TECHNICAL REPORT:
Impact Analysis of a Potential MBTA Fare Increase and Restructuring in 2007

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TECHNICAL REPORT: Impact Analysis of a Potential MBTA Fare Increase and Restructuring in 2007

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EXECUTIVE SUMMARY

CTPS has conducted a fare increase impacts analysis to assist MBTA staff and the MBTA Board of Directors in determining the impacts of the proposed 2007 fare increase and restructuring on the following: revenue, ridership, air quality, and environmental justice. The analysis will also assist the MBTA in determining the impacts of potential service reductions in lieu of a fare increase.

CTPS used two models to project ridership and revenue impacts of the fare increase and restructuring. The regional travel demand model uses the traditional four-step process to describe regional travel patterns and can be used to model the impacts of various changes in service or price on these patterns and their effect on ridership and revenue. A spreadsheet model was developed by CTPS specifically for the fare restructuring effort and presents a second method for modeling ridership and revenue impacts. The two models predict relatively similar changes in revenue and ridership, both in absolute and percentage terms. The predicted percentage increase in revenue was 18.4% by the travel demand model and 21.2% by the spreadsheet model. The predicted decrease in ridership was 2.8% by the travel demand model and 6.1% by the spreadsheet model.

The regional travel demand model was also used to estimate the air quality impacts of the proposed fare increase and restructuring. According to the model, very little impact on air pollution is expected as a result of the changes. The projected increase in the estimated levels of carbon monoxide, nitrogen oxides, and volatile organic compounds is, in each case, below 0.3%.

Based on the results of the travel demand model, CTPS was able to analyze the equity implications of the proposed fare increase and restructuring on minority and low-income communities. The findings indicate that the proposed fare structure and fare levels, as well as the current structure and prices, do not place a disproportionate burden on environmental justice communities. Indeed, low-income and minority communities pay lower average fares than the systemwide average. In moving from the existing to the proposed fare structure, however, the difference between the monetary increase in average fares paid in environmental justice communities and the systemwide average price increase is very small, resulting in percentage increases in price that are slightly higher in environmental justice communities. In effect, since environmental justice communities already experience lower average fares than the systemwide average, absolute changes of relatively equal magnitude will have a greater percentage impact on those specific communities.

Finally, in case the 2007 fare increase and consequent gain in operating revenue does not occur, MBTA Service Planning prepared a list of service reductions that would save a substantial portion of annual operating expenses. These reductions targeted some of the highest net-cost-per-passenger bus routes as well as weekend and weekday evening subway and commuter rail service, along with cuts to other programs and services. The reductions, while aimed at avoiding a substantial degradation in regional transit mobility, would lead to an estimated 6.5% decrease in ridership and a 15.8% savings in operating expenses.

INTRODUCTION

During the period since the last fare increase in early 2004, the MBTA has devoted considerable time to evaluating the revenue and ridership impacts of potential substantial changes to its fare structure. These changes are meant to take advantage of the flexibilities in pricing and payment options afforded by the new automated fare collection system. In cooperation with its Rider Oversight Committee, the MBTA arrived at a final proposal for this new fare structure that provides for reduced-rate intermodal transfers and incentives for smart card use, among other features. These changes have been included as part of a fare increase and restructuring proposed for early 2007.

CTPS has been asked to provide technical assistance in projecting the impacts of such a potential fare increase and restructuring, as it did in 1991, 2000, and 2004. For the 2004 fare increase, CTPS produced a report that included projections of revenue, ridership, environmental, and socioeconomic impacts, along with the impacts of alternative service reductions that would have been necessary if the fare increase was not implemented. The analyses in this report address the same issues for the 2007 proposal, utilizing the Boston Region Metropolitan Planning Organization (MPO) regional travel demand model, along with a spreadsheet estimation model for revenue and ridership impacts that was developed specifically for fare-change proposals like this one.

THE PROPOSED FARE STRUCTURE: DESCRIPTION AND RATIONALE

The Rider Oversight Committee was established in response to the previous MBTA fare increase in 2004 to better incorporate the public and advocacy voices into the planning process. At its inception, the Committee was specifically charged with reviewing the existing fare structure and, should it have any suggestions for change, discussing those suggestions with the MBTA. Most of the structural features described in this report are the result of this process.

The principal characteristics of the proposed fare structure are as follows:

- Flat fares by mode for all local bus and rapid transit trips and a reduction of express bus fare zones to two;
- A “step-up” transfer privilege between local bus, rapid transit, and express bus whereby the transfer price equals the “step-up,” or difference, in price from a lower-priced mode to a higher-priced mode, such that the customer never pays any more than the single flat fare for that higher-priced mode;
- The merging of the subway-only and combo pass categories; and
- Single-ride fare surcharges ranging from 18% to over 100% on trips not made with the new CharlieCard technology.

There are several reasons for why the Rider Oversight Committee and the MBTA decided on these changes to the fare structure. The new flat-fare-by-mode with simple “step-up” transfer privileges between local bus, rapid transit, and express bus responds to the MBTA’s enabling legislation to provide for free or substantially reduced-rate bus-rail transfers on the system. Indeed, by instituting the “step-up” transfer, the MBTA can ensure that basic transit mobility for those living beyond a walking distance of a rapid transit line remains in fiscal reach of those with the least economic means. Where currently a local bus-rapid transit transfer trip would generally cost $2.15 (and even more if the trip was made on a zoned-local bus or through an extra-fare station on the rapid transit system), the new maximum fare would actually decrease to $1.70. This logic also applies to the merging of the subway-only and combo pass categories. Whereas the current combo pass price is $71.00, the new merged pass price will be $59.00.

There is a compelling business interest in implementing this major fare restructuring requested by the Rider Oversight Committee at the same time as the institution of a new automated fare collection (AFC) system. The restructuring eliminates more than a dozen anomalies in the fare structure that are the product of various political and operating considerations over the years – many of which have little ongoing justification. It is expected that these changes will contribute to increased ridership among potential customers currently unfamiliar with the transit system who may be intimidated by the complicated fare structure. The installation of AFC equipment also permits the adoption of the “step-up” transfer privilege. As mentioned, this will lower the cost of bus-rapid transit transfer trips and thus encourage more customers to make better use of the entire MBTA system. Finally, in the interest of encouraging customers to use the CharlieCard, which is the most efficient mode of payment using AFC, the MBTA is assessing a surcharge on all single-ride trips that are not made using this fare payment mechanism. In addition, the step-up transfer privilege will only be offered to CharlieCard customers.

The proposed fare structure mirrors the most commonly used approach to pricing among peer transit agencies throughout North America. In particular, a single price is set for travel throughout an urban core on local bus and rapid transit, and rapid transit time-based pass holders receive unlimited rides on local buses as well. This approach acknowledges that, within the rapid transit and local bus service area, customers value transit service based on whether it gets them to their destination safely and efficiently – not based on the distance they travel or the transfers they make. This approach to value lies at the center of the new fare structure proposed by the MBTA and the Rider Oversight Committee.

ESTIMATION METHODS USED

Two separate approaches were used by CTPS in attempting to project the impact on MBTA ridership and revenue. The first approach consisted of applying the Boston Region MPO’s regional travel demand model to forecast demand for each MBTA mode with the present and increased fare levels. The second approach used a set of spreadsheets originally created by CTPS and the MBTA to project impacts. In the past, CTPS had used solely a spreadsheet-based approach to compute ridership and revenue impacts. The regional travel demand model was employed in this fare impacts analysis to complement the spreadsheet model, with the two models together providing some indication of the potential range of impacts that could be expected. The regional travel demand model, as in previous analyses, was used to conduct the air quality and environmental justice impact analyses.

Travel Demand Model Approach

The regional travel demand model used by CTPS simulates travel on the entire eastern Massachusetts transit and highway systems. As such, it contains all MBTA rail and bus lines and all private express bus lines. The regional travel demand model contains service frequency (i.e., how often trains and buses arrive at a given transit stop), routing, travel time, and fares for all these lines. In the highway system, all express highways, principal arterial roadways, and many minor arterial and local roadways are included.

The travel demand forecasting procedure used in this analysis is based on a traditional four-step, sequential process: trip generation, trip distribution, mode choice, and trip assignment. This process is used to estimate average daily transit ridership, primarily on the basis of estimates of population and employment, projected highway travel conditions (including downtown parking costs), and projected transit service to be provided.

The entire eastern Massachusetts geographic area represented in the regional travel demand model is divided into several hundred smaller areas known as traffic analysis zones (TAZs). This model set employs sophisticated and complex techniques in each of the four steps of the process. The following paragraphs describe very briefly what each step does.

Trip Generation

In this step, the regional travel demand model estimates the number of trips produced in and attracted to each traffic zone. To do this, the regional travel demand model uses estimates of population, employment, and other socioeconomic and household characteristics of that zone.

Trip Distribution

In the trip distribution step, the regional travel demand model links the trip ends estimated in the trip generation step to form zonal trip interchanges or movements between two zones. The output of this second step of the four-step process is a trip table, which is a matrix containing the number of trips occurring between every origin-destination zone combination.

Mode Choice

The mode choice step allocates the person trips estimated from the trip distribution step to the two primary competing modes, automobile and transit. This allocation is based on the desirability or utility of each choice a traveler faces, based on the attributes of that choice and the characteristics of the individual. The resulting output of the mode choice step is the percentage of trips that use automobiles and the percentage that use transit for each trip that has been generated.

Trip Assignment

In this final step, the regional travel demand model assigns the transit trips to different transit modes such as subway, commuter rail, local bus, or express bus. To do this, it uses multiple transit paths from one zone to another that minimize generalized cost. These paths may involve just one mode, such as a local bus or commuter rail, or multiple modes, such as a local bus and a transfer to the subway. The highway trips are assigned to the highway network. Thus, the traffic volumes on the highways and transit ridership on different transit lines can be obtained from the regional travel demand model outputs.

Population and employment data are key inputs to the demand forecasting process. The data used here were obtained from the Metropolitan Area Planning Council (MAPC). The highway travel times used in the analysis are those used in other recent CTPS transit and highway studies. Downtown parking costs are also those used in other recent studies. The regional travel demand model assumes that, in general, people wish to minimize transfers. They may also wish to minimize travel time, even if it costs more.

Spreadsheet Model Approach

The spreadsheet tools used to estimate revenue and ridership impacts of the proposed 2007 fare increase and restructuring were considerably updated from those used for the 2004 fare increase. The new spreadsheet model reflects many more of the fare complexities in the MBTA system and incorporates the ability to analyze several structural changes to MBTA pricing, many of which are included as part of the 2007 fare increase.

Inputs to these spreadsheets call for ridership to be broken down not only by mode and fare-payment method, but also by subcategories such as passengers making combination bus and rapid transit trips. These subcategories represent a finer level of detail than was pursued in recent MBTA fare-mix studies,[1] so in some cases it was necessary to make assumptions about the proportions of passengers paying full or reduced cash fares or with passes. In addition, some multimodal trips do not fit into any of the categories included in the spreadsheet. For example, although there are categories for trips using combinations of local bus and rapid transit, there are none for express bus combined with rapid transit or for local bus combined with surface Green Line. Survey results show that such trips do take place, albeit in fairly small numbers. Time constraints did not allow for modification of the spreadsheets to provide for additional categories. Therefore, ridership for such trips was generally combined with ridership in similar categories.

[1] MBTA fare-mix studies are conducted periodically as a means of determining the proportion, or “mix,” of passengers using various forms of fare payment. With this information, the average fare per passenger may be determined.

Price Elasticities

Fares are one of many factors that influence the level of ridership on transit services. Price elasticity is the measure of either the expected or observed rate of change in ridership relative to a change in fares if all other factors remain constant. On a traditional demand curve that describes the relationship between price, on the *y*-axis, and demand, on the *x*-axis, elasticities are equivalent to the slope along that curve. As such, price elasticities are generally expected to be negative, meaning that a positive price increase will lead to a decrease in demand (with a price decrease having the opposite effect). As the absolute value of the price elasticity increases, the projected impact on demand also grows. Larger (or more negative) price elasticities are said to be relatively "elastic," while smaller negative values closer to zero are said to be relatively "inelastic." Thus, if the price elasticity of the demand for transit is assumed to be elastic, a given fare increase would cause a greater loss of ridership than if demand were assumed to be inelastic.

At its most elemental level, the spreadsheet model is based on this simple price elasticity relationship, and requires four inputs: original demand, original fare, new fare, and the price elasticity. The formula for calculating new demand is the following:

$$\textit{New Demand} = \textit{Original Demand} \times [(\textit{New Fare} / \textit{Original Fare})^{(\textit{Price Elasticity})}]$$

Note that this formula uses a point elasticity to project the change in demand due to a change in price; the spreadsheet model also offers the ability to calculate demand using arc elasticities.[2] The decision was made to use point elasticities in this application in order to provide consistency with the demand forecasting methodology used in the regional travel demand model.

As an example, assume that original ridership equals 100 and that the impact that is being modeled is a 10% fare increase from \$1.00 to \$1.10. Also assume that the price elasticity is -0.25.

$$\textit{New Demand} = 100 \times [(\$1.10 / \$1.00)^{(-0.25)}] = 97.65$$

Thus, a simple price elasticity model using an elasticity of -0.25 projects that a 10% increase in price will lead to a 2.35% decrease in demand. With the fare increased from \$1.00 to \$1.10, this simplified model projects a 7.42% increase in revenue (\$100.00 to \$107.42).

[2] Point and arc elasticities are two different methods of measuring the impact on demand of price changes. Arc elasticities measure the slope on the demand curve between two points (generally the *x*-intercept and *y*-intercept) and thus assume a constant slope/elasticity throughout the curve. Point elasticities measure the slope on the demand curve at a single point, thus allowing for the possibility of different slopes along the curve, which is much more realistic. The difficulty (and reason why many analyses use arc elasticities rather than point elasticities) lies in knowing what point along the demand curve to choose.

Diversion Factors

An additional complexity – providing increased accuracy – of the spreadsheet model occurs with the use of ridership diversion factors. These factors reflect estimates of the likelihood of a switch in demand for one good to another that is related to the change in the relative prices of those goods. As an example using price elasticities and diversion factors for cash and pass customers, assume that original ridership equals 100 cash riders and 1,000 pass riders. Also assume that original prices for cash tickets and passes equal $2.00 and $100.00, respectively, and that the new prices are set at $1.50 for cash tickets and $50.00 for passes, representing price decreases of 25% and 50%. Assume that the cash price elasticity equals -0.35 and the pass price elasticity equals -0.25. Finally, assume a cash-to-pass diversion factor of 0.05 and a pass-to-cash diversion factor of 0.00. In these pairs of diversion factors, one of the factors must always equal zero, indicating that the diversion is expected to occur in one direction only. The direction of the diversion, and thus the diversion factor values, depends on the categories' respective price changes. The category with the greater respective price decrease (or the smaller respective price increase), in this case, passes, where the price decrease is 50% compared to 25% for cash tickets, would gain riders from the diversion while the other category with the smaller respective price decrease (or the greater respective price increase) would lose riders from the diversion. One would therefore expect that cash customers would switch to passes, but not that pass customers would switch to cash tickets (hence the 0.05 cash-to-pass and 0.00 pass-to-cash diversion factors).

The diversion factors essentially work to redistribute demand between the two categories after the respective price elasticities have been applied. For instance, after the cash fare is decreased from $2.00 to $1.50, the projected effect of price elasticity is that cash demand grows to 111. Similarly, the pass price decrease from $100 to $50 leads to a projected increase in pass demand, due to price elasticity, to 1,189, for a total ridership of 1,300. However, the percentage decrease in the pass price is larger than that for cash fares (50% versus 25%); thus, one would expect some customers to switch from cash to passes. This diversion is estimated by taking the ratio of new-to-original cash prices ($1.50 / $2.00, or 75%), dividing that ratio by the ratio of new-to-original pass prices ($50 / $100, or 50%), subtracting 1, and multiplying this result by the 0.05 diversion factor and the price-elasticity-estimated cash ridership (111). The number of riders "diverted" from cash to pass equals 3, giving final ridership estimates of 108 for cash and 1,192 for passes, again summing to a total ridership of 1,300.

New Cash Demand (Price Effect), $\mathbf{C^P} = 100 \times [(\$1.50 / \$2.00)^{(-0.35)}] = 111$
New Pass Demand (Price Effect), $\mathbf{P^P} = 1{,}000 \times [(\$50 / \$100)^{(-0.25)}] = 1{,}189$

Total Demand = 111 + 1,189 = 1,300

$$\textit{Diverted Riders from Cash to Pass} = \left[\left(\frac{\$NewCash / \$OldCash}{\$NewPass / \$OldPass}\right) - 1\right] \times Diversion \times \mathbf{C^P}$$

$$\textit{Diverted Riders from Cash to Pass} = \left[\left(\frac{\$1.50/\$2.00}{\$50/\$100}\right) - 1\right] \times 0.05 \times \mathbf{C}^{\mathbf{P}} = 3$$

$$\textit{New Cash Demand} = \mathbf{C}^{\mathbf{P}} - \textit{Diverted Riders from Cash to Pass} = 108$$

$$\textit{New Pass Demand} = \mathbf{P}^{\mathbf{P}} + \textit{Diverted Riders from Cash to Pass} = 1{,}192$$

$$\textit{Total Demand} = 108 + 1{,}192 = 1{,}300$$

These diversion rates are applied to specific pairs of categories, such as bus cash versus bus pass, bus cash versus subway cash, bus pass versus combo pass, etc. The rates were determined based on similar estimates of diversion factors by the New York City Transit Authority (NYCTA) and, as was the case with the NYCTA analysis, they are fairly conservative, meaning that small estimated shifts from categories with larger percent price increases (or smaller percent price decreases) to categories with smaller percent price increases (or larger percent price decreases) are expected. For example, a less-conservative diversion rate of 0.15, compared to the 0.05 rate used above, would result in a shift of 9 passengers from cash to pass, compared to 3.

Examples of Ridership and Revenue Calculations

Simple Example (Price Elasticity only)

- *Original Demand:* 100,000
- *Original Fare:* \$1.50
- *New Fare:* \$2.50
- *Price Elasticity:* -0.05

$$\textit{New Demand} = 100{,}000 \times [(\$2.50 / \$1.50)^{(-0.05)}] = 97{,}478$$

More Complex Example (Price Elasticity plus Ridership Diversion – Cash-Pass)

- *Original Cash Demand:* 10,000
- *Original Cash Fare:* \$2.25
- *New Cash Fare:* \$2.00
- *Cash Price Elasticity:* -0.30

$$\textit{New Cash Demand (Price Effect)}, \mathbf{C}^{\mathbf{P}} = 10{,}000 \times [(\$2.00 / \$2.25)^{(-0.3)}] = 10{,}360$$

- *Original Pass Demand:* 5,000
- *Original Pass Price:* \$71.00
- *New Pass Price:* \$50.00
- *Pass Price Elasticity:* -0.25

$$\textit{New Pass Demand (Price Effect)}, \mathbf{P}^{\mathbf{P}} = 5{,}000 \times [(\$50 / \$71)^{(-0.25)}] = 5{,}458$$

Total Demand = 10,360 + 5,458 = 15,818

- *% Change in Cash Price:* \$2.25 to \$2.00: -11%
- *% Change in Pass Price:* \$71 to \$50: -30%
- *Cash-Pass Diversion Factor:* 0.05
- *Pass-Cash Diversion Factor:* 0.00

Diverted Riders from Cash to Pass = $\left[\left(\frac{\$2.00/\$2.25}{\$50/\$71}\right)-1\right]\times 0.05\times \mathbf{C^p}$ = 136

New Cash Demand = $\mathbf{C^p}$ – *Diverted Riders from Cash to Pass* = 10,224

New Pass Demand = $\mathbf{P^p}$ + *Diverted Riders from Cash to Pass* = 5,594

Total Demand = 10,224 + 5,594 = 15,818

Additionally Complex Example (Price Elasticity plus two Ridership Diversions – Cash-Pass and Cash-Multiride)

- *Original Cash Demand:* 10,000
- *Original Cash Fare:* \$2.20
- *New Cash Fare:* \$3.50
- *Cash Price Elasticity:* -0.30

New Cash Demand (Price Effect), $\mathbf{C^p}$ = 10,000 × [(\$3.50 / \$2.20)$^{(-0.3)}$] = 8,700

- *Original Pass Demand:* 50,000
- *Original Pass Price:* \$71.00
- *New Pass Price:* \$90.00
- *Pass Price Elasticity:* -0.25

New Pass Demand (Price Effect), $\mathbf{P^p}$ = 50,000 × [(\$90 / \$71)$^{(-0.25)}$] = 47,122

- *Original Multiride Demand:* 5,000
- *Original Multiride Per-Trip Price:* \$2.00
- *New Multiride Per-Trip Price:* \$3.50
- *Multiride Price Elasticity:* -0.30

New Multiride Demand (Price Effect), $\mathbf{M^p}$ = 5,000 × [(\$3.50 / \$2.00)$^{(-0.3)}$] = 4,227

Total Demand = 8,700 + 47,122 + 4,227 = 60,049

- *% Change in Cash Price:* \$2.20 to \$3.50: 59%
- *% Change in Pass Price:* \$71 to \$90: 27%
- *% Change in Multiride Per-Trip Price:* \$2.00 to \$3.50: 75%

- *Cash-Pass Diversion Factor:* 0.05
- *Pass-Cash Diversion Factor:* 0.00
- *Cash-Multiride Diversion Factor:* 0.00
- *Multiride-Cash Diversion Factor:* 0.25

$$\textit{Diverted Riders from Cash to Pass} = \left[\left(\frac{\$3.50/\$2.20}{\$90/\$71}\right) - 1\right] \times 0.05 \times \mathbf{C^P} = 111$$

$$\textit{Diverted Riders from Multiride to Cash} = \left[\left(\frac{\$3.50/\$2.00}{\$3.50/\$2.20}\right) - 1\right] \times 0.25 \times \mathbf{M^P} = 106$$

New Cash Demand = $\mathbf{C^P}$ – *Diverted Riders from Cash to Pass*
+ *Diverted Riders from Multiride to Cash* = 8,695

New Pass Demand = $\mathbf{P^P}$ + *Diverted Riders from Cash to Pass* = 47,233

New Multiride Demand = $\mathbf{M^P}$ – *Diverted Riders from Multiride to Cash* = 4,121

Total Demand = 8,695 + 47,233 + 4,121 = 60,049

Note that as each additional ridership diversion factor is introduced, and more and more cells in the spreadsheet become linked, the complexity of the spreadsheet model increases significantly. However, the basic methodology explained above with regard to price elasticities and ridership diversion factors remains the same.

PRICE ELASTICITY ESTIMATION

The price elasticities used in the spreadsheet model are based in part on the MBTA's own past experiences as well as a survey of the elasticities being used in the models of peer agencies. In previous exercises to forecast the effect of price changes on ridership and revenue, the MBTA has generally done a good job at accurately projecting changes at the systemwide level. The elasticity model has been less accurate, however, with regard to projecting the specific impacts on various modes and passenger categories.

It is admittedly difficult to isolate the effects of price elasticity alone on changes in demand. Over the course of a year (in which time it is assumed the effects of price changes are largely internalized by the population), economic, demographic, and other factors may play as much, if not more of, a role in influencing transit demand than price. With these caveats, it is possible, however, to compare ridership in the year before and the year after the previous fare increase, in January 2004, to arrive at some estimation of price elasticity.[3]

[3] Note that pass prices did not increase until February 2004.

Observed Price Elasticities of the MBTA and Peer Transit Agencies

Observed Elasticity of the 2004 MBTA Fare Increase

The first step of any elasticity estimation methodology is to compute the true demand before and after the price change. The most accurate estimate of MBTA ridership comes from fare-mix studies. However, the dates of the two previous studies – 2002 and 2005 – are too far apart to provide an accurate representation of ridership changes due only to the January 2004 price increase. Given that monthly revenue information is more readily available and generally more reliable than ridership estimates, it is possible to use revenue as a proxy for ridership. With regard to cash transactions, the MBTA records monthly cash revenues for all rapid transit and surface modes. Ridership is assumed to equal the 2003 and 2004 revenue figures for each mode divided by the respective fare. For example, 2003 and 2004 bus cash revenue totaled $26.0 million and $28.5 million, respectively. By dividing these two figures by the appropriate bus cash fare – $0.75 in 2003 and $0.90 in 2004 – estimates of 34.7 million bus cash riders in 2003 and 31.6 million bus cash riders in 2004 are obtained. While revenue increased due to the fare increase, ridership is estimated to have decreased. True average fare and pass values can also be used in place of nominal prices (the actual dollar value of fares) to estimate ridership.

Price elasticity equals the ratio of the percent change in demand to the percent change in price. In the example of bus cash ridership explained above, the percent change in demand (as measured by ridership) equals -9%, while the percent change in price (as measured by the fare) equals +20%. The ratio of -9% to +20% gives a price elasticity estimate of -0.44. In performing the same analysis for rapid transit cash demand, a price elasticity of -0.42 is obtained. These numbers are significantly more elastic than those used in previous models.

An estimation of pass elasticities presents some different conclusions. While the combo pass has an elasticity of -0.32, the other major pass types all appear much more inelastic. The combo+ elasticity equals -0.15, while the bus pass elasticity equals -0.14. The average commuter rail pass price elasticity is quite inelastic at -0.04. Finally, due to an increase in the estimated demand for subway passes from 2003 to 2004, the subway pass price elasticity is actually positive. It seems unreasonable to suggest, however, that the demand for subway passes should grow in response to a price increase (which is what a positive price elasticity means). In order to arrive at a more realistic elasticity value for subway, we first note that the price elasticity for all core pass ridership categories (bus, subway, and combo) combined equals -0.09. Next, the bus pass elasticity is -0.14, and bus boardings represent 32% of total bus + subway + combo pass ridership (the ratio of bus ridership plus one-half of combo ridership to the sum of all three categories). If it were assumed that the subway pass elasticity represented the remaining 68% of this ridership, subway pass elasticity should be closer to -0.066 in order to lead to an average core pass price elasticity equal to -0.09. This is admittedly an imperfect method of arriving at an estimate of elasticity; however, it does provide an estimate that is more realistic than a positive subway elasticity.

These results lead to some general conclusions regarding the appropriate price elasticities for the MBTA to use to forecast the ridership impact of fare changes. First, it appears that a difference in price elasticities should continue to be used for the different payment categories of cash versus pass. For instance, bus elasticity was estimated to be -0.44 for cash customers, while it was estimated at -0.14 for pass customers. It is likely that a gradual shift in MBTA customers over the years from paying with cash to paying with passes (due to the convenience of paying for and with passes rather than any price effect) is responsible for some of this estimated difference. Indeed, between the 1996 and 2005 fare-mix studies, monthly pass ridership increased by 2.6%, while adult cash ridership decreased by 9.4%, indicating that some former cash customers may have switched to passes. Nevertheless, setting a difference in price elasticities between cash and pass customers is appropriate.

A second conclusion drawn from the analysis of historical demand and price changes is that price elasticities should differ between modes. In both the pass and cash modal categories, bus ridership appears to be the most elastic, followed by subway, with commuter rail being quite inelastic. Demographic patterns that have led to increases in commuter rail and subway ridership over the past decade, combined with bus ridership decreases, are likely contributors to these differences.

Comparative Elasticities Used by Peer Transit Agencies

A survey of the elasticities being used by peer transit agencies corroborates our conclusion that varying elasticities according to fare category is necessary to reach the most refined estimates of revenue and ridership changes. NYCTA, the nation's largest transit property with the greatest number of transit-dependent riders (and thus the most inelastic relationship between demand and price), uses price elasticities between -0.10 and -0.15. The fare model used by the Chicago Transit Authority (CTA), which models a system much more comparable in terms of size and ridership to that of the MBTA, uses peak price elasticities that range from -0.41 for a transit card to -0.49 for a pass to -0.56 for cash transactions. Off-peak elasticities are even higher. The model used by the Toronto Transit Commission (TTC) also employs a range of elasticities. Pass elasticities range from -0.10 to -0.30, ticket elasticities range from -0.13 to -0.38, and cash elasticities range from -0.80 to -1.35.

Data from peer agencies also seem to indicate that generally higher absolute values for elasticities are more appropriate than the MBTA has used in the past. In the previous MBTA fare impacts analysis, cash elasticities that were used ranged from -0.12 to -0.17, and pass elasticities ranged from -0.17 to -0.21. Various surveys have shown peak bus fare elasticities such as -0.32 in Spokane, Washington, and -0.21 in Los Angeles, with off-peak elasticities often twice as elastic. Peak bus and metro (subway) elasticities in London are estimated to range between -0.20 and -0.30. Summaries of public transport elasticities show short-run elasticities ranging from -0.20 to as high as -0.50, with even higher long-run estimates.

Description of Spreadsheet Elasticities

The current MBTA spreadsheet model employs many of the elements used in the models of these peer agencies. Four ranges of price elasticities are available for use in the spreadsheet model. The "Low" range generally represents the level of elasticities that the MBTA has used in previous fare modeling exercises. The "Mid" range decreases these elasticities by 0.10 (making them more elastic) and the "High" range decreases them 0.10 further. Finally, an "Extreme" range applies a price elasticity of -0.75 to most categories.

Elasticities are divided between two payment categories: "Cash" (or pay-per-ride) and "Pass." "Cash" price elasticities are assumed to be 0.05 less than "Pass" elasticities, signifying that the spreadsheet model projects "Cash" customers to be slightly more responsive to price than "Pass" customers. Elasticities are further divided into several modal categories: Bus, Subway, Combo (Bus plus Subway), Commuter Rail, Parking, Water, and THE RIDE. All modes have both a "Cash" and "Pass" price elasticity except for THE RIDE, which applies only to "Cash" customers. Generally, Bus elasticities are expected to be the most elastic, followed by Subway and Combo, then Commuter Rail and Water, THE RIDE, and, finally, Parking. The Bus price elasticity is 0.05 less than the Subway and Combo price elasticity, which is itself 0.05 less than the price elasticity used for Commuter Rail and Water. THE RIDE price elasticities are set at -0.05 and Parking price elasticities are set at -0.01 across all categories except that of "Extreme," indicating that demand in both categories, despite the range, is quite inelastic.[4]

The spreadsheet model uses the "Mid" range for price increases and the "High" range for price decreases. These ranges of elasticities are higher than previous figures used by the MBTA, but seem to better conform with the observed elasticities from previous MBTA fare increases, as well as the surveys of peer transit agencies. For example, a price elasticity of -0.30 for bus cash demand is slightly less elastic than the MBTA's observed elasticity (-0.44); however, this "Mid" range value seems to be in line with the values being reported by peer transit agencies.[5] The differences in elasticities between cash and pass and between modes also mirror the experiences of other agencies. The potential ranges of cash and pass elasticities used in the spreadsheet model are shown in Table 1.

Elasticity Sensitivity Analysis

The price elasticities used in the spreadsheet ridership and revenue projection model are perhaps the key inputs to those projections. Greater absolute numbers for elasticity (for example, 0.3 versus 0.2) will lead to a more dramatic response of riders to changes in price, which will have a corresponding impact on revenue. As described above, the elasticities used in the spreadsheet model were arrived at through an analysis of past MBTA fare increases, the experiences of peer agencies, and literature about transit fare

[4] The notably low elasticity for parking is partly due to the fact that parking demand is currently greater than capacity at many park-and-ride lots throughout the region. While higher parking prices may result in these facilities filling later than they currently do, it is likely that many would still fill up with the same number of customers.

[5] It should be noted that in the second-to-last fare increase, in 2000, the observed elasticity for the system as a whole was close to zero.

changes. This section demonstrates the extent to which the spreadsheet model is sensitive to various price elasticities.

TABLE 1
Potential Ranges of Cash and Pass Elasticities in the Spreadsheet Model

	Low	Mid	High	Extreme
Cash Elasticities				
Bus	-0.20	-0.30	-0.40	-0.75
Subway	-0.15	-0.25	-0.35	-0.75
Combo	-0.15	-0.25	-0.35	-0.75
Commuter Rail	-0.10	-0.20	-0.30	-0.75
Parking	-0.01	-0.01	-0.01	-0.25
Water	-0.10	-0.20	-0.30	-0.75
THE RIDE	-0.05	-0.05	-0.05	-0.50
Pass Elasticities				
Bus	-0.15	-0.25	-0.35	-0.75
Subway	-0.10	-0.20	-0.30	-0.75
Combo	-0.10	-0.20	-0.30	-0.75
Commuter Rail	-0.05	-0.15	-0.25	-0.75
Parking	-0.01	-0.01	-0.01	-0.25
Water	-0.05	-0.15	-0.25	-0.75

The general assumptions described above regarding elasticities and their relationships to each other are applied here. Additionally, this sensitivity analysis assumes that the elasticities for price decreases will not be more than one level above those for price increases (i.e., if price increases receive the "Low" range of elasticities, price decreases cannot receive the "High" range). Similarly, the level of elasticities for "Cash" customers can exceed those of "Pass" customers by no more than one level. Four runs of the spreadsheet model were conducted to test its sensitivity to different ranges of elasticities (see Table 2).

As seen in Table 3, the elasticity estimates used in the spreadsheet model can have a dramatic impact on the ridership and revenue projections. Note that ridership is defined as the sum of linked trips, a total that includes transfers between modes or vehicles. These transfer trips are added to the linked trip total to attain unlinked trips. The change in ridership differs by as much as 11.2 million from the first run to the fourth, which leads to differences in the revenue projections of as much as $16.2 million. The elasticity levels chosen for the final spreadsheet model projections ("Mid" elasticities for price increases and "High" elasticities for price decreases) result in revenue and ridership projections that are between the two extremes, yet are still conservative in terms of additional revenue and liberal in terms of ridership loss expected.

TABLE 2
Assumptions for Spreadsheet Model Sensitivity Analysis

	Price Increase	Price Decrease
Sensitivity Run 1		
Cash Elasticity	Low	Mid
Pass Elasticity	Low	Mid
Sensitivity Run 2		
Cash Elasticity	Mid	High
Pass Elasticity	Low	Mid
Sensitivity Run 3		
Cash Elasticity	Mid	High
Pass Elasticity	Mid	High
Sensitivity Run 4		
Cash Elasticity	High	High
Pass Elasticity	Mid	High

TABLE 3
Results of Sensitivity Analysis

	Ridership (Linked Trips)	Trips (Unlinked Trips)	Revenue
Sensitivity Run 1			
Absolute Change	-9.6 million	-8.8 million	$82.0 million
Percent Change	-3.5%	-2.7%	24.1%
Sensitivity Run 2			
Absolute Change	-13.6 million	-12.8 million	$75.8 million
Percent Change	-4.9%	-4.0%	22.3%
Sensitivity Run 3*			
Absolute Change	-16.8 million	-16.2 million	$72.1 million
Percent Change	-6.1%	-5.0%	21.2%
Sensitivity Run 4			
Absolute Change	-20.8 million	-20.3 million	$65.8 million
Percent Change	-7.5%	-6.3%	19.3%

**Sensitivity Analysis 3 ("Mid" elasticities for price increases and "High" elasticities for price decreases) was the final modeled scenario*

REVENUE AND RIDERSHIP IMPACTS

Spreadsheet Model

Information Sources and Modal Apportionment for Existing Ridership

Existing ridership (to which price elasticity figures are applied) is estimated from several sources. The MBTA 2005 Fare-Mix Study provides total system ridership. The Fare-Mix Study also breaks down total system ridership into the major modal categories (subway, surface light rail, bus, and commuter rail) as well as by the various types of payment (cash versus pass, adult, senior, student, etc.). The spreadsheet model maintains these modal distinctions, but further divides them. For instance, while the Fare-Mix Study reports total "bus" ridership, the spreadsheet model distinguishes local buses as well as local zoned routes and express routes under the "bus" category. The ridership for the two latter subcategories is estimated separately using manual station-count data, which is then subtracted from the total "bus" ridership figure in the Fare-Mix Study, the remainder of which is set equal to local bus ridership. The same is done for rapid transit, where the ridership for individual modal/fare categories, such as the Red Line South Shore branch and Braintree boardings, is calculated separately using ridecheck data and then subtracted from the total ridership associated with the "Red, Orange, Blue & Central Subway" category in the Fare-Mix Study.

The two remaining modal categories in the Fare-Mix Study are the surface Green Line and commuter rail. With regard to the surface Green Line, ridership for each of the corresponding potential trip categories was calculated separately using manual station counts and then scaled to the aggregate number in the Fare-Mix Study. Meanwhile, commuter rail zone-level and aggregate ridership data were both obtained from the Fare-Mix Study. Visitor Pass usage figures were also taken from the Fare-Mix Study and split among the 1-, 3-, and 7-day pass types.

Many of the modal/fare categories in the spreadsheet model are not directly applicable to the ridership estimates in the Fare-Mix Study. These include the Silver Line Waterfront and Washington Street, the Mattapan High-Speed Line, subway and commuter rail park-and-ride customers, water transportation, and combo riders. For each of these categories, ridership was determined separately and entered into the spreadsheet model. In the case of the Silver Line, ridership was based on the latest CTPS ridecheck information available, as was the case for the Mattapan High-Speed Line. Park-and-ride trips were estimated using parking statistics for each station from the latest CTPS parking utilization inventory. Water transportation ridership was based on the latest fiscal year ridership counts. Appropriate corrections were then made to ensure that these riders were not double-counted in multiple categories. For example, the number of park-and-ride customers at Forest Hills Station was subtracted from the aggregate totals for all subway ridership.

Combo riders were calculated separately based on assumptions about the number of passengers transferring between modes and were then subtracted from both of the corresponding single-ride categories that make up the combo trip (to avoid double-counting). For instance, the number of local bus-subway combo riders was estimated by multiplying the total bus ridership from the Fare-Mix Study by the percent of bus riders reported to transfer to the subway in the latest MBTA Bus Passenger Survey. This figure was then subtracted from the total bus ridership as well as total rapid transit ridership categories.

As an example, assume that there are 100 reported bus riders, 125 reported subway riders, and 50 reported bus-subway combo riders. In the spreadsheet model, the number of combo riders would equal 50, the number of bus-only riders would equal 100 minus 50, or 50, and the number of subway-only riders would equal 125 minus 50, or 75. The total ridership among these categories then amounts to 175 (50 + 75 + 50).

As a slightly more complicated example, assume 100 reported subway riders, 75 reported commuter rail riders, 25 reported subway-commuter rail combo riders, 30 reported commuter rail park-and-ride riders, and 10 reported subway-commuter rail combo park-and-ride riders. The methodology used to apportion ridership to each of the modal categories is demonstrated below. Since all of the subway-commuter rail combo park-and-ride riders would also have been reported under the subway, commuter rail, subway-commuter rail combo, and commuter rail park-and-ride categories, the 10 riders in this category should be subtracted from all the others. Similarly, the remaining 20 commuter rail park-and-ride riders would also have been reported under the commuter rail category, so these 20 riders should be subtracted from the commuter rail category. Finally, the 15 remaining subway-commuter rail combo riders would also have been reported under the subway and commuter rail categories, thus necessitating their subtraction from these categories.

Ridership Apportionment Methodology

	Subway-Commuter Rail Combo Park-&-Ride	Commuter Rail Park-&-Ride	Subway-Commuter Rail Combo	Commuter Rail	Subway
Reported	10	30	25	75	100

Actual	**= 10**	- 10	- 10	- 10	- 10
		= 20		- 20	
			= 15	- 15	- 15
				= 30	**= 75**
Total Actual Ridership = 10 + 20 + 15 + 30 + 75 = 150					

Projected Changes in Core System Revenue and Ridership

Projected changes in cash fare revenue and corresponding unlinked trips on the core system (rapid transit, Green Line, bus/trackless trolley) from the proposed fare increase and restructuring are shown in Table 4. The impacts on customers paying with cash on board vehicles or using stored value on CharlieTickets are generally expected to be greater than those on customers using CharlieCards, given the surcharge placed on non-

CharlieCard fares. Particularly in the core system, where the step-up transfer discount is allowed only when fares are paid using a CharlieCard, customers paying by other means will be subject to the steepest fare increases. As such, the number of customers using cash or CharlieTickets to pay for their ride is expected to decline the most dramatically. Surface Green Line customers will also experience a larger proportional fare increase due to the elimination of free outbound fares on all surface lines. The impact of charging fares in the outbound direction is mitigated somewhat by the institution of one flat fare on all branches and the removal of distance-based fares on the D Branch.

All monthly passes are valid on more than one mode, so pass ridership changes by mode are more difficult to calculate than cash-fare changes. Changes in sales of any given pass form could reflect shifts to or from the use of other pass forms or cash fares rather than actual ridership gains or losses. Most passengers obtaining monthly Bus, Subway, Combo, or Combo Plus passes use them mostly on core system service, but the latter three forms are also valid for travel between the downtown Boston commuter rail stations and stations in commuter rail Zones 1A or 1B. The spreadsheet model does attempt to account for these shifts through the use of ridership diversion factors.

TABLE 4
Core System Cash/Stored Value Fare Revenue and Ridership
Before and After Fare Increase and Restructuring

	Annual Total Fare Revenue			**Annual Fare Rides (Unlinked Trips)**		
Mode	Existing	Projected	% Chg.	Existing	Projected	% Chg.
Rapid Transit and Central Subway	$75.8 m	$96.1 m	+26.8%	65.9 m	61.4 m	-6.9%
Surface Green Line	11.6 m	17.1 m	+47.7%	16.4 m	13.8 m	-16.0%
Bus and Trackless Trolley	22.0 m	29.5 m	+34.1%	48.2 m	44.5 m	-7.8%
Total	**$109.3 m**	**$142.7 m**	**+30.5%**	**130.5 m**	**119.6 m**	**-8.4%**

Projected changes in pass revenue and corresponding unlinked trips on the core system due to the proposed fare increase and restructuring are shown in Table 5. Compared to single-ride customers paying with cash on board vehicles or using stored-value CharlieTickets, pass customers are expected to bear a smaller share of the burden of the fare increase. As was stated earlier, the largest revenue impact is in the Surface Green Line category, due to the elimination of free outbound fares. This is expected to lead many customers to switch from single-ride cash fares to passes. Due to a smaller overall percentage increase in pass prices, a lesser impact on revenue and ridership was projected in the pass category. Also lessening the revenue gains and ridership losses for passes in the core system is the introduction of the LinkPass, which will provide benefits equivalent to the previous Combo and Combo+ passes, at a lower price than currently charged for those passes.

TABLE 5
Core System Monthly Pass Revenue and Ridership
Before and After Fare Increase and Restructuring

	Annual Total Pass Revenue			**Annual Pass Rides (Unlinked Trips)**		
Mode	Existing	Projected	% Chg.	Existing	Projected	% Chg.
Rapid Transit and Central Subway	$73.4 m	$83.8 m	+14.2%	89.5 m	87.4 m	-2.4%
Surface Green Line	6.3 m	9.2 m	+47.0%	13.9 m	12.8 m	-8.4%
Bus and Trackless Trolley	28.5 m	29.7 m	+4.2%	53.2 m	52.0 m	-2.3%
Total	**$108.1 m**	**$122.6 m**	**+13.5%**	**156.6 m**	**152.1 m**	**-2.9%**

Projected Changes in Non-Core System Revenue and Ridership

Projected changes in cash fare revenue and unlinked trips outside of the core system (express bus, commuter rail, ferry services, and THE RIDE) from the proposed fare increase and restructuring are shown in Table 6. As was the case with the core system, the impacts on customers paying with cash are generally expected to be greater than for pass customers. Unlike the core system, however, where surcharges result in a significant increase in price for customers paying with cash on-board vehicles or using CharlieTickets, the difference in impacts for express buses, commuter rail, and boats is due mainly to the relative increase in cash and pass prices. This is because the installation of automated fare-collection (AFC) technology is not scheduled to occur for these modes with the exception of express buses by the time the fare increase and restructuring would take effect.

Commuter rail contributes the bulk of the ridership and revenue outside of the core system. The percentage increase in single-ride cash prices is slightly less than in the core, and this is one of the reasons for the smaller percentage increase in commuter rail fare revenue. However, the ridership loss for commuter rail is also projected to be less than in the core, due in part to its smaller percentage fare increase but also to the spreadsheet model's assumption of smaller elasticities for commuter rail customers. Ridership and revenue for express bus and ferry service are projected to remain relatively consistent, since the fares for these modes were either unchanged (in the case of commuter boats) or restructured (in the case of express buses and inner-harbor ferries). This restructuring was designed to provide simpler pricing and to result in smaller overall fare increases.

Projected changes in pass revenue and unlinked trips outside the core system as a result of the proposed fare increase and restructuring are shown in Table 7. As was the case with the core system, the smaller percentage price increases in commuter rail passes compared to cash fares leads to a smaller revenue gain and less ridership loss. The effective lowering of pass prices for some express bus customers and inner-harbor ferry customers leads to projected revenue losses and ridership gains for these modes.

TABLE 6
Non-Core System Cash/Stored Value Fare Revenue and Ridership
Before and After Fare Increase and Restructuring

	Annual Total Fare Revenue			**Annual Fare Rides (Unlinked Trips)**		
Mode	Existing	Projected	% Chg.	Existing	Projected	% Chg.
Express Bus	$ 1.6 m	$ 1.7 m	+2.9%	1.0 m	1.0 m	+0.8%
Commuter Rail	42.7 m	52.4 m	+22.8%	9.9 m	9.5 m	-3.6%
Ferry Services	4.9 m	5.0 m	+0.6%	1.0 m	1.0 m	-0.9%
THE RIDE	2.4 m	2.7 m	+10.0%	1.3 m	1.3 m	-0.7%
Total	**$51.7 m**	**$61.7 m**	**+19.5%**	**13.2 m**	**12.9 m**	**-2.7%**

TABLE 7
Non-Core System Pass Revenue and Ridership
Before and After Fare Increase and Restructuring

	Annual Total Pass Revenue			**Annual Pass Rides (Unlinked Trips)**		
Mode	Existing	Projected	% Chg.	Existing	Projected	% Chg.
Express Bus	$1.0 m	$0.9 m	-12.8%	0.8 m	0.9 m	+11.9%
Commuter Rail	$67.9 m	$82.1 m	+20.9%	19.9 m	19.5 m	-2.4%
Ferry Services	$0.9 m	$0.9 m	-1.1%	0.2 m	0.2 m	+3.2%
Total	**$80.2 m**	**$96.5 m**	**+20.1%**	**21.0 m**	**20.6 m**	**-1.8%**

Travel Demand Model

Projected Changes in System Revenue and Ridership

The changes in systemwide cash fare and pass revenue and unlinked trips from the proposed fare increase and restructuring, as projected using the travel demand model, are shown in Table 8. Aside from commuter rail, the change in unlinked trips projected by the travel demand model for all modes is quite modest. Trips on bus and ferry were actually projected to increase under the fare increase and restructuring scenario. Revenue is projected to increase by 18.4% systemwide.

Comparison of Spreadsheet and Travel Demand Models

Although the spreadsheet and travel demand models use two different methods to arrive at their forecasts for ridership and revenue, the numbers generated by each are justifiable. Indeed, differences between the models' results – so long as they are not extreme – may serve as indicators of the range of impacts the MBTA might expect from the fare increase and restructuring.

TABLE 8
System Fare and Pass Revenue and Ridership
Before and After Fare Increase and Restructuring

	Annual Total Fare and Pass Revenue			**Annual Rides (Unlinked Trips)**		
Mode	Existing	Projected	% Chg.	Existing	Projected	% Chg.
Rapid Transit				265.3 m	260.2 m	-1.9%
Bus and Trackless Trolley				104.5 m	107.7 m	+3.1%
Commuter Rail				32.3 m	27.1 m	-16.1%
Express Bus				11.7 m	11.8 m	0.7%
Ferry				0.2 m	0.1 m	-8.6%
Total	**$368.8 m**	**$436.9 m**	**+18.4%**	**414.0 m**	**406.9 m**	**-1.7%**

Table 9 presents the ridership and revenue estimates of both models under the existing conditions as well as the projected fare increase and restructuring scenario. The table compares the absolute numbers generated by the models as well as the percentage changes expected for each measure.

Projected Changes in Revenue and Ridership

The two models' estimations of linked trips under existing conditions are close to one another, with slight differences resulting from the methodologies associated with each. As described earlier, the spreadsheet tool estimates ridership based on recent MBTA revenue reports and specific average fare factors for each mode. The travel demand model is calibrated to represent existing ridership as close to revenue-based ridership estimations as possible, but also must take into account the relative proportions of trips made regionwide via transit and other modes, in accordance with household survey, U.S. Census, and other demographic data. The two forecasting tools also use different approaches to estimating current fare revenue, with the spreadsheet model's estimates based on the most recent MBTA revenue collection reports and the travel demand model deriving revenue from average fare factors applied to estimated ridership.

While the difference between the models' estimates for linked trips lies below 5.0%, the two estimates for unlinked trips differ by 22.2%. There are several likely reasons for this difference. First, the travel demand model, unlike the spreadsheet model, includes ridership for non-MBTA regional transit agencies. Many of these trips, and particularly those that are oriented towards Boston commuting, likely necessitate a transfer upon arrival to or departure from Boston, thus inflating the unlinked trip total for the regional travel demand model. A second reason for the higher estimate of transfers (1.42 transfers per linked trip for the travel demand model versus 1.16 for the spreadsheet model) lies with the travel demand model's assumption of unconstrained parking. Removing parking capacity as a constraint to trip decisions helps to more clearly elicit the effect of prices on travel demand; however, this also results in many more park-and-ride trips from lesscostly commuter rail stations that are close to the urban core than from the relatively more expensive parking lots at rapid transit stations. Since commuter rail riders are more likely to transfer to another mode as part of their trip, this assumption further increases the travel demand model's estimate of unlinked trips.

Notable differences are also shown in the percentage changes projected by the two forecasting tools for both ridership and revenue. In particular, the spreadsheet model projects that the fare changes will result in a greater ridership loss – 5.0% for unlinked trips and 6.1% for linked trips. The travel demand model estimates losses of 1.7% and 2.8%, respectively. This effect is likely due in part to the multimodal scope of the travel demand model and its assumption that all trips currently made in the region (regardless of mode – auto, transit, walking, etc.) will continue to be made after a fare change.

Whereas the travel demand model starts with a set number of trips and then distributes these trips to various modes such as driving or transit, thus conserving the total number of trips in the region, the spreadsheet model only considers transit trips and the cost of those trips in isolation. It does not consider the relative costs of driving versus transit. For any given price increase in the spreadsheet model, the use of price elasticities will lead to a percentage decrease in demand, regardless of whether it may or may not be truly feasible for someone to switch from transit to driving, for example. On the other hand, the travel demand model's conservation of the total number of trips does not account for the overall decrease in travel that would be expected to realistically occur when the price for that travel increases. This conservation in effect lowers the sensitivity of transit riders with respect to the overall price of transit, which is the likely reason for the lower percentage changes projected by the travel demand model compared to the spreadsheet model. However, given the uncertainty associated with forecasting demand, the two models provide what could be considered a reasonable range of estimates for the impact on ridership of the price increase and restructuring.

Estimates of revenue changes range from 18.4% for the travel demand model to 21.2% for the spreadsheet model. This result is somewhat counterintuitive, given that the ridership decrease projected by the spreadsheet model is much greater. However, as noted above, the travel demand model projects a substantially greater loss in commuter rail ridership than the spreadsheet model. Since commuter rail riders pay much higher fares, on average, than rapid transit or bus riders, and since they use park-and-ride facilities at a higher rate than bus and rapid transit users, their contribution to the travel demand model's projected revenue loss is substantial.

Overall, the results of the spreadsheet and travel demand models appear to fall within a reasonable range of variability. In terms of absolute figures, the range of the projected revenue increase as a result of the proposed fare changes and restructuring is between approximately $68 million and $72 million per year, and passenger boardings are projected to decrease by 7.1 million to 16.1 million per year, or approximately 24,500 to 55,500 per typical weekday. What differences there are in these ranges can be explained in large part by certain assumptions used for each model with regard to elasticities, trip conservation, and transfer activity.

TABLE 9
Comparison of System Revenue and Ridership
Before and After Fare Increase and Restructuring

Indicator	Existing: Travel Demand Model	Existing: Spreadsheet Model	Existing: Difference	Projected: Travel Demand Model	Projected: Spreadsheet Model	Projected: Difference	Projected Change: Travel Demand Model	Projected Change: Spreadsheet Model
Linked Trips	290.9 m	276.7 m	-4.9%	282.9 m	260.0 m	-8.1%	-2.8%	-6.1%
Unlinked Trips	414.0 m	322.1 m	-22.2%	406.9 m	306.0 m	-24.8%	-1.7%	-5.0%
Transfers per Linked Trip	1.42	1.16	-18.2%	1.44	1.18	-18.2%	+1.1%	+1.1%
Fare Revenue	$368.8 m	$340.3 m	-7.7%	$436.9 m	$412.4 m	-5.6%	+18.4%	+21.2%
Fare Revenue per Linked Trip	$1.27	$1.23	-3.0%	$1.54	$1.59	+2.7%	+21.8%	+29.0%
Fare Revenue per Unlinked Trip	$0.89	$1.06	+18.6%	$1.07	$1.35	+25.6%	+20.5%	+27.6%

AIR QUALITY IMPACTS

The air quality impacts of alternative transportation scenarios can be analyzed using standard traffic forecasting models, including the one maintained by the Boston Region MPO. These models can be used to estimate future traffic volumes, average highway speeds, vehicle miles, and vehicle hours traveled within the transportation network at a highly disaggregate level. Since the amount of air pollution emitted by highway traffic depends on the prevailing highway speeds and vehicle miles traveled, it is possible to estimate these air quality impacts with reasonable accuracy.

Air pollutants produced by highway traffic generally fall into two groups: gaseous and particulate pollutants. Examples of gaseous pollutants include carbon monoxide (CO), unburned hydrocarbons (HC), nitrogen oxides (NOx), and sulfur oxides (SOx). In addition, photochemical oxidants are not directly emitted from vehicles but are formed when HC and NOx chemically react in the presence of sunlight and warm temperatures. Particulate pollutants include carbon particles and lead compounds. In the case of Boston, which is in attainment for particulate emissions, the U.S. Environmental Protection Agency (EPA) is primarily interested in the gaseous pollutants produced by the transportation sector. More particularly, the EPA requires that planning agencies report the amount of CO, NOx, and VOC (volatile organic compounds) produced by the transportation system in such documents as the Transportation Improvement Program and the Regional Transportation Plan.

CTPS employs EPA MOBILE 6.2 emission factors[6] for calculating the pollutants. For each link within the highway network, the travel demand model applies the MOBILE 6.2 emission factors corresponding to the link's average speed and estimates the pollutants based on the vehicle miles traveled on that link. The amount of total pollutants for the entire region is obtained by summing all the pollutants associated with each link in the system.

Results of the Travel Demand Model Application

With respect to the proposed fare increase and restructuring, the air quality impacts are primarily those associated with existing transit users choosing to drive to their destinations instead of using transit. These additional automobile trips generate pollutants that can be measured in kilograms of carbon monoxide, nitrogen oxides, and volatile organic compounds, as discussed in the previous paragraph. It should be noted as well that as the number of automobile trips increases, so does congestion on area roadways. This additional congestion results in lower travel speeds for all automobiles – not just those of former transit users.

After the ridership impacts of the fare increase and restructuring were calculated as described in the first section of this memo, the Boston regional travel demand model was used to estimate the change in regional automobile vehicle miles and vehicle hours traveled. Specifically, the travel demand model identifies the path of each automobile trip made by former transit users and also estimates the travel times for all automobile

[6] Kilograms of pollutant per vehicle mile traveled.

trips. These data were applied to emission factors provided by the EPA that are associated with each of the three pollutants identified above. As shown in Table 10, the projected regional increase in each of these pollutants is below 0.3%. Any loss in transit ridership that results in a gain in vehicle miles and hours traveled will lead to an increase in pollutants. However, given that the margin of error associated with the model is likely larger than the estimated increase, the actual change could be negligible.

TABLE 10
Projected Weekday Increases in Selected Pollutants (Regionwide)

Indicator	Absolute Increase	Percent Increase
Vehicle Miles Traveled	252,484	0.212%
Vehicle Hours Traveled	14,553	0.389%
Carbon Monoxide	4,026 kg	0.213%
Nitrogen Oxides	475 kg	0.219%
Volatile Organic Compounds	226 kg	0.274%

ENVIRONMENTAL JUSTICE IMPACTS

Definition of Environmental Justice Neighborhoods

To assess the impacts of the potential 2007 fare increase and restructuring on minority and low-income communities, an environmental justice impacts analysis was undertaken. Environmental justice neighborhoods were identified based on a methodology developed from Federal Transit Administration guidance to the MBTA's ongoing Title VI program and past practice of the Boston Region MPO. First, the income levels and percentages of minority populations in all traffic analysis zones (TAZs) in the region were identified. Low-income TAZs were then defined as areas with income levels at or below 75% of the MBTA service area median household income ($41,850). Minority TAZs are those in which the non-white or Hispanic population is greater than the average for the MBTA service area (approximately 20%). Any TAZ which qualifies as either minority or low-income is considered an environmental justice community.

Equity Determination of Proposed Fares

After identifying the minority and low-income communities, the equity of the system's fare structure and levels was assessed, in terms of both the existing and proposed conditions, using the Boston Region MPO's regional travel demand model. Under the current fare structure, the average fare for low-income TAZs is estimated to be $1.15, which is $0.04 below the systemwide average[7] of $1.19. The estimated average fare for minority TAZs is lower, at $1.11. Under the proposed fare increase and restructuring, the

[7] "Systemwide" refers to the entire modeled area of the regional travel demand model, which encompasses the entire bus, rapid transit, and commuter rail networks.

average fares for low-income and minority TAZs are estimated to be $1.43 and $1.38, respectively, while the systemwide average is estimated to be $1.46. Table 11 compares these average fare values and Table 12 compares the monetary increases associated with each category.

TABLE 11
Existing and Proposed Average Fares for Environmental Justice TAZs

	Existing Average Fare	Proposed Average Fare
Low-income TAZs	$1.15	$1.43
Minority TAZs	1.11	1.38
Systemwide Average	1.19	1.46

Table 11 indicates that the proposed fare structure and fare levels, as well as the current structure and prices, do not place a disproportionate burden on environmental justice communities. Indeed, low-income and minority TAZs pay lower average fares than the systemwide average. In moving from the existing to the proposed fare structure, as shown by Table 12, the difference between the monetary increase in average fares paid by low-income and minority TAZs and the systemwide average is less than $0.012. Since these differences are approximately equal for each of the three categories shown in Table 12, the proposed fare structure maintains lower fares on average for environmental justice communities. Note that pass users typically pay lower average fares than customers who pay for one ride at a time. This benefits the MBTA's most committed ridership and those who are transit-dependent.

TABLE 12
Projected Absolute Changes in Fares for Low-Income and Minority TAZs

	$ Change in Fare
Low-income TAZs	+$0.281
Minority TAZs	+ 0.273
Systemwide Average	+ 0.269

Comparative Percentage Changes in Average Fare

While the proposed fare structure clearly does not place a disproportionate burden on environmental justice communities, as described above, one may note that when the absolute price changes shown in Table 12 are converted to percentage changes, minority and low-income neighborhoods appear to experience slightly higher impacts than the system as a whole. The systemwide increase in revenue per trip projected by the travel demand model equals 22.5%, while the percentage change estimated for low-income TAZs is 24.4% and for minority TAZs is 24.7%. However, these differences should be understood with two qualifications.

First, since the existing average fare for environmental justice communities is lower than the systemwide average, the nearly equal *absolute* price increases shown in Table 12 will affect these environmental justice communities relatively more on a *percentage* basis. Second, even though the regional travel demand model has no defined margin of error, it is reasonable to assume that such differences, or at least part of such differences, may lie within the inevitable error of a model trying to predict human behavior. This margin of error applies as much to the average fare values shown in Tables 11 and 12 as to the differences in the percentage changes.

In an effort to better understand the cause of this difference in percentage changes, several attempts were made to reduce or eliminate them by modeling variations on the proposed fare structure. None of these attempts was entirely successful, either alone or in combination, at eliminating them; however, each did have the effect of lowering the absolute changes in average fares for environmental justice communities, and therefore, the percentage changes as well. Reducing rapid transit prices from the original proposal, for example, did reduce the percentage differences slightly. This is because there is a greater proportion of environmental justice TAZs than systemwide TAZs within a one-mile radius of rapid transit stations. Thus any decrease in rapid transit prices will affect environmental justice communities relatively more than the system, thereby reducing, but not eliminating, the difference between their estimated percentage change in average fare and that of the system as whole.

The inability of price adjustments to totally eliminate the modeled differences in percentage increases suggests that the proposed structural changes to fare payment categories, irrespective of any price increases, may be contributing factors. It should be noted that several aspects of the proposed fare structure were incorporated to promote equity upon recommendations of the MBTA Rider Oversight Committee. These new features actually appear to result in relatively higher percentage price changes for environmental justice communities, according to the model. The step-up transfer, for example, was intended by the Rider Oversight Committee to eliminate the perceived penalty faced by riders who live beyond a reasonable walking distance to rapid transit and must therefore transfer between bus and rapid transit. Under the current fare structure, these residents pay a bus fare plus a rapid transit fare, for a total of $2.15, when transferring. The step-up transfer will lower the cost of this trip to $1.70, undoubtedly benefiting many transit-dependent low-income and minority residents, especially those in sections of Dorchester (such as the Grove Hall and Four Corners neighborhoods) and all of the City of Chelsea, who tend to transfer between bus and rapid transit.

However, the regional travel demand model projections suggest that this transfer privilege would actually benefit non-low income and non-minority communities more (since a greater *proportion* of non-environmental justice TAZs lie outside the radius of rapid transit stations that is considered to be a reasonable walking distance by the model). In addition, the elimination of premium fare zones on the rapid transit system in Newton, Quincy, and Braintree was intended by the Rider Oversight Committee to simplify the fare structure and make it easier to understand. However, the model projects that this simplification would provide greater benefits to residents of non-low income and non-minority TAZs, thus lowering the systemwide average percentage increase in comparison to that of environmental justice TAZs.

While these efforts to explore various adjustments to the proposed fare structure are instructive, no changes are ultimately necessary in the context of environmental justice or Title VI considerations. First, the results shown above in Tables 11 and 12 clearly indicate that environmental justice communities will continue to pay average fares that are less than the systemwide average, even after the implementation of the proposed fare increase and restructuring. Second, each of the potential adjustments suggested above is inconsistent with the intent of the proposed structural changes to create a simpler and fairer pricing system. In particular, the proposed step-up transfer responds to the legal mandate included in the MBTA enabling legislation to provide free or substantially reduced transfers between bus and rapid transit. This was a key component of the MBTA's discussions regarding the fare structure with the Rider Oversight Committee, whose participation and recommendations consistently emphasized a concern for equity. Per those recommendations, a single fare of $1.70 will now allow one to travel from one end of the core network to the other on any combination of bus or rapid transit routes: one trip equals one fare.

SERVICE REDUCTIONS IN LIEU OF A FARE INCREASE

Earlier this year, MBTA Service Planning was asked to identify a list of service reductions that could be implemented in the event that the potential 2007 fare increase and restructuring are not approved. While these reductions would not generate nearly the level of cost savings necessary to fully offset the loss of new revenue, they represent to MBTA Operations the maximum cuts that could be tolerated without a substantial degradation in regional transit mobility.

Potential service reductions were divided into the following seven categories:

- Eliminate 20 highest net-cost-per-passenger bus routes;
- Reduce weekend light rail, heavy rail and bus service by 50%;
- Reduce weekday evening light rail, heavy rail, and bus service by 50%;
- Stretch weekday subway headways for a savings of $2.8 million;
- Reduce weekday evening, Saturday, and Sunday commuter rail service by 50%;
- Eliminate RIDE van service to Framingham, Natick, Concord, Nahant, Beverly, Wenham, Danvers, Middleton, and Topsfield; and
- Eliminate the Suburban Transportation Program.

These reductions would result in a total projected savings of $57 million and an annual ridership loss of 18 million (see Table 13).

Elimination of 20 Least Cost-Effective Bus Routes

This category of service reductions would completely eliminate service on the 20 least cost-effective bus routes in the system. The impacts would be most acute in North Shore communities, which would see the elimination of seven bus routes. More specifically, all bus service to Peabody, Danvers, and large portions of Salem and Lynn would no longer operate. Also under this scenario, Newton Centre and Newton's Oak Hill neighborhood would be left without bus service, and certain local bus routes in Jamaica Plain and

Quincy, which primarily serve as circulator routes for senior citizens and students, would also be eliminated. Local route service to parts of Cambridge, Arlington, and Lexington would be discontinued. Express bus service from parts of Waltham, Woburn, and Medford to Boston would be discontinued. Early morning service from Roxbury and Dorchester, which brings residents to jobs at Logan Airport, would be discontinued. Bus service connecting North Station to the South Boston waterfront would also end.

Table 13 details the potential savings from each of these bus routes, as well as the number of riders that would likely be lost.

50% Reduction in Weekend Rapid Transit and Bus Service

The next category of service cuts analyzed in the event that a fare increase is not approved is a 50% reduction in weekend rapid transit and bus service. This would result in a significant increase in average waiting time for the Red, Green, Orange, and Blue lines on Saturdays and Sundays. For example, on the Red Line Braintree Branch on Sundays, the current service frequency of every 14 minutes would be stretched to nearly 21 minutes. Waiting times for bus service would vary greatly by route; however, many routes would have service frequencies worse than one bus per hour if weekend service is reduced 50% across the board.

A 50% reduction in Saturday bus service is expected to result in a loss of 35,000 riders per Saturday, or 26% of all Saturday bus riders. A 50% reduction in Sunday bus service is expected to result in a loss of 34,000 riders per Sunday, or 32% of all Sunday bus riders.

A 50% reduction in Saturday rapid transit service is expected to result in a loss of 58,300 riders per Saturday, or 20% of all Saturday rapid transit riders. A 50% reduction in Sunday rapid transit service is expected to result in a loss of 47,500 riders per Sunday, or 20% of all Sunday rapid transit riders.

50% Reduction in Weekday Rapid Transit and Bus Service After 9:00 PM

In addition to the potential reductions in weekend service, the analysis also includes reducing service by 50% on weekdays after 9:00 PM. Again, this would result in a significant amount of time between scheduled trips on the Red, Orange, Blue, and Green lines. For example, on the Orange Line during late weekday evening hours, the current service frequency of every 15 minutes would be stretched to over 20 minutes.

TABLE 13
Twenty Highest Net-Cost-per-Passenger Bus Routes

Route		Incremental Weekday Gross Cost	Wkdy. Riders	Net Fully Allocated Cost/Pass.	Annual Ridership Loss	Annual Net Cost Savings
4	North Station-World Trade Ctr.	$1,510	271	$ 4.97	67,479	$ 335,371
48	Centre & Eliot Sts.-JP Loop	751	101	6.84	25,149	172,019
52	Dedham Mall-Watertown Yard	3,856	640	5.07	159,360	807,955
76	Hanscom AFB-Alewife	4,365	626	6.02	155,874	938,361
78	Arlmont-Harvard	6,073	1,135	4.47	282,615	1,263,289
171	Logan Airpt.-Dudley	129	21	4.28	5,229	22,380
217	Quincy Center-Ashmont	1,473	207	6.52	51,543	336,060
245	Quincy Center-Mattapan	2,026	407	4.38	101,343	443,882
325	Elm St-Haymarket	2,432	359	4.90	89,391	438,016
351	Bedford Woods-Alewife	1,581	180	6.91	44,820	309,706
354	Woburn-Boston	5,574	802	4.10	199,698	818,762
435	Liberty Tree Mall-Central Sq. Lynn	3,348	536	5.65	133,464	754,072
436	Liberty Tree Mall-Central Sq. Lynn	3,705	686	4.80	170,814	819,907
439	Nahant-Central Sq. Lynn	1,038	66	15.13	16,434	248,646
448 /449	Marblehead-Downtown Crossing	1,965	257	4.79	63,933	306,748
451	North Beverly-Salem Depot	1,843	227	7.52	56,523	425,053
456	Salem Depot-Central Sq. Lynn	805	100	4.63	24,900	115,287
465	Liberty Tree Mall-Salem Depot	1,820	290	5.68	72,210	410,153
468	Danvers Sq.-Salem Depot	179	17	9.93	4,233	42,034
505	Cent. Sq., Waltham-Downtown Boston	7,023	896	4.99	223,104	1,113,289
	Total		**7,824**		**1,948,116**	**$10,120,990**

A 50% reduction in rapid transit service after 9:00 PM on weekdays would result in an overall loss of 20.5% of the riders who have been traveling at those times. In absolute terms, this would be about 8,400 riders per weekday.

Stretch Weekday Rapid Transit Headways

Lengthening peak headways by removing one train set from each time period before 9:00 PM on weekdays is projected to result in a ridership loss of about 3%. This equates to about 14,000 riders per weekday.

50% Reduction in Commuter Rail Service on Weekdays After 9:00 PM and on Weekends

In conjunction with the bus and rapid transit service cuts described above, the analysis includes even more substantial cuts in commuter rail service, should the 2007 fare increase not be approved. In particular, half of all commuter rail trips on weekdays after 9:00 PM and half of all weekend trips would be eliminated. On most lines, this would result in only one outbound trip operating from Boston after 9:00 PM on weekdays, and the typical two-hour frequency for weekend service would be stretched to four hours. At the extreme, stations along the Fitchburg Line beyond South Acton Station, and the entire Haverhill/Reading Line, would be left with only two to three trips on Saturday and Sunday.

A 50% reduction in commuter rail service after 9:00 PM on weekdays would result in an overall loss of 32.5% of the riders who have been traveling at those times. In absolute terms, this equates to about 890 riders per weekday. A 50% reduction in commuter rail weekend service would be expected to reduce weekend ridership by around 33%. This would be a loss of about 9,300 riders per Saturday and 5,100 per Sunday.

Elimination of THE RIDE Service in Natick, Framingham, Concord, Nahant, Beverly, Wenham, Danvers, Middleton, and Topsfield

THE RIDE service in Natick, Framingham, Concord, Nahant, Beverly, Wenham, Danvers, Middleton, and Topsfield would be eliminated. Since there is no local transit service directly operated by the MBTA in Natick, Framingham, Concord, Wenham, Middleton, and Topsfield, and since directly operated service in Nahant, Beverly, and Danvers would be eliminated because those routes are among the 20 worst-performing bus routes, the MBTA would not be legally obligated to operate THE RIDE service there.

Elimination of Suburban Transportation Program

The Suburban Transportation Program, which provides partial funding for local municipal bus services in Beverly, Bedford, Burlington, Framingham, Natick, Dedham, and Needham, as well as the Mission Hill Link bus, would be discontinued. Participating communities would be obligated to obtain additional funding from other sources or discontinue these local circulator and commuter rail feeder bus services. The total annual ridership on these bus routes is 400,000.

TABLE 14
Projected Revenue and Ridership Impacts of Service Reduction Scenarios

Potential Service Reduction	Amount Saved (millions)	Annual Ridership Loss
Eliminate 20 highest net-cost-per passenger bus routes	$10.1	1,948,116
Reduce weekend light rail, heavy rail, and bus service by 50%	23.0	9,089,600
Reduce weekday evening light rail, heavy rail, and bus service by 50%	4.2	2,091,600
Stretch weekday subway headways	2.8	3,486,000
Reduce weekday evening, Saturday, and Sunday commuter rail service by 50%	11.8	970,410
Eliminate RIDE van service to 9 communities	1.5	68,930
Eliminate the Suburban Transportation Program	0.5	400,000
Total	**$53.9**	**18,054,656**