ESTIMATING COMMUTER RAIL DEMAND TO KENDALL SQUARE ALONG THE GRAND JUNCTION CORRIDOR

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Abstract

Since acquiring the Grand Junction Railroad in June 2010 from CSX, the Massachusetts Bay Transit Authority (MBTA) has explored the possibility of using the line for commuter rail service. In addition the Grand Junction right-of-way has been the subject of other proposals, including a multi-use path by the City of Cambridge and a Bus Rapid Transit (BRT) line as part of the MBTA's Urban Ring study.

In September of 2010, our team was asked to examine the possibility of adding passenger service along the Grand Junction Railroad in Cambridge, MA. This new service would allow the current Worcester/Framingham commuter rail line to serve both North and South stations. In response, we performed an analysis based on the existing conditions of the railroad and projected future growth of the Kendall Square business area.

To perform this analysis a demand model was developed using the 2010 MIT Transportation Survey and 2000 Census Bureau Journey to Work data. The demand model was used to forecast ridership on the Grand Junction Railroad, for multiple alternatives which included the addition of a commuter rail station at Kendall Square, use of diesel multiple units to improve frequency, and a short high frequency route starting at Auburndale.

The results of the analysis demonstrate that a high frequency service from Worcester along the Grand Junction Corridor attracts the most riders, approximately 1,800 peak morning commuters. With the Auburndale service and lower frequency Worcester trains having moderate ridership estimates. This forecast combined four types of riders: new inbound riders to Kendall Square, redirected inbound riders to Kendall Square, new inbound riders to Boston, and redirected reverse riders from North Station.

In addition to demonstrating how the demand model and the rider survey dataset were developed this report provides a framework for a more detailed study into potential uses for passenger service along the Grand Junction Railroad.

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Chapter 1

Project Description

The Grand Junction rail corridor passes through Cambridge, Massachusetts. It is the sole connection between the northern and southern halves of the Boston area commuter rail network, and is currently used for non-revenue commuter rail equipment movements and very limited freight service. In this thesis we explore the demand for commuter rail service along the corridor and estimate ridership for several service alternatives. This thesis is part of a larger assessment of Grand Junction commuter rail service contained within [30] and [3].

Boston has a radial commuter rail network with trains from the northwest and north terminating at North Station and trains from the west, southwest, and south terminating at South Station, as shown in Figure 1-1. This effectively creates two separate commuter rail systems. It also creates a disutility for commuters who begin their trips in the south with destinations in the north: those passengers must transfer downtown to the subway system (known as the 'T'), the bus network, or some other mode to complete their journey. The only connection between the southern and northern systems is the Grand Junction railroad.

Figure 1-2 shows the Grand Junction railway. On the western end it connects with the Massachusetts Bay Transportation Authority (MBTA) Worcester/Framingham line, which runs from Worcester to South Station as shown in Figure 1-3. On the eastern end the Grand Junction connects with the MBTA Fitchburg/Acton line. North Station is a short distance from the junction.

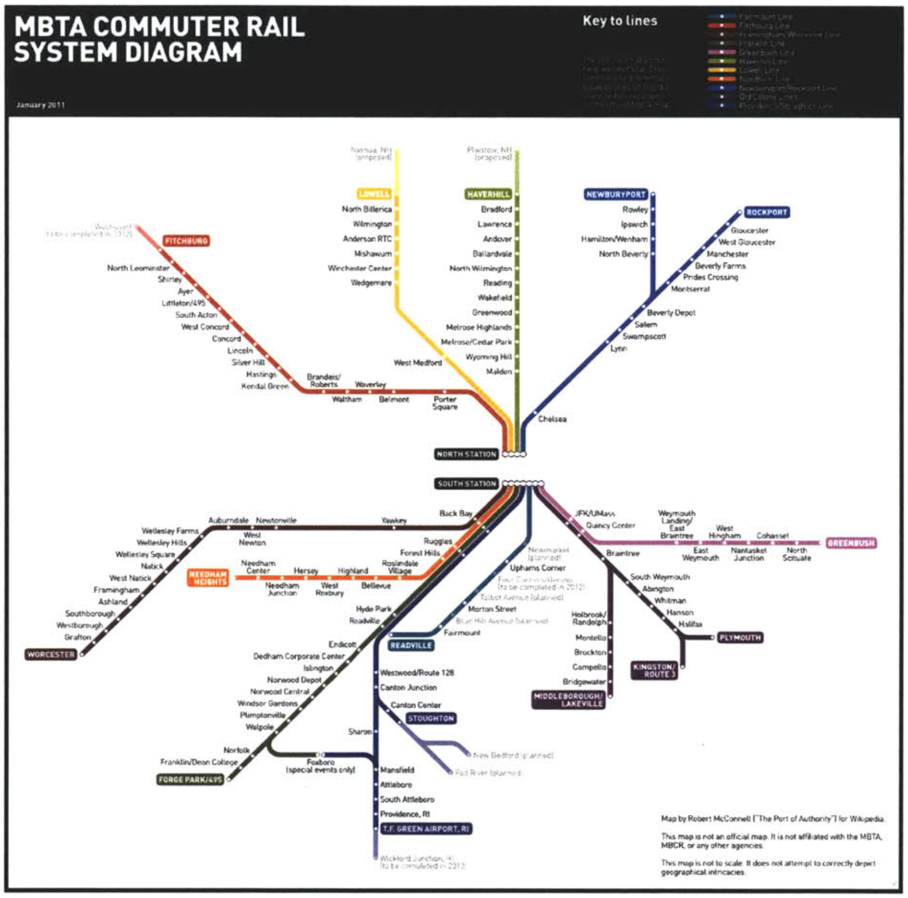

Figure 1-1: Commuter Rail System Schematic
Adopted from [33]

Between the the connection with the Worcester and Fitchburg/Acton lines, the Grand Junction passes through the heart of Kendall Square, a business district and the home of the Massachusetts Institute of Technology (MIT). As business activity in Kendall Square grows the current transportation system will experience increasing stress. Combined with constraints the City of Cambridge places on parking growth, improvements to the public transportation system will be required to accommodate this growth.

This thesis assess potential Grand Junction services through ridership projections derived from a detailed description of the service alternatives, employment estimates, and a commuter mode choice model. Grand Junction service would commence in Worcester or Auburndale, run along the Worcester corridor with existing service, and diverge to the Grand Junction corridor near Boston University. The service would call at a new station at Kendall Square and continue east to join the MBTA Fitchburg/Acton line to North Station. Figure 1-4 shows a schematic of the services. The Grand Junction would provide Worcester corridor commuters direct access to Kendall Square and North Station without additional transfers.

Employment figures are based on current estimates and 2035 projections from the City of Cambridge and the Boston Metropolitan Area Planning Council (MAPC). Current estimates are used because introducing service along the Grand Junction is relatively low cost and easily implementable. Thus, if a decision were made to start service, initial ridership numbers would be expected to match predictions based on current employment levels. Predictions for 2035 are used because a Grand Junction service should be sustainable, so long term ridership forecasts approximating the predictions based on 2035 employment estimates are necessary.

This thesis uses service alternatives developed by Iglesias Cuervo and Neov in [30]. The commuter mode choice model estimates commuter preferences based on responses to an MIT commuting survey and the authors' assessment of commuting options throughout the Boston area.

The thesis begins with a review the history of the Grand Junction in Chapter 2, including an overview of past studies of the line. Chapter 3 introduces our methodology and outlines the ridership estimation process. Chapter 4 establishes the primary driving force behind the project—rapidly growing employment in the Kendall Square area. Chapter 5 describes the theoretical foundation

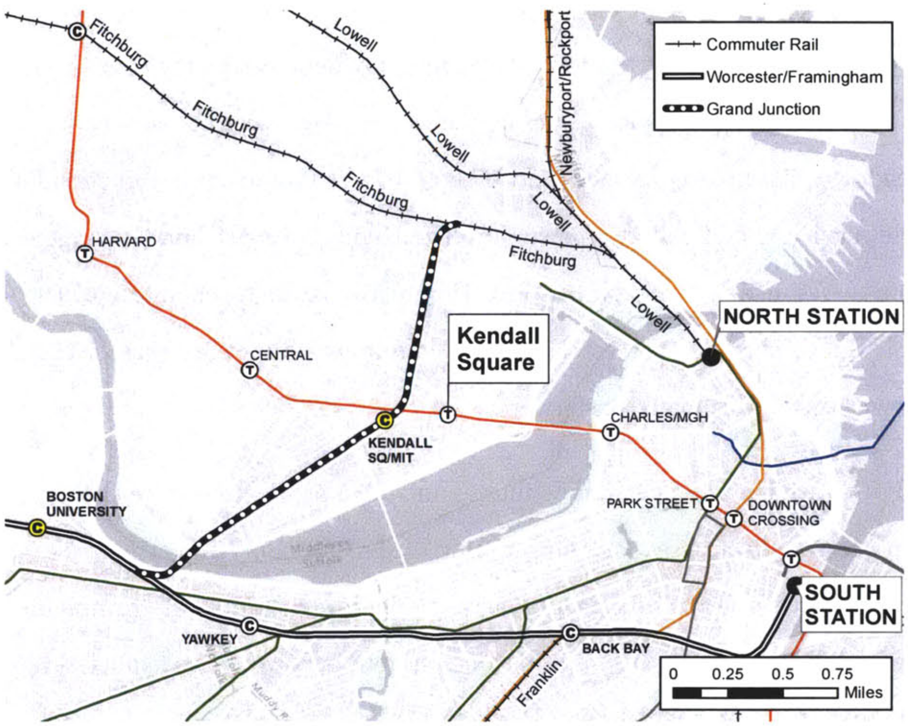

Figure 1-2: Kendall Square Transportation

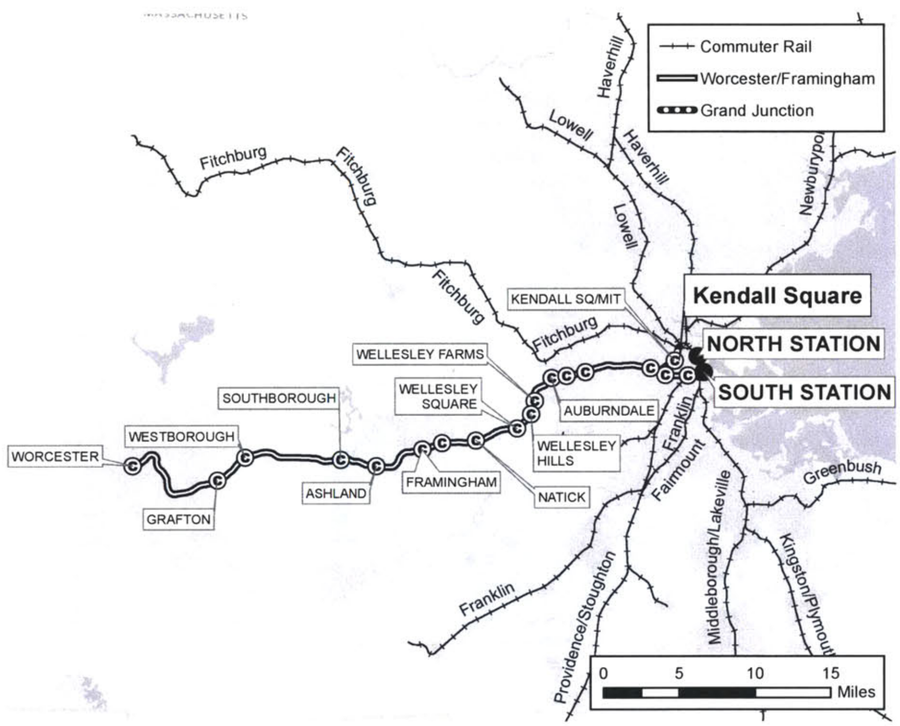

Figure 1-3: Worcester Corridor

Figure 1-4: Schematic of Grand Junction Services

for the cornerstone of our ridership estimation model, a discrete choice model. Chapter 6 details our data collection and processing, describes the primary factors that influence commuting choices, and details our mode choice model and assess its performance. The application of the model and ridership estimates are detailed in Chapter 8, and Chapter 9 concludes the thesis and provides some commentary on the methodology and results.

Chapter 2

Grand Junction History

This chapter summarizes past studies performed on the Grand Junction Corridor as well as the results of the most recent MassDOT suitability study. Then a comparison is made between the approach taken in this study with the CTPS Regional Demand Model.

2.1 Corridor History

The Grand Junction Corridor is an 8.5 mile rail line that connects Beacon Yard in Allston through East Cambridge to Chelsea in the North of Boston. It was opened in 1855 by the Grand Junction & Depot Company to serve a variety of factories and warehouses in the newly industrialized east end of Cambridge. The line is currently owned by the MBTA and is used for infrequent freight service and to shuttle commuter trains from the southern part of the system to the maintenance facility located in Somerville, MA.

2.2 Previous Grand Junction Studies

The Grand Junction corridor has been studied for several different purposes. In 1995 the Urban Ring proposal was conceived as an MBTA initiative, with three phases: initially, phase I would improve crosstown bus service, then phase II would add Bus Rapid Transit (BRT) intermodal connectors. Finally phase III would add rapid rail transit service, with segments of phases II and III utilizing the Grand Junction corridor. Thus by providing direct connections with MBTA's existing radial transit and commuter rail network, the Urban Ring would improve access to jobs and homes of the residents of Boston. The City of Cambridge commissioned a feasibility study in 2006 to add a multi-use path adjacent to the existing tracks. Their recommendation was either to incorporate the trail with the proposed Urban Ring or to utilize the western edge of the corridor for the trail [15]. In 2008, MBTA further studied the use of the Grand Junction right of way for a bus rapid transit (BRT) alignment as a link for the Urban Ring project. However, due to budgetary constraints the Urban Ring was suspended as of January 2010, with only portions of phase one and initial planning of phase two complete. [24].

In 2010, the Massachusetts Lieutenant Governor raised the possibility of connecting the Framingham/Worcester Line over the Grand Junction to provide MBTA Commuter Rail service from Worcester to North Station. MBTA conducted a suitability study which concluded that while demand for an increased service is high, the ridership forecast are comparable between adding the Grand Junction service to North Station in a "Build" scenario and expanding service to South Station in a "No-Build" scenario, as shown in Table 2.1. Although South Station faces significant capacity constraints [20], an expanded South Station could support the additional Framingham/Worcester trains. MassDOT decided not to pursue the Grand Junction option [25].

Increasing service to South Station is a viable long term, but not short term, choice because the station expansion process is lengthy and expensive. However, the alternatives analyzed in this thesis could be implemented relatively quickly and easily. In addition, this study considers options for the Grand Junction not considered by MassDOT, such as diesel multiple units (DMUs), which have greater acceleration and deceleration than conventional locomotives.

The MassDOT Grand Junction study is based on the Central Transportation Planning Staff (CTPS) Regional Travel Demand Model (RTDM), but the study did not describe the model parameters. The procedures used in the Green Line Extension (GLX) were studied to understand the CTPS RTDM [8]. While the RTDM as implemented in the GLX and the model developed in this thesis differ in some areas—the GLX RTDM uses 2009 as a base year and projects to 2030, while the model in this thesis uses 2010 as a base year and predicts to 2035, and the GLX RTDM uses 1990 and 2000 census data, passenger counts, and passenger surveys while the model in this thesis uses an MIT survey and 2000 census data—overall the RTDM developed in the GLX should be similar to the model in this thesis. The GLX study encompassed a similar area, road network, and transportation network. The RTDM coefficients were compared to the coefficients of the model developed in this study to evaluate this model.

Table 2.1: MassDOT Grand Junction Ridership Predictions

	2009	2035	
	Existing	**No-Build**	**Build**
Total Inbound Boardings	6,700	9,000	9,300
Kendall/MIT destined	5%	5%	6%
North Station destined	8%	7%	7%
South Station Financial District	35%	35%	35%

Chapter 3

Methodology

Ridership was estimated for each potential Grand Junction service through three principal steps. First an analysis was performed on current and predicted Kendall Square employment, current Kendall Square transportation options, and current commuting habits to produce a basic set of model inputs. Second, we developed and tested a mode choice model for the Worcester corridor. Third, we applied the mode choice model to the projected employment estimates for a range of service alternatives defined in [30] and Chapter 7.

3.1 Ridership Components

Ridership on any future Grand Junction service has several components of varying importance:

1. Inbound commuters to points west of Kendall Square
2. Inbound commuters to Kendall Square
3. Inbound commuters to North Station and beyond
4. Outbound commuters from North Station to Kendall Square
5. Outbound commuters to points beyond Kendall Square

Each of these components has a temporally-heterogeneous demand distribution. The commuter rail system primarily moves commuters into Boston and Kendall Square in the morning and away from Boston and Kendall Square during the evening. Because commuting mode choices are inherently round trip decisions—a person cannot drive home if they do not drive to work—it is reasonable to assume that flows in both directions are balanced: people who commute in one direction by commuter rail will likely also commute in the opposite direction by commuter rail. With this simplifying assumption the scope of this analysis can be limited to morning traffic, specifically the morning peak period (defined as arriving in Kendall Square or other terminal station between 6:00 AM and 9:00 AM). The scope of this work is further reduced by assuming that in the morning ridership components 1 and 5 are minor in comparison to other traffic on the corridor. According to the 2008-2009 system-wide MBTA passenger survey, about 80% of all inbound trips on the Worcester line ultimately terminate in downtown Boston or Cambridge, and more than 80% of morning traffic on the line is inbound [9]. Hence, inbound ridership to points west of Kendall Square is low, and few people make a true reverse commute. Component 4 is included because it is currently served only by the Charles River Transportation Management Association's EZRide shuttle. Grand Junction services have the potential to divert a significant portion of riders, which could impact EZRide's overall viability.

The business population of Kendall Square drives ridership components 2 and 4—these flows are people commuting from the Worcester corridor and other commuter rail corridors respectively to Kendall Square. As described in Chapter 4, Kendall Square employment has two sources: an upper bound estimate from the City of Cambridge, and a lower bound estimate from MAPC. Both sources provide current and projected 2035 employment.

3.2 Mode Choice Model

Using data from an MIT transportation survey a discrete mode choice model was developed and used to estimate the overall mode share for any Grand Junction service.

The model is based on revealed preferences, meaning individuals' commuting preferences are determined by examining their commuting choices given the available commuting options. Many commuting options are available to people commuting to Kendall Square. In general, people commuting from within the core Boston area—the area roughly outlined by MA-128 and shown in Figure 6-1—can realistically drive, take the subway, or take a bus. Commuter rail is generally not a realistic option in this zone because stations are further apart and headways are much longer than for the subway. People commuting from outside the core Boston area, however, have very limited subway and bus access; taking commuter rail and driving are the realistic commuting options. To reduce the scope of the mode choice model this analysis only considers commuters living in areas where driving and commuter rail are the only realistic commuting modes. This area is everything outside the exclusion zone defined in Figure 6-1. Given the reduced focus of this model, it is reasonable to assume that the factors influencing mode choice are cost, access time, wait time, and in-vehicle travel time.

A binary logit model was built, with the coefficients in a driving and a commuter rail utility equation estimated from the transportation survey responses. This implies MIT commuters have similar travel preferences to all future Grand Junction commuters, which may be reasonable given the high-tech nature of Kendall Square businesses. The MIT surveys were the only recent high quality disaggregate commuting preference data source available. Chapter 5 provides a general discussion of disaggregate binary logit models, Chapter 6 a detailed description of the dataset used to estimate the logit model and a detailed description of the model calibration and sensitivity assessment. Chapter 8 provides a detailed description of the ridership estimates.

3.3 Ridership Estimates

A list of Grand Junction service alternatives was provided by [30] and was used to develop an application dataset, which contained estimates for the costs, access time, wait time, and in-vehicle travel times each commuter would face under each alternative.

The application dataset contains randomly generated points, representing the home location of a hypothetical Kendall Square commuter, matching the spatial distribution of current Kendall

Square commuters. The application dataset features the same exclusion zone shown in Figure 6-1. In addition, as described in Subsection 8.1.3, the application dataset contains commuters only within the Worcester corridor. One set of points was used for all alternatives and employment scenarios; Section 4.4 describes how points were scaled to account for the range of employment levels. A set of travel parameters for each alternative was estimated for each point in the dataset, (see Section 8.3 for details).

Each ridership component was estimated separately. Component 2, inbound riders to Kendall Square, consists of two subcomponents: new riders who previously commuted to Kendall Square by car, and riders who currently commute to Kendall Square by commuter rail through South Station but would switch to a Grand Junction service. New ridership is estimated by applying the binary mode choice model to the application dataset and examining the change in ridership under each alternative, compared to the No Build alternative, as detailed in Section 8.5. The ridership diverted from existing services to South Station is estimated by comparing the frequency of the introduced service and the existing service. It is assumed that if any Grand Junction service offers frequencies at least as high as the existing service, the Grand Junction service will be at least as convenient as the existing service, and faster, so commuters will choose the Grand Junction service. Section 8.5 describes this estimation in more detail.

Component 3, inbound riders to North Station and beyond, consists of two subcomponents: new riders who previously commuted to Boston by car, and riders who currently commute to Kendall Square by commuter rail through South Station but would switch to a Grand Junction service. New ridership is estimated by applying the average elasticity of wait time developed in Section 6.8. For example, if the average elasticity is -2.0, a 1% reduction in wait time corresponds to a 2% increase in ridership. The percent change in ridership is multiplied by the current corridor ridership to downtown Boston to estimate the new ridership. Because the Grand Junction service does not offer an overall travel time improvement to downtown Boston—it would be more convenient for commuters to the North End, but less convenient for commuters to the Financial District—it is assumed that a Grand Junction service would not divert any current Worcester corridor commuter rail users.

Component 4, outbound riders from North Station to Kendall Square, consists of riders who currently transfer at North Station from other commuter rail lines or the Orange Line to the EZRide shuttle. A Grand Junction service would reduce the in-vehicle travel time from North Station to Kendall Square, but EZRide stops at multiple locations within Kendall Square and therefore provides shorter access times. Overall, it is assumed that commuters do not prefer one option over the other. The ridership share of the total North Station to Kendall Square market for each service, therefore, is assumed to be the frequency share of the two services. See Section 8.7 for more details.

Combined, these three ridership components provide an estimate for the majority of the morning peak traffic a Grand Junction service would likely generate. Section 8.8 contains final ridership estimates.

Chapter 4

Employment and Growth

This chapter presents the methodology used to develop future employment estimates for Kendall Square. In the first section, the area of study is defined. The next section includes estimates of current employment. The final section describe the approach used to estimate future employment and the application of peak arrival times for workers in Kendall Square.

4.1 Area Definition

The area defined for study included all Traffic Analysis Zones (TAZ) located within a one mile radius of the Kendall Square Red Line station. The Red Line station was selected as the center of Kendall Square, which is bounded by Main St, Broadway, Wadsworth and 3rd St (see Figure 4-1). In addition this location is also near the proposed Grand Junction commuter rail station. A one mile radius was used as it takes the average person approximately 15-20 minutes to walk a mile and this would encompass most of the MIT campus.

All TAZ located across the Charles River were excluded as they can be served better by North Station. TAZs identified as within walking distance of Kendall Square, using TransCAD's radius selection, were joined with the employment data from MAPC thus providing the employment estimates for the study area. While TAZs delineate relatively large areas and some portions of the zones are further than one mile from Kendall Square Red Line station, the use of TAZs are common in transportation planning and were therefore considered to produce a reasonable estimate for this study. In addition, using TAZ(s) allows for direct interpretation of MAPC's employment estimates.

4.2 Current Employment

Current employment estimates were developed for the Kendall Square area using data from the MetroFuture 2035 Update [28], published by Metropolitan Area Planning Council (MAPC) and estimates provided by the Kendall Square Business Association.

Since the 2010 census data is not yet available, MAPC's regional employment projection which is an update to the 2000 census data was utilized in the Grand Junction study. MAPC's employment projection, which is based on employment estimates from the state's Division of Employment and training [8] is utilized by many other state, regional and local planning efforts and therefore was assumed to reflect current employment throughout the region. Since the MAPC's employment estimates are designated by TAZ and projected for 2010 the methodology described in Section 4.2 was used to tabulate current Kendall Square employment.

The City of Cambridge estimate was provided by, Mr. Travis McCready, head of the Kendall Sq. Business Association who stated, "The city estimates that there is a daytime population of 99,307 (not including MIT students, estimated at 10,384) with a ratio of workplace to residential at 2-1. Per the city's estimates, this places workforce at around 66,000." Consequently MAPC and the City's estimates provide lower and upper bounds respectively for current Kendall Square employment, see Table 4.1.

4.3 Future Employment

To estimate future employment, projections were obtained from MAPC, using the defined study area. MAPC prepares these projections to support Eastern Massachusetts' long-range transportation plan, and consequently are a logical source for future employment estimates in this study.

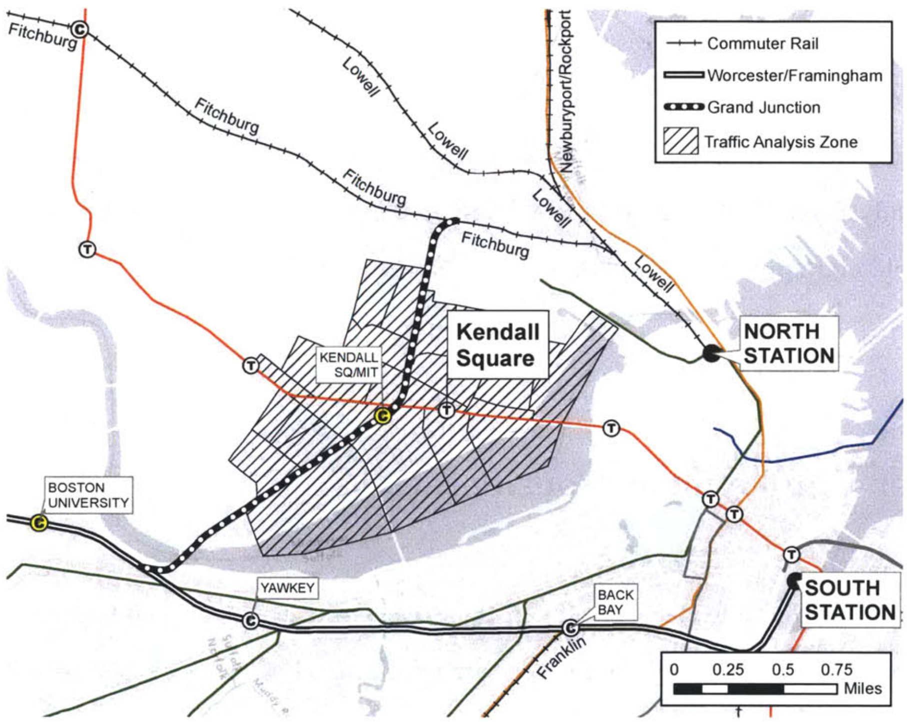

Figure 4-1: Traffic Analysis Zones in Kendall Square

Due to uncertainty in the development process and to balance regional growth totals; MAPC applies discounting rules to future developments, because of this their projections are often considered conservative. A comparison with the municipality employment estimate, which was assumed to be slightly higher, was performed to develop the projected employment range. This forecast was developed from the current Kendall Square employment projection provided by Mr. McCready (see Section 4.2).

To forecast 2020 and 2035 employment, the current employment estimates were expanded using MAPC MetroFuture 2035 growth rates [28]. The annual employment growth rate of approximately 1.35% is the resultant of comparison between MAPC's forecast employment growth in 2010 with their forecast growth in 2020. With the total employment for the United States expected to increase by 1.4% annually from 2010 to 2020 [4], by comparison MAPC's growth estimates were assumed to be reasonable and applied to Kendall Square employment forecast.

4.4 Other Employment Considerations

Each employment estimate is then multiplied by a scalar to account for the temporal distribution in commuting habits since not all commuters arrive during the AM peak period. Therefore, the effective employment population scalar is the ratio of Worcester corridor Kendall Square commuters who could reasonably choose to commute by commuter rail during the morning peak period under each employment scenario to the employment estimate used to generate the application dataset. A scalar was generated for each of the six Kendall Square employment estimates listed in Table 4.1. The scalar is given by three factors:

$$E^e = f_c^e \, f_t \, f_o \tag{4.1}$$

where E^e is given in Equation 8.4, f_c^e is a scalar for employment scenario e, f_t is a scalar, and f_o is a scalar.

Corridor Employment (f_c^e) The sum term in Equation 8.4 finds the expected commuter rail ridership for all data points in the fully processed application dataset, assuming that the total forecast employees commute to Kendall Square. This expected ridership is then scaled for each employment scenario:

$$f_c^e = \frac{N^0}{N^e} \tag{4.2}$$

where $N^0 = 47,744$ (see Table 8.7) is the employment number used to generate the application dataset and N^e is Kendall Square employment under employment scenario e.

Time (f_t) As shown in Table 4.2 census data indicates that 61.7% of Kendall Square employees arrive at work between 6:00 AM and 9:00 AM (the defined AM peak period). Thus, $f_t = 0.617$.

Other Modes (f_o) Because the Grand Junction Corridor model only considers commuter rail and driving options and in some areas outside the exclusion zone the subway system presents a reasonable commuting option, a portion of commuters cannot be accounted for in this model. MIT survey data indicates that 77.9% of people living in the Worcester corridor outside the exclusion zone commute by driving or commuter rail, with the remaining 22.1% commuting by some other mode. Thus, $f_t = 0.779$.

Combined, these scaling factors establish the effective target population scalar for each employment scenario as listed in Table 4.3. The scalar indicates the number of Kendall Square commuters represented by each point in the Application Dataset (see Section 8.1). For example, in the Cambridge 2035 employment scenario, each point in the Application Dataset represents about 0.8 commuters to Kendall Square.

Table 4.1: Future Employment for Kendall Square

	2011	2020	2035
MAPC (TAZ)	41,498	46,487	48,877
City of Cambridge	66,000	74,935	78,787

Table 4.2: Kendall Square Commuter Arrival Time Distribution

Total Workers	Peak AM	Other AM	PM	Overnight
48,877	30,157	13,295	4,497	489
100%	61.7%	27.2%	9.2%	1.0%

Table 4.3: Effective Target Population Scalars

Scenario	Employment	Scalar
MAPC 2011	41,000	0.413
Average 2011	53,500	0.539
Cambridge 2011	66,000	0.664
MAPC 2035	49,000	0.493
Average 2035	64,000	0.644
Cambridge 2035	79,000	0.795

Chapter 5

Modeling Discrete Choice

This chapter discusses the model used to forecast ridership for potential Grand Junction services. The first section introduces the theory of discrete choice modeling. The second section provides detail on the specific model developed to predict ridership for the Grand Junction Corridor.

5.1 Discrete Choice Theory

Discrete choice models are used to model behavior and predict the choice an individual makes among several different alternatives. Unlike regression models which use a continuous variable to calculate an optimum quantity, a discrete choice model uses a categorical variable to predict the individual's preferred choice [2]. This makes the discrete choice model the preferred approach for transportation planners to estimate mode choice, from a discrete set of alternatives.

All discrete choice models are based on simplified interpretations of an individual's behavior. Two types of models exist: disaggregate and aggregate. Disaggregate models make predictions for individuals, while aggregate models make predictions for groups of individuals. Disaggregate models require more precise and detailed input data than aggregate models, but produce more precise and detailed predictions. While an aggregate model might be used to forecast inter-zonal mode shares, the results produce limited behavioral insight. The disaggregate travel demand model, which uses micro-data to explain behavior of an individual or household, results in a better understanding of how the variables affect travel behavior. A disaggregate travel demand model was chosen for the Grand Junction Corridor analysis as it will more effectively forecast travel behavior given the MIT transportation survey dataset.

Discrete choice travel demand modeling also requires a finite, complete and mutually exclusive list of travel options faced by each individual.

In a discrete choice model, individuals condense the attributes of each available alternative through a single function, or utility, and are assumed to select the alternative which maximizes this utility. Not all of these attributes can be observed, so the utilities are characterized as random variables. With this in mind the theoretical basis for the discrete choice model is a random-utility model [27], where the decision maker n faces discrete alternatives $j = 1, \ldots, J$ and selects the alternative with maximum utility given by:

$$U_{jn} = V(x_{jn}, s_n : \beta) + \epsilon_{ijn} \tag{5.1}$$

With V as the systematic utility[1], x_{jn} a vector of attributes of the alternatives (travel time, cost, etc..) as they apply to the individual, s_n is the vector characteristics of the individual and β is the vector of unknown parameters. Finally ϵ_{ijn} is the random component which reflects the eccentricities of the decision maker's tastes and the inability by the decision maker or modeler to completely measure all of the factors affecting utility.

In a disaggregate model the choice between alternatives becomes probabilistic. The probability that individual n will choose mode i can be written as:

$$P_{in} = \mathrm{P}(U_{in} > U_{jn}) \quad \forall j \in C_n \tag{5.2}$$

[1] the portion of the utility that can be readily measured by the decision maker or modeler

$$P_{in} = \mathrm{P}(\epsilon_{jn} - \epsilon_{in} < V_{in} - V_{jn}) \quad \forall j \in C_n \tag{5.3}$$

Where C_n is the set of alternative choices available to individual n.

The systematic utility, V, is typically specified as a linear function of the modal attributes and can be written as:

$$V_{in} = \beta_1 x_{in1} + \beta_2 x_{in2} + \cdots + \beta_k x_{ink} \tag{5.4}$$

Where x_{ink} is the k^{th} attribute for mode i and individual n. β_k is an unknown coefficient produced by a maximum likelihood estimation implemented in transportation planning software.

Before probabilities can be estimated the ϵ term must be defined. Since the random component represents a large number of unobservable attributes of the individual's choice it is reasonable to assume it is approximately normally distributed. Several different models can be used to calculate ϵ. A probit model assumes ϵ follows a true normal distribution. Since the cumulative density function of a normal distribution lacks a closed form, the choice probability with a probit model must be represented by an integral. To improve tractability, a logit model is used. Logit models approximate a normal distribution: the random terms are assumed to be identical and independently distributed (iid) with an extreme-value distribution, often called a Gumbel or Weibull distribution. The density function for each random component then becomes [6]:

$$F(\epsilon) = we^{-e^{-\omega(\epsilon - y)})}e^{-\omega(\epsilon - y)} \tag{5.5}$$

Where ω and y are parameters of the distribution assumed to have the values of $\omega = 1$ and $y = 0$. This then allows the choice probability to be expressed as follows:

$$P_n(i) = \frac{e^{\mu V_{in}}}{\sum e^{\mu V j_n}} \quad \forall j \in C_n \tag{5.6}$$

It is the convention to normalize by setting $\mu = 1$, for all real numbers x where μ is a scale parameter. In binary form where $i = 1$, the choice probability becomes [2]:

$$P_n(1) = \frac{1}{1 + e^{\mu V_n}} \tag{5.7}$$

A binary logit model was selected for the Grand Junction corridor analysis since commuters are assumed to have two mode choices: driving or commuter rail. A logit model was selected because of its ability to predict an individual's choice, its computational properties, and its common use in transportation planning.

5.2 Grand Junction Model

The discrete choice model to analyze the Grand Junction Corridor models morning inbound home-based work trips. The attributes used in the Grand Junction Corridor analysis include times and cost for each mode. These attributes were selected because they complied with the following guidelines for utility function inputs [5]:

- Data must be availed for the variable, with sufficient variability to provide statistically significant estimates of the corresponding coefficient.
- The variable must be forecastable—it must be possible to estimate the variable for an application dataset.

Using these guidelines, the following model was formulated to analyze the Grand Junction Corridor:

$$V_D = \alpha_D + \beta_{TT} TT_D + \beta_{COST} COST_D \tag{5.8}$$

$$V_C = \alpha_C + \beta_{TT} TT_C + \beta_{AT} AT_C + \beta_{WT} WT_C + \beta_{COST} COST_C \tag{5.9}$$

$$P(D) = \frac{e^{V_D}}{e^{V_D} + e^{V_C}} \doteq \text{Probability of Driving} \tag{5.10}$$

where:

V is systematic utility.

TT is travel time (minutes).

AT is access time(minutes).

WT is wait time (minutes).

D means driving.

C means ommuter Rail.

Cost is cost in US dollars.

β are coefficients, found by a maximum likelihood estimator.

α are alternative-specific constants, fixed at zero for driving and found by maximum likelihood estimation for commuter rail.

The alternative-specific constants are added to the model to help explain any unobserved non-random alternative specific attributes. Since adding a constant to each utility does not alter the choice probability, the alternative-specific constants must be normalized for one of the alternatives. The remaining constant is then interpreted relative to the normalized alternative. For the Grand Junction Corridor analysis, the drive mode was normalized to zero. Thus, α_C represents an underlying preference or dislike for commuter rail.

Chapter 6

Model Estimation

This chapter presents the development of datasets and analysis of the binary logit model used in the Grand Junction Corridor study. In the first several sections the development of datasets and generation of points is discussed. This is followed by the estimation of travel parameters. Then the dependent and independent variables are discussed along with the assumptions made for model estimation. In Section 6.6, the estimated coefficients are presented along with analysis of the model's statistics demonstrating model calibration. In Section 6.7, the model is validated against another set of revealed choices from the MIT survey. An elasticity analysis is performed in Section 6.8 demonstrating sensitivity to changes made to alternatives. In the final section comparisons are made between the estimated coefficients with those from CTPS Green Line Extension demand model.

6.1 Developing Datasets

The first step in estimating ridership for the Grand Junction was to develop a disaggregate dataset: a set of points representing the home location of employees of the Massachusetts Institute of Technology who responded to the the Institute's bi-annual commuting survey in 2010. This set of points included information on the person's preferred commuting mode.

6.2 Spatial Data Sources

Spatial information was obtained from MassGIS, ESRI, the Census Bureau, and MAPC. MassGIS is the official Geographic Information System (GIS) repository for the state of Massachusetts. MassGIS data included the location of commuter rail tracks and stations, subway tracks and stations, and tollbooths. ESRI, Environmental Systems Research Institute, created the ArcGIS suite of programs and offers productivity datasets. The ESRI Streets Network, which is a network dataset of all major and minor roads within the United States and Canada, and ESRI Basemaps, which are background images were used. The Census Bureau provides boundary information for census-related statistical areas; we used Census 2000 Census Tracts, Block Groups, and County Subdivisions (towns). MAPC, the Boston Metropolitan Area Planning Council, plans transportation and land use for the Boston region. Traffic Analysis Zone boundary files were obtained from MAPC.

6.3 Generating Points

The Estimation Dataset includes one point per employee commuting to the main MIT campus who responded to the 2010 MIT Transportation Survey [26]. This data was received in an Excel spreadsheet with one entry per eligible MIT respondent. Respondents' addresses were automatically retrieved from Institute databases, and their home location was stored as a latitude/longitude coordinate randomized by an average of 200 feet to protect respondents' identities.

The primary mode field in the survey did not correspond exactly to the desired modes for the Grand Junction Corridor analysis (driving and commuter rail). The primary survey modes were mapped to the desired list of modes as outlined in Table 6.1. None of the primary mode options distinguished between different transit modes. Responses were examined against a set of questions asking how often a respondent used a set of MBTA services in the week prior to the survey. Thus the logic statements were applied Table 6.2, in order, to assign transit modes.

The original MIT survey data had 18,514 entries. That number was reduced considerably during

Table 6.1: Primary Mode Mapping.

Survey Mode	**Analysis Mode**	**Number of Responses**
Bicycle	Other	435
Bicycle and take public transportation	*Transit*	133
Drive alone the entire way	Drive	1,463
Drive alone, then take public transportation	*Transit*	322
Dropped off at work	Drive	24
Other	Other	138
Ride in a private car with another person	Drive	279
Ride in a private car with 2–6 other people	Drive	44
Ride in a vanpool (7 or more commuters) or private shuttle (e.g. TechShuttle, SafeRide)	Drive	29
Share a ride/dropped off, then take public transportation	*Transit*	172
Take a taxi	Drive	2
Walk	Walk	470
Walk, then take public transportation	*Transit*	1,611
Work at home	Other	9
Total		5,131

the analysis by applying the following methodology:

- 9,348 responses that lacked an address were removed (i.e. the person was eligible for the survey but did not respond, or the person did respond but lived in on-campus housing).
- 4,035 responses were removed because they did not include information about the respondents' primary mode of transportation to MIT.
- 163 responses were removed because the respondent selected public transportation as their primary mode but did not indicate a selection for commuter rail, subway, or bus services.
- 25 responses were removed for those that could not have travel parameters fully estimated, generally because the geocoded address could not be placed on the ESRI Streets Network (see Section 6.4).
- 3,740 responses from towns in an exclusion zone designed to reduce the reasonable commuting options to driving and taking commuter rail were removed. The exclusion zone is roughly the area inside MA-128, with the exception of Newton, which is not in the exclusion zone because it is of important ridership source for several service alternatives (see Chapter 7). The exclusion zone is shown in Figure 6-1.
- 86 responses that did not drive or take commuter rail to MIT were removed.

The final estimation dataset has 1,117 responses. The dataset was randomly divided into two halves: a calibration dataset and a validation dataset. The logit model coefficients were estimated with the calibration dataset, and the model estimation was confirmed with the validation dataset (see Section 6.7). Figure 6-2 shows the spatial distribution of the fully processed Estimation Dataset.

6.4 Estimating Travel Parameters

Travel options available to each point in the estimation dataset were estimated based on existing commuter rail service. Information was collected for the two primary modes in the study: driving

Table 6.2: Assigning Public Transportation Modes

Condition	Assigned Public Transportation Mode
Commuter rail use eight or more times per week	Commuter rail
Subway use eight or more times per week	Subway
Bus use eight or more times per week	Bus
Commuter rail use five or more times per week	Commuter rail
Subway use five or more times per week	Subway
Bus use five or more times per week	Bus
Commuter rail use more than subway or bus use	Commuter rail
Subway use more than commuter rail or bus use	Subway
Bus use more than commuter rail or subway use	Bus

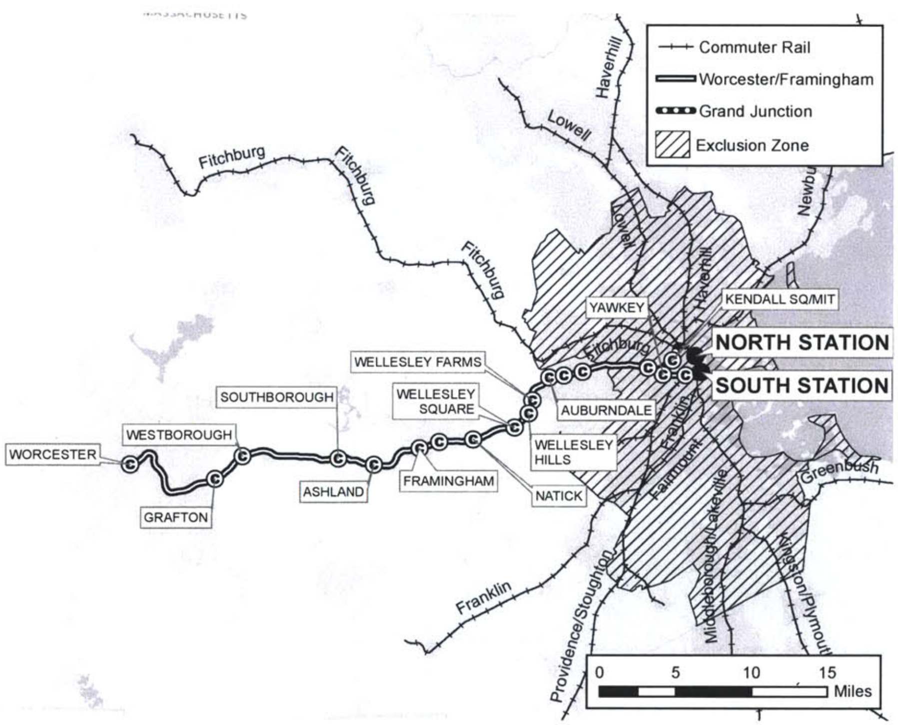

Figure 6-1: Exclusion Zone

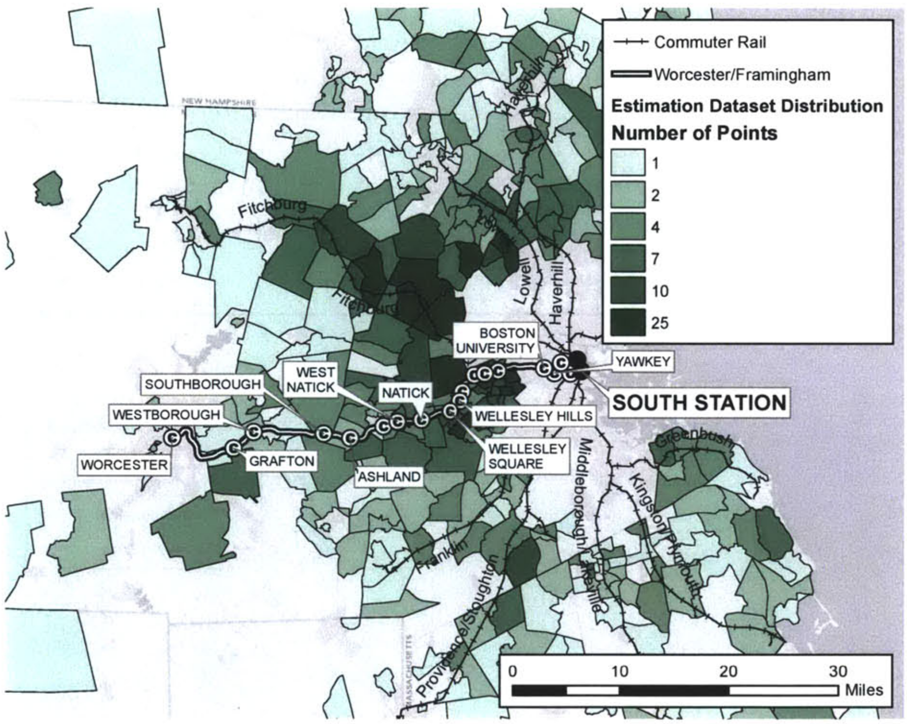

Figure 6-2: Distribution of MIT Commuters

and commuter rail. For cost calculations it was assumed that commuters will purchase the transit pass, parking pass, and/or EZPass that minimizes their commute cost.

Travel time and cost were assumed to be the primary factors influencing a person's perceived utility of driving and that in-vehicle travel time, access time, wait time, and cost were the primary factors influencing a person's perceived utility of taking commuter rail.

6.4.1 Drive Time

Driving time was estimated in minutes by car from each point to Kendall Square. The ESRI Streets Network was imported into ArcGIS; the dataset includes all major and local roads within the United States and Canada, including speed limits and information about one way restrictions. The network provides turning and routing information and is accurate up to 30 feet. We applied the output of a static congestion model supplied by Mikel Murga, a research scientist at MIT. The model estimated congested driving times for the area within the jurisdiction of the Boston Metropolitan Area Planning Council (MAPC), shown in Figure 6-3. Static congestion models assign general traffic flows to streets, minimizing each person's travel time assuming free flow traffic speeds. The model then recalculates travel times based on the effective congested speed for each road segment. Effective congested speeds are a function of the road characteristics and the assigned traffic volume. The model also estimates congestion delays at key traffic lights throughout Cambridge. Because it is a static, not a dynamic model, it provides only a first order approximation of actual congested travel times. The model assigned congested travel times from the centroid of each Traffic Analysis Zone (TAZ) within the MAPC area to Kendall Square; the travel time for the centroid was assumed to apply to the entire TAZ.

The points datasets and the location of Kendall Square were imported into ArcGIS. Points lying within the MAPC were assigned the congested travel time of the surrounding TAZ. For points outside the MAPC a Closest Facility Layer (CFL) was created within the ArcGIS Network Analyst. A Closest Facility Layer finds the minimum time or distance between origins and destinations. To incorporate the impacts of congestion the CFL was used to find the minimum of the time to drive to the MAPC boundary under free flow speeds plus the time to travel from the boundary crossing

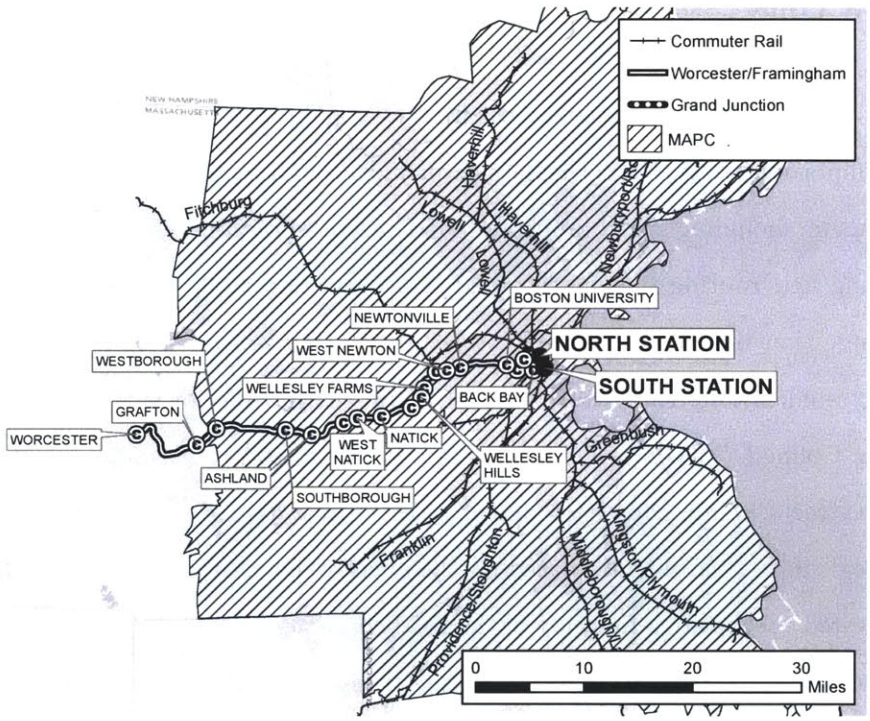

Figure 6-3: Boston Metropolitan Area Planning Council

to Kendall Square. The Closest Facility Layer prohibited U-turns and enforced one-way restrictions on roads.

Ten minutes were added to the drive time calculations to account for local access time and time spent finding a parking spot after arriving in Kendall Square.

The final output was a table listing the drive time, in minutes, from each point to Kendall Square, assuming that traffic flows at the posted speed limit outside the MAPC region at a congested speed within the MAPC. See Figure 6-4 for a display of drive times.

6.4.2 Drive Cost

One way driving cost in dollars were estimated from each point to Kendall Square with three components: vehicle cost, toll cost, and parking cost. All status-quo costs are in 2010 dollars.

The ESRI Streets Network were imported providing the points datasets, and the location of Kendall Square into ArcGIS. A Closest Facility Layer (CFL) was created to find the route associated with the fastest uncongested drive time between the point and Kendall Square. The length of the route was multiplied by one of two cost factors to determine vehicle cost (see Table 6.3): 2010 American Automobile Association (AAA) estimates for the per-mile vehicle operating cost (including gas and maintenance, but excluding general ownership costs) [1] and 2010 Internal Revenue Service (IRS) standard tax deduction rates for the per-mile total vehicle ownership cost (including gas, maintenance, and general ownership costs) [19].

Each tollbooth within the study area was manually loaded into ArcGIS using a combination of state-provided GIS files and Google Maps satellite imagery. Tollbooths were placed on the ESRI Streets Network and assigned the toll for each booth to each route intersecting the toll booth. Toll rates provided by MassDOT [23] are indicated in Table 6.4 and reflect an EZPass discount where available.

Parking cost were calculated as the effective one way daily cost of a monthly parking permit: half the effective daily parking rate, which was calculated as the monthly parking rate divided by 21.67,

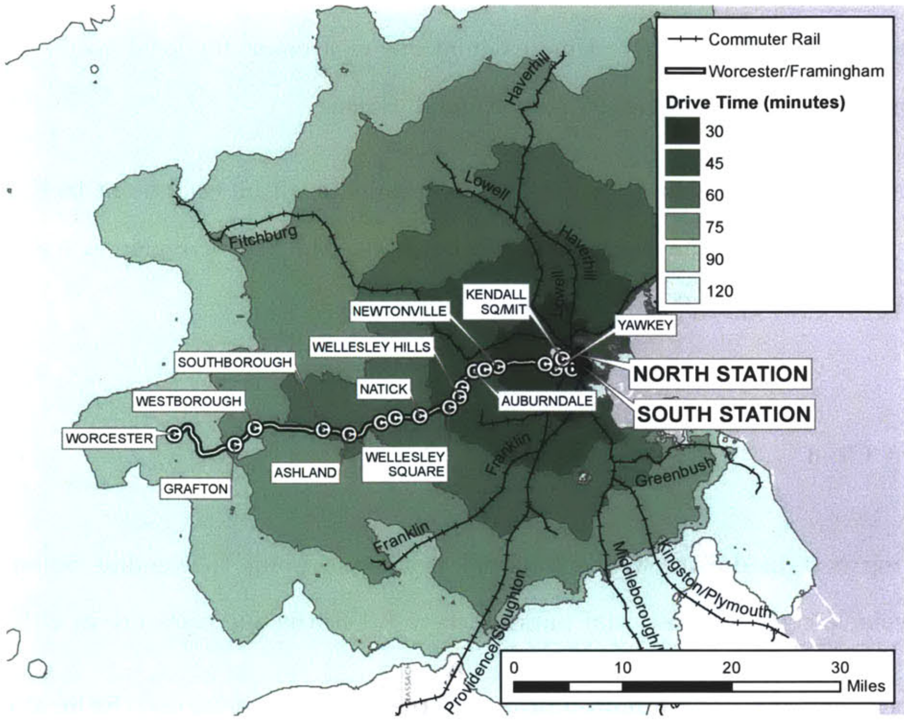

Figure 6-4: Drive Times

Table 6.3: Per-mile Vehicle Costs.

Method	**2010 Cost** ($/mi)	**Includes**
AAA	0.167	Operating cost only
IRS	0.500	Total ownership cost

the average number of working days per month. The monthly parking rate for MIT commuters is one-twelfth the annual rate for a Regular Commuter parking pass according to the MIT parking office [29]; see Table 6.5.

The final drive cost is a sum of the vehicle cost, toll cost, and parking cost. See Figure 6-5 for a display of drive costs.

6.4.3 Commuter Rail Access Time

The time in minutes from each point to a commuter rail station was estimated to be the minimum of the walking time and driving time. The walking time is the time to walk to the closest commuter rail station. The driving time is the minimum time to drive to a commuter rail station with a parking lot.

Walking access time was calculated by importing the ESRI Streets Network, points datasets, and commuter rail station locations into ArcGIS. A Closest Facility Layer was created to find the minimum distance to a commuter rail station, and converted that to a walking time assuming an average speed of 5 kph. The Closest Facility Layer neglected one-way restrictions and permitted U-turns at all intersections.

Driving access time was calculated by importing the ESRI Streets Network, points datasets, and commuter rail station locations for stations with parking lots into ArcGIS. A Closest Facility Layer was created to find the minimum time to a commuter rail station using posted speed limits, prohibiting U-turns, and enforcing one-way restrictions. Ten minutes were added to the calculated time to account for the time spent looking for a parking space.

The final output was the minimum of the two times, and the station corresponding to the fastest option, assigned as the commuter rail access time and preferred commuter rail station. The walking access time and driving access time occasionally selected different stations due to a lack of parking lots or the layout of the road network.

Table 6.4: Tollbooths and Toll Costs

Tollbooth	**2010 Toll** ($)
I-90 EB: Entry 1-6 to Weston	3.60
I-90 EB: Entry 7 to Weston	3.40
I-90 EB: Entry 8 to Weston	3.00
I-90 EB: Entry 9 to Weston	2.65
I-90 EB: Entry 10 to Weston	2.20
I-90 EB: Entry 10A to Weston	2.10
I-90 EB: Entry 11 to Weston	2.00
I-90 EB: Entry 11A to Weston	1.60
I-90 EB: Entry 12 to Weston	1.40
I-90 EB: Entry 13 to Weston	1.20
I-90 EB: Entry 15 to Weston	1.00
I-90 EB: Weston to Exit 16	1.00
I-90 EB: Weston to Boston	1.00
I-90 WB: Ted Williams Tunnel	3.00
MA-1A WB: Sumner Tunnel	3.00
US-1 SB: Tobin Bridge	2.50

SB: Southbound. EB: Eastbound. WB: Westbound.

Table 6.5: Parking Pass Costs

Parking Pass	**2010 Cost** ($/mo)
MIT Regular Commuter	81

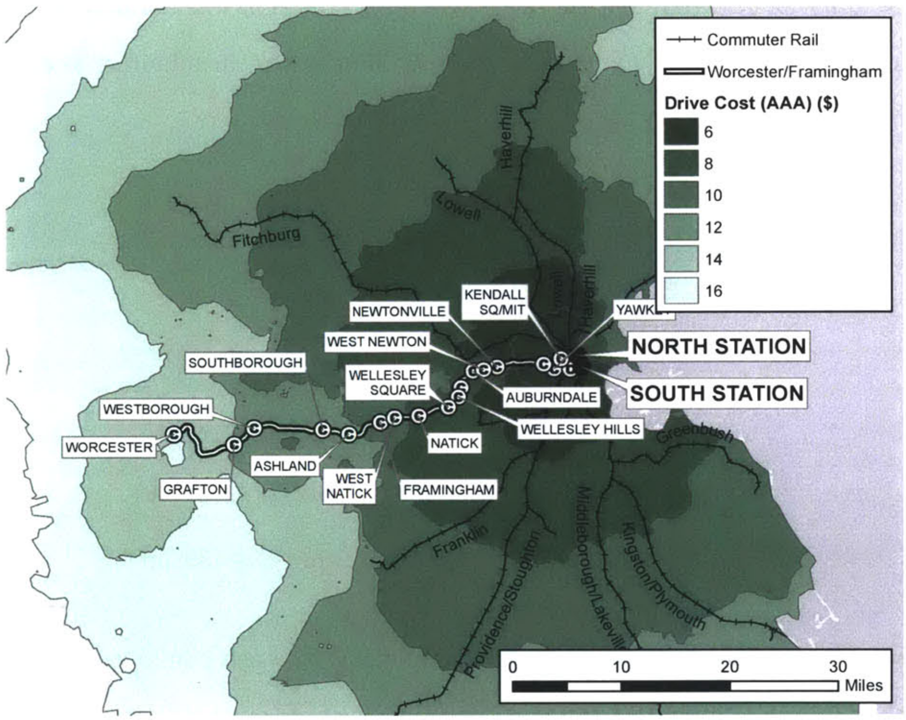

Figure 6-5: Drive Costs (AAA)

6.4.4 Commuter Rail Wait Time

The expected wait time was estimated in minutes for each commuter rail station. Commuter rail service was approximated as having even headways, and counted the number of inbound trains departing each station that arrived at the terminal station between 6:00 AM and 9:00 AM according to Winter 2011-2012 MBTA schedules [21]. Headways were converted to an expected wait time by assuming that people arrive randomly for high frequency services, but that people time their arrival more carefully for less frequent services. A scaling equation was adopted from [7], where F is frequency, in trains per three hour peak period; H is headway, in minutes; and W is expected wait time, in minutes:

$$H(F) \doteq \frac{180}{F} \tag{6.1}$$

$$W(H) \doteq \begin{cases} 0.5 * H & \text{for } H \in [0, 15) \\ 7.5 + 0.25 * (H - 15) & \text{for } H \in [15, 30) \\ 12.25 + 0.125 * (H - 30) & \text{for } H \in [30, \inf) \end{cases} \tag{6.2}$$

The final output was the expected commuter rail wait time for each commuter rail station, which was linked to the preferred commuter rail station to produce the expected commuter rail wait time for each point. See Figure 6-6 for a display of wait times along the Worcester corridor.

6.4.5 Commuter Rail Travel Time

Travel time was estimated in minutes from each commuter rail station to Kendall Square. Travel time was assigned from each station to the terminal station as the average travel time for each service arriving at the terminal station between 6:00 AM and 9:00 AM. A transfer was assigned at South Station for Red Line service to Kendall Square for all services terminating at South Station. A transfer at Porter Square for Red Line service to Kendall Square was assigned for

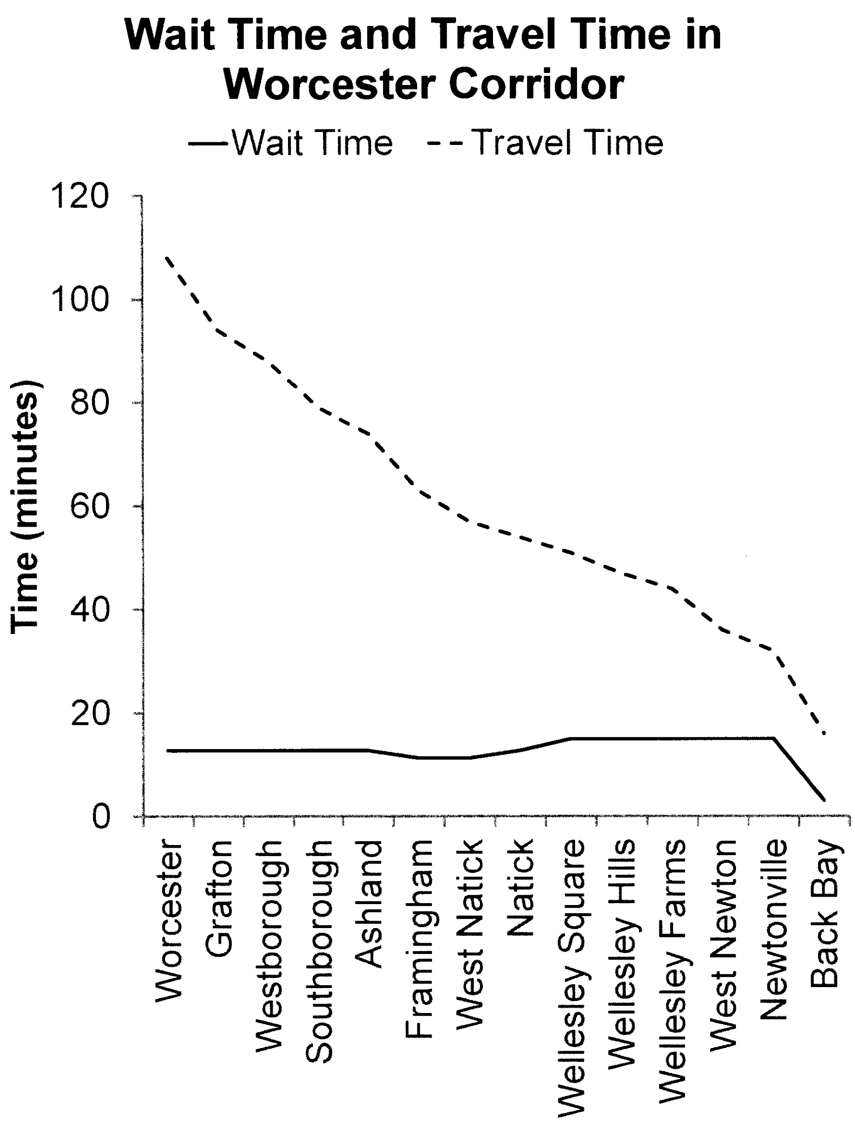

Figure 6-6: Wait Times and Travel Times along Worcester Corridor

the Fitchburg/Acton line. A transfer at North Station for EZRide service to Kendall Square was assigned for all other North Station-bound services. The travel time was calculated from South Station and Porter Square to Kendall Square as the average travel time for several arbitrarily selected weekday trips in the MBTA General Transit Feed Specification data products [22]. The travel time from North Station to Kendall Square was calculated from the EZRide schedule [11].

A transfer time of half the headway of the connecting service was assigned, which is about 3 minutes for the Red Line and 5 minutes for EZRide.

The final output was the travel time from each station to the connecting station, plus half the headway of the connecting service, plus the travel time to Kendall Square on the connecting service. The station travel times were linked to the preferred commuter rail station for each point to estimate the commuter rail travel time for each point. See Figure 6-6 for a display of travel times along the Worcester corridor. See Figure 6-7 for a display of total commuter rail journey times, including access, wait, and travel.

6.4.6 Commuter Rail Cost

The estimated one way commuter rail cost in dollars from each point to Kendall Square as comprised of three components: access vehicle cost, access parking cost, and commuter rail fare. All costs are in 2010 dollars.

For points that access commuter rail by walking the access vehicle and access parking costs are zero. For points that access commuter rail by driving, the access vehicle cost is the driving distance from the point to the preferred commuter rail station multiplied by the AAA or IRS per-mile cost factor (see Table 6.3), and the parking cost is half the daily parking rate. Parking costs along the Worcester line are listed in Table 6.6.

Commuter rail fares were estimated as the effective daily one-way fare based on a monthly pass for the cheapest allowable zone and assuming 21.67 work days per month with two one-way trips per work day. The MIT Parking Office subsidizes half the cost of commuter rail passes, up to $120 per month. The monthly costs are listed in Table 6.7.

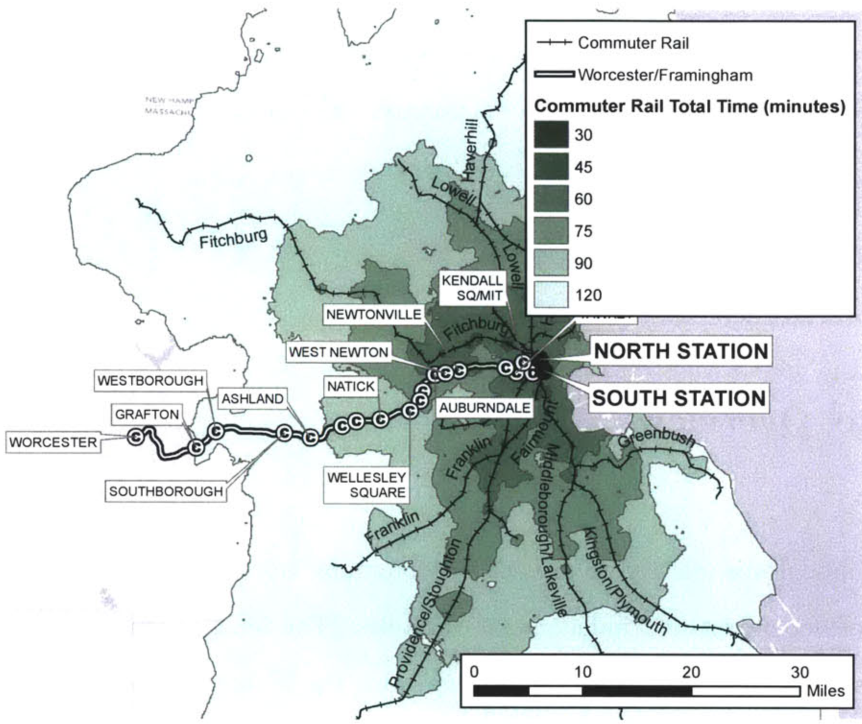

Figure 6-7: Commuter Rail Total Journey Times

Table 6.6: Parking Costs for Worcester Line Commuter Rail Stations.

Station	**2010 Cost** ($/half day)
Newtonville	3.75
West Newton	2.00
Auburndale	2.00
Wellesley Farms	2.25
Wellesley Hills	2.25
Wellesley Square	2.25
West Natick	2.00
Framingham	2.00
Ashland	2.00
Southborough	2.00
Westborough	2.00
Grafton	2.00
Worcester	4.13

The final output was the total one way commuter rail cost for each point, calculated as the sum of the access vehicle cost, access parking cost, and commuter rail fare based on the preferred commuter rail station. See Figure 6-8 for a display of commuter rail costs.

6.5 Model Overview

A binary logit model was selected to predict the commuter rail mode share of different alternatives given our set of dependent and independent variables. The binary logit model was developed to estimate ridership for new commuter rail service along the Worcester commuter rail corridor.

The dependent variables or "choices" include commuter rail and drive. Because the model only considers the area outside the exclusion zone shown in Figure 6-1 and described in Section 6.3, the set of possible choices is limited to driving and taking commuter rail. As discussed in Section 5.2, the independent variables include travel time, access time, wait time, cost, and alternative-specific constants (ASCs). An ASC determines an individual's preference for commuter rail when all other factors are equal.

The model coefficients were estimated using statistical maximum likelihood methods, implemented in estimation software. Model statistics were then compared with previous model's statistics to determine whether the model's explanatory power can be improved.

Once a model was selected, the results were evaluated through validation, elasticity calculations, and parameter comparison. The parameter comparison compares the model's parameters with those used by CTPS on the Green Line Extension.

Numerous software packages can estimate and apply logit models. For the Grand Junction Corridor analysis model two software packages were used: TransCAD, a commercial transportation planning software suite, and Biogeme, an open source discrete choice model estimation program.

Table 6.7: Commuter Rail Fares

Zone	2010 Cost (Unsubsidized) ($/half day)	(Subsidized) ($/half day)
LinkPass	59	30
1A	59	30
1	135	68
2	151	76
3	163	82
4	186	93
5	210	105
6	223	112
7	235	118
8	250	130
9	265	145
10	280	160

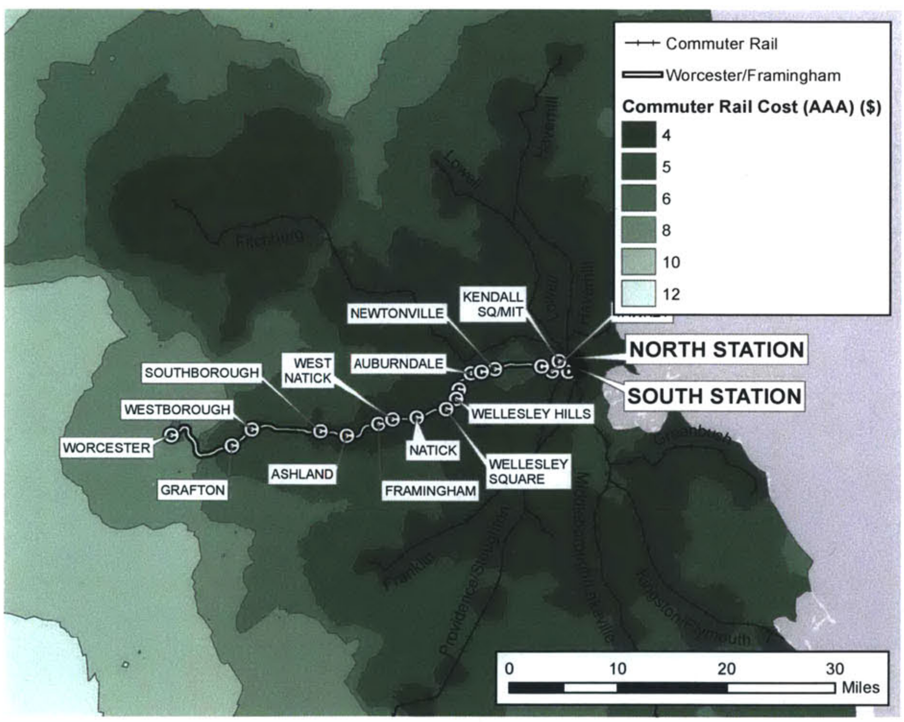

Figure 6-8: Commuter Rail Costs (AAA)

6.6 Model Estimation

An incremental process was used to develop the Grand Junction model. This approach was preferred as it demonstrates impacts of minor changes in the model formulation. A simple base model was developed, which was then gradually refined. At each refinement, various statistics were compared to measure the increase in the model's overall explanatory power. Three sets of statistics were considered: the model's rho-squared value, the p-values of the coefficients, and a comparison of the coefficient values and ratios to coefficients estimated by CTPS for the Green Line Extension (see Section 2.2).

A model's adjusted rho-squared statistic indicates its overall explanatory power. Adjusted rho-squared measures the proportion of variation in the data explained by the model [18]. Adjusted rho-squared AR^2 is the ratio of the sum of the squared residuals SSE and the total sum of squares SST adjusted by the degrees of freedom df for each measure [12]:

$$AR^2 = 1 - \frac{SSE}{SST}\frac{df_t}{df_e} \tag{6.3}$$

$$df_t = n - p - 1 \tag{6.4}$$

$$df_e = n - 1 \tag{6.5}$$

$$SSE = \sum_{i=1}^{n} (y_i - \widehat{y}_i)^2 \tag{6.6}$$

$$SST = \sum_{i=1}^{n} (y_i - \overline{y})^2 \tag{6.7}$$

where n is the number of data points, p is the number of independent variables in the model, y_i is a data point, $\widehat{y_i}$ is the model estimate of y_i, and $\overline{y}$ is the mean value of all data points.

Since a Rho-squared value of 1.0 indicates a perfect fit between the regression line and the data, the closer the model's rho-squared value is to 1.0 the better it explains the observed choices. During model development each rho-squared statistic was compared against the previous model's rho-squared thus demonstrating the model's relative significance.

Each estimated coefficient has a p-value, which is the probability that the maximum likelihood estimation process would provide the value of the coefficient, given its true value is zero. Thus, smaller p-values are "better" because the coefficient value is more likely to be significant. A widely accepted threshold for p-values is 0.05, meaning there is a 95% probability the coefficient differs from zero; coefficients with a p-value greater than 0.05 are considered insignificant. Discrete choice models estimate p-values, which assumes that if the true value of all coefficients were zero, estimating their values based on different samples would produce a normal distribution for each coefficient. The true variance of the distributions, however, are unknown and are estimated from the sample.

As stated in Section 6.3, the calibration dataset, which was used to estimate the utility equation coefficients, has 558 data points, representing every MIT commuter who lives outside the exclusion zone shown in Figure 6-1 and drives or takes commuter rail to MIT. Single travel time and cost coefficients were used for commuter rail and drive travel time and travel cost respectively. This assumption was made because the long travel distance in the train can have a similar stress on an individual as driving due to the negative perception multiple train stops has on the rider.

Two versions of the model were estimated; one using AAA vehicle operating costs and one using IRS vehicle total ownership costs. Below are the independent variables and corresponding coefficients included in the model:

TRAVELTIME_D minutes to drive from home to Kendall Square, as described in Subsection 6.4.1. Coefficient: B_TRAVELTIME.

TRAVELTIME_C minutes to take commuter rail from the nearest station to Kendall Square, excluding access time or wait time, as described in Subsection 6.4.5. Coefficient: B_TRAVELTIME.

ACCESSTIME minutes to travel from home to nearest commuter rail station, as described in Subsection 6.4.3. Coefficient: B_ACCESSTIME.

WAITTIME minutes to wait at nearest commuter rail station for inbound train, as described in Subsection 6.4.4. Coefficient: B_WAITTIME.

Two different sets of cost variables were used. All costs have the same B_COST coefficient.

- AAA Model

  COST_D_AAA dollars to drive from home to Kendall Square, as described in Subsection 6.4.2. Considers vehicle operating costs only.

  COST_C_AAA dollars to take commuter rail from home to Kendall Square, including access costs, as described in Subsection 6.4.6. Considers vehicle operating costs only.

- IRS Model

  COST_D_IRS dollars to drive from home to Kendall Square, as described in Subsection 6.4.2. Considers total vehicle ownership costs.

  COST_C_IRS dollars to take commuter rail from home to Kendall Square, including access costs, as described in Subsection 6.4.6. Considers total vehicle ownership costs.

ASC_DRIVE drive specific constant; fixed at zero.

ASC_TRANSITC commuter rail specific constant.

The estimated coefficients of the Grand Junction Corridor Analysis Model are expected to have the following properties:

- Travel time should have a negative coefficient; as travel time increases we expect the relative utility of the mode to decrease.

- Access time coefficient should have a negative sign; as an increase in access time is undesirable and would result in a decreased utility.

- Wait time coefficient should have a negative sign; as an increase in wait time is undesirable and would result in an decreased utility. This variable is also expected to have a higher perceived penalty than travel time, due to notion of not moving or completing the commute.

- Cost coefficient should be negative as any increase in cost would be perceived as decreasing utility.

The estimated coefficients for the two different versions of the model are listed in Table 6.8 and Table 6.9. As expected, Biogeme and TransCAD provided identical results.

The results indicate that all of the coefficients have the correct sign. The p-value for the commuter rail constant is greater than 0.05, indicating that it is statistically insignificant. The ASC was kept in the model, however, as the National Cooperative Highway Research Program suggests keeping insignificant alternative specific constants [32]. The sign of the commuter rail constant is positive, which suggests that there is some *a priori* tendency to choose commuter rail, all other factors equal.

For the remaining comparisons, the IRS values were used as the IRS model has a higher adjusted rho-squared.

6.7 Validation

Once the coefficients were estimated with the calibration dataset, the model was applied to validation dataset. The results were then compared to the actual choice made by the survey respondents. Since the validation dataset is distinct from the calibration dataset, this test is an independent check the on validity of the model's estimated coefficients. While a perfect match is not anticipated, a range of results $\pm$ 2% are assumed to provide a reasonable model.

The probability of taking commuter rail was estimated for each individual in the validation dataset using the validation dataset travel parameters and the estimated utility model coefficients. Summing these probabilities gives the expected number of commuter rail riders for the validation dataset. Figure 6-9 shows the expected number of commuter rail riders and drivers compared with the number of respondents who indicate that they take commuter rail or drive, for the validation dataset. Since the predictions are within one percent we assume the model can be used to estimate ridership within the Grand Junction corridor.

6.8 Elasticity

The elasticity of a variable shows how much a change in the variable impacts the model output. For example, an elasticity for a variable less than negative one indicates that an increase (or decrease) of one percent in the variable causes demand to drop (or increase) by more than one percent. In this case, demand is elastic. An elasticity greater than negative one indicates that an increase (or decrease) of one percent in the variable causes demand to drop (or increase) by less than one percent. In this case, demand is inelastic [16]. Elasticity ϵ has the general form:

$$\epsilon_y^x = \frac{\%\delta x}{\%\delta y} = \frac{y}{x}\frac{\partial x}{\partial y} \tag{6.8}$$

where x is the model output and y is a model input. We investigated the elasticity of travel time and wait time since they change with each alternative:

$$\epsilon_{TT_C}^{ECR} = \frac{TT_C}{ECR}P\frac{\partial CR}{\partial TT_C} \tag{6.9}$$

$$\epsilon_{WT}^{ECR} = \frac{WT}{ECR}P\frac{\partial CR}{\partial WT} \tag{6.10}$$

where ECR is expected commuter rail ridership, CR is commuter rail mode share, P is population size, TT_C is commuter rail travel time, and WT is wait time.

The estimated elasticities for each station are shown in Table 6.10 and Figure 6-10. The columns represent the travel time and wait time, while rows represent the stations along the Worcester Line. Both travel and wait times are elastic for every station with the exception of Back Bay, which is

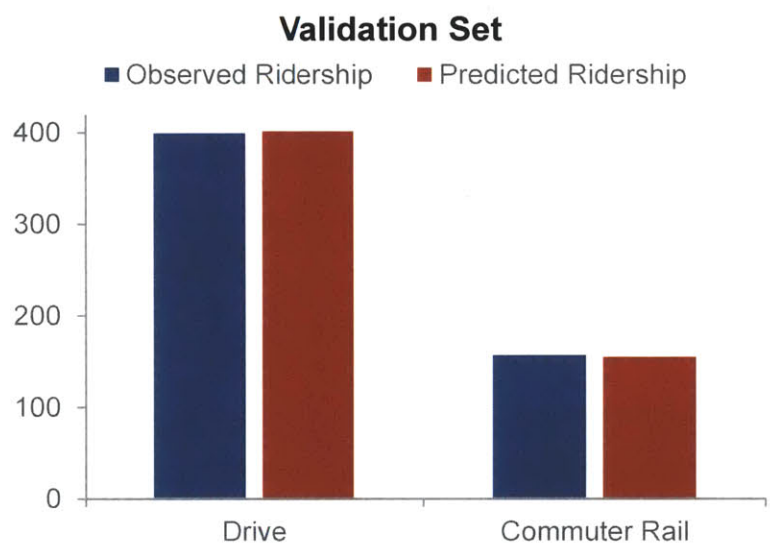

Figure 6-9: Validation Results (IRS)

inelastic because Back Bay is close to the end of the line. The travel time elasticities decline along the line as the travel time decreases.

6.9 Parameter Comparison

The estimated coefficients from the Grand Junction Corridor analysis were compared with values from the Central Transportation Planning Staff's Green Line Extension Home Based Work (GLX-HBW) trip model. Table 6.11 compares the coefficients from the two models.

Comparing the Grand Junction model's estimates[1] with CTPS shows that all parameters have the same signs. The models, however, are constructed with a different set of variables. CTPS uses many more variables than the Grand Junction model. Because the models consider different types of inputs, direct comparisons between coefficient values have limited value. Instead, ratios between the variables listed in Table 6.11 form the basis of comparison.

In general terms, the tradeoff, or marginal rate of substitution, between two inputs is the rate at which an individual gives up one input in exchange for the other input, while maintaining the same level of utility [2].

To compare how transit wait time relates to travel time, the wait time coefficient was divided by the travel time coefficient. This provides the marginal rate of substitution between wait time and travel time. This is then compared against the CTPS values to better understand the model's performance.

$$\frac{\beta_{WT}}{\beta_{TT_{TransitC}}} = \frac{-0.153}{-0.031} = 4.89 \text{ minutes} \tag{6.11}$$

This implies that one minute of wait time is equivalent to 4.89 minutes of transit travel time. The

[1] The estimates for TransCAD and Biogeme were run on two separate computers at different times using the same dataset. Since the software packages provided the same results we used Biogeme for our comparisons as it produces p-values in addition to other statistical data.

Table 6.8: Grand Junction Model Estimation Result (IRS).

Parameter	Value	Robust Std err	Robust t-test	p-value
ASC_TRANSITC	0.489	0.576	0.85	0.40
ACCESSTIME	-0.073	0.013	-5.38	0.00
COST	-0.163	0.024	-6.75	0.00
TRAVELTIME	-0.031	0.006	-5.03	0.00
WAITTIME	-0.153	0.042	-3.66	0.04

Rho-squared = 0.285; Adjusted Rho-squared = 0.273

Table 6.9: Grand Junction Model Estimation Result (AAA)

Parameter	Value	Robust Std err	Robust t-test	p-value
ASC_TRANSITC	0.600	0.588	1.19	0.23
ACCESSTIME	-0.059	0.013	-4.54	0.00
COST	-0.295	0.057	-5.20	0.00
TRAVELTIME	-0.038	0.006	-6.27	0.00
WAITTIME	-0.125	0.042	-3.01	0.04

Rho-squared = 0.259; Adjusted Rho-squared = 0.246

Table 6.10: Elasticity of Commuter Rail Demand along Worcester Line (IRS)

Station	Travel Time	Wait Time
Worcester	-2.91	-1.68
Grafton	-2.05	-1.36
Westborough	-2.43	-1.72
Southborough	-2.26	-1.78
Ashland	-1.99	-1.67
Framingham	-1.72	-1.50
West Natick	-1.56	-1.51
Natick	-1.30	-1.50
Wellesley Square	-1.49	-2.14
Wellesley Hills	-1.38	-2.15
Wellesley Farms	-1.32	-2.20
West Newton	-1.08	-2.20
Newtonville	-0.97	-2.23
Back Bay	-0.36	-0.33

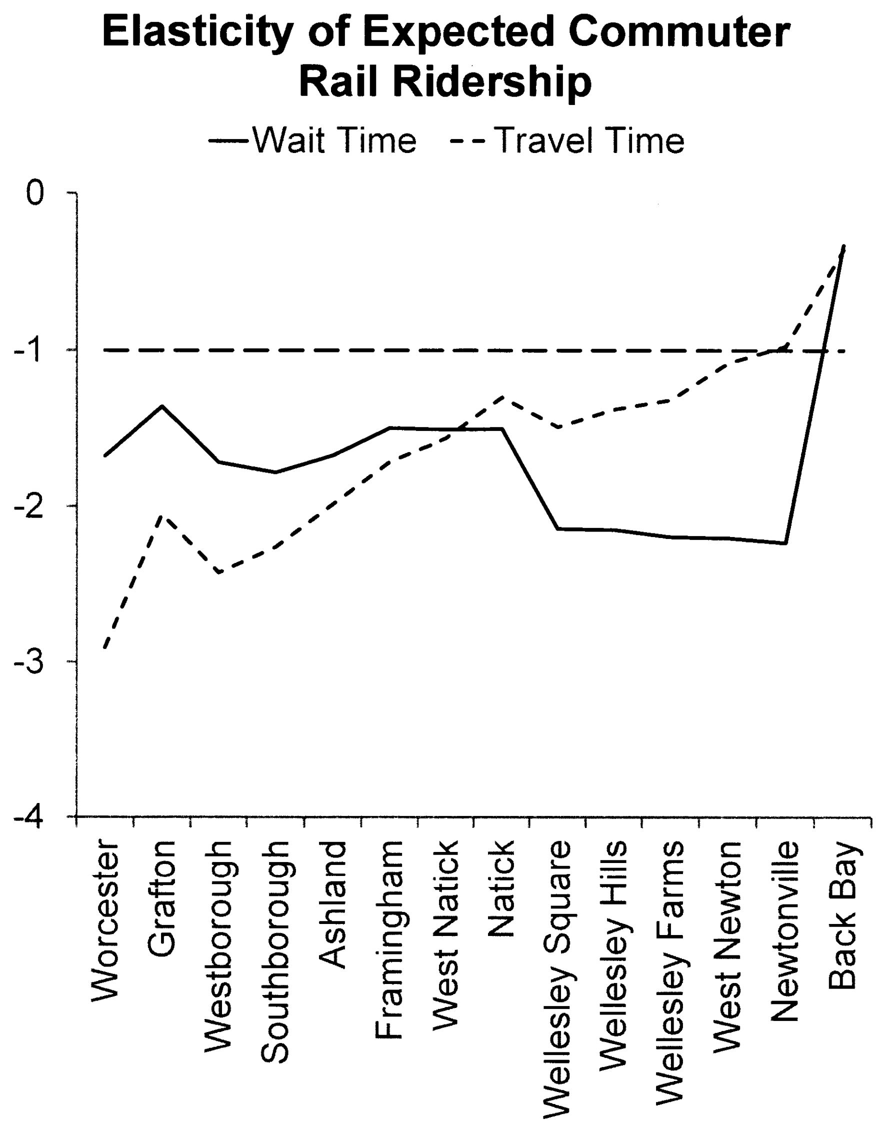

Figure 6-10: Elasticity Results (IRS)

corresponding CTPS ratio for transit is:

$$\frac{-0.148}{-0.080} = 1.84 \text{ minutes} \tag{6.12}$$

This implies that one minute of waiting time is equivalent to 1.84 minutes of transit travel time, with the Grand Junction model having over twice the perceived wait substitution as the CTPS estimate. This difference can be attributed to the fact that CTPS uses transit as their variable, which is a single variable for bus, subway and commuter rail. The wait time calculation includes the scaling equation from Section 6.4.4. This equation has a larger impact on long headway services, which means it impacts the CTPS all-transit figure differently from the Grand Junction commuter rail-only figure.

To compare how access time relates to travel time, the access time coefficient is divided by the travel time coefficient for commuter rail. For this comparison, the CTPS drive to transit coefficient was used instead of the walk to transit coefficient as the majority of the commuter rail users live in outlying areas, and therefore drive to the commuter rail station.

$$\frac{\beta_{AccT}}{\beta_{TT-TransitC}} = \frac{-0.073}{-0.031} = 2.33 \text{ minutes} \tag{6.13}$$

Which implies a penalty of 2.33 minutes per minute of transit travel time. Comparing this with CTPS values for auto-access time and travel time:

$$\frac{-0.201}{-0.080} = 2.51 \text{ minutes} \tag{6.14}$$

This implies that the passenger perceives 2.51 minutes of travel time for each minute of access time. These two variables are similar as both include access to the transit station. This experience would be expected to be the same regardless of transit mode as the access experience is not different. These results are comparable, thus demonstrating that the Grand Junction model is consistent with CTPS' model.

For value of time (VOT) the cost coefficient is divided by the the travel time coefficient and converted from minutes to hours by dividing by 60. This provides an estimate of the cost a rider perceives for their travel time. CTPS used a slightly different methodology, by translating cost to time assuming a VOT of $12 per hour (using 1991 dollars) and doubling the out-of-vehicle time (walk and wait times) before adding it to in-vehicle time. The Grand Junction model VOT estimate is shown below:

$$\frac{\beta_{Cost}}{\beta_{TT-TransitC}} = \frac{-0.163}{-0.031} = 5.21 \text{ mins/\$ or } 11.52 \text{ \$/hr} \tag{6.15}$$

The CTPS VOT for transit is:

$$\frac{-0.471}{-0.080} = 10.19 \text{ \$/hr} \tag{6.16}$$

These values are comparable since the CTPS results are in 2009 dollars and Grand Junction values are in 2010 dollars. To equate the values, an annual inflation rate of 2.72% is used, thus CTPS' VOT becomes 10.47 $/hr in 2010 dollars. While this is approximately one dollar per hour less than the Grand Junction estimate of 11.52 $/hr, this difference may be attributed to the fact that CTPS uses all modes of transit and the Grand Junction model focuses only on commuter rail, as discussed above.

Overall, the parameter comparisons demonstrate that the value of time, access to travel time ratio, and wait to travel time ratio for the Grand Junction model align with CTPS estimates. This comparison with CTPS coefficients, in addition to the validation results and elasticities, indicate that the Grand Junction model should produce realistic ridership estimates.

Table 6.11: Comparison of coefficients.

Parameter	Biogeme Estimate	CTPS Estimate
β_{TT_D}	-0.031	-0.055
β_{TT_C}	-0.031	-0.080
β_{Cost}	-0.163	-0.32
β_{AT}	-0.073	-0.201 (drive)
β_{WT}	-0.153	-0.148
$ASC_{TransitC}$	0.489	

Chapter 7

Alternatives

Travel parameters (and ridership numbers) were estimated for seven different alternatives identified by [30], including a no build alternative which does not differ from existing service. The following alternatives were considered: full commuter rail service to Worcester, Diesel Multiple Unit service to Worcester, and Diesel Multiple Unit (DMU) service to Auburndale, as listed in Table 7.1. A not-to-scale schematic of the service plans is shown in Figure 1-4. Existing service originates in Worcester or Framingham and terminates at South Station. Alternatives 2–4 augment existing service with trains originating in Worcester and terminating in North Station; alternatives 6 and 7 augment existing service with train originating in Auburndale and terminating in North Station. Alternatives 2–7 include two new stations at Boston University and Kendall Square.

7.1 Worcester

Four alternatives originate service in Worcester, the westernmost terminus of current commuter rail service. All four alternatives operate between Worcester and North Station, calling at all intermediate stops. Alternatives 2 and 3 operate the service with Diesel Multiple Unit (DMU) trains, which are a type of self-propelled heavy rail car. DMUs offer better acceleration and deceleration than traditional commuter rail trains, which makes for shorter travel times. Alternatives 4 and 5 operate the service with traditional heavy trains, which have the advantages of being compatible with the current MBTA fleet and higher capacities. Travel times from each station to Kendall Square are listed in Table 7.2. Alternative 1 makes no changes to existing service and uses No Build times. Alternatives 2 and 3 supplement the No Build times with additional service following the DMU times. Alternatives 4 and 5 supplement the No Build times with additional service following the Full Trains times. Frequencies throughout the AM peak at each station vary between 4 and 6 inbound trains for the No Build service as not all trains stop at all stations. Alternatives 2 and 4, the high frequency options, provide an additional 6 inbound trains, and Alternatives 3 and 5, the low frequency options, provide an additional 3 inbound trains throughout the AM peak at all stations.

7.2 Auburndale

Two alternatives originate service in Auburndale, the western edge of the town of Newton, a Boston suburb. West of Auburndale development is much less dense. Because the Auburndale to North Station journey is short we only considered DMUs for the service. Travel times are slightly greater than the Worcester DMU service because we replace powered cars with unpowered trailers to reduce costs. Table 7.3 shows a comparison of travel times to Kendall Square. The high frequency option, Alternative 6, supplements the No Build service with 15 inbound Auburndale to North Station trains during the AM peak. The low frequency option, Alternative 7, supplements the No Build service with 7 inbound Auburndale to North Station trains during the AM peak. All additional service calls at all stations.

Table 7.1: Service Alternatives

Number	Outbound Terminal	Type	Frequency (trains/3 hour peak)
1		*No Build*	
2	Worcester	DMU	6
3	Worcester	DMU	3
4	Worcester	Full Train	6
5	Worcester	Full Train	3
6	Auburndale	DMU	15
7	Auburndale	DMU	7

Table 7.2: Travel Times for Worcester Alternatives

	Minutes to Kendall Square		
Station	**No Build**	**DMU**	**Full Trains**
Worcester	111	75	82
Grafton	97	62	69
Westborough	91	58	64
Southborough	82	50	55
Ashland	77	46	50
Framingham	66	41	45
West Natick	60	38	41
Natick	57	34	36
Wellesley Square	54	27	31
Wellesley Hills	50	24	27
Wellesley Farms	47	22	24
Auburndale	42	18	20
West Newton	39	16	17
Newtonville	35	12	13
Boston University	26	6	7
Yawkey	22	—	—
Back Bay	16	—	—

Table 7.3: Travel Times for Auburndale Alternatives

Station	Minutes to Kendall Square No Build	DMU
Auburndale	42	18
West Newton	39	16
Newtonville	35	12
Boston University	26	6
Yawkey	22	—
Back Bay	16	—

Chapter 8

Model Application

This chapter presents the development of the dataset used to generate ridership estimates, and the application of the logit model estimated in Section 6.6. The Section 8.1, Section 8.2 and Section 8.3 detail the development of the application dataset, including the generation of points, inflation estimates, and travel parameter estimates. Section 8.4 provides an overview of the ridership estimates produced by applying the logit model to the application dataset. Subsequent sections detail the individual ridership components: inbound riders to Kendall Square (Section 8.5), inbound riders to North Station and beyond (Section 8.6), and outbound riders from North Station to Kendall Square (Section 8.7). Section 8.8 provides total ridership numbers.

The application dataset includes one randomly generated point per hypothetical person commuting to Kendall Square from a point in the Worcester corridor. Because it is built from census data for all of Kendall Square, the application dataset more accurately reflects the geographic distribution of Kendall Square commuters than the data from the MIT survey. The application dataset includes one set of points, used for all employment scenarios and alternatives, and several sets of travel parameters—one for each alternative. Each set of travel parameters contains estimates of the drive time, drive cost, commuter rail access time, commuter rail wait time, commuter rail in-vehicle travel time, and commuter rail cost for each point. Costs were estimated in 2010 and 2035 terms.

Ridership estimates are provided for a range of employment estimates for the present and for 2035.

Ridership was predicted in two timeframes for two reasons. First, introducing service along the Grand Junction is relatively low cost and easily implementable. Thus, if a decision were made to start service, initial ridership numbers would be expected to match predictions based on current employment levels. Second, a Grand Junction service should be sustainable, so long term ridership forecasts approximating the predictions based on 2035 employment estimates are necessary.

8.1 Generating Points

Because a representative survey of all Kendall Square commuters is unavailable, we generated the application dataset point randomly based on US Department of Transportation (USDOT) statistics. The US Census Bureau and the USDOT jointly produce the Census Transportation Planning Products (CTPP), a suite of census-derived information designed to aid transportation planners in understanding regional and local commuting habits. The data is available as a series of tables describing where people work, where people live, and how people commute. The most recent complete release uses data collected on the 2000 census long form, a more detailed questionnaire than the basic form that each household in the country receives. The long form was asked of roughly 1 in 6 households, which varies by population density: in rural areas about 1 in 2 houses received the survey, whereas only 1 in 8 houses received the survey in dense urban areas [13]. The Census Bureau discontinued the long form after the 2000 census; future CTPP data will be based on a similar questionnaire collected as part of the American Community Survey.

8.1.1 CTPP Data

CTPP data comes in three sections: Part I includes compilations based on residence location, Part II includes compilations based on workplace location, and Part III includes compilations based on flows between residence and workplace location. CTPP data is provided at varying levels of geographic aggregation and for various universes (e.g., tables may list the total number of workers for each county in a state, or they may list the total number of workers over 16 in each census tract in a state, etc.). The data considered in this analysis is "All Workers," which includes all persons who describe themselves as being regularly employed.

CTPP data is subject to various rounding and truncations designed to protect the privacy of individuals who respond to the survey. All values within a CTPP dataset are rounded according to the rules outlined in Table 8.1: values between one and seven inclusive are rounded to four and values over eight are rounded to the nearest multiple of five. Rounding is applied after summary aggregations (such as sums or means) are calculated, which can make the data appear to have discrepancies. An example of CTPP rounding is provided in Table 8.2; note that the total workers value is not a sum of the rounded number of workers from each mode.

Certain Part III CTPP tables are subject to truncation, which removes all entries with a value less than three. For example, if only two people commute from area C to area A, their entry in the corresponding trip table will be deleted. An example is shown in Table 8.3 and Table 8.4. Truncation impacts are significant for small geographies (such as Traffic Analysis Zones (TAZs), census tracts, and census blocks): a study of CTPP data from the San Francisco area shows a 1.5% decrease in total workers (CTPP Table P3-001, untruncated) when moving from County to County tabulations to Census Tract to Census Tract aggregation; the same shift in aggregation produces a 34% decrease in total workers for a truncated table (P3-006, workers by transportation mode) [14].

8.1.2 Census Geography

The US Census Bureau aggregates information at many different geographical levels, from national estimates (such as the population of the entire country) to state estimates (such as the population of Massachusetts) to local estimates, based on census blocks, block groups, census tracts, or other geographical entities.

A census block is an area bounded on all sides by visible features (such as roads and rivers) or by invisible political/statistical boundaries (such as a county or state line). Urban census blocks are one city block, but blocks in rural areas may cover vastly larger areas. Several census blocks are combined to form a block group, which have an approximate population of 600 to 3,000 people, which the Census Bureau aiming for 1,500 people [31].

Table 8.1: CTPP Rounding Standards

Original Value	**Rounded Value**
0	0
1–7	4
8+	Nearest mutliple of 5

Table 8.2: CTPP Rounding Standards Example

Field	**True Value**	**CTPP Value**
Workers commuting by car	123	125
Workers commuting by train	48	50
Workers commuting by bicycle	1	4
Total Workers	172	170

Table 8.3: CTPP Threshold Example

	Home A	**Home B**	**Home C**
Work A	25	10	*2*
Work B	10	25	10

Table 8.4: CTPP Threshold Example

Home	**Work**	**Records**
A	A	25
A	B	10
B	A	10
B	B	25
C	B	10

While census blocks and block groups may change frequently, census tract are statistical delineations designed to last several decades. Census tracts generally have 1,500 to 8,000 people, with the Census Bureau aiming for 4,000 people. The physical size of census tracts ranges greatly—from a few blocks in very dense areas to entire counties in rural areas. Tracts are designed to be relatively homogeneous in socioeconomic factors [31].

Traffic Analysis Zones (TAZs) are statistical areas delineated by transportation planning departments. They generally consist of one or more census blocks, block groups, or census tracts. The Census Bureau does not calculate information for all geographic aggregation levels for all parts of the country.

8.1.3 Creating Points

To create the set of points representing Kendall Square commuters we examined Journey to Work (JTW) data from CTPP Part III. JTW tables are a matrix showing the number of commuters traveling between different home and work locations. The primary data source was Table P3-001 aggregated at the census tract level, which shows the total number of workers commuting between census tracts. Mode share estimates were obtained from P3-006 aggregated at census tract level, a table that breaks P3-001 values into estimates for flows by sixteen different modes. As P3-001 is untruncated, it provides a better estimate of total flows than P3-006. Census tract aggregation was selected as it provided the best balance of small-geography precision and large-geography accuracy (rounding errors accumulate faster in small geographies).

The number of people commuting from each census tract were tabulated into the census tracts that compose Kendall Square. Our selection of Kendall Square census tracts was visual; the selected tracts are shown in Figure 8-1 and Table 8.5. All commuters who live outside Massachusetts, New Hampshire, Connecticut, and Rhode Island were excluded. Table 8.6 shows that CTPP data estimates 47,744 people commute to Kendall Square; 637 (1%) of these people live outside the listed states. To understand the rounding errors associated with using a smaller aggregation geography we summed the flows from each block group in all states to the block groups that compose Kendall Square (see Figure 8-1). Also calculated were the total number of workers in the census tracts composing Kendall Square using data from CTPP Part II data (P2-001). Table 8.7 shows that the total flow of workers from all states to Kendall Square when estimated by census tract is within 1% of the overall estimate and when estimated by block group is within 3% of the overall estimate.

Within ArcGIS 10 the Create Random Points geoprocessing tool within the Data Management toolbox was used to generate a point for each commuter from each tract within Connecticut, Massachusetts, New Hampshire, and Rhode Island—a total of 47,107 points. During analysis the number of points was considerably reduced:

- 33,027 points that fell within the exclusion zone described in Section 6.3 and depicted in Figure 6-1 were removed.
- 11,059 points that fell outside the Worcester corridor were removed. Points were defined outside the corridor if the preferred commuter rail station (see Subsection 6.4.3) is not served by the existing Worcester/Framingham service.
- 43 points that could not have travel parameters fully estimated, generally because the location could not be placed on the ESRI Streets Network were removed.

The final application dataset had 2,978 points. Figure 8-2 shows the spatial distribution of the fully processed application dataset. The travel parameters for each point were estimated, as outlined in the following sections.

8.2 Inflation

The application dataset contains estimates for travel parameters for the various alternatives (see Chapter 7) in 2010 and 2035. Employment growth estimates between 2010 and 2035 are provided by MAPC and the City of Cambridge, as described in Chapter 4. Costs were assumed to grow uniformly based on historical inflation rates. To calculate historic inflation we analyzed changes in the urban Consumer Price Index (CPI-U) provided by the US Bureau of Labor Statistics. The CPI-U tracks the change in price for a group of goods likely to be purchased by a typical urban

Table 8.5: Kendall Square Census Tracts.

Tract
3521
3523
3524
3526
3531

Table 8.6: Distribution of Kendall Square Commuters.

Region	**Commuters**
All States	47,744
CT, MA, NH, RI	47,107
Difference	637
	(1%)

Table 8.7: Comparison of CTPP Employment Estimates for Kendall Square.

	Total Workers	**Total Commuters**	
	(P2-001, Tract)	(P3-001, Tract)	(P3-001, Block Group)
Number	48,255	47,744	46,595
Loss (%)	—	1%	3%

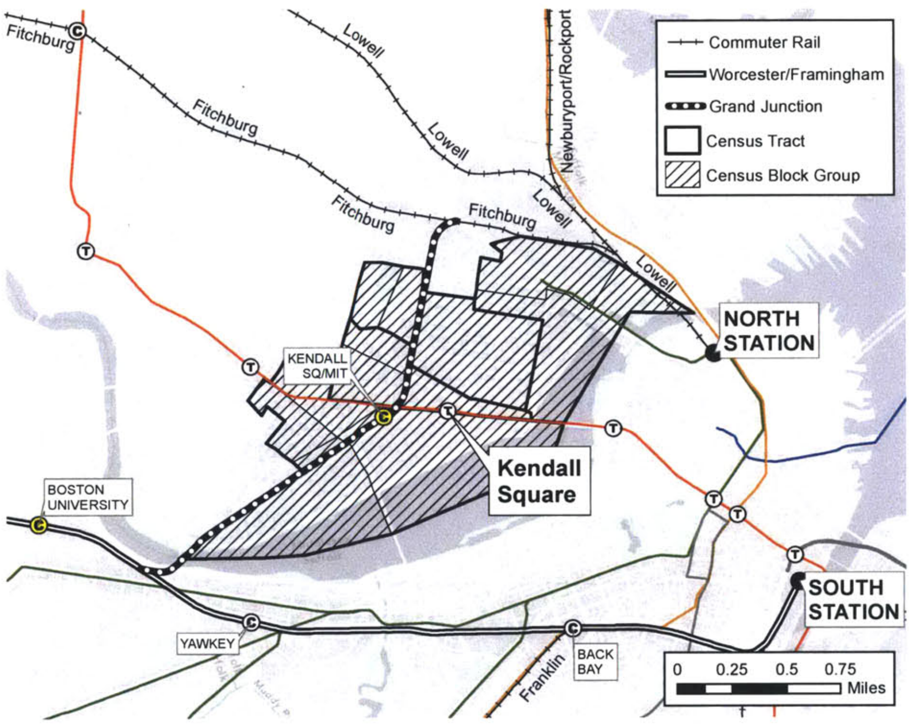

Figure 8-1: Kendall Square Census Tracts and Block Groups

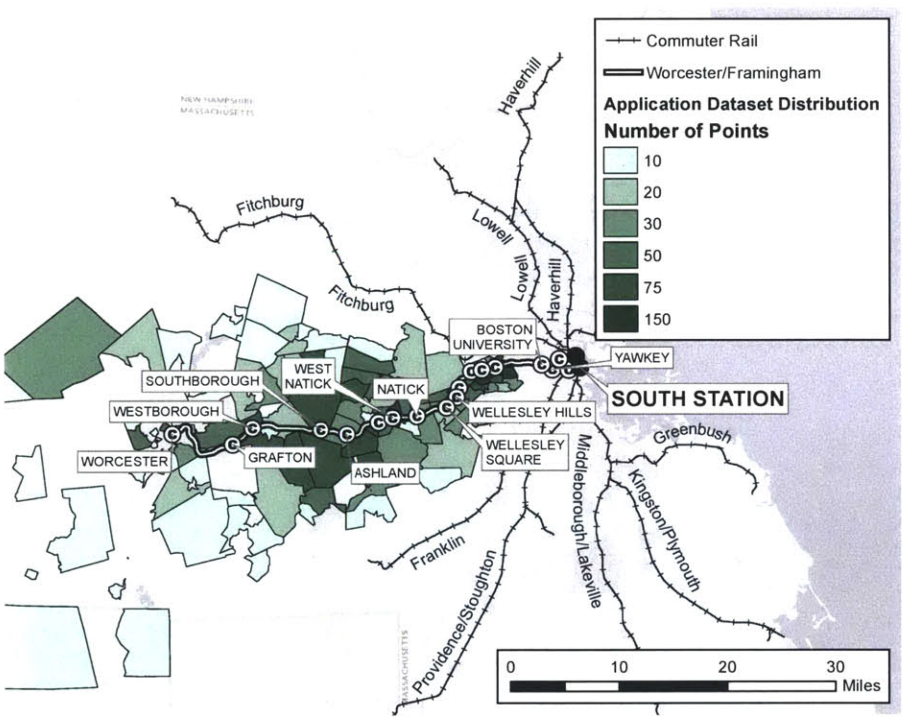

Figure 8-2: Distribution of Kendall Commuters

consumer, and includes transportation and basic necessities such as food. Table 8.8 lists the average monthly inflation for the decade ending in 2010. We calculated the overall annual inflation rate as:

$$I = \frac{1}{12} \sum_{y=2001}^{2010} \sum_{m=1}^{12} i_{my} = 2.1\% \tag{8.1}$$

$$f = (1 + I)^{25} = 1.68 \tag{8.2}$$

where i_{my} is the monthly inflation rate in month m of year y, I is the average annual inflation rate over the year, and f is a scaling factor representing the compounded inflation between 2010 and 2035. Thus, all 2035 costs are 1.68 times the corresponding 2010 cost.

Table 8.8: CPI-U Monthly Inflation Rates

Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2001	0.6	0.4	0.2	0.4	0.5	0.2	-0.3	0.0	0.5	-0.3	-0.2	-0.4
2002	0.2	0.4	0.6	0.6	0.0	0.1	0.1	0.3	0.2	0.2	0.0	-0.2
2003	0.4	0.8	0.6	-0.2	-0.2	0.1	0.1	0.4	0.3	-0.1	-0.3	-0.1
2004	0.5	0.5	0.6	0.3	0.6	0.3	-0.2	0.1	0.2	0.5	0.1	-0.4
2005	0.2	0.6	0.8	0.7	-0.1	0.1	0.5	0.5	1.2	0.2	-0.8	-0.4
2006	0.8	0.2	0.6	0.9	0.5	0.2	0.3	0.2	-0.5	-0.5	-0.1	0.1
2007	0.3	0.5	0.9	0.6	0.6	0.2	0.0	-0.2	0.3	0.2	0.6	-0.1
2008	0.5	0.3	0.9	0.6	0.8	1.0	0.5	-0.4	-0.1	-1.0	-1.9	-1.0
2009	0.4	0.5	0.2	0.2	0.3	0.9	-0.2	0.2	0.1	0.1	0.1	-0.2
2010	0.3	0.0	0.4	0.2	0.1	-0.1	0.0	0.1	0.1	0.1	0.0	0.2

8.3 Estimating Travel Parameters

We estimated the travel options available to each point in the application dataset based on existing Worcester corridor service and station locations for Alternative 1, and based on existing Worcester corridor service and station locations plus introduced service and station locations for all other alternatives. A discussion of the various alternatives can be found in Chapter 7. The dataset includes information for the two primary modes in our study: driving and taking commuter rail. For cost calculations it is assumed that commuters will purchase the transit pass, parking pass, and/or EZPass that minimizes their commute cost.

8.3.1 Driving Parameters

The primary factors that influence a person's perception of the driving mode are travel time and cost. Travel times were calculated in the same manner as travel times for the Estimation Dataset (see Subsection 6.4.1). Travel time was assumed to remain constant between 2010 and 2035. Drive costs were calculated in the same manner as drive costs for the estimation dataset, with a few exceptions:

- The 2010 parking rate is the effective one way daily cost of a market-rate monthly parking permit, which the City of Cambridge estimates at $220 per month [17].

- All costs for 2035 projections were scaled by 1.68 (see Section 8.2). Per-mile drive costs are listed in Table 8.9. Parking costs are listed in Table 8.10, and toll costs are listed in Table 8.11.

The final output was a table listing the drive time, in minutes, from each point to Kendall Square, and a table listing the drive cost, in dollars, from each point to Kendall Square in 2010 and 2035.

Table 8.9: Per-mile Vehicle Costs.

Method	**2010 Cost** ($/mi)	**2035 Cost** ($/mi)	**Includes**
AAA	0.167	0.281	Operating cost only
IRS	0.500	0.840	Total ownership cost

Table 8.10: Parking Pass Costs

Parking Pass	**2010 Cost** ($/mo)	**2035 Cost** ($/mo)
Cambridge Market Rate	220	370

Table 8.11: Tollbooths and Toll Costs

Tollbooth	**2010 Toll** ($)	**2035 Toll** ($)
I-90 EB: Entry 1-6 to Weston	3.60	6.05
I-90 EB: Entry 7 to Weston	3.40	5.71
I-90 EB: Entry 8 to Weston	3.00	5.04
I-90 EB: Entry 9 to Weston	2.65	4.45
I-90 EB: Entry 10 to Weston	2.20	3.70
I-90 EB: Entry 10A to Weston	2.10	3.53
I-90 EB: Entry 11 to Weston	2.00	3.36
I-90 EB: Entry 11A to Weston	1.60	2.69
I-90 EB: Entry 12 to Weston	1.40	2.35
I-90 EB: Entry 13 to Weston	1.20	1.68
I-90 EB: Entry 15 to Weston	1.00	1.68
I-90 EB: Weston to Exit 16	1.00	1.68
I-90 EB: Weston to Boston	1.00	1.68
I-90 WB: Ted Williams Tunnel	3.00	5.04
MA-1A WB: Sumner Tunnel	3.00	5.04
US-1 SB: Tobin Bridge	2.50	4.20

SB: Southbound. EB: Eastbound. WB: Westbound.

8.3.2 Commuter Rail Parameters

The primary factors that could influence a person's perception of the commuter rail option are access time, wait time, in-vehicle travel time, and cost. Access times were calculated in the same manner as access times for the Estimation Dataset (Section 6.4), with one exception:

- The Closest Facility Layer included new commuter rail stations at Boston University and Kendall Square for Alternatives 2–7.

Driving and walking access times were assumed to remain constant between 2010 and 2035. Wait times were calculated in the same manner as wait times for the Estimation Dataset with one exception:

- The alternatives were included when computing the inbound peak period frequency. For Alternative 1, the no build scenario, wait times at each station are exactly the same as the Estimation Dataset.

Wait times were assumed to remain constant between 2010 and 2035. In-vehicle travel times were calculated in the same manner as in-vehicle travel times for the Estimation Dataset with a few exceptions:

- Under Alternatives 2–7 travel times were increased slightly for all existing services to account for the new Boston University station.
- Under Alternatives 6 and 7 all existing services call at Auburndale. (Currently two services bypass Auburndale).
- Under Alternatives 6 and 7 all existing services transfer passengers at Auburndale to the DMU service to Kendall Square.
- Travel time to Kendall Square is the average travel time, including transfers, of all available

services under each Alternative:

$$T^s = \frac{\sum f_i^s t_i^s}{\sum f_i^s}; \quad \forall i \in I, s \in S \tag{8.3}$$

where T^s is the calculated travel time from station s, f_i^s is the frequency of service i from station s, t_i^s is the total travel time to Kendall Square of service i from station s, I is the set of all services (existing and alternative), and S is the set of all stations.

Travel times are assumed to remain constant between 2010 and 2035. Costs were calculated in the same manner as costs for the estimation dataset with a few exceptions:

- Because many employers in Kendall Square encourage employees to take public transportation, the MIT transit pass subsidy rates were applied to all of Kendall Square. This subsidy rate grows with inflation.
- All costs for 2035 projections were scaled by 1.68 (see Section 8.2). Table 8.12 lists parking costs at commuter rail stations and Table 8.13 lists commuter rail fares.

The final output was a table listing the access time, in minutes, from each point to the closest commuter rail station for each alternative; a table listing the wait time, in minutes, at each commuter rail station for each alternative; a table listing the travel time, in minutes, from each commuter rail station to Kendall Square for each alternative; and a table listing the commuter rail cost, in dollars, from each point to Kendall Square for each alternative in 2010 and 2035.

8.4 Ridership Overview

Ridership estimates are the integration of employment, population, and growth estimates, dataset development, and model estimation. The models estimated in Chapter 6, employment scenarios described in Chapter 4, and application dataset described in this chapter were combined to estimate the daily morning peak inbound ridership on the Grand Junction under each alternative described in Chapter 7.

Table 8.12: Parking Costs for Worcester Line Commuter Rail Stations.

Station	**2010 Cost** ($/half day)	**2035 Cost** ($/half day)
Newtonville	3.75	6.30
West Newton	2.00	3.36
Auburndale	2.00	3.36
Wellesley Farms	2.25	3.78
Wellesley Hills	2.25	3.78
Wellesley Square	2.25	3.78
West Natick	2.00	3.36
Framingham	2.00	3.36
Ashland	2.00	3.36
Southborough	2.00	3.36
Westborough	2.00	3.36
Grafton	2.00	3.36
Worcester	4.13	6.94

Table 8.13: Commuter Rail Fares

Zone	**2010 Cost**		**2035 Cost**
	(Unsubsidized) ($/half day)	(Subsidized) ($/half day)	(Subsidized) ($/half day)
LinkPass	59	30	50
1A	59	30	50
1	135	68	114
2	151	76	128
3	163	82	138
4	186	93	156
5	210	105	176
6	223	112	188
7	235	118	198
8	250	130	218
9	265	145	244
10	280	160	269

Services along the Grand Junction have three primary types of riders: inbound to Kendall Square, inbound to North Station and beyond, and outbound from North Station to Kendall Square. The first component was estimated in detail and includes the new daily peak morning inbound ridership to Kendall Square and the redirected daily peak morning inbound ridership to Kendall Square—the number of people who currently use Worcester corridor commuter rail via South Station who would switch to a Grand Junction service. The second component was roughly estimated and includes only new riders. The third component was roughly estimated and includes only people diverted from the Charles River Transportation Management Association's EZRide shuttle. Combined, these four estimates provide the total peak morning users of each alternative, in current and 2035 employment figures.

As described in Subsection 8.5 the expected new daily peak morning inbound riders to Kendall Square for each alternative, model, and employment scenario are estimated by applying the logit model coefficients developed in Table 6.8 to the travel parameters estimated for the application dataset (see Section 8.1). Averaging each point's predicted commuter rail probability gives the commuter rail mode share, which is then scaled by the effective target population, a function of Kendall Square employment that accounts for people who commute outside the morning peak period and people who commute by subway or other modes. Information on employment scaling can be found in Section 4.4. For each employment scenario and model combination the increase in daily peak morning inbound riders to Kendall Square under each alternative (relative to Alternative 1) are assigned to the Grand Junction service as new ridership.

As described in Section 8.5 the ratio of introduced service frequency to existing service frequency gives the redirected daily peak morning inbound ridership to Kendall Square for each alternative, assuming all current riders Worcester corridor riders switch to a Grand Junction service with frequency equal to or greater than current service.

As described in Section 8.6, applying the average elasticity of commuter rail ridership with respect to wait time to the average change in wait time under each alternative gives the expected percent change in Boston-bound riders. Multiplying this by the capturable Boston commuting demand estimates the new daily peak morning inbound riders to downtown Boston. We chose not to develop a separate application dataset for Boston-bound commuters—which would produce ridership estimates in the same manner as the new and diverted Kendall Square ridership—because the primary focus of this study is demand to Kendall Square.

As described in Section 8.7 the captured daily peak morning reverse ridership from North Station to Kendall Square for each alternative is a function of the ratio of introduced service frequency to existing service frequency. In this model all current EZRide users switch to the Grand Junction service according to the frequency share of Grand Junction service.

8.5 Inbound Kendall Square Ridership

Inbound Kendall Square ridership has two components: new riders, who currently drive but are attracted to the increased frequency along the Worcester corridor and shorter travel times, and redirected riders, who currently take a Worcester/Framingham service to South Station but are attracted to the shorter travel times. Our primary focus, and thus the most detailed estimates, are for new riders. The total daily peak morning inbound Kendall Square ridership via the Grand Junction and South Station r^{ime} for alternative a, model m, and employment scenario e is given by:

$$r^{ame} = (\sum p_j^{am})E^e \tag{8.4}$$

where p_j^{am} is the probability that a commuter from point j takes commuter rail under alternative a and model m and E^e is the effective target population scalar for employment scenario e defined in Section 4.4.

The new ridership Δr^{ame} for alternative a, model m, and employment scenario e is the change from baseline Alternative 1 (the No Build alternative):

$$\Delta r^{ame} = r^{ame} - r^{1me} \tag{8.5}$$

It was assumed that under Alternatives 2–7 all Worcester corridor users have access to the Grand Junction: either direct from their preferred station (Alternatives 2–5) or by taking an existing service to Auburndale and transferring (Alternatives 6 and 7). In all cases the introduced service offers a significant time savings, and for most alternatives does not reflect a frequency reduction. The redirected ridership δr^{ame} for alternative a, model m, and employment scenario e is the portion of total daily peak morning inbound Kendall Square ridership excluding new riders who use the Grand Junction:

$$\delta r^{ame} = \begin{cases} (r^{ame} - \Delta r^{ame}) & \text{for } F'_a \geq F_1 \\ (r^{ame} - \Delta r^{ame})\frac{F'_a}{F_a} & \text{for } F'_a < F_1 \end{cases} \tag{8.6}$$

where F_a is the total average service frequency for alternative a (introduced and existing service) and F'_a is the additional introduced service frequency for alternative a. We assume that existing riders are satisfied with the no build frequency $F_1 = 6$. Therefore, when the introduced frequency is greater than the no build frequency, *all* existing Worcester corridor ridership to Kendall Square is redirected to the introduced service. When the introduced frequency is less than F_1, only a portion of existing Worcester corridor ridership to Kendall Square is redirected to the introduced service.

8.5.1 New Ridership

A summary of the new ridership for each alternative is given in Figure 8-3 and Figure 8-4. The bar charts show the mean new ridership for each alternative averaged over all 2011 or 2035 employment scenarios and both sets of costs, with the error bars showing the minimum and maximum estimates. In general, we expect the most new rider generation for the high frequency Worcester services (Alternatives 2 and 4), between 300 and 500 daily inbound peak morning riders. New rider generation for the low frequency Worcester services and high frequency Auburndale service (Alternatives 3, 5, and 6 respectively) is less, between 200 and 350 daily inbound peak morning riders. The low frequency Auburndale service (Alternative 7) has slightly lower new rider generation. The no build alternative does not generate any new riders.

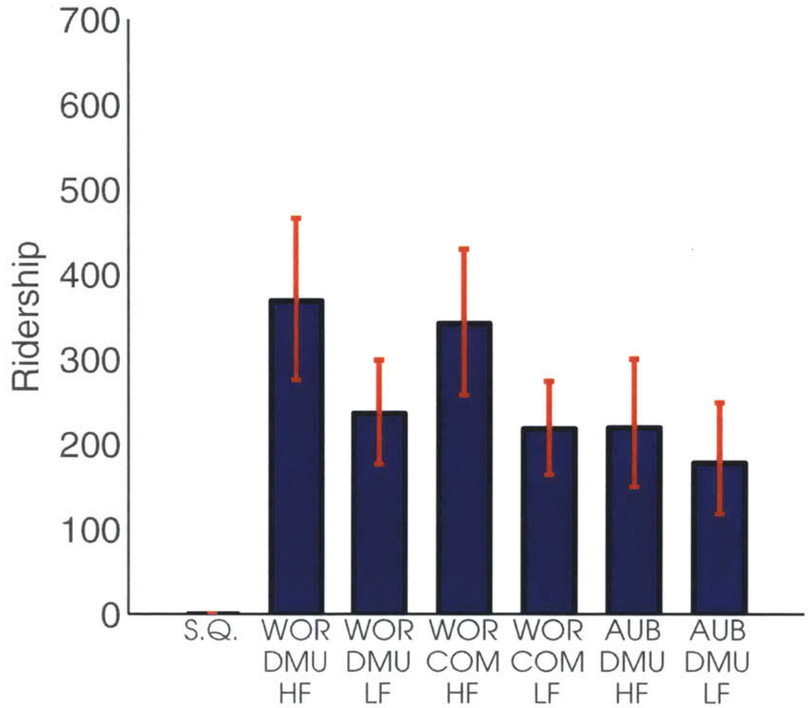

Figure 8-3: New Daily Peak Morning Inbound Ridership to Kendall Square, 2011

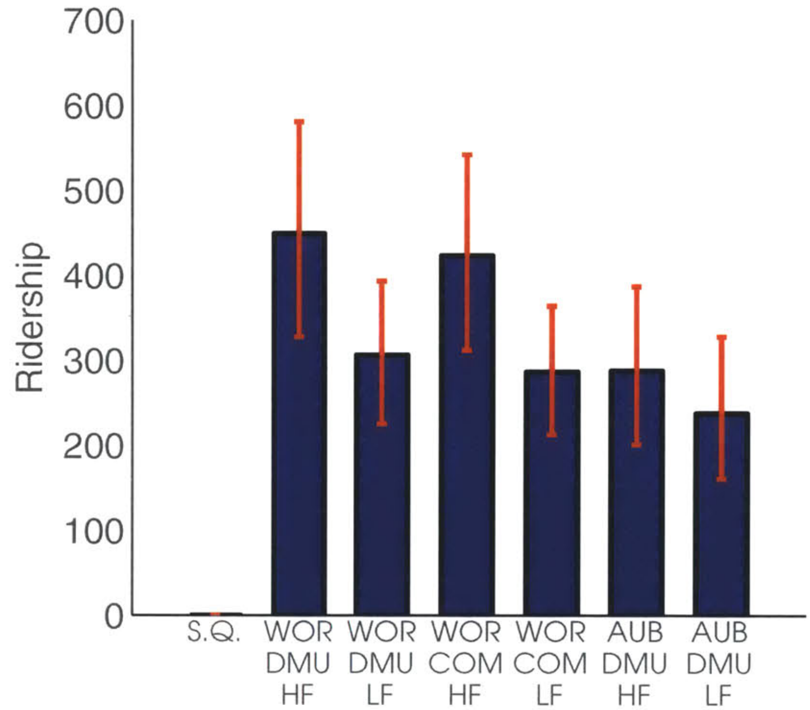

Figure 8-4: New Daily Peak Morning Inbound Ridership to Kendall Square, 2035

For a sense of comparison, the Massachusetts Department of Transportation's (MassDOT) December 2011 study of the Grand Junction corridor predicted that about 400 new riders would use a Kendall Square station served by trains from Worcester.

8.5.2 Redirected Ridership

A summary of the redirected ridership for each alternative is given in Figure 8-5 and Figure 8-6. The bar charts show the mean redirected ridership for each alternative averaged over all 2011 or 035 employment scenarios and both sets of costs, with the error bars showing the minimum and maximum estimates. In general, *all* of the no-build ridership—several hundred daily peak morning inbound riders—switches to the Grand Junction for Alternatives 2, 4, 6, and 7 because the introduced service offers a significant time savings. For Alternatives 3 and 5, the low frequency Worcester services, half of the no build ridership to switches because the Grand Junction service offers a faster travel time but a longer headway.

8.5.3 Total Ridership

The total daily peak morning inbound ridership to Kendall Square is a sum of new riders and redirected riders: roughly 500–1000 riders to Kendall Square under 2011 employment estimates and 1000–1500 under 2035 employment estimates.

8.6 Inbound Boston Ridership

Inbound Boston ridership is a rough estimated based on the estimated commuter rail ridership elasticities, given in Section 6.8. The percent change in Boston ridership $\%\Delta b_a$ for alternative a is given by:

$$\%\Delta b_a = \frac{WT_a - WT_1}{WT_1}\epsilon \tag{8.7}$$

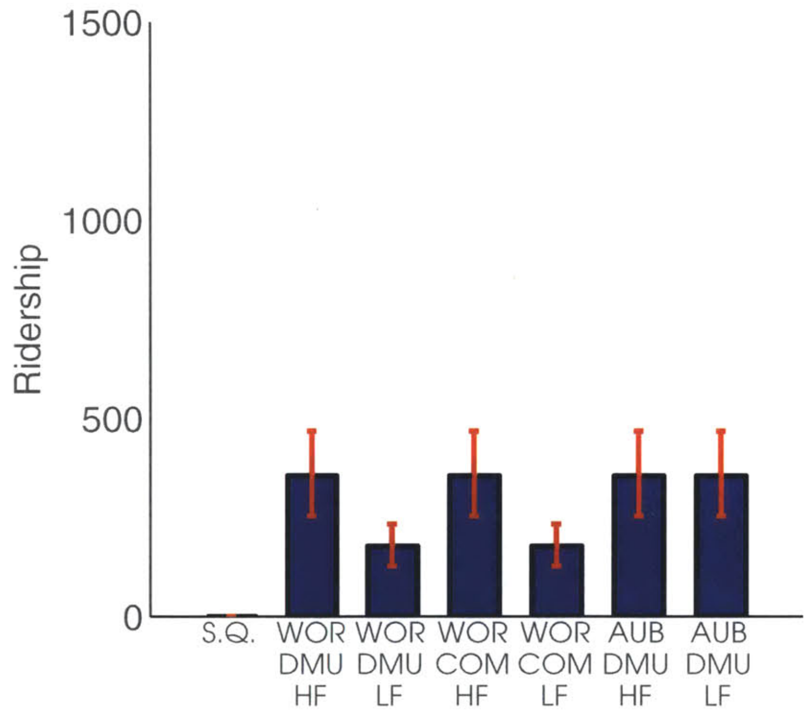

Figure 8-5: Redirected Daily Peak Morning Inbound Ridership to Kendall Square, 2011

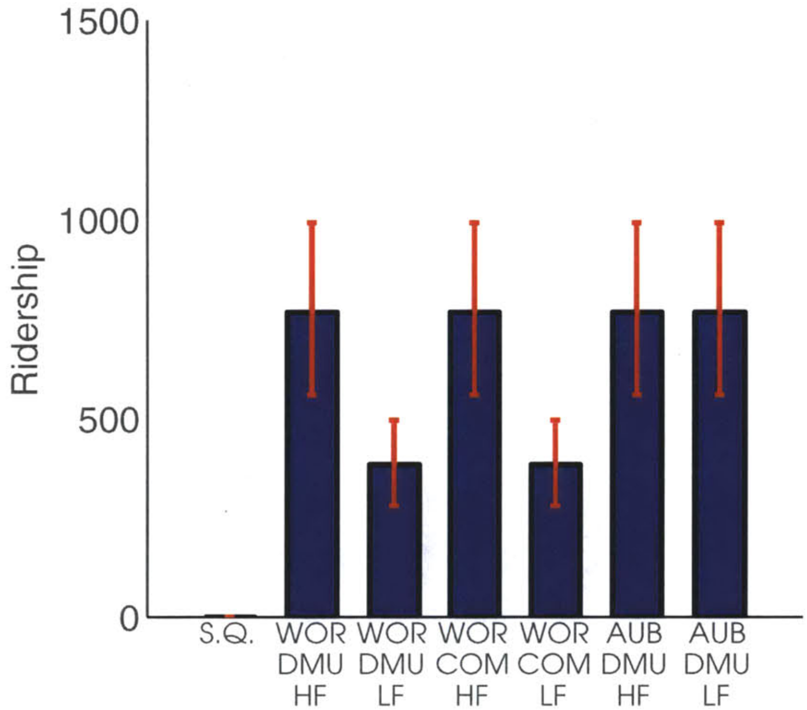

Figure 8-6: Redirected Daily Peak Morning Inbound Ridership to Kendall Square, 2035

where WT_a is the average wait time for alternative a given by Equation 6.2 and $\epsilon = -1.573$ is the average commuter rail ridership elasticity with respect to wait time from Section 6.8. Multiplying the number N_B^0 of daily peak morning inbound Worcester corridor commuter rail users who currently travel to downtown Boston by the percent change in Boston ridership to produces ridership estimate b_a for alternative a:

$$b_a = \%\Delta r_a * N_B^0 \tag{8.8}$$

where N_B^0 is provided by the MBTA System-wide Passenger Surveys [10]. According to the surveys, about 3,700 people per day use existing Worcester services to reach areas of downtown Boston easily accessible from North Station: the Financial District, the Prudential and Hancock buildings, the waterfront, Back Bay, Government Center, and Park Street. About 390 people commute by Worcester/Framingham services to the same areas from Auburndale and Newton. Because some of these areas have better access from South Station and some have better access from North Station, and to provide conservative estimates, we assume that only 75% of these flows could commute by a Grand Junction service. We also assume that Boston commuters share the temporal distribution of Kendall Square commuters—only 61.7% of the Boston commuter flows occur during the morning peak period. Combining these factors gives two values for N_B^0:

$$N_B^0 = \begin{cases} 3,700 \cdot 0.75 \cdot 0.617 = 1,712 & \text{for Worcester services} \\ 390 \cdot 0.75 \cdot 0.617 = 180 & \text{for Auburndale services} \end{cases} \tag{8.9}$$

Solving Equation 8.8 gives ridership estimates for each alternative as shown in Figure 8-7. The high frequency Worcester services (Alternatives 2 and 4) generate the most new Downtown riders, about 900 daily peak morning inbound riders. The low frequency Worcester services (Alternatives 3 and 5) generate about two-thirds as many new riders. The Auburndale services generate few new Boston riders, largely because there is little immediate demand from Auburndale and Newton and we do not consider transfers.

We did not estimate ridership to downtown Boston under a 2035 employment prediction.

8.7 Reverse Kendall Square Ridership

Ridership for general reverse commuting was not estimated; only ridership from North Station to Kendall Square. Currently, people commuting to Kendall Square from most northern commuter rail lines transfer at North Station for a shuttle service to Kendall Square provided by the Charles River Transportation Management Association. The EZRide shuttle departs about every ten minutes and carries about 1000 inbound (to Kendall Square) passengers a day. Services along the Grand Junction will capture a portion of this market by offering a short travel time than EZRide (by avoiding surface street congestion). Though faster while in-vehicle, a Grand Junction service will be less convenient than EZRide, which has multiple stops in Kendall Square. Put together, these assumptions indicate that commuters will not have a strong preference for either service; a commuter arriving at North Station will select whichever service departs soonest. Therefore it was assumed that the ridership n_a captured by alternative a will be:

$$n_a = \frac{F'_a}{F'_a + F^z} N_n \tag{8.10}$$

where F'_a is the frequency of the additional service provided by alternative a, $F^z = 18$ is the frequency of the existing EZRide service (trips per morning peak), and $N_n \approx 617$ is the number of daily peak morning North Station to Kendall Square commuters, taking into account only 61.7% of Kendall Square commuters arrive during the morning peak period.

Figure 8-8 shows the number of people expected to use such a service for each alternative. The high frequency Auburndale service (Alternative 6) has the highest ridership, about 300 daily peak morning riders, because it has the highest frequency. The low frequency Auburndale service and high frequency Worcester services (Alternatives 7, 2, and 4, respectively) all capture under 200 daily peak morning riders. The low frequency Worcester services (Alternatives 3 and 5) capture the smallest ridership, about 100 daily peak morning riders.

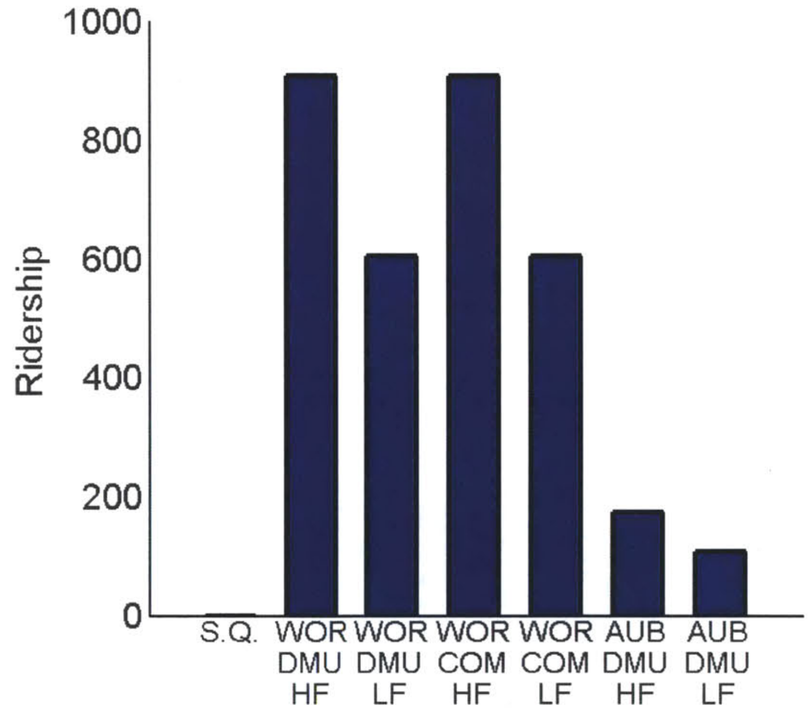

Figure 8-7: New Daily Peak Inbound Ridership to Downtown Boston

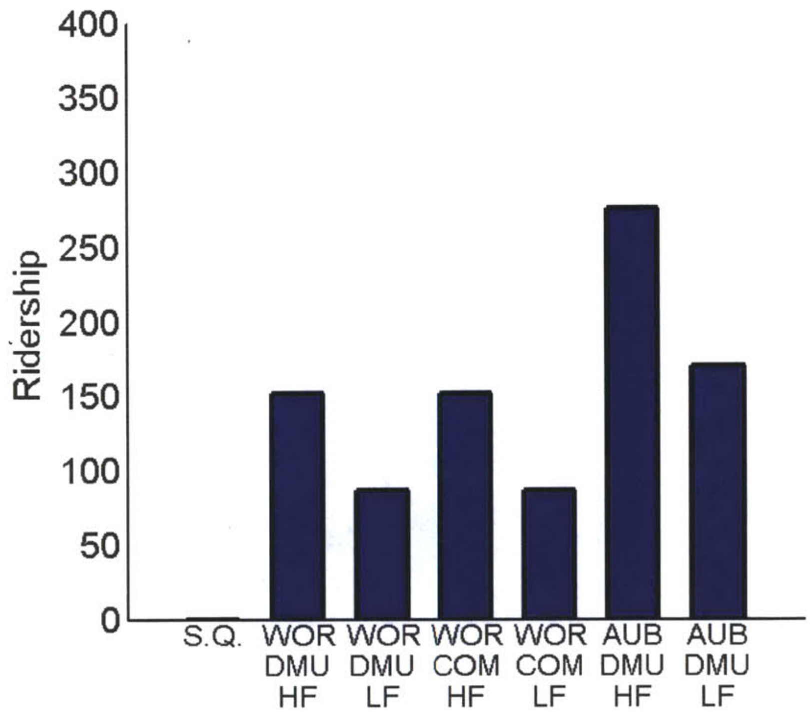

Figure 8-8: Daily Peak Morning Reverse Ridership, North Station to Kendall Square

Reverse commuting under a 2035 employment prediction was not estimated.

8.8 Total Ridership

The total peak morning ridership for each alternative is the sum of the four ridership components—new inbound riders to Kendall Square, redirected inbound riders to Kendall Square, new inbound riders to Boston, and redirected reverse riders from North Station to Kendall Square. Figure 8-9 shows the estimates under current employment (blue) and 2035 employment (red), with the blue and red error bars representing the range in ridership estimates for each alternative for current employment and 2035 employment, respectively. The high frequency Worcester services (Alternatives 2 and 4) have the highest ridership—about 1800 daily peak morning riders—because they (1) attract the most new riders to Kendall Square, (2) capture the most existing riders to Kendall Square, and (3) attract the most new riders to downtown Boston. The low frequency Worcester services and high frequency Auburndale service (Alternative 3, 5, and 6) have a moderate ridership, with the Worcester services carrying more long distance passengers and the Auburndale services carrying more short distance passengers. The low frequency Auburndale service (Alternative 7) has the lowest ridership.

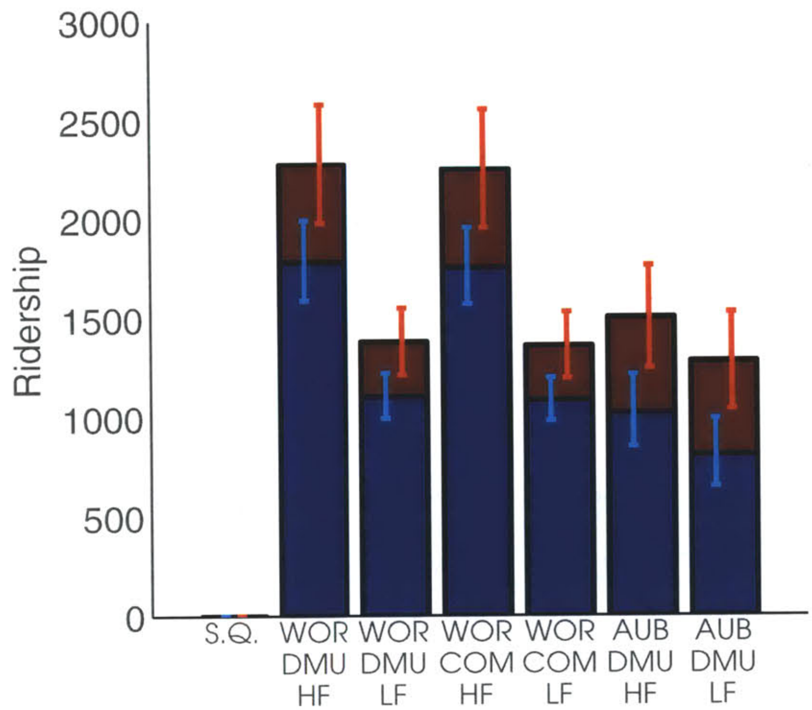

Figure 8-9: Total Grand Junction Ridership

Chapter 9

Conclusions

Our thesis concludes by providing a summary of the analysis, as well as recommendations for further studies and lessons learned while developing the dataset and model.

9.1 Overall Corridor Assessment

The Grand Junction Corridor will most likely observe highest ridership with a long, frequent service. Since most commuter rail riders travel large distances, providing a long service will capture a larger demand in the Worcester corridor than a short service. The addition of higher frequency Grand Junction commuter rail service along the Worcester line will increase the reliability and amount of service without crowding facilities at South Station. Frequency, as demonstrated by the model's elasticity, in addition to reliability, is essential to making commuter rail service more desirable and thus capturing more commuters.

9.2 Recommendations and Lessons Learned

Below are our recommendations for further studies and lessons learned during the analysis of the Grand Junction Corridor.

- Include socioeconomic data in the discrete choice model. Since travel demand models depend on the link between land use and the characteristics of transportation network, the model inputs should include socioeconomic data which better describes this relationship. While the current model produces a reasonable forecast, the addition of disaggregate information on vehicle ownership, employment, income, and other socioeconomic factors would produce more reliable forecasts by accounting for mode choices within the population. While the 2000 census data is available, we feel using the 2010 census as model input would provide the necessary data to produce a more robust model.

- Expand the sensitivity analysis. While this study considered the elasticity of travel time and wait time, variability of many model inputs was omitted. An analysis of the impacts of varying inflation rates, or specific inflation rates for individual cost components (e.g. a better understanding of the impact of potential commuter rail fare increases or variations in the price of parking in Kendall Square) would strengthen the study.

- Explore the potential use of Grand Junction Railroad as a link for current subway lines. While the primary focus of this study was on commuter rail use of the corridor, the potential for inner city travel was recognized during the analysis of reverse ridership. The reverse ridership study for service from North Station to Kendall Square forecasted the highest ridership for the high frequency Auburndale service (see Section 8.7), indicating a potential for further study. In addition this link would provide more direct connections in Boston's radial transit network and could be integrated into phase III of the Urban Ring project.

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Commuting to MIT

Welcome [firstname lastname]!

(If you are not [FIRSTNAME] [LASTNAME], please request your unique web link to this survey.)

The Parking and Transportation Office, the Environment, Health and Safety Office and the Office of the Provost are jointly sponsoring a survey on commuting to the MIT campus. The State of Massachusetts and the City of Cambridge require that MIT collect data related to how you get to MIT every day. In addition, this survey gives MIT the opportunity to find out if the services we offer (subsidized public transportation, bicycle racks, parking access, etc.) are meeting your needs. This survey has multiple sections and should take 10-15 minutes to complete.

As an incentive to participate in this survey, we are offering several prizes. MIT Community members who complete the survey will be entered into a lottery for the following:

- YOUR CHOICE OF GRAND PRIZE AT THE END OF THE SURVEY
  $500 in American Express Gift Cheques OR $500 TechCash
- 25 TechCASH credits valued at $100
- 50 TechCASH credits valued at $50
- 325 TechCASH credits valued at $25
- 10 $50 Zipcar Gift Certificates

Your participation is completely voluntary, and all replies will be confidential. You may answer as few or as many questions as you wish. Thank you for your participation.

Enter the Survey >>

The survey has multiple sections, and your answers will be saved on each page when you select the Next button at the bottom of the page. You may return to the survey at a later time to finish the survey by visiting the same link you used to get to this page. Your previously submitted answers will be displayed for you to edit if you wish. If you edit answers in a section, you must click the "Next" button for that section to save the changes. The results of this study will be reported in summary form only.

If you have any questions about this survey, please contact commute@mit.edu.

Locations where TechCash may be spent are listed on http://web.mit.edu/mitcard/techcash/locations.html.

Zipcar has seven locations on campus and more close by. You could use Zipcar for your MIT departmental driving -- allowing you to leave your own car at home. Contact a Zipcar Rep by visiting http://www.zipcar.com/z2b/contact/. Also, if you are already a regular Zipcar user you should consider switching to one of their Extra Value Plans like the EVP50. This makes sense if your Zipcar bill is typically more than $50 a month -- you'll then get a 10% discount on your usage fees.

zipcar

About You

1. Is MIT your primary employer/school?

- Yes
- No, I am a student at another institution
- No, MIT is my secondary employer
- No, I am a visitor
- Other, please specify:

2. How many hours do you normally work/study on campus each week?

- Less than 17 hours
- 17-30 hours
- More than 30 hours

3. What time do you usually arrive on campus?

Before 6:00 AM	7:00-7:30 AM	8:30-9:00 AM	After 10:00 AM
6:00-6:30 AM	7:30-8:00 AM	9:00-9:30 AM	
6:30-7:00 AM	8:00-8:30 AM	9:30-10:00 AM	

4. What time do you usually depart from campus?

- Before 4:00 PM
- 4:00-4:30 PM
- 4:30-5:00 PM
- 5:00-5:30 PM
- 5:30-6:00 PM
- 6:00-6:30 PM
- 6:30-7:00 PM
- 7:00-7:30 PM
- 7:30-8:00 PM
- After 8:00 PM

Your Commute

1. We are interested in learning how long it takes you to get to and from MIT. Using whatever method of transportation you normally use, please indicate your estimated commute time door-to-door under different conditions.

Condition	Your commute to MIT?	Your commute from MIT?
Normal Day	Please select...	Please select...
Good / Fast Day	Please select...	Please select...
Bad / Slow Day	Please select...	Please select...

2. Thinking about the last year, what would you say is your PRIMARY commuting method?

Select your primary commuting method...

3. Are you considering changing the way you commute over the next year?

- Yes
- No

If YES, please tell us what commuting method you are CONSIDERING:
Select how you might commute in the future...

How You Got to Campus Last Week

1. Please indicate how you commuted TO CAMPUS each day LAST WEEK. Please make one entry for each day of the week.	**LAST WEEK**						
	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Scheduled day off (e.g., weekend)							
Drove alone the entire way							
Drove alone, then took public transportation							
Walked, then took public transportation							
Shared ride/dropped off, then took public transportation							
Bicycled and took public transportation							
Rode in a private car with another person							
Rode in a private car with 2-6 commuters							
Rode in a vanpool (7+ commuters) or private shuttle (e.g. TechShuttle, SafeRide)							
Dropped off at work							
Took a taxi							
Bicycled							
Walked							
Out of office (sick, vacation, jury duty, business trip)							
Worked at home							
Other, please specify:							

2. On any day last week, did you travel BACK TO YOUR HOME from MIT using a different mode than indicated above?

- Yes
- No

If YES, how many days last week did you use a different method to get home?
Select # of days...

Public Transportation

1. Do you currently purchase a monthly MBTA pass?

- Yes, from MIT
- Yes, from somewhere other than MIT
- No

2. How many months in the past year did you purchase a public transit pass, from MIT or elsewhere?

Please select...

If you have a Charlie Card Number or Charlie INSIDE! Card:

3. As part of the ongoing research initiatives involving travel patterns, we are interested in understanding how you use the MBTA system. If you would like to participate, please enter your Charlie Card number below. MIT will confidentially monitor the total transit usage of this card.

Charlie Card Number or Charlie INSIDE! Number:

Enter your Charlie INSIDE # from the back of your MITID --OR-- the # on the front of your CharlieCard.

You may rescind your participation in this program at any time by contacting John Attanucci at jattan@mit.edu.

MIT Transportation Services

MIT offers a number of transportation services and would like to know how many community members are aware of and use the services.

	SERVICE AWARENESS			SATISFACTION WITH SERVICE				
Please indicate if you have used or are aware of the following services. If you have used this service, please indicate your level of satisfaction.	Aware of service, USE IT	Aware of service, DO NOT USE IT	Not aware of service	Very DIS-satisfied	Generally DIS-satisfied	Generally Satisfied	Very Satisfied	Not applicable
Flexible hours to accommodate schedules								
MIT Parking and Transportation Office website								
On-site information on transit routes and schedules (e.g., brochures, shuttle schedules, bicycle maps available in W20 and around campus)								
Transportation Programs	Aware of service, USE IT	Aware of service, DO NOT USE IT	Not aware of service	Very DIS-satisfied	Generally DIS-satisfied	Generally Satisfied	Very Satisfied	Not applicable
MBTA Pass Program								
MassRIDES (carpool matching program)								
VPSI (vanpool matching program)								
Carpools/Vanpool Parking Programs								
Economy Parking Programs								
Emergency Ride Home Program								
Zipcar (car sharing)								
Alternative Transit Subsidy								
Smartway Elite Discount								
Biking	Aware of service, USE IT	Aware of service, DO NOT USE IT	Not aware of service	Very DIS-satisfied	Generally DIS-satisfied	Generally Satisfied	Very Satisfied	Not applicable

Secure bike storage								
Outdoor bike storage								
Bicycle Repair Stations								
Qualified Bicycle Commuter Benefit								
Locker and/or shower facilities for runners / bicyclists in or near your building								
Shuttles	Aware of service, USE IT	Aware of service, DO NOT USE IT	Not aware of service	Very DIS-satisfied	Generally DIS-satisfied	Generally Satisfied	Very Satisfied	Not applicable
Safe Ride								
Tech Shuttle								
Airport Shuttle								
Boston Shuttle								
NextBus (real time tracking of MIT shuttle services, formerly ShuttleTrack)								
The Lincoln Lab Shuttle								
M2 Shuttle (Longwood - LMA)								
EZ Ride / Northwest Shuttle								

In general, how satisfied are you with MIT's transportation services?

- Very satisfied
- Somewhat satisified
- Neither satisfied nor dissatisfied
- Somewhat dissatisified
- Very dissatisified

Biking

1. Do you own a bike?

- Yes
- No

2. Whether you cycle to campus or not, what one thing would make you more inclined to cycle to campus?

- Safer bike routes to campus
- More bike routes to campus
- Better bike parking facilities
- Locker and/or shower facilities in or near your building
- Better weather
- Shorter commute distance
- Nothing would make me more inclined to cycle to campus
- Not an option (e.g., health reasons, safety concerns, not near a bike path)
- Other (please specify)

3. If you ever use a bike to commute to campus or get around on campus, which best describes your cycling behavior:

- Single-trip rider (store bike in one location on campus during the day)
- Multiple-trip rider (store bike in several locations on campus during the day)
- Not applicable - I never bike to or on campus

PROGRAMMING NOTE: if bikecomm=3 (do not bike to or on campus), skip p6a.html and go to p7.html

Biking & Bike Storage

1. When on campus, where do you usually store your bike?

- At an outdoor bike rack
- At an outdoor object such as a sign post, street lamp, tree, parking meter, etc.

In an indoor bike storage room

In a private office/lab

Other (please specify)

2. Please select the building where your bike is usually stored, or the building closest to where your bike is stored:

Select building (listed by number)

3. Is the location where you usually store your bike ever filled to capacity?

Yes

No

4. Which of the following would most improve bike storage on campus?

More outdoor open-air bike racks

More outdoor covered bike racks

More secure outdoor bike storage areas (bike cages)

More secure indoor bike storage rooms

Other (please specify)

5. What is the primary reason you choose to cycle to campus or get around on campus?

It's healthy

It's economical

It's convenient

It's fun

It reduces air pollution

Driving is too expensive/inconvenient

Other (please specify)

6. How often do you utilize the do-it-yourself bike repair stands (metal stands with tools and air pumps) on campus?

Once a week

Once a month

Once a year

I do not utilize them

I am not aware of the bike repair stands on campus

Driving & Automobile Ownership

1. If you live off-campus:
How many total licensed drivers reside in your current household?

0 1 2 3 4 5+

Not applicable; I live on campus

2. How many total motor vehicles are CURRENTLY registered to members of your household?

0 1 2 3 4 5+ Not applicable

3. If you drive to campus, how many times a month, on average, do you use your <u>own motor vehicle for institute-related business</u> during the day?

None

1 to 4 times per month

5 or more times per month

Not applicable

4. If you drive to campus, where is your motor vehicle usually parked?

MIT parking lot (MIT sticker required)

Other paid parking lot

On-street parking

- Not applicable
- Other (please specify)

Your Use of the MBTA

MIT is looking at potential ways of improving its T-pass programs and needs additional information about how often you ride the MBTA. The information you provide below will assist MIT researchers who are designing potential transportation benefit programs.

How many times did you get on each of these routes in the **past 7** days? *(e.g., Oct 24-30)*	
# of times you got on	Red Line
# of times you got on	Green Line
# of times you got on	Orange Line
# of times you got on	Blue Line
# of times you got on	Commuter Rail to (or from) South Station
# of times you got on	Commuter Rail to (or from) North Station
# of times you got on	1 Bus
# of times you got on	47 Bus
# of times you got on	64 Bus
# of times you got on	68 Bus
# of times you got on	70/70a Bus
# of times you got on	83 Bus
# of times you got on	85 Bus
# of times you got on	91 Bus
# of times you got on	CT1 Bus
# of times you got on	CT2 Bus
# of times you got on	Other MBTA route (bus or boat)
# of times you got on	Private (non-MBTA) bus
# of times you got on	Amtrak or other rail
# of times you got on	EZRide Shuttle
# of times you got on	M2 Shuttle
# of times you got on	MIT Shuttle (e.g., SafeRide, Tech Shuttle)

Cell Phones

As MIT thinks about additional services to improve transportation to and around campus, we'd like to understand how the community uses cell phones to get information.

1. What kind of cell phone do you primarily use?

- iPhone / iOS
- Android
- Blackberry/RIM
- Other
- None

2. Do you use your cell phone at least occasionally to:	Yes	No
Read text messages	○	○
Read your email	○	○
Browse the web	○	○
Use an application to view bus or train schedules	○	○
☐ I do not use a cell phone		

Last Section: Almost Done!

What is the most important thing MIT could do to improve commuting?

May we follow up with you if we have questions about your commuting patterns for additional MIT research? If so, please provide the best email address where MIT researchers may reach you:

Thank You Drawing

As our thanks for completing the survey, all survey completers will be entered into the drawing for a $500 grand prize, TechCash credits of $100, $50 and $25, and $50 Zipcar gift certificates. Please tell us which grand prize you would prefer:

$500 MIT TechCash

$500 American Express Gift Cheques

I do not wish to be entered in the drawing.

Thank you for taking the time to answer the survey. Prize winners will be notified by November 19, 2010.

The MIT Parking and Transportation Office offers a wide variety of options for the MIT community to commute. MIT encourages the community to carpool, use public transportation, bike, and walk when traveling to work or learn in Cambridge or MIT. Select options are listed below; more information may be found at http://web.mit.edu/facilities/transportation/.

Commuting Options

MassRIDES, the Massachusetts Department of Transportation's statewide travel options program, provides assistance to commuters for alternative modes of transportation. For more information go to www.commute.com or call 1-888-4COMMUTE.

MassBike, the Massachusetts Bicycle Coalition is the statewide bicycling advocacy organization and has information, maps, events, and other bicycle commuter information available on their web site at www.massbike.org.

MIT's T-pass program allows registered students and employees who do not have a full parking permit to purchase subsidized MBTA monthly passes. The Massachusetts Bay Transportation Authority (MBTA) has schedules, maps, transit updates, and other information that will help you with your commute to MIT at www.mbta.com.

Emergency Ride Home (ERH) Program eliminates the uncertainty of using an alternative commute. Should an emergency change your travel plans, the ERH can ensure that you are not stranded at work. As a member of Charles River TMA, MIT employees are eligible to take advantage of the Emergency Ride Home Program.

MIT sponsors Zipcar membership for both Staff and Graduate Students, and hosts seven Zipcars in convenient locations on campus. An MIT Sponsored Member pays no application fee, no security deposit and a $25.00 annual fee. Zipcars can reserved online at any time, and can be used by the hour. Faculty and staff should Zipcar for your MIT departmental driving -- allowing you to leave your own car at home. Contact a Zipcar Rep from http://www.zipcar.com/z2b/contact/. Also, if you're already a regular Zipcar user you should consider switching to one of their Extra Value Plans like the EVP50. This makes sense if your Zipcar bill is typically more than $50 a month -- you'll then get a 10% discount on your usage costs. For more information about the Zipcar program, please visit www.zipcar.com.

MIT operates a number of shuttles, and provides campus stops to other local area shuttles:

- **MIT's SafeRide** provides a safe means of transportation at night within and around the MIT campus, with two Cambridge and two Boston routes.
- **MIT's TECH Shuttle & Northwest Shuttle**provides transportation around the MIT campus on weekdays, looping around the campus from Kendall Square to Westgate.
- **MIT's Winter Shuttles and Airport Shuttles** are run during certain times of year to assist commuters get to and from campus.
- Additional shuttles with stops on campus include the Bates Shuttle, Lincoln Lab Shuttle, Wellesley College Shuttle, Grocery Shuttle, EZ Ride and M2 Shuttle.

Charles River Transportation Management Association is a group of Cambridge businesses created to improving commute options for employees that commute to Cambridge. MIT is a founding member of CRTMA. Among CRTMAs programs are MIT's Emergency Ride Home program and EZRide shuttle.