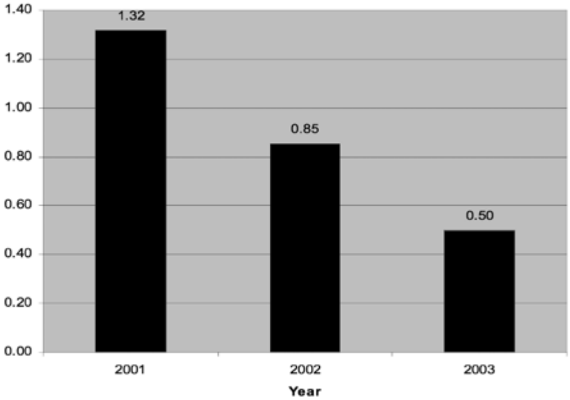


Figure 8. Change of Crash Rates, 2001 – 2003

(accidents per million entering vehicles)

The critical crash rate method was used to determine the safety level of the study intersection. This statistical tool can be used to screen for high-accident locations by utilizing a confidence interval that can be adjusted up or down to accommodate the needs of a particular safety program. If a segment has an actual crash rate higher than the critical rate, the location may have a potential highway safety deficiency and may need additional analysis. To compute the critical crash rate for a site, the following equation was used:

$$F_c = F_\alpha + k(F_\alpha / M)^{1/2} + 1/(2M)$$

Where:

F_c = the critical crash rate

F_α = statewide average crash rate

K = a probability constant. K = 3.291 for a 99.95% confidence level for urban area

M = vehicle exposure, calculated per million entering vehicles (MEV)

The Florida statewide average crash rates for intersections that have the characteristics of being 4-5 lanes, 2-way, divided, raised, and 4-leg are 0.479, 0.473, and 0.445 crashes per million vehicles for the years 2001, 2002, and 2003, respectively. Based on the above equation, the corresponding critical crash rates for the year 2001, 2002, and 2003 are 1.26, 1.32, and 1.19, respectively. The crash rates in the years 2002 and 2003 are less than their critical crash rates. The crash rate in the year 2001 is a slightly higher than its critical crash rate. However, the actual average crash rate for the three-year period is 0.89 at the intersections, which is lower than the critical crash rate of 1.25 during the same period. This implies that the location has no potential safety deficiency.

Conflicts Analysis

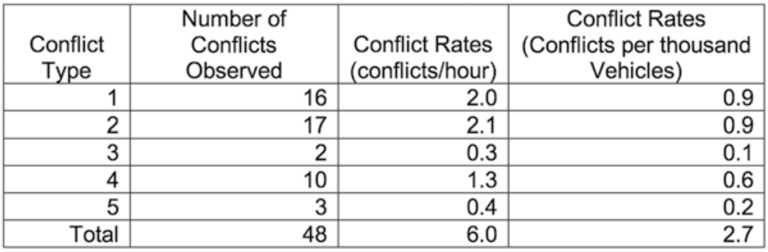
The purpose of the conflicts analysis is to identify the potential conflicts between buses and other vehicles or pedestrians/bicyclists. Traffic conflicts are interactions between two or more drivers where one or both drivers take an evasive maneuver to avoid a collision (Robertson et al. 1994, Parker and Zegeer 1988, Parker and Zegeer 1988a). In this study, traffic conflicts at the intersection were used as an additional measure to quantify the safety effects of bus U-turns at the intersection. These conflict types are:

- slow vehicle, same direction conflict (C1)
- lane change conflict (C2)
- bus U-turn conflict (C3)
- angle conflict (C4)
- pedestrian and vehicle conflict (C5)

Based on this definition of traffic conflict, an occurrence was considered as a conflict when a vehicle applied brakes, swerved, or noticeably decelerated to avoid a collision. Data were extracted by tracking each vehicle movement from videotapes for an eight-hour period.

As shown in Table 2, a total of 48 conflicts were recorded by videotape. Most of the conflicts were of type C1 (16 rear-end conflicts), and type C2 (17 lane change conflicts). This is due to the fact that there is a bus stop on the outside lane of southbound SR A1A that becomes a right-turn-only lane providing access to the Lehman Causeway.

Table 2. Summary of Traffic Conflicts Observed in the Field



Conflict Type	Number of Conflicts Observed	Conflict Rates (conflicts/hour)	Conflict Rates (Conflicts per thousand Vehicles)
1	16	2.0	0.9
2	17	2.1	0.9
3	2	0.3	0.1
4	10	1.3	0.6
5	3	0.4	0.2
Total	48	6.0	2.7

The signal phase sequence at this intersection has the bus U-turn, followed by the northbound protected-left-turn (with concurrent through-traffic), followed by the northbound and southbound through-green, then the east-west movements. Due to the heavy use of the bus stop mentioned above, passenger loading and unloading time is typically greater than the time allotted for the northbound protected-left-turn phase. Thus, the southbound through-vehicles are released prior to the bus leaving the stop. This results in brief periods of congestion where vehicles have to slow down or make a quick lane change to avoid the stopped bus. This is how most of the observed rear-end and sideswipe conflicts occurred.

A total of 10 angle conflicts (type C4) were recorded. A few vehicles (average 2-4 vehicles per hour) were observed attempting to make a left turn from southbound

SR A1A into Ocean One, which caused angle conflicts with northbound through-vehicles because it is a prohibited movement. Some conflicts also were observed between left-turning vehicles from Ocean One and right-turning vehicles from OceanView. A total of two conflicts caused by bus U-turns were observed in eight hours.

Two types of conflict rates were calculated. The first one is the ratio between conflicts and the number of hours of observation. The number of conflicts per hour shows the conflicts that might be found during different hours of the day. The second one corresponds to the ratio between conflicts and traffic volumes. This rate is defined as the number of conflicts per thousand involved vehicles by maneuver type. As shown in Table 2, there were, on average, 6 conflicts in an hour and approximately 2.7 conflicts per thousand vehicles involved at the intersection.

Overall, it was found that the results of the conflict study are very consistent with the crash analysis. Based on the limited number of conflicts and crashes caused by bus U-turns, there is no indication that U-turning buses are a major safety concern at the subject intersection.

Observations and Conclusions

To overcome geometric constraints, an unconventional design was implemented to accommodate the U-turn of the buses at the intersection. Based on our observations at the intersection, Florida DOT and Dade County Traffic Engineers have done an outstanding job in accommodating this unusual situation in the best manner possible. With the use of optically-programmed traffic signals, the confusion to the motorists should be minimal. To unsuspecting motorists, there should not be any conflicting information displayed—they simply see standard traffic signal indications. When it is the bus's turn to go, the motorists see a red signal and should be expected to understand and abide by it.

The results of operational analysis show that the subject intersection currently operates at LOS "A" during AM peak hours and LOS "B" in PM peak hours. The average delay for the overall intersection is approximately 9-12 seconds per vehicle. Signal timing and the phase sequence are proper for accommodating the special bus U-turn movements and appear to do so as effectively and efficiently as can be expected. The more-detailed operational analysis indicates that implementation of the unconventional bus U-turn design at the signalized intersection will not cause major operational problems when the total entering volumes is less than 4,000 vehicles per hour at the studied location.

The eight-hour conflicts analysis showed that very few conflicts were caused by bus U-turn movements. A review of accident data for the subject intersection indicates that accidents related to the bus U-turn occur infrequently. There are, on average, 1.7 crashes related to the bus U-turns per year. The accidents involving the bus were caused primarily by careless driving or the ignoring of the traffic signal by other drivers. Crash analysis also indicated that intersection safety has improved significantly over the three-year period. Based on these limited accident frequencies and number of conflicts, there is no indication that the bus U-turn at the subject intersection constitutes a major safety concern.

Of significance is the fact that approximately 64 percent of total crashes are rear-end and sideswipe collisions. These two types of crashes are caused by unexpected left turns from southbound SR A1A and the blockage problem of the right-turn-only lane by the bus stop approximately 200 feet south of the intersection.

It was observed that most buses did not stop behind the stop bar on the bus-U-turn-only lane. The bus lane's stop line is set back from the stop bar for northbound through-traffic on A1A to provide adequate sight distance for vehicles that are turning right into Ocean One. On some occasions, the buses initially stopped in the proper location, but continued to creep up over the stop bar and, on one occasion, completely over the crosswalk.

Some buses were observed making much larger U-turns than the U-turn pavement markings in the intersection. As indicated by the City, the bus is close to the curb as it completes its U-turn. Figure 9 shows the damaged curb from vehicles making the U-turn maneuver. However, as U-turning speeds are typically very low, the potential for serious crashes is also relatively low.

Relocating the U-turn to Hallandale Beach Boulevard, as suggested by the City, would add approximately 10 minutes to the bus routes. This would require the addition of another bus to the route to maintain the current bus headways. Additionally, this represents an unwanted increase in travel time to the existing bus patrons. It is doubtful that extending these routes would help to serve any additional transit customers, in that the areas to the north are currently served by other Miami-Dade Transit and Broward County Transit routes.

Figure 9. Possible Damage on the Curb from Bus U-Turns

Acknowledgments

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