

IS THE RED LINE REALLY THAT BAD?  
AN ASSESSMENT OF THE ACTUAL AND PERCEIVED SERVICE PROVIDED  
BY THE MBTA'S RED LINE

by

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Submitted to the Sloan School of Management  
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ABSTRACT

An analysis of the service provided by the MBTA's Red Line was prompted by a significant public outcry about the "problems on the Red Line". This paper focuses on the critical issues regarding service: reliability, predictability, congestion, communications and relative performance. To do so, four questions were analyzed: (1) What is the actual level of service provided? (2) What do people think that level of service is? (3) Is there a difference between perception and reality? (4) What can be done about it [both improving actual and perceived service]?

The data collected centered on the main performance variables of the service: headways (time between trains), waiting times, travel times and riders' perceived waiting times. Although prior to the survey numerous delays in service were reported, during the survey service was fairly close to schedule. However, riders perceived the service provided as much worse than it really was, even when compared to a control group on a similar rapid transit line. It was concluded that although operational improvements can and should be made, to address public perception of the service significant strides to improve communications and information about the service should be undertaken.

Thesis Supervisor: Dr. Arnold I. Barnett  
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My thesis supervisor, Professor Arnold I. Barnett deserves special mention and praise. Arnie provided countless hours of time, support and guidance by not only gathering data (several times on the subway platforms) but also presenting much of the theoretic basis of the statistical concepts and formulas used, critiquing and suggesting improvements and providing constant encouragement - to him I offer my special thanks.

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## Introduction

In late 1983 the MBTA was engaged in extending the Red Line about three miles north of Harvard Square in Cambridge, a project that required new track and a new station with separate north and southbound tunnels be built at Harvard Square. It also meant that a train entering Harvard Square must first travel northbound about a mile to Davis Square and then head back before resuming southbound passenger service, which takes about 13 minutes.<sup>1</sup> Because of this lag time and the somewhat temporary nature of the facilities being used, as well as some operational and safety reasons, not as many trains could head northbound toward Harvard Square as did previously; if they did, the trains would simply 'backup' and wait inside the tunnel for the (first) train to return from Davis Square. As this process was first being implemented during late 1983, many delays in service occurred. Today however, even though trains must still go to Davis Square to turn around, the MBTA has reportedly addressed the "problems" and, by the first of the year, service was supposedly returned to normal.

However, during the first few months of 1984, complaints about the MBTA's Red Line could be found (almost daily) somewhere in either the print or broadcast media. Excerpts such as these were typical:

"She is a daily commuter, a rider on the MBTA's Red Line...She feels beaten down and discouraged.

Simply put, this transit system, this Red Line spoils too many of her days."

- The Boston Sunday Globe  
Magazine Section, 22 April 1984

"The Globe and the Herald are full of little stories [about the Red Line problems]. Mass transit is getting worse, not better. The T is a disgrace, a headache and a nightmare. I pity those forced to rely on it."

- The Cambridge TAB  
Commentary Section,  
8 February 1984

"It [Red Line service] is going to be a disaster."

- The Patriot Ledger  
20 February 1984

In fact, when daily Red Line riders were surveyed, the words they used most frequently to describe service were, "terrible", "horrible" and "awful".<sup>2</sup> Although these are somewhat nebulous complaints, after discussions with over 250 Red Line riders, I found that their complaints focus on a few basic issues. These are predictability, reliability, congestion, relative performance and poor communications.

Predictability refers to the "unpredictable" length of time spent waiting for train(s) to arrive. Although usually a small fraction of total trip time, waiting time is often the most aggravating - "especially during cold winter days and nights". Riders report that waiting times can vary by over 100 percent: "[from] five, ten, to sometimes even fifteen minutes!"<sup>4</sup> Lewjean Holmes, currently Executive Director of the MBTA Advisory Board, has stated that

"unpredictable on-time performance is a persistent problem with the system."<sup>5</sup>

Reliability refers to the variance over the entire trip time - which is waiting time plus time in transit. Riders complain that while en route, trains frequently make unplanned, "unexplained" temporary stops. To some extent, since the Red Line tracks form essentially a closed loop, reliability variance is reflected in the waiting times (predictability) - but the combination of "long" waiting times and "significant" variance in travel times result in even further frustration. These two quantifiable performance variables (reliability and predictability) will be the basis for most of the empirical work presented in Chapters 2 and 3.

Conversations with riders also reveal there is much confusion surrounding the relative level of service provided to the two southbound areas the Red Line serves: for example, one (Ashmont) rider noted that the MBTA schedules at least twice as many trains to Braintree as to Ashmont, yet within fifteen minutes, a (Braintree) rider mentioned that he 'often' sees two Ashmont trains in a row, before a Braintree train arrives. [When Red Line trains leave southbound out of Boston, they separate onto one of two tracks: some head for the South Shore (Braintree), and others for Dorchester (Ashmont).] As with reliability, objective performance measures can be derived, and will be presented in subsequent chapters. The fourth concern,

congestion, on both the station platforms and the trains will be addressed similarly. Finally, confounding all four of these issues, are the communications problems cited by nearly all riders. Specific complaints address the inadequate information regarding the arrival time of the next train, its destination, the reasons for 'problems', and the 'daily' announcements, noting that, "the delays on the Red Line are due to a disabled train at...". This will also be examined fully in subsequent chapters.

Riders mentioned other issues: coordination with buses, cross-overs and express trains, expensive fares and parking fees, cleanliness of the platforms and trains, general mismanagement and "The Union".<sup>6</sup> These are important issues and are studied annually by the MBTA Advisory Board and the Massachusetts State Auditors Department; I will devote some time to these issues in later chapters as well. However, the majority of this thesis will emphasize the five major issues described above - since they represent the dominant concerns of most riders.

To examine these issues, I'll address four general questions:

- (1) What is the level of service the Red Line "really" provides?
- (2) What do most people "think" the level of service is?
- (3) What, if any, is the difference between "reality" and perception?

- (4) What can be done to improve the actual service and the difference between reality and perception?

Answering these questions will not only provide the means to examine the main concerns of the Red Line riders, but also be the method of attaining the three main goals of this thesis.

This first goal is simply to provide an objective assessment of the service provided by the MBTA's Red Line. Very little data regarding the distributions (mean and variance) of either waiting times or travel times are available - "unbiased" statistics are even more scarce: presently the MBTA's main performance measures are throughput (number of trains through given station in given amount of time) and scheduled runs accomplished - yet, neither of these give accurate indications of the variance (or distribution) of waiting times or travel times. Since it appears that many (if not most) of the Red Line riders are dissatisfied with service, a comprehensive survey that addresses the issues enumerated above will, at least, provide better insight for both riders and management of the Red Line. In this sense, the impact of this paper is meant to be immediate and pragmatic.

A second goal is meant to be a logical extension of the first. The Red Line is not unique in being a highly utilized urban mass transit system. In Boston alone we have

three similar transit lines, not to mention the many other similar transit systems in other urban centers such as New York, Washington, D.C., Paris, and London. Although some of the operational issues are singular to the Red Line, the basic questions, sampling techniques, statistical methodologies, general scope and suggestions for improvement should be applicable to these other transit networks. Consequently, this second goal, though longer term and inductive, is meant to be somewhat straight forward.

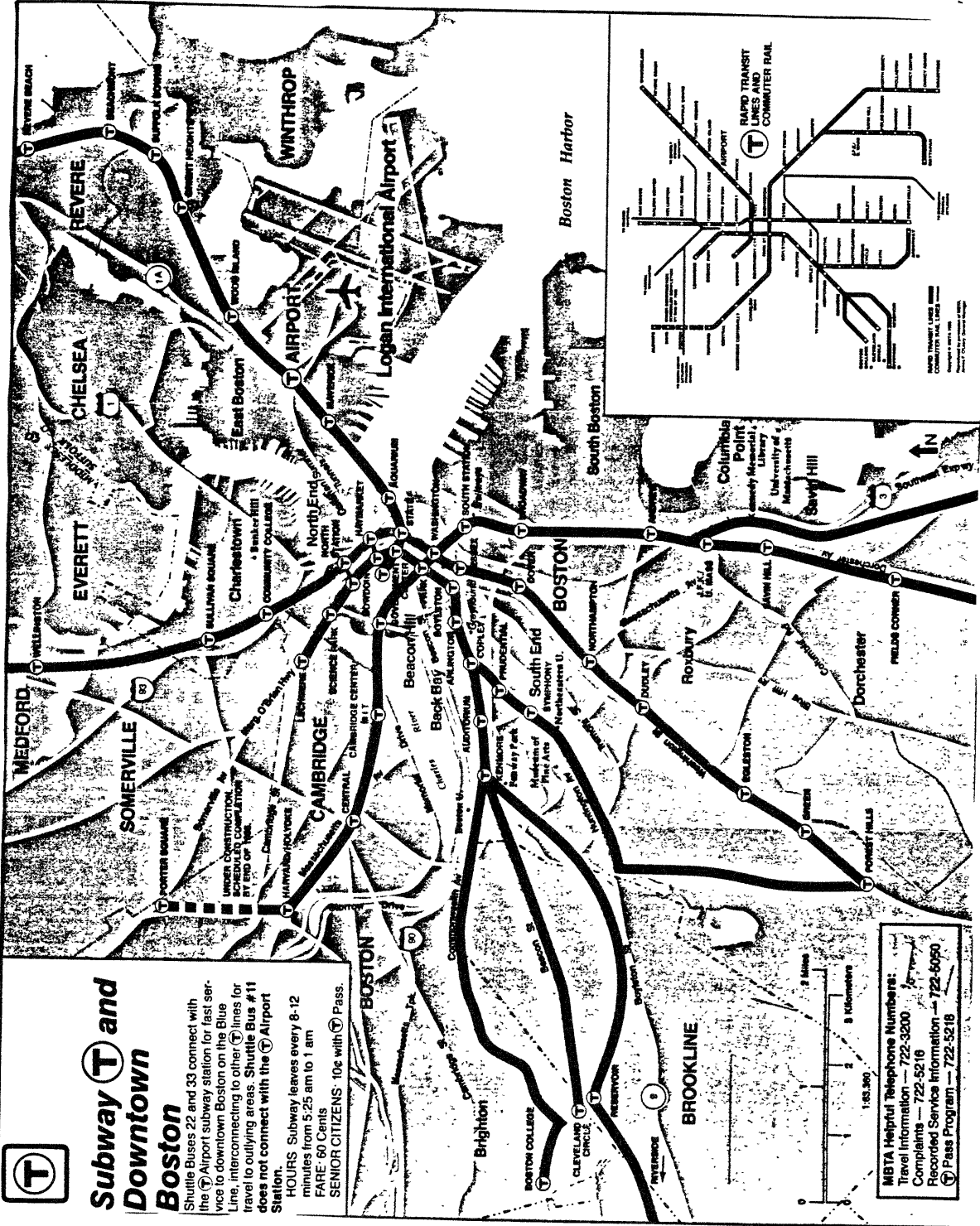
The final goal, however, is more elusive, yet possibly more widely applicable. As the Red Line is not unique in its role as transit network, it is also not unique in its "attraction" of complaints regarding service. In Boston, other subsets of the transit system are subject to public criticism: other subway lines, commuter rail lines, buses and so forth. Other cities' transit systems are subjective to similar criticism as well. Throughout this thesis, the difference between reality and perception is analyzed for waiting times for subway trains, but the experimental design and implications for management may possibly be applied to other services involving waiting times as well; for examples, elevator usage, airline reservation systems, waits for professional services (medical, etc.), and many other activities involving travel. The difference between perception and reality is everpresent; as a final goal, this thesis will address this phenomenon.

As an outline, the four questions listed previously form the basis for the four main chapters which address: actual service, perceived service, the difference between the two and suggestions for improvement. Specific methodologies, experimental design, decision variables, statistical methods and data analysis are described in detail within each respective chapter. For illustrative purposes, I first offer a brief chapter describing the MBTA, and specifically, the operational issues regarding the Red Line.

## Chapter 1: Operational Issues of the Red Line<sup>7</sup>

The Massachusetts Bay Transportation Authority (MBTA or more commonly known as simply, the "T") is responsible for providing "safe, reliable transportation for the commuting public" in 79 cities and towns within the Boston metropolitan area. To do so, the MBTA operates three rapid transit lines (subways, elevated and surface third rail trains), which includes the Red Line, an extensive street car system (known as the Green Line), a commuter rail network and about 1000 buses. Each weekday over 530,000 people use one or more of the MBTA's services. This, the nation's oldest urban mass transit system, has a 1984 annual operating expense of about 400 million dollars - about a third of which comes from passenger fares, the remainder being provided by a combination of local, state and federal funding. [For comparison, Washington, D.C.'s METRO system operates on an annual budget of about 400 million dollars, carries only about 300,000 riders daily; New York City's Transit Authority operates with an annual budget of about 1.4 billion dollars, yet services nearly 3.4 million riders daily.]<sup>8</sup>

The Red Line carries 39% of all riders on the MBTA rapid transit system - about 125,000 passengers each weekday - over two-thirds of whom ride during the morning and peak commuting "rush" hours. The Red Line (see map on the following page) runs underground (except for one bridge) from Harvard Square in Cambridge to the north, southbound



**Subway T and Downtown Boston**

Shuttle Buses 22 and 33 connect with the Airport subway station for fast service to downtown Boston on the Blue Line, interconnecting to other lines for travel to outlying areas. Shuttle Bus #11 does not connect with the Airport Station.

**HOURS:** Subway leaves every 8-12 minutes from 5:25 am to 1 am  
**FARE:** 60 Cents  
**SENIOR CITIZENS:** 10¢ with Pass.

**MBTA Helpful Telephone Numbers:**  
 Travel Information — 722-3200  
 Complaints — 722-5216  
 Recorded Service Information — 722-5050  
 Pass Program — 722-5218

through Boston's central business district (CBD) and then separates into two surface lines at Andrew Station in South Boston whereupon Braintree trains head southeast to the south shore, and Ashmont trains head southwest into Dorchester. Between Andrew station and Harvard Square station, riders can use either an Ashmont or a Braintree train. Unlike parts of New York City's subway system the Red Line has only two tracks - consequently, there are no separate local and express trains. Most riders therefore attempt to board the next available train.

The Red Line is a major commuter link - between 15,000 and 18,000 people use the Braintree line, 10,000 to 12,000 use the Ashmont line and about another 10,000 to 12,000 come in on the train from Cambridge (north of the city) during each rush, morning and afternoon. Most trips on the Braintree line originate from Quincy Center, Quincy Adams and Braintree stations; on the Ashmont line, from Ashmont, Shawmut and Fields Corner stations; and on the north side of the line from Harvard Square and Central Square stations. Most trips end up at Boston's CBD, which is serviced by the Park and Washington Street stations. As the map illustrates, these stations, which are only about one-quarter of a mile apart, provide access to the other rapid transit lines of the MBTA system. Not surprisingly, the origin and destination patterns are basically reversed for the afternoon rush.

[Some statistics to help interpret the accompanying maps: Harvard Square to Braintree is 15.2 miles, Harvard Square to Ashmont is 9.2 miles; for a train to go to Braintree and back from Harvard Square takes about 90 minutes, to Ashmont and back, a little under 80 minutes. Between Park Street and Harvard Square station, a train is scheduled to take about 10.5 minutes (about 3.5 miles). The approximately two miles between Park Street and Andrew station is scheduled to take about seven minutes: proportionately longer because there are more stations that are more heavily patronized. From Andrew to Ashmont, a train is scheduled to take about nine minutes (3.7 miles); to Braintree nearly 20 minutes (9.6 miles).]

Operationally, besides the aforementioned construction project extending service northbound from Harvard Square, there are several noteworthy features regarding the Red Line. These include a somewhat experimental automatic train operator system (ATO), which sets the speed and the distance between trains; the use of some of the oldest equipment in the MBTA system; significant logistics "problems" regarding resource (train-car) availability, preventative maintenance, repair yard locations and the actual on-line daily scheduling system of the Red Line trains. These issues, though only mentioned here, are addressed fully in Appendix 1. One operational issue however demands further elaboration.

Currently, the main automobile commuting expressway into Boston from the south is undergoing reconstruction. This has increased patronage on the Red Line, especially the Braintree line. To address this, the "T" has scheduled more trains to Braintree and planned "cross-overs" (turnarounds) at a mechanical switch at Park Street station for between four to six trains each rush. This reduces round trip times to Braintree by over half an hour, thereby reducing headways, waiting times and congestion. It also helps avoid backups to Harvard Square as mentioned earlier. [This particular scheduling pattern began on March 10, 1984, hence, the two different headway figures for the Braintree line presented in Table 1.1, which will be discussed later.]

Although this scheduling pattern is not planned substantially to affect service either northbound to Harvard Square or southbound to Ashmont, riders on these routes often complain that these turnarounds are examples of the "problems" on the Red Line. Further, it must be noted that currently there is undercapacity for the south side service [i.e., the number of trains available are not fully sufficient to carry the amount of people on the trains at design capacity (170 people/car), although at extremely "crowded" (250 people/car) crush capacity it is possible] and over-capacity (more than enough to carry at design payload) on the northside. On Red Line cars, there are seats for between 65 and 75 people; so, it is planned that nearly 100 will stand, but as this increases over 100, it

gets (very) uncomfortable. This congestion factor is a major complaint since waiting for a second train, or riding a long time in a hot (or cold) car standing jammed against many others, are both undesirable. This is a complex issue and will be addressed in the following chapters.

Finally, with these operational considerations mentioned and the material in Appendix 1 presented, I will briefly describe the overall scheduling process for Red Line trains. The key variable is headways, which is the length of time between trains. [For this report headways are further defined to include the time spent in station and to exclude trains taken out of service or those unavailable for passengers]. Headway length, for the most part, defines service levels such as waiting time, reliability and congestion.

Headway lengths are chosen with many of the aforementioned factors in mind; foremost of these are the number of expected riders, the number of cars/trains available and the planned trip times for certain routes. For example, about 10,000 people ride the Ashmont line each rush hour. Since trains consist of four cars each, (each car with a capacity of about 225 people), each train can carry about 900 people. (Actually, this fluctuates between about 750 and 1000 depending on size of the "crush" congestion). If each train makes a single trip per rush, then 11 trains are needed to get the 10,000 people home. Therefore, if 11 trains are available for the Ashmont line,

since each round trip takes about 80 minutes, the "T" will schedule a uniform headway of 7.3 minutes apart. In practice however, due to fluctuations in car and personnel availability and patronage patterns, scheduling is a bit more complicated, but this is essential in the process: Table 1.1 offers the MBTA's scheduled headways for the Red Line during the first four months of 1984.

Table 1.1

SCHEDULED HEADWAY TIMES (RUSH HOURS ONLY)\*\*

<u>Station</u>	<u>Planned Headway (minutes)</u>
<u>Northside:</u>	
Morning - From Harvard Sq. Southbound	
* To Park/Wash. (as far as Andrew)	4
Ashmont line only	8
Braintree line only	8
Afternoon - Northbound	
* From Park/Wash. (from Andrew)	4
<u>Southside:</u>	
Morning and Afternoon	
* To and From Ashmont	8
* To and From Braintree	
January 18 - March 10	6.5-7
March 10 - Present	5.5-6

\*\* Note: Headways are increased to about 11 minutes during the non-peak hours to/from Ashmont and Braintree; to/from Harvard Square increased to 5.5 to 6 minutes. The coordination of Ashmont and Braintree trains is discussed in Appendix 1.

\* Service that is examined further in Chapters 2 and 3. It should be noted that the planned headways do fluctuate about half a minute over the course of an entire rush hour.

## Chapter 2: The Actual Service

In this chapter, I will analyze the actual service provided by the Red Line during the first four months of 1984. Since over two-thirds of all riders used the Red Line during the peak commuting hours of 7:30 AM to 9:30 AM and 4:15 PM to 5:50 PM, I'll focus analysis on these weekday times. Furthermore, since reliability and predictability are the main concerns of riders, the distributions for headways, waiting times and travel times will be the main performance (decision) variables analyzed.

Our "population" will be the rush hour service provided on the 71 non-holiday weekdays between January 18, 1984 and May 2, 1984. It was impractical to gather data for two rush hours, each day, at every station. Consequently, a sampling method was devised to be representative of the most heavily travelled routes and stations (see Appendix 2). Briefly, since the distribution of headways is independent across days, yet less so (due to the effect that long delays cause) during a given rush hour, sampling days were randomly chosen in advance to reflect a "fair" (equally likely) representation of rush hours during the week (Monday, Tuesday, Wednesday, etc.) and across the four month study period. For example, on the north side of the line, data was collected on 15 separate afternoon rush hours, yielding over 300 headways (and waiting times) and nearly 80 travel times. More data was collected for the north side of the line (between Park Street and Harvard Square), because, as

mentioned earlier, operational delays in late 1983 affected the service noticeably more. Given that and the fact that passengers usually use either the north side (Harvard Square to Park or Washington Street), or the south side of the line (Ashmont/Braintree to Park); I'll address these two areas separately - the northbound side first.

As mentioned during the morning rush, the "T" plans about a 4 minute headway out of Harvard Square southbound to Park and Washington Streets (in fact by estimates from my sampling and the "T" this is the headway that 85-90% of the riders face who get off before Andrew station). A sample of six days (88 headways generated a mean headway of 4.93 minutes) with a standard deviation of 3.14 minutes (see Table 2.1). This in turn generates an average wait for passengers at Harvard Square in the morning of 3.47 minutes (standard deviation of 3.2 minutes).<sup>9</sup>

Note that the mean waiting time is not simply half of the average headway time because since people arrive at the station platform at approximately a uniform rate during the rush hours, more people will arrive during longer headway, skewing the waiting time distribution to the left as compared to the headway distribution. This "hogging effect"<sup>10</sup> concept is critical to the derivation of the expected waiting times. Consequently the method of deriving these statistics follows. [The formulas described are used throughout the paper.]

Table 2.1

SUMMARY STATISTICS FOR SURVEY DATA\*

<u>Station/Rush</u>	<u>Planned Headway</u>	<u>Actual Mean Headway (s.d.)</u>	<u>Derived Mean Waiting Time (s.d.)</u>	<u>Total # Headways</u>	<u>Min.</u>	<u>Max.</u>	<u>Range</u>
Morning rush from Harv. Sq.	4	4.93 (3.14)	3.47 (3.20)	88	1.5	19.0	17.5
Afternoon rush from Harv. Sq.	4	4.34 (2.83)	3.09 (2.58)	309	0.5	15.0	14.5
Afternoon rush from Park/Wash. to Ashmont	8	8.16 (3.62)	4.88 (3.64)	148	2.0	21.5	19.5
Afternoon rush from Park/Wash. to Braintree							
<u>Before Mar. 10</u>	<u>6.5-7</u>	<u>6.94 (3.28)</u>	<u>4.25</u>	<u>85</u>	<u>1.5</u>	<u>17.0</u>	<u>15.5</u>
<u>After Mar. 10</u>	<u>5.5-6</u>	<u>6.05 (3.67)</u>	<u>4.14</u>	<u>105</u>	<u>0.5</u>	<u>18.5</u>	<u>18.0</u>
<u>TOTAL (combined)</u>		<u>6.45 (3.53)</u>	<u>4.19 (3.31)</u>	<u>190</u>	<u>0.5</u>	<u>18.5</u>	<u>18.0</u>

\* All times are in minutes.

In general, if the total number of headways for a given rush hour route (e.g., morning rush from Harvard Square) is  $N$ , and the average headway length is  $M_x$ , then the total amount of time for all headways (of each rush hour route) is  $N M_x$ . Therefore, assuming a uniform arrival rate, a person arriving in a headway of length  $x$  waits, on average,  $x/2$  minutes. Moreover, if  $f_x$  is the proportion of headways of length  $x$  [i.e., number of headways in a sample of length  $x$  divided by total number of headways in the sample,  $N$ ], then the probability a rider arrives in a headway of length  $x$  is  $(x N f_x / N M_x)$ . Note that this fraction is simply the ratio of the number of minutes (riders spent waiting) in a headway of length  $x$  divided by the (total) number of minutes for all headways of the given rush examined.

The  $x$  in the numerator of the last expression incorporates the "hogging effect", that is, for longer headways,  $x$  is larger and so is the probability of arriving in a headway of  $x$ . Multiplying the probability of arriving in a headway of length  $x$  times the average wait for a given headway, and summing over all headways (values of  $x$ ) yields the average wait for a given rush  $E(w)$ . That is

$$E(w) = \sum_{x=.5}^{\infty} \left( \frac{x}{2} \right) \left[ \frac{x N f_x}{N M_x} \right]$$

which is equivalent to

$$\frac{1}{2M_x} \sum_{x=.5}^{\alpha} x^2 f_x = \frac{E(x^2)}{2M_x}$$

An algebraic rearrangement using the formula for variance yields:

$$E(w) = \frac{\sigma_x^2 + M_x^2}{2M_x}$$

In a similar manner we can derive the variance for waiting times  $\sigma^2(w)$  as

$$\sigma^2(w) = \frac{E(x^3)}{3E(x)} - \left[ \frac{E(x^2)}{2E(x)} \right]^2$$

[For the calculations I'll use the sample mean and variance as the maximum likelihood estimator for the population statistics. Moreover, since the data gathered can be used to generate sample distributions, the waiting time distribution can be derived. This derivation will appear in Chapter 3.]

Since this is a relatively small sample size, I'll compare the derived values with a regular rider's actual travel times during the morning rush hour out of Harvard Square. Ms. Grace Locke, a rider on the north side of the MBTA's Red Line for several years, timed her trips nearly every morning between February 8, 1984 and April 27, 1984, a total of 53 days, representing nearly 75% of the entire population of morning rush hours. A summary of the data she

gathered is presented in Table 2.2. A comparison with this data may not only corroborate the sample, but it may be more representative of what regular riders actually face (i.e., one trip per rush hour). Although travel times ranged from 6 to 28 minutes, her mean travel time was 11 minutes (standard deviation of about four minutes). Since the trip is scheduled to take about 6 minutes, by subtraction this indicates an average wait of about 5 minutes for the trains out of Harvard Square during the morning rush. However, when a minute is subtracted from the mean waiting time to account for the approximate amount of time Ms. Locke spent walking to (and from) the platforms [from the collection booth turnstiles], the mean waiting time is closer to the 4 minutes scheduled for this route. [Note that these figures do not deny that on several occasions people waited more than five minutes; rather, they simply provide an estimate of the average waiting time. A more extensive distribution is derived in Chapter 3 that offers probabilities for several times.]

For the afternoon service the "T" also has about a 4 minute headway. A sample of 15 days (309 headways) out of Park Street bound for Harvard Square generated a mean headway of 4.34 minutes (standard deviation of 2.83 minutes). Deriving the waiting time distribution as was done for the morning rush, yields a mean waiting time of 3.09 minutes (standard deviation of 2.58 minutes). Although this is a much larger sample size, Ms. Locke's data for 49

Table 2.2

SUMMARY STATISTICS FOR ACTUAL TRAVEL TIMES\*  
 BETWEEN HARVARD SQUARE AND KENDALL SQUARE

<u>Station/Rush</u>	<u>Mean</u>	<u>Standard Deviation</u>	<u>Median</u>	<u>Min.</u>	<u>Percentile 25th</u>	<u>75th</u>	<u>Max.</u>	<u>Total # of Trips</u>
Harvard Sq. to Kendall Morning Rush	11.09	3.94	10	6	9	12	28	53
Kendall to Harvard Sq. Afternoon Rush	12.06	5.63**	10	6	9	14	40	50

\* Travel Times in minutes

\*\* Increased variance due to (1) operational decisions mentioned in the paper, (2) several noteworthy outliers (e.g. 40 minutes) and (3) few occurrences of opting for the next (second) train to arrive. Note: removing the 40 minute outlier drops the mean to 11.49 and the standard deviation to 3.97.

actual afternoon travel times yielded a waiting time of a little over four minutes, which is fairly close to planned. However, it should be noted that the trains are often already crowded by the time they get to Kendall Square during the afternoon rush; consequently, there were several more outliers in the afternoon data, e.g., 40 minutes, as Ms. Locke waited several times for a second train due to congestion on the first. So, in conclusion, an analysis of the sample data gathered indicates service during the survey period was close to as planned. [See Table 2.1.]

As a final statistic, a sample of afternoon travel times between Park and Harvard Square was completed over four days (85 travel times): the mean was 11.01 minutes, (standard deviation was 1.65 minutes). This is extremely close to the planned travel times of 10.5 minutes. From the data gathered, it appears that most of the variance in total travel times is due to waiting at the station variance (versus time in transit variance) - this can be seen in the relatively low standard deviations for actual trip times versus the relative high standard deviations for waiting times. [This again is surprising for many people mentioned that time in transit varies greatly.]

Assessing the southbound afternoon rush-hour service out of Park or Washington Street stations is a bit more complex for a number of reasons. First of all, over 75% of the riders can only take either a Braintree or an Ashmont train. Secondly, there is undercapacity on both south sides

of the line. Lastly, there is the changing of planned headways in the Braintree line. (These three issues are discussed in Chapter 1). The Ashmont line is a bit easier so I will address it first.

The "T" plans a headway of eight minutes on the Ashmont line (during the rush). My sample of 14 days (148 headways) generated an actual headway mean of 8.16 (standard deviation of 3.62). This in turn indicates a waiting time mean of 4.88 minutes (standard deviation of 3.64). [See Table 2.1 and Appendix 3A for further data.]

On the Braintree line, before March 10, the "T" planned between a 6.5 and 7.0 minute headway; my sample of seven days (85 headways) indicated a mean headway of 6.94 and a standard deviation of 3.28 minutes - which in turn implies a mean waiting time of 4.25 minutes. After March 10, the "T" increased the number of trains and planned to reduce the headways to between 5.5 and 6.0 minutes. My sample of seven days (105 headways) reveals a headway mean of 6.05 minutes with a standard deviation of 3.67 minutes, but because of the higher variance, this generated a mean wait of 4.14 minutes - nearly as long as when the "T" had fewer trains on the Braintree line<sup>11</sup> [see Table 2.1]. This variance may be due to the initial operational difficulties experienced when changing the schedule, but much of this data was gathered during the last few days of April - over a month and a half later. Initially, the plan was implemented in response to the increased round trip travel times to

Braintree and the increased patronage. So this is not meant to imply the "T" should abandon this new schedule, since at the least this reduces congestion, but consideration may be warranted on how to allocate their scarce resources (i.e., maybe shift more trains to Ashmont as well?).

Although not as extensive, data was gathered for the morning southside service and some important information can be highlighted. During the morning rush, one Braintree line rider gathered his actual waiting times at Wollaston station (near Quincy Center); his sample of 20 days yielded an average wait of 3.75 minutes (standard deviation of 2.3 minutes) and an average trip time of about 24 minutes to Kendall Square - which were both within schedule times.

[Trips only as far as Park Street are much more common and are subject to less variance due to the crossover trains and some delays due to the mechanical problems on the Longfellow Bridge between Charles and Kendall Square stations.]

Unfortunately, no morning data was gathered from the Ashmont line.

As with the northside, it appears that service is surprisingly close to schedule; though with a little more variability. But what of the numerous complaints of poor service noted in the introduction? The next chapter addresses this question.

### Chapter 3: Perception of Service

In this chapter, I will present what people think about the Red Line service, compare it with the actual service and analyze the difference. To do so, I'll focus on the variable of waiting time. Waiting time captures many of the critical issues cited by riders (from their perspective): unpredictability, reliability and congestion. Before presenting the data on the perception of service, I'll describe the methodology used to obtain the data.

The general plan is to derive and compare two probability distributions, one for the actual waiting times and one for the perceived waiting times. Deriving the first, given the sample data collected for Chapter 2, is actually relatively straight-forward. Using the concept discussed in Chapter 2<sup>12</sup>, we can derive the probability of waiting exactly  $z$  minutes. As shown the probability of arriving in a headway of exactly  $x$  minutes is  $x f_x / M_x$ . Moreover, the chance of waiting more than  $z$  minutes for a train, given that one arrives in a headway of length  $x$  is  $(x-z)/x$ . [Note:  $x$  must be greater than  $z$  for someone to wait over  $z$  minutes.] Multiplying these two generates the probability of waiting at least  $z$  minutes:

$$\Pr(\text{wait at least } z \text{ minutes}) = \left( \frac{x-z}{x} \right) \left( \frac{x f_x}{M_x} \right)$$

To get the probability of waiting  $z$  minutes or more, one just sums for all values greater than  $z$ , that is

Pr (waiting z minutes or more) =

$$\frac{1}{M_x} \sum_{x=z+5}^{\infty} (x - z) f_x$$

[The derived probabilities are presented in Table 3.1 - the data for the Blue Line Government Center is explained later.]

I have chosen to examine four values (or more accurately the probabilities of waiting four or more specific amounts of time): 3, 5, 7 and 10 minutes. There are several reasons for choosing these times, all having to do with the derivation of the second distribution - riders' perceived waiting times.

Since I would be asking numerous people how long they waited for "x" minutes, I wanted "x" to correspond with reality somewhat, therefore, encouraging rational responses. These particular four numbers were chosen because they seem to represent numbers often used when estimating time, for examples: "I'll be there in ten minutes," or "give me five minutes, will ya?" For the survey, riders were asked for the "percentage of time that [they] waited "x" minutes or more for [their] train [to arrive at the station]". Riders were asked for only one estimate each, thereby avoiding someone from revising their estimate as a new "x" value is offered. [Each rider surveyed had to have ridden the particular Red Line route in question at least four days a

Table 3.1

DERIVED ACTUAL WAITING TIME PROBABILITIES

Probability of Waiting More Than:

<u>Station/Rush</u>	<u>3 min.</u>	<u>5 min.</u>	<u>7 min.</u>	<u>10 min.</u>
At Harvard Sq. during morning rush - south*	55.2%	22.8%	13.7%	6.1%
At Park/Wash. - north (to Harvard Sq.)	57.9%	29.1%	12.0%	2.6%
At Park/Wash. - south (to Ashmont only)	61.1%	42.1%	26.4%	16.9%
At Park/Wash. - south (to Braintree)	52.9%	30.9%	16.4%	5.3%
At Govt. Ctr. - outbound Blue Line	45.0%	9.9%	2.8%	0.1%

\* Includes aforementioned headway of 45 minutes due to fire on March 9, 1984.

week from at least the beginning of the year.] About 100 people, chosen as randomly as possible (over several days at many different places on the platform) during the rush hour in question, were asked for estimates - about 25 at each "x" value. Consequently, a distribution of perceived waiting times could be derived - as Table 3.2 presents.

Even before comparison with the actuals in Table 3.1, an examination of Table 3.2 reveals a few surprising results. Given the nature of the question, one would expect the highest probability for three minutes or more and a decrease for the subsequent three numbers (that is, if one waited ten minutes, s/he would have waited 3, 5, and 7 minutes as well). For most of the data, this is exactly the case. However, just slightly at "x=7" for the northside to Harvard Square passengers in the afternoon, and noticeably more for the southside to Ashmont afternoon riders, a minor deviation occurs. There are few reasons why this may have occurred. For example, sampling error (the sample standard deviation was about 20 percentage points), unexpected perception of the value "x=7" or a desire on the riders' part to "exaggerate" his/her perception for these higher numbers in hopes that this may lead to a "fixing" of the service. However, the difference this phenomenon make is actually quite minor; therefore I'll "smooth" these particular figures to "give the riders (and the survey) the

Table 3.2

PERCEIVED WAITING TIME PROBABILITIES\*

Probability of Waiting More Than:

<u>Station/Rush</u>	<u>3 min.</u>	<u>5 min.</u>	<u>7 min.</u>	<u>10 min.</u>
At Harvard Sq. during morning rush - south	58% (55)	43% (23)	39% (14)	30% (6)
At Park/Wash. - north (to Harvard Sq.)	72% (58)	45% (29)	49% (12)	40% (3)
At Park/Wash. - south (to Ashmont only)	80% (61)	54% (42)	79% (26)	84% (17)
At Park/Wash. - south (to Braintree)	80% (53)	73% (31)	58% (16)	54% (5)
At Govt. Ctr. - outbound Blue Line	44% (45)	23% (10)	11% (3)	8% (0)

\* Actual probabilities from Table 3.1 in percentage are presented in the parentheses.

benefit of the doubt". As Table 3.2A illustrates, the change is only very slight - consequently only the adjusted figures will be used hereafter.

Given that, Table 3.3A presents the difference between the perceived and actual waiting times (by both subtraction of the corresponding data values and ratios). It is clear that there is substantial difference between reality and perception for the Red Line service. In fact, several points are worth noting.

For instance, even though the actual service provided to the north side of the line (to/from Harvard Square) is about the same for the morning and afternoon rushes, the difference between actual and perceived waits, which are derived from essentially the same population of riders, are noticeably larger for the afternoon rush (by about 10% at each value of "x"). This may be because people are more tired and frustrated at the end of the day versus the beginning and consequently tend to exaggerate more. Another reason may be that in the afternoon while at Park Street riders northbound can "see" more activity than when at Harvard Square (i.e., the trains on the other side heading southbound and the cross-over or turnarounds trains on their side), and subsequently expect more service. In fact, these cross-over trains (as described in Chapter 1) were mentioned by many riders as something that in particular bothered them about the service. [Although the cross-over trains do

Table 3.2A

ADJUSTED PERCEIVED WAITING TIME PROBABILITIES\*\*

Probability of Waiting More Than:

<u>Station/Rush</u>	<u>3 min.</u>	<u>5 min.</u>	<u>7 min.</u>	<u>10 min.</u>
At Harvard Sq. during morning rush - south	58% (55)	43% (23)	39% (14)	30% (6)
At Park/Wash. - north (to Harvard Sq.)*	72% (58)	47% (29)	47% (12)	40% (3)
At Park/Wash. - south (to Ashmont only)*	80% (61)	72% (42)	72% (26)	72% (17)
At Park/Wash. - south (to Braintree)	80% (53)	73% (31)	58% (16)	54% (5)
At Govt. Ctr. - outbound Blue Line	44% (45)	23% (10)	11% (3)	8% (0)

\* Contains adjusted values.

\*\* Actual probabilities from Table 3.1 in parentheses.

Table 3.3A\*

ADJUSTED DIFFERENCES BETWEEN PERCEIVED AND  
ACTUAL WAITING TIMES

Probability of Waiting More Than:

<u>Station/Rush</u>	<u>3 min.</u>	<u>5 min.</u>	<u>7 min.</u>	<u>10 min.</u>
At Harvard Sq. during morning rush - south	4% (1.1)	22% (1.9)	28% (2.8)	25% (5.0)
At Park/Wash. - north (to Harvard Sq.)	14% (1.2)	18% (1.6)	35% (3.9)	37% (13.3)
At Park/Wash. - south (to Ashmont only)	20% (1.3)	30% (1.7)	46% (2.8)	55% (4.2)
At Park/Wash. - south (to Braintree)	27% (1.5)	46% (2.4)	42% (3.6)	49% (10.8)
At Govt. Ctr. - outbound Blue Line	1% (1.0)	13% (2.3)	8% (3.7)	8% (**)

\* For further illustration the values in the parentheses are the ratios of (perceived wait)/(actual wait).

\*\* Undefined.

lengthen specific headways they are relatively inconsequential on their impact on service over the duration of the route.

Another highlight of the table illustrates that the riders on the north side of the line often make "better" estimates than the southside riders. For instance, at "x=3 minutes or more", afternoon riders to Harvard Square exaggerate by 14%, while afternoon riders to Ashmont exaggerate by 20%, and riders to Braintree exaggerate by 27%. At ten minutes or more, Harvard Square riders exaggerated by 37%, Ashmont riders exaggerated by 55%, and Braintree riders exaggerated by 49%. This occurrence may also be due to a number of the operational factors discussed in Appendix 1. For instance, the southside line is run under capacity, while the north side is run with over capacity - that is, southside riders are more congested. It may be that northside riders make better estimates because they ride in less congested, crowded conditions. Conversely, southside riders who are more crowded may be more frustrated which may lead to comparative "over-exaggeration". Another confounding factor may be that while northside riders can take the first available train out of Park Street, southside riders must wait for a specific train, either Ashmont or Braintree. Since trains do not arrive in a strictly alternating pattern, confusion also arises, which may lead to frustration and further exaggeration. Finally, there is the simple fact that trains

run more frequently northbound to Harvard Square - headways are roughly half that of the headways faced by southbound riders.

The last example deals with the inference that people on all the Red Line routes exaggerate more for bigger values of "x". For examples, afternoon northbound riders exaggerated by 4% at three minutes or more, but 25% at 10 minutes or more, afternoon Braintree-bound riders exaggerated by 49% at 10 minutes or more, and so on. [Note: the increase in the ratios illustrate this as well. For instance, Braintree riders said they waited 7 minutes or more 3.6 times as often as they actually did; whereas they said only 1.5 times as often for 3 minutes or more.] Some of the variation across "x-values" can be attributed to the fact that, if "x" is low enough, a rider cannot exaggerate at all. In other words, if people tend to exaggerate at all levels of "x", then for larger (actual) values of "x", there cannot be as much exaggeration since the limit of the probability is 100%; conversely, when the probability is low (as for higher values of "x"), there is simply more range over which one can exaggerate. Another reason many people were more liberal with their estimates for relatively high values of "x" may be that perhaps ten minutes seems more "abstract" or flexible than "three minutes", therefore making it easier to exaggerate.

However, is it really surprising that people exaggerate about waiting times? Doesn't "everybody"

exaggerate about how much time they "spend waiting", not just Red Line riders. [In the beginning of this thesis we noted that during late 1983 there were many delays that (actually) occurred on the Red Line; however, as shown, these were effectively reduced (fixed) during the first four months of 1984.] Was it the combination of these past experiences and public attention that led to the exaggeration by the Red Line riders? To answer these questions, an examination of the differences between actual and perceived waiting times for riders of another rapid transit line is necessary - that is, one must establish a "control group". [It must be stressed that this will not "prove" that the past troubles "caused" the exaggeration.] The "control group" examined was the Blue Line.

The Blue Line is another of the MBTA's rapid transit lines.<sup>13</sup> It carries about 30,000 riders a day, is a little over six miles long and also acts as a commuter link between the CBD and the outlying area. Although much smaller than the Red Line, the Blue Line (in effect) is much like the north side of the Red Line - riders take the first train that comes along and it is relatively over capacity. [Although the Blue Line riders don't face the capacity problems and the exclusive choice of Ashmont or Braintree line riders a comparison of southside service will be enlightening as well]. Operationally, the Blue Line is much simpler; the cars and track are relatively new; there is no ATO system, just wayside signalling, no capacity problems

and no planned extensions, and perhaps most importantly there were no "problems" as with the Red Line in 1983 - service has been reliable, predictable and (mostly) uncongested. [In short, a fairly good control group.]

A sample of six days (9 headways) generated a mean headway of 3.74 minutes (standard deviation of 1.52 minutes - much smaller than for any Red Line route). This, in turn, indicates a mean waiting time of 2.18 minutes (standard deviation 1.57 minutes). The derived actual waiting times are shown in Table 3.1. 100 passengers were asked essentially the same questions as were asked of Red Line riders - therefore, providing a distribution for perceived waiting times. These values are presented in Table 3.2 and the differences (as for the Red Line data) is presented in Table 3.3A. [All data was gathered at Government Center station which is analogous to Park Street on the Red Line.]

Examination of these numbers reveal some surprising results.<sup>14</sup> Although Blue Line riders did exaggerate, they did not exaggerate by nearly as much as the riders on any of the Red Line routes - even the afternoon northbound riders. In fact, such accuracy is somewhat unexpected - perhaps, since the variance is so low, Blue Line riders know what to expect and they can make accurate estimates. Or perhaps, they were not subject to the earlier delays or the present aggravation of congestion (and somewhat more variance) that face many Red Line riders.

With the data presented, it is relatively safe to say that Blue Line riders make better estimates than Red Line riders - but why? Intuitively, it seems plausible that Red Line riders' "over-exaggeration" may be due to the combination of a number of reasons: the frustrations experienced in late 1983 and the present capacity issues are only two. The fact that not all Red Line riders make equally "bad" estimates confounds matters as well. For instance, at all values of "x", morning riders from Harvard Square make better estimates than any of the afternoon riders, especially the southbound ones, which again is probably due to a combination of complex cognitive processes that attempt to incorporate the notions of congestion, relative performance, reliability and so forth. There are many issues left to explore - especially those dealing with the difference between perception and reality. These issues are addressed somewhat in Chapter 4. However, before concluding this chapter, I will analyze the issue of relative performance - a related phenomenon in the realm of perception versus reality.

As stated before several times, there was/is much confusion as to the amount of trains that go to Ashmont and Braintree. [Recall that each lines' riders feel the other often gets more trains.] Over the course of the survey I counted 358 southbound trains out of Park Street. [This is 20 more than presented in the earlier data because I was slightly less stringent on the rush hour times.] Of these

358 trains, 156 were headed to Ashmont and 202 headed to Braintree. Note that the "T" plans more trains on the Braintree line because more people use it and round-trips take longer. But without very accurate patronage values, how many trains is enough? This question can only be answered with better data on patronage patterns. One issue that can be addressed is the expectancy of alternating trains, that is, riders expect that if a Braintree train is at the station currently, an Ashmont train "should" be the next train. In fact, many riders complain that they often see "two or three Braintree [or Ashmont, for Braintree riders] in a row before an Ashmont [or Braintree] train arrives". During my study, two Braintree trains came in a row 60 times, as compared to 15 times for two Ashmont trains in a row. [On six times, three Braintree trains came consecutively and twice, three Ashmont trains came consecutively.] Clearly, the operational issues discussed in both Chapter 1 and Appendix 1 must be acknowledged - i.e., the order in which trains enter the tunnel at Andrew cannot be altered and the fact that the "T" currently (after March 10) schedules 17-18 Braintree trains and only 12-13 Ashmont trains per rush - but that would ignore the issue addressed in Chapter 3. Perception is different than reality, so at the very least, the "T" should address people's expectations of alternating trains - which is logistically impossible given the entrance into the tunnel

and simply the planned ratio of Braintree to Ashmont trains,  
but informing riders of these "constraints" is not  
impossible and will be addressed in Chapter 4.

#### Chapter 4: Suggestions

In this chapter, I will offer suggestions to improve the perception of service. I have made numerous suggestions for improving actual service, most of which regard material presented in appendix 1. Consequently, the suggestions are presented in appendix 1a. Although there are definite capacity problems and occasional long delays in service, it may be that the most immediate "problem" of the Red Line is the difference between reality and perception. If effective information dissemination is the key to reducing this difference, "better" communications is essential. First and foremost, MBTA public relations should inform the public about what is actually going on with the Red Line. This could be simply and relatively inexpensively accomplished by commissioning advertisements in the daily newspapers explaining the important aspects of service - from the rider's point of view. A good start would be answering such questions as: why there are more Braintree than Ashmont trains; why there are crossovers (turn-arounds) at Park Street; what happens when there are delays, not just that there are delays; if the often congested, sometimes dangerous conditions on the stairs at Harvard Square station are only temporary and why trains "stop for no apparent reason" on the Longfellow Bridge between the Charles and Kendall Square stations? [These last two are relatively straightforward. First, the congestion on the stairs will be markedly reduced when the nearly completed bus terminal

is finished; until then, however, it may take nearly three minutes to climb 30 stairs due to crowding. Secondly, it is reported that trains often stop on the Longfellow Bridge for a minute (or sometimes longer) before proceeding to Kendall Square station - although there are sometimes mechanical difficulties, often this is a simple safety procedure to ensure trains from rolling into one another as Kendall Square is downhill from the bridge.]

Secondly, the "T" must address the current public addressing system that notifies riders of delays and so forth. During peak hours, due to noise from people and trains, very often announcements cannot be understood or even heard. Moreover, when the announcements are heard they are so frequent they often annoy more than assist. On the many days I was in the station, when announcements stating that there were delays occurring - which happened at least once on about half of the days - many people on the platform offered collective snide remarks. Granted most riders do not stay the entire rush, but most riders none-the-less mentioned they "hear about" delays frequently; which effectively (perceptively) has the impact of making delays seem usual, which is not the case. As a related issue, it is also reported that during non-peak hours the reverse occurs - not enough notifications are made. For example, during the preparation of this thesis, a friend asked me how long she could expect to wait for a train - although it was slightly past the rush hour, I told her about six or seven

minutes ( being very conservative for the north side of the line). The next day she told me she timed her wait - it was 28 minutes - although statistically a very rare occurrence. The "really aggravating thing" was that there were no announcements to inform riders of delays at the station (Kendall Square) during the entire waiting time. Since she had to be somewhere at a certain time, if she knew or was told that a train wouldn't be arriving for a half hour (due to delays) she could have decided to leave and take a cab (or walk) - instead of waiting anxiously minute after minute. Granted, Kendall Square is not most heavily used station, and procedures do slip a little during non-peak times, but more effort must be made. Since one of the biggest distortions is in the perception of waiting time, better notification of the arrival times of trains to at least certain stations would help alleviate this problem; at the very least, it would allow passengers to decide whether they would like to wait for the trains to arrive or seek alternative methods of transportation. Although time consuming and possibly impractical, if the central public address system currently employed is inadequate for this; local station public address systems which may be more effective should be used.

A better, yet more costly method would be the installation of information signs that tell of the arrival and destination of the next available train(s), much like the monitors used in airports. This would be especially

useful during delays; as mentioned, delays cause excessive congestion on the trains. Due to operational factors, several trains often get "backed up" behind a disabled train. For example, a single 15 minute headway is often followed by a couple of 3-minute headways. However, as occurred many times during survey days, announcements stating that there were/are several trains just behind the disabled train were not made. Consequently, passengers crammed into the first, already crowded (disabled) train - often over 250 people/car or nearly 50% over design capacity. Not only is this extremely uncomfortable, it is also potentially dangerous, and highly unnecessary, since the next few trains often just outside the station entrance roll through at about 25-50% capacity. A sign-board, at maybe just the most heavily patronized stations if funding is a constraint, would let the passengers know of soon-to-arrive trains, easing the congestion on trains and demands on the central announcer. This would have to be an on-line real time system similar in many respects to the one currently used by the central dispatcher, though not nearly as elaborate. Extended arrival times need not be exact but would put the passengers' at ease more than the current lack of communication system. This may be particularly useful for addressing riders' expectations of alternating Ashmont and Braintree trains; which due to the operational factors mentioned earlier, does not always occur. Many riders agree.

Another issue regards congestion. As mentioned, present capacity is an issue for southside much more than the north - although, when the northside extension is complete and the new cars arrive and stations and trains are extended for six cars each, it will be a much more complex issue. Until then, besides better scheduling and more preventative maintenance, there are other ways to address congestion. First of all, trains headed southbound are crowded, but passengers make them more crowded than need be. On numerous occasions, at several different stations, I saw passengers crowd on to either the two front or the two middle cars of the train and leave the other much less utilized: the difference in car load (between different cars) was as much as 100% at certain times. Although people have many reasons for getting in only certain cars (being closer to the entrance or exit staircases for example), encouraging them with directional signs and verbal messages by train starters to spread out more evenly on the platform would not only make conditions on the train and platform more comfortable, but also reduce the "dwell" or boarding time spent in stations. [Saving 10 or 15 seconds a stop can add up to the 6 or so minutes per round trip necessary to be able to drop a train entirely, which saves money without reducing service substantially.]

Another complaint of riders regards the coordination between buses and trains at such stations as Ashmont, Quincy Center and Harvard Square. One rider mentioned that "no

matter when [she] leaves Park Street, [she] arrives at Harvard Square two minutes after [her] bus leaves - so [she] has to wait another 20 minutes for the next bus [to arrive]." A second example occurs when buses pull into the station and many (e.g. 50) people run toward the platform and miss a train just as it pulls out - this, of course, is made worse during non-peak hours when trains and buses run less often. Even though the "T" has a policy of holding infrequently scheduled buses [or trains] when the other arrives late - rigid practice even proactive efforts by the station masters would help alleviate these problems - since even if these "misses" are out of the ordinary, these events are "very frustrating", as shown, riders form their perception by weighting the aggravating experience more than the usual events.

The final suggestion is on somewhat of an upbeat note. That is, currently at several stations, musicians often set up on the platform and play. When I asked riders about the music, they were often pleased (when it was good) that the musicians were there. Since this paper has addressed the big difference in perception and reality; it may be that, even without major operational changes, an implementation of the more subtle recommendations mentioned (such as the sign-board, encouraging musicians and other diversions like newspaper and sundry stands, etc.) may be the most effective way of reducing distortions in perception.

## Appendix 115

There are several important operational issues that should be understood when evaluating service on the Red Line - these include the ATO system, scheduling, maintenance and so forth. This appendix presents a complete, though brief, study of these issues. These issues will be referred to in Chapter 4 when suggestions for improvement are discussed.

The automatic train operator system (ATO) sets the speed and distance between trains. The ATO system replaces a wayside signalling system - a reliable, old fashioned method that keeps the trains two signals, or roughly 600 yards, apart. Although fundamentally sound, prudent, and safety-conscious, the ATO is very temperamental; malfunctions occur frequently. The ATO system communicates to the central dispatching center (and other trains) via radio waves; however, these radio waves can be distorted many ways. For example, excessive braking can flatten out the metal wheels on the trains slightly, which, when the train is in motion, causes a resonance of a similar frequency as that used by the ATO system; this in turn distorts or even impedes the ATO's signals. There are other eccentricities with the system, but the main result is that when malfunctions occur, a train must be taken off the ATO system and put on a backup system (not wayside signaling) which requires that a train travel at a speed of only 25 miles per hour (often only half of its planned speed); which

will cause delays until either the malfunction is fixed or the train is taken out of service (discussed later).

Another, somewhat related issue is preventative maintenance. The Red Line currently operates with a fleet of 164 cars, most of which are over 20 years old and have traveled nearly 1,000,000 miles. Currently, only about 120 are available for usage, the remainder being in various stages of (dis)repair. Consequently, car availability becomes a weekly, sometimes even daily concern. Recently, there was a major public disagreement about the MBTA's 1977 decision to refurbish 88 of the Red Line cars in-house at a then estimated cost of about a quarter of a million dollars per car. However, the project was scratched in 1981 when the "T" had only fixed 18 cars, at a cost of about \$600,000 apiece. The "T" cited many reasons for this overrun, including the installation of the previously unscheduled ATO system; regardless, the job is now being completed by an outside contractor who has completed about a dozen cars and is scheduled to finish the rest within a year. [In early 1984, the MBTA also purchased 54 brand new Red Line cars to be delivered in early 1986, by a Detroit company, for about 52 million dollars.]<sup>16</sup>

In the meantime however, preventative maintenance, especially at the repair yard, remains a somewhat constant battle. To combat this, the "T" has appropriately scheduled repair crews on a night shift from 9:30 PM to 6:00 AM so that inspections and more work can be done. Yet, a major

obstacle at the repair yard remains between management and two separate repair groups. One group repairs only the ATO system, while the other repairs only the more traditional parts of the car (hydraulics, on-board electrical system, brakes, propulsion motors, etc.). A problem often arises because it is sometimes difficult to decide whether the problem is due to an ATO or a traditional car body problem; consequently, significant time is lost as the two groups try to decide who will actually work on the problem. This issue is further complicated by the fact that the Red Line currently uses the most antiquated equipment (which includes the track, tunnels, signals and power cables as well as cars) of any of the MBTA's rapid transit lines (RTL), which by itself accounts for many of the "problems" on the Red Line. [In contrast, the Orange Line - another of the MBTA's RTL - has all new cars and has one of the best performance records in the country, completing nearly 99% of all scheduled trips on time.] When both the rebuilt and the new cars arrive, these problems may not be as critical, but until then, effort must be made to rectify these issues.

Another issue regarding maintenance is the actual location of the repair yards. During the weekdays, Red Line trains are composed of four cars. However, repair and storage for 4-car trains are available only at one place, the Cabot yard which is in the center of the line, between Broadway and Andrew Stations. Consequently, if a train is disabled (due to either an ATO malfunction, or the automatic

car doors not opening properly, or a braking or communications problems, etc.), with few exceptions the train must travel from wherever it is on the line to this single repair yard - usually unloaded and at a reduced speed. Therefore, since the track is a closed loop, as this train travels to the repair yard it usually causes backups throughout the entire system. In effect, one disabled train can often propagate delays (that can last as long as 30-45 minutes) throughout the entire system. A possible solution to this would be temporary repair or storage yards placed at the endpoints of the line (Harvard Square, Ashmont and Braintree stations), so that a train need only travel to its nearest repair yard, and the entire system is not held up while an empty train heads to the central repair yard. [This is costly as well; it is estimated that the "T" currently spends nearly \$100,000 a year just moving empty trains to this repair yard.] Although there is a small 2-car repair yard at Ashmont, it is inadequate; repair or storage yards have been unavailable due to economic and (mostly) local political reasons.

The actual ongoing operations of scheduling the trains are noteworthy as well. There is a central command center in downtown Boston that is connected to the entire Red Line system. Via a console panel about 20 feet long and four feet high that displays the position of trains in color, dispatchers and schedulers have access to real-time information about the location of trains and their status

(whether on ATO or not) and the capability to change most signals and switches. While on the ATO system, trains basically "run" themselves. However, if delays occur (or if off the ATO) these planners dictate where and when the train should move. As mentioned previously, the "T" plans uniform headways - in practice however, due to many reasons (long dwell time in stations, minor track or car body malfunctions, etc.), this rarely occurs for an entire rush. Consequently, when "problems" occur, with the use of this console, dispatchers try to even out the headways by a number of methods, including cross-overs, "holding-up" at certain stations briefly and/or express trains. Dispatching is a difficult and critical job - requiring almost as complex communications and fast actions as for air traffic controllers. It is important to remember that once a train enters the tunnel between Andrew and Harvard Square, its relative position cannot be changed; that is, Ashmont and Braintree trains are scheduled to enter the tunnel at two minutes apart. Due to delays, however, two Ashmont (or Braintree) trains can (and often do) enter the tunnel successively; and not until they return out of the tunnel can they switch relative positions (get a Braintree between them). Again, each of these factors are discussed further in subsequent chapters.

Appendix 1A<sup>17</sup>

First of all, when the stations north of Harvard Square are opened in 1985, due to the increased track length (trip time) and patronage (a potential of 20,000 new riders daily) if service (headway/waiting times) is to remain even at its present level, many more Red Line cars, than used presently, will be needed. Furthermore increasing train sizes to six cars each - which is planned within the next few years as current station platforms are extended - although a sound strategy for relieving congestion, puts even further demands on the necessary number of cars. Arrival of the newly ordered and refurbished cars (over 100 cars in total) will be of great help, yet by that time many of the present fleet will be in need of repair. Consequently, I reiterate: preventative maintenance on the cars, tracks, tunnels, power cables, communication lines and the ATO system is essential for success; coordination and cooperation of repair personnel and effective, proactive management are critical; continual lobbying for the repair and/or storage facilities at the lines' endpoints (Ashmont, Braintree and/or Ailewife stations) must be stressed. As the performance of the Orange Line mentioned earlier indicates, there is no replacement for properly maintained equipment.

The second recommendation is (also) primarily management's responsibility. Preventative maintenance,

station and track extensions and the purchase of new Red Line cars are very expensive: the 3.2 mile extension north of Harvard Square will cost nearly \$600 million, alone. Strict internal audit control and validation of outside vendors' claims must be emphasized. A recent state auditors' report indicated that an electrical subcontractor for the Red Line's recently opened, Quincy Adams station, misappropriated over \$150,000 by simply installing inferior-grade lighting fixtures as specified.<sup>18</sup> System-wide, between 1977 and 1981 alone, well over \$230 million has been paid without independent verification. And, on the Green Line, although the manufacturer had to pay substantial fines, recently ordered streetcars were so faulty that each one required nearly 300 separate repairs. Other issues, such as payouts of questionable workmen's compensation benefits, unnecessary finance charges and simply inoperative collection machines have been costly. (Presently about 10% of the automatic pass-readers on the Red Line are malfunctioning). Simply put, better financial control is warranted.

There are other recommendations: (1) considering planned express trains southbound (for the evening rush) out of Park and Washington Street stations to near the lines' endpoints (e.g. Quincy Center and Fields Corner; this may alleviate some "local" congestion for passengers who must endure longer trips, (2) better communication within the ranks of the "T" itself - getting ideas from motormen to

management and vice versa as fast as possible; and (3) continually estimating usage (ridership) patterns, striving to schedule headways (trains) to meet peak (usage) times: perhaps by planning asymmetric headway patterns versus uniform ones. In fact, this final suggestion may be the most easily implemented. Simply compiling the statistics as presented in this report will provide an inexpensive way of getting "better" performance measures - at least from the rider's point of view.

## Appendix 2

To gather data that would be most representative of what the majority of riders experienced, I concentrated data-gathering efforts on weekday rush hours only. Moreover, most of the data was gathered at Park, Washington and Harvard Square stations - the most heavily patronized. These stations provide representations of both morning and afternoon northside service and afternoon southside service; only morning southside service is "under-represented" - this is discussed in the body of the paper. The actual data-gathering days (rush hours) were randomly selected in advance and spanned over the four month period to approximate different conditions such as weather patterns and within (and across) week variation in patronage. The data that was gathered ranged from:

- 1) January 18 to May 1 (14 individual days each) for both the afternoon rush toward Ashmont and toward Braintree.
- 2) January 18 to May 1 (15 individual days) for the afternoon rush toward Harvard Square.
- 3) January 20 to April 27 (6 individual days) for the morning rush out of Harvard Square.
- 4) January 26 to March 28 (4 individual days) for afternoon travel times from Park to Harvard Sq.
- 5) April 4 to April 26 (6 individual days) for afternoon Blue Line service (discussed in Ch. 3).

### Appendix 3

For further illustration, histograms of the data are presented on the following pages. All headway times have been rounded to the nearest half-minute.

- Note: (1) The number of observations are the number of headways.
- (2) The intervals are half-minute wide (e.g., if middle of interval is 1.5 then the asterisks represent the number of headways that were 1.5 minutes long).

NORTHSIDE SERVICE

Morning Rush from Harvard Square Southbound (towards Park/Wash.)

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	NUMBERS OF OBSERVATIONS
0.500	0	
1.000	0	
1.500	0	
2.000	9	*
2.500	10	*
3.000	16	*
3.500	11	*
4.000	4	*
4.500	3	*
5.000	6	*
5.500	11	*
6.000	4	*
6.500	1	*
7.000	1	*
7.500	1	*
8.000	0	*
8.500	0	*
9.000	0	*
9.500	0	*
10.000	1	*
10.500	1	*
11.000	1	*
11.500	0	*
12.000	0	*
12.500	0	*
13.000	0	*
13.500	0	*
14.000	0	*
14.500	0	*
15.000	0	*
15.500	0	*
16.000	0	*

Afternoon Rush towards Harvard Square Northbound (from Park/Wash.)

EACH \* REPRESENTS 2 OBSERVATIONS ABOVE THE LAST CLASS.

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	NUMBERS OF OBSERVATIONS
0.500	2	*
1.000	6	*
1.500	17	*
2.000	52	*
2.500	30	*
3.000	31	*
3.500	13	*
4.000	16	*
4.500	17	*
5.000	14	*
5.500	13	*
6.000	9	*
6.500	21	*
7.000	10	*
7.500	15	*
8.000	5	*
8.500	5	*
9.000	6	*
9.500	5	*
10.000	1	*
10.500	1	*
11.000	0	*
11.500	0	*
12.000	0	*
12.500	0	*
13.000	0	*
13.500	0	*
14.000	0	*
14.500	0	*
15.000	0	*

SOUTHSIDE SERVICE

Afternoon Rush Southbound (from Park/Wash.) toward Braintree

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS
0.500	1
1.000	1
1.500	2
2.000	13
2.500	11
3.000	5
3.500	6
4.000	13
4.500	12
5.000	20
5.500	12
6.000	14
6.500	11
7.000	8
7.500	6
8.000	6
8.500	4
9.000	8
9.500	5
10.000	6
10.500	6
11.000	2
11.500	0
12.000	4
12.500	0
13.000	3
13.500	0
14.000	4
14.500	0
15.000	1
15.500	2
16.000	1
16.500	1
17.000	1
17.500	1
18.000	0
18.500	1
19.000	0
19.500	1

Afternoon Rush Southbound (from Park/Wash.) toward Ashmont

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS
0.500	0
1.000	0
1.500	0
2.000	2
2.500	7
3.000	2
3.500	0
4.000	3
4.500	6
5.000	11
5.500	16
6.000	12
6.500	19
7.000	18
7.500	9
8.000	9
8.500	3
9.000	8
9.500	9
10.000	10
10.500	6
11.000	5
11.500	2
12.000	4
12.500	0
13.000	5
13.500	1
14.000	1
14.500	1
15.000	0
15.500	2
16.000	1
16.500	1
17.000	1
17.500	1
18.000	0
18.500	0
19.000	0
19.500	1
20.000	1
20.500	0
21.000	0
21.500	1

ACTUAL TRAVEL TIMES (NORTHSIDE)

Morning Travel Times from Harvard Square to Kendall Square  
(outliers of 22.5 and 28 minute omitted)

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS
0.500	0
1.000	0
1.500	0
2.000	0
2.500	0
3.000	0
3.500	0
4.000	0
4.500	0
5.000	0
5.500	0
6.000	1
6.500	4
7.000	8
7.500	5
8.000	6
8.500	0
9.000	0
9.500	19
10.000	0
10.500	5
11.000	0
11.500	7
12.000	0
12.500	2
13.000	3
13.500	0
14.000	0
14.500	0
15.000	0
15.500	0
16.000	10
16.500	0
17.000	0
17.500	10
18.000	0
18.500	0
19.000	0
19.500	0
20.000	0
20.500	0
21.000	0
21.500	0
22.000	0
22.500	0
23.000	1
23.500	0
24.000	1
24.500	0
25.000	0

Afternoon Travel Times from Kendall Square to Harvard Square

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS
6.000	**
6.500	**
7.000	**
7.500	**
8.000	**
8.500	**
9.000	*****
9.500	*****
10.000	14
10.500	4
11.000	***
11.500	***
12.000	3
12.500	0
13.000	0
13.500	0
14.000	5
14.500	***
15.000	***
15.500	0
16.000	0
16.500	0
17.000	0
17.500	0
18.000	1
18.500	0
19.000	0
19.500	0
20.000	2
20.500	0
21.000	0
21.500	0
22.000	0
22.500	0
23.000	0
23.500	0
24.000	1
24.500	0
25.000	0

BLUE LINE AND "TIME-IN-TRANSIT" VARIANCE

Blue Line Data-Outbound from Government Center

TIME INTERVAL	NUMBER OF OBSERVATIONS
0+500	0
1+000	0
1+500	3
2+000	15
2+500	10
3+000	15
3+500	12
4+000	14
4+500	18
5+000	9
5+500	2
6+000	4
6+500	1
7+000	1
7+500	0
8+000	0

Actual Afternoon Travel Times from Park to Harvard Square

TIME INTERVAL	NUMBER OF OBSERVATIONS
5+500	0
6+000	0
6+500	0
7+000	0
7+500	0
8+000	0
8+500	0
9+000	13
9+500	10
10+000	10
10+500	10
11+000	10
11+500	9
12+000	6
12+500	6
13+000	15
13+500	7
14+000	10
14+500	1
15+000	1

## FOOTNOTES

- 1 This data and most of the material in this paragraph was completed from a combination of sample distributions generated from data gathered at Harvard Square, conversations with the Supervisor of the Red Line, John Hogan, and a September 1983 MBTA document entitled, "Red Line Operating Plan".
- 2 From comments of randomly selected regular riders I surveyed during data gathering over the four month period.
- 3 These terms were generated for this report by a composite of riders' perceptions.
- 4 See footnote 2.
- 5 From an article in the Cambridge TAB, "The Track Record" by Brian Murphy, March 21, 1984.
- 6 See footnote 2.
- 7 The material presented throughout the next two chapters was based on the sources mentioned in footnote 1 and other data gathered during the many days of sampling throughout the MBTA's Red Line system - unless otherwise noted.
- 8 See footnote 5 and the Cambridge TAB, February 8, 1984.
- 9 There was a fire at Andrew Station that halted service on the Red Line for about 45 minutes on March 9. At first, just incoming northbound service was affected, but eventually southbound from Harvard Square was (although not apparent in the aforementioned rider's data who was travelling that day) reportedly affected; consequently, even though I was not gathering data at Harvard Square, the figures presented in the next chapter will include this "outlier" to offer a more representative sample.
- 10 Professor Barnett's (my thesis advisor) term. Most of the derivations for waiting time distributions and much of the conceptual framework that follow here and in Chapter 3 are generated from numerous discussions with Professor Barnett and referencing his paper, "Control Strategies for Transport Systems with Nonlinear Waiting Costs," published in Transportation Science, vol. 12, No. 2, May 1978.

FOOTNOTES (cont.)

- 11 In Chapter 3, I will analyze the perception of riders. In doing so, the probability distributions for these actual waiting times will be derived. For comparisons, riders are asked about their perceptions over the last three months (regardless and usually incognizant of the change in schedule); consequently, I'll simply combine the two headways as if no change was made. This sample of 14 days (190 headways) generates a mean headway of 6.45 (standard deviation of 3.53); which indicates a waiting time mean of 4.19 minutes (standard deviation of 3.31 minutes).
- 12 See footnote 10.
- 13 See footnotes 1 and 7.
- 14 Note: Although differences in percentages between the Blue and Red Line are substantial, the ratios are less so. Due to a combination of the exaggerating effect outliers have on the mean (of perceived waits) and the relatively low actual waits, Blue Line ratios appear "inflated". This is especially evident when comparing the difference between the mean and median (of perceived waits)-for the Red and Blue Lines: Red Line generates a much smaller difference.
- 15 See footnotes 1 and 7.
- 16 Ibid and recent articles in local papers such as the Boston Globe, Magazine section article by Charles Kenney, April 22, 1984 and the Patriot Ledger.
- 17 See footnotes 1 and 7.
- 18 From Massachusetts' "State Auditor's Report on the Activities of the Massachusetts Bay Transportation Authority, January 2, 1981 to December 31, 1981," and 1983 report no. 83-583-6 from the same agency.

## BIBLIOGRAPHY

### Interviews

- 1) John Hogan, MBTA Supervisor, Red Line (several times over the early months of 1984).
- 2) Mike Francis, Chief Dispatcher, Red Line.
- 3) Many, many Red Line riders and MBTA personnel.
- 4) Professor Arnold Barnett (for the conceptual framework, mathematical derivations, etc.).

### Journal Articles

(see footnote 10)

### Newspapers

The Cambridge TAB

The Boston Globe

The Patriot Ledger