The Journey to Work: 25 Years on the Jamaicaway

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Submitted to the
TRANSPORTATION RESEARCH FORUM

December 15, 2004

View along the Jamaicaway, Boston, MA c. 1986 (Photo: C.D. Martland)

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ABSTRACT

More than 600 observations were recorded for the author's home-to-work trip for the same route over the period 1980 to 2004. With this data, it is possible to graph the pattern of travel times and travel time reliability as a function of departure times during the morning rush hour. The image of rush hour performance that emerges from this study is more complex than what is often used in network models or abstract economic analysis. For example, as rush hour progresses, variability increases even though expected travel times start to decline. There may also be lulls in rush hour, i.e. intervals of 10-15 minutes when expected performance temporarily improves. This type of performance cannot realistically be modeled as a linear function of traffic volume, nor can it be approximated using a steady state queuing analysis. It will be far better to view rush hour performance as a steady state cyclical queuing phenomenon: every day may start afresh, but expected conditions on next Tuesday at 830 am are likely to be similar to conditions last Tuesday at that time.

Over the 25-year period, there was surprisingly little change in rush hour performance on this congested urban route. Average travel times were mostly in the range of 25-27 minutes with a standard deviation of 3-4 minutes. There was some spreading of the peak, especially during periods involving major construction, but performance in the most recent period was actually equivalent to performance in the 1980s.

INTRODUCTION

Despite increasing traffic, restricted parking, and what feels like increasing congestion, travel times for one man's journey to work have changed less than 10% over the past 25 years. Peak hour travel times and standard deviations rose slightly and the length of the morning rush widened slightly over most of this period. Road and bridge construction projects along the route periodically hurt commuting times, and traffic diversions during the Big Dig were a burden for several years. However, commuting performance in 2003-2004 was equivalent to the best periods of the 1980s in terms of both travel time and travel time reliability. If improvements in quality of life are considered – better music, better coffee, air conditioning, more comfortable seats, and more reliable cars – the commute is actually less onerous now than it was 25 years ago.

The morning rush hour is an example of what has been called a "steady state cyclical queue" [Martland and Jin, 1997]. Rush hour delays occur because the highway system lacks capacity to handle the peak traffic volumes: queues result because the arrival rate of cars into the system is greater than the service rate of the system. The queues are cyclical in nature, because the queue behavior varies from the beginning of the day through the end of rush hour, and the queues always dissipate overnight. The situation is in steady state in a cyclical sense, because expected traffic conditions at 8am on a Tuesday will be the same as they were on previous Tuesdays at 8am, with some predictable modifications for holidays, school vacations, and extreme weather conditions.

This paper uses trip time data for the author's home-to-work trip. More than 600 observations were recorded for the same route over the period 1980 to 2004. Each observation provides the start time, the time of arrival and departure from the two most complex intersections, and the arrival time. There are sufficient observations to understand how trip times vary with departure time and to see how the pattern of rush hour performance has varied over the decades.

It is naturally impossible to form any general conclusions regarding traffic congestion on a study of a single route. However, a single well-documented example can be sufficient to cast doubt upon the validity of commonly used assumptions concerning traffic congestion. The image of rush hour performance that emerges from this study is more complex than what is often used in network models or abstract economic analysis. In particular:

- Trip times cannot be estimated as a linear function of traffic volume, because travel time depends on the length of the queues and the queues build up during rush hour (so that the end of rush hour is worse than the beginning, even though the traffic volumes are the same)
- Trip times cannot be estimated using a steady state queuing analysis, because the queues are never close to steady state, except in the cyclical sense described above

It will be far better to view rush hour performance as a steady state cyclical queuing phenomenon. This methodology can accept arrival rates that are sometimes above service rates, it will predict increasing delays and decreasing reliability as rush hour progresses, and it will allow lingering delays even after arrival rates drop below service rates.

Understanding the options faced by one commuter may not seem like very much, but "one" is better than "none". The concepts displayed in this study are indeed general, and they should allow traffic engineers, modelers and highway officials to formulate better strategies for dealing with congestion.

LITERATURE REVIEW

There are various approaches to talking about and modeling highway congestion. To the public, traffic congestion is expressed in units of frustration rather than equations; studies periodically document the time spent in commuting in various metropolitan areas and document the trends toward longer travel times. To emphasize the increasing magnitude of the congestion problem, these studies sometimes focus on particular aspects of the problem. For example, it is possible to estimate the increase in travel times for a metropolitan area or to estimate the increase in delays. Since delays are only a portion of the total trip time, the increase in delays will always be greater – and therefore more alarming - than the percentage increase in travel times. Another factor is that people choose to live in more distant suburbs; as metropolitan areas have grown, more people have long commutes because of where they choose to live and work. Despite the headlines [e.g. Greenberger, 2004], longer travel times often result from traveling longer distances, not just from longer times traveling on the same routes. Moreover, the commuters are presumably getting enough benefit from their trips to justify their time and expense. If not, then they would move or change jobs.

Economists such as Mohring [1999] emphasize that there is a tradeoff between the costs of delays and the costs of adding to highway capacity: even with the optimal level of capacity, there will usually be delay, as it is seldom possible to size facilities for the peak load. Economists also note that delays would decline if people had to pay for their marginal impacts on congestion.

A different approach is used by traffic engineers, who address congestion in a very thorough and pragmatic manner. Using observations and theory, traffic engineers develop detailed equations to represent the capacity of roads and intersections, they can estimate the performance of a road or an intersection as a function of the traffic mix and traffic volume. This approach is used to guide highway design, but it is far too detailed to be used in modeling a metropolitan network. More aggregate approaches have been developed to study how networks respond to increasing traffic flows. The differences between the traffic engineering and the network modeling approaches are worth considering in more detail in order to understand how they view congestion.

In the 1960s, a group of professors at MIT began to teach a series of classes on what they called "transportation systems analysis". Today, nearly 40 years later, students studying for the Master of Science in Transportation still take a class that is directly descended from 1.201, Transportation Systems Analysis, which was developed to a large extent by Marvin Manheim. The first text for 1.201 was not published until much later [Manheim, 1979], but it embodies the concepts that I was taught 10 years earlier and that students were still being taught 10 to 20 years later.

The basic concepts emphasized in the text include "supply/demand/equilibrium" and "systematic analysis". The book discusses performance at increasing levels of detail, but always in the context of these two concepts. The performance of a transport system depends upon the demand and the operating strategy – but the demand also depends upon the performance of the system. The system is assumed to reach an equilibrium such that the performance and demand are consistent.

The simplest equilibrium analysis is introduced by defining three different volumes:

- Equilibrium volume
- Capacity volume
- Demand volume

The text notes that "the equilibrium volume cannot exceed capacity" [ibid, p. 177], so that the equilibrium volume cannot exceed the minimum of capacity or demand. My margin notes (from 1979 or 1980) beg to differ with this: "Not true for peak periods, which cause congestion and service problems. Key is time: Ve < Vc for long time periods, but not for short periods." And at the end of this chapter I wrote "Demand assumed constant, whereas random and cyclic fluctuations are key."

Manheim subsequently draws upon the concepts of steady state queuing to develop equations that cause queues to build up as the arrival rate of the system approaches the service rate. He notes that the arrival rate may exceed the service rate, but only for "non-steady-state conditions", so that the queue is eventually dissipated [ibid, p. 270]. Despite this mention of the obvious characteristic of rush hour (and of most interesting transport problems), Manheim quickly reverts to the steady state assumption, discusses the difference between various types of capacity to show that practical capacity is less than physical capacity. Later, he notes that it is usually possible to represent "such transient saturated systems … by an equivalent unsaturated system … if we take a long enough time interval that the transient effect is averaged out." [ibid, p. 272]. He notes that this method may not be "a good assumption in a practical analysis" – but then he goes on with the use or development of steady state queuing relationships. His goal is to show that it is in fact possible to analyze the equilibrium conditions if you understand both the performance capabilities of the system and the responsiveness of demand to performance. He goes on to show the usual charts for highway level of service that show how operating speed deteriorates as volume approaches capacity.

Manheim certainly understood the complexities of performance analysis, but he also recognized the importance of systematic analysis that could identify and illuminate the key issues for decision-makers. In this text, he was able to employ fairly simple, widely used concepts to illustrate what he felt were the main issues and the most important methodologies.

Haefner [1986] takes a traffic engineer's approach to capacity analysis. In a chapter on highways, he devotes nearly 100 pages to a discussion of the capacity of a free-flowing road or highway and of a highway intersection. Throughout, he follows the procedures recommended in the Highway Capacity Manual. The ratio of traffic volume to capacity is a key factor for both roads and intersections, and numerous charts and equations are given to provide a means of determining the maximum volume that can be handled at a suitable level of service.

Haefner shows the level of service definitions for signalized intersections. Level of service A has less than an average of 5 seconds of stopped delay per vehicle; LOS F has average delays greater than 60 seconds per vehicle [ibid, p. 121]. He notes that the lower bound of LOS E, with an average delay of 40 seconds, is often taken to be "the limit of acceptable delay" and an estimate of the capacity of the intersection; he also notes that site characteristics might be very important, with serious delays occurring at what the methodologies might compute to be a better level-of-service. There are no charts of actual highway performance, nor is there any discussion of rush hour behavior in this text.

There is no shortage of research in any of the three areas noted in this brief introduction to the literature. Many people have written about congestion from the perspective of an economist, a network modeler, or a highway planner. There are good studies of trends in average commuting time and congestion, most notably the Texas Transportation Institute's periodic studies of urban mobility [Schrank and Lomax, 2004]. What is not as common are good descriptions of what it is like for the commuter, which is the topic of the remaining sections of this paper.

THE COMMUTING OPTIONS

Anyone living and working in or near Boston has an option of driving to work or taking the T. There are always multiple routes for either option, and the relative advantages of driving and transit are quite site-specific, depending upon access to transit and the ability to use local streets to bypass major bottlenecks in the street and highway networks. The choice is not obvious, and spouses facing the exact same decision may select different routes. However, after some practice, perhaps a month of commuting and certainly within a year, an inquisitive individual will select one or two favorite routes. For me, the highway option was very simple – follow the parkways from my home near the Arnold Arboretum to the Charles River, cross the BU Bridge, and head for MIT. There are other routes, but the parkways are prettier and, I believe (based upon sporadic forays into the wider network), faster. A creature of habit, I have in fact commuted on the same route from the same house to the same office building for more than 30 years.

My basic route is depicted in Exhibit 1, which is based upon lecture notes for a class that I taught in 1979. I used my journey to work as an example of an origin-to-destination trip plan in an introductory class on transportation systems. I measured the distance, counted the stoplights, and estimated the travel times for each segment of the trip. The trip time includes the time to leave the house, get in the car, and back out of the driveway (segments 1 and 2), as well as the time to walk from the parking lot or the parking garage to my office. I estimated travel times for the 6.3 mile trip to be:

- Off-peak: 20 – 22 minutes (including 5 minutes walking)
- Near-peak: 24 - 30 minutes (including 5 minutes walking)
- Peak: 30 – 45 minutes (including 5 minutes walking)

I did not begin to measure trip times until the next year, so these were my perceptions of travel times, not actual travel times. What this says is that I had to leave 45 minutes for the trip if I had a 9am meeting (peak hour departure at 8:15), but I only had to allow 30 minutes for a meeting at 9:30 (near peak departure at 9:00), and only 22 minutes for a meeting at 1100 (off peak departure at 10:38).

I suggested to the class that the expected trip time could be calculated as the sum of the expected time for the various line haul and intersection segments. I noted that the expected times could be estimated as finely as one liked, utilizing detailed calculations regarding cruise speed, acceleration and braking capabilities, the number of intermediate stops, and intersection times. However, I emphasized that the variability in the trip time came predominantly from the difficult intersections, since delays at those locations could amount to several minutes or more, far outweighing variations in time related to traffic flow, the day-to-day variation in the number of red lights encountered in the other intersections, or nuances in flow characteristics along the roads. I therefore hypothesized that the variance of the trip time could be estimated as the variance of the times associated with troublesome intersections.

At that time, there were four key intersections:

- Segment 4: the rotary where Center Street meets the Arborway (in the am peak, the heaviest flows are conflicting at this rotary)
- Segment 8: the intersection where the Jamaicaway crosses Brookline Avenue at the west end of the medical area (traffic could back up more than a mile from this intersection, especially if traffic inbound to the medical area blocks Brookline Avenue)
- Segment 10: the so-called "jug handle" intersection where inbound traffic on the Jamaicaway is routed back-and-forth across Brookline Avenue before heading toward the BU Bridge (2 lanes of traffic from the northwest heading S and E merge with 2 lanes from the south heading NW, N, and E at a 5 point intersection; when traffic is heavy, capacity can decline as people jockey more aggressively for position; anyone driving to Fenway Park from the South has gone through this intersection)

- Segment 12: the complex intersection at Commonwealth Avenue by the BU Bridge (this is where heavy N-S flows from the bridge intersect heavy E-W flows on Commonwealth Avenue; there is an entrance to Storrow Drive and many possible routes through this unusual intersection. For my route through this area, there are three stoplights, and it is seldom possible to get through in less than a minute, even if there is no traffic.)

Exhibit 1 - Initial Perceptions Concerning the Drive to Work
Source: Personal Lecture Notes, November 28, 1979

	Segment	**Typical Elapsed Time**	**Distance**
1	Walk to car	0.5 minutes	30 feet
2	Start car, leave driveway	0.5	
3	Drive to rotary, Center St. & Arborway	4.0 – 5	2 miles, 1 light
4	Queue at Rotary	0 - 5.0	
5	Drive to Intersection of Jamaicaway and Pond Street	2 - 2.5	1 mile
6	Queue at light	0 - 3.0	
7	Drive to First Intersection of Jamaicaway and Brookline Avenue	2 - 3.0	1 mile, 1 light
8	Queue at light	0 - 8.0	
9	Drive to Second Intersection of Jamaicaway and Brookline Avenue	1 - 2.0	0.3 miles, 1 light
10	Queue at light; go through jughandle; queue at next light	0 – 4.0	
11	Drive to Commonwealth Avenue	1.5 – 3.5	0.7 miles, 3 lights
12	Queue at first light; cross Turnpike bridge; queue at Commonwealth avenue light; queue at BU Bridge light	0 – 10	
13	Drive to MI West Garage	2 –2.5	1 mile, 1 light
14	Park in garge	1 – 3	
15	Walk to office	5	0.3 miles

Exhibit 2 shows the transit alternative. I had used transit for most of the 1970s, so I knew this route as well as I knew the automobile option. The typical range of travel times was:

- Off-peak: 50-75 minutes (erratic headways)
- Near-peak: 53-63 minutes (frequent service, infrequent disruptions)
- Peak: 55 - 70 minutes (frequent service, but lengthy time at stations and bunching)

Exhibit 2 - Initial Perceptions Concerning the Transit Trip
Source: Personal Lecture Notes, November 28, 1979

	Segment	Typical Elapsed Time	Distance
1	Walk to bus stop in Roslindale Square	7 – 8 minutes	0.5 miles
2	Wait for bus	0 – 10	
3	Bus to Forest Hills	4 – 6	1.5 miles
4	Climb stairs, pay fare	1 – 1.5	
5	Wait for train	0 – 15	
6	Orange Line to Washington Street	15 – 18	
7	Transfer to Red Line Platform	1 – 2	
8	Wait for Red Line	0 – 10	
9	Red Line to Kendall Square Station	5 – 10	
10	Depart station and walk to office	8 – 10	

The time advantage for driving was clear. To allow a reasonable probability of making a meeting, I had to leave 75 minutes for an off-peak transit trip compared to only 22 for the auto trip. I had to allow 70 minutes during peak periods compared to only 45 for driving – closer, but still not close. If you had a car, and if your decision were based purely upon time, then you would surely drive.

Time was not the only consideration, however. The transit trip required 15-20 minutes of walking and climbing stairs, more than double of what was needed to walk to my office from the parking garage. The extra time spent walking could be viewed as a bonus. Indeed, I frequently would choose to walk to Forest Hills through the Arboretum, which added another 15 minutes of walking – but resulted in a wonderful half-hour stroll through one of the finest parks in the region. The 20-30 minutes on the train plus some of the waiting time could also be useful – especially good for reading novels, checking notes for a presentation, or contemplating a lecture. Thus at least 2/3 of the transit trip was actually useful or beneficial, particularly in near- and off-peak conditions when you were likely to get a seat. The time "lost" by taking transit was therefore on the order of 10-20 minutes, which was no worse and perhaps less than the time "lost" driving to work.

Cost was an interesting matter. The out-of-pocket cost for the T was a transit token (initially a quarter, now $1.25) and a bus fare (initially $0.20 and now $0.90). The variable cost for driving includes gas and mileage-related maintenance and servicing, which was about $0.05 per mile initially and about $0.10 to $0.15 today (prices are up, but cars are more reliable). Since parking was an employee benefit in 1980 and more recently can be purchased in bulk for a year, my variable costs associated with parking have been zero for the entire period. For a 6-mile trip, my variable costs of driving have always been less than the costs of taking the T.

Over the period of this study, I have generally driven to work (80%-90%), but I still take the T once in a while (5-10%) and sometimes get a ride to work with my wife (5-10%).

Since I have flexibility in setting my own schedule, I don't have a fixed time that I am supposed to be at work. As a result, I am apt to experience the whole range of rush hour conditions. In the early 1980s, I usually accompanied my son to the bus stop, and I commonly left home for work at about 8:30. For most of the last 20 years, however, I have tried to avoid driving during rush hour. My major lifestyle choice is therefore whether to leave early or leave late. Since I much prefer extra sleep in the morning to an earlier arrival home in the evening, I habitually leave home after rush hour and avoid congestion entirely. Still, there are always some days when early arrivals are necessary, even for an academic, so I do get plenty of observations of rush hour conditions.

I started to collect data during the fall term in 1980 to find out:

- What are my actual travel times and how do they vary with the time of departure?
- Is it reasonable to treat the delays at the major intersections as independent?
- How long does it take for traffic flows to reach equilibrium?

The first two questions related directly to my original 1979 lecture. At one level, I simply wanted to have some actual data to show to my next class. I also wanted to test my hypothesis that the variance of the trip could be estimated as the sum of the variances at the major intersections. If so, then it would straightforward to show how changes at a single difficult intersection would propagate into the network. The third question related to the time dimension of traffic equilibrium, a matter of interest to me because the notion of equilibrium is so embedded in transportation network analysis. As a commuter, it was obvious to me that it takes many days for traffic to reach equilibrium. Congestion was always terrible just after Labor Day, when the academic year began at local schools and colleges. I knew that it took a while for traffic to "get back to normal", and I wanted to see how travel times varied for a couple of months after Labor Day.

I began to record trip time data in September 1980. In addition to the date, day-of-week, special characteristics of the day (e.g. school vacation or holiday), I recorded the information shown in Exhibit 3. The departure time represents the time that I walk out my front door; in practice, I sit down in the car, pull out the notebook, look at my watch, and enter the previous minute or half-minute (if the time is 8:22:34, I would enter 8:22:00); there is probably a minor variation of 15-30 seconds in the start time introduced by the lack of an accurate recording of a specific starting event. The next time is termed the "arrival at the 1st Brookline Avenue intersection", which is intended to represent the arrival time at the queue that is nearly always backed up from this intersection. This queue can extend a mile back along the parkway without fouling any other intersections. If the light at the intersection is working properly and if traffic on Brookline is not blocking the intersection when the light changes, then about 15-17 cars per lane will make it through during each approximately 2-minute cycle. Under these conditions, it will take about 12 minutes to traverse a mile-long queue that is backed up all the way to Willow Pond Street. If the light is not working or if there is a tendency to gridlock, then the queue moves more slowly. At the start of the period, there was often a traffic officer at the intersection, which generally helped avoid grid-lock, but otherwise did not have much effect on capacity. If there is an accident, or some other restriction on capacity, the queue could back up all the way to the rotary (segment 4 in Exhibit 1), but that is rare.

Exhibit 3 – Data Recorded for the Journey to Work

Time	Description	Comments
Departure	Time of walking out of the house	Estimated to nearest minute or half-minute (does not include clearing snow off car or returning inside for forgotten cup of coffee or briefcase)
Arrive First Brookline Ave Intersection	Time that I stop in a queue of cars backed up from the 1st Brookline Ave intersection with the Jamaicaway	There is a half-mile without any intersections, so it is usually clear where the queue starts. In rare cases, the queue backs up even further, and the time of arriving at the queue is a judgment call.
Depart First Brookline Ave Intersection	Time that I cross Brookline Ave	Well-defined
Arrive Commonwealth	Time of arrival at the queue by the light at the bridge that crosses the Turnpike	Well-defined
Depart Commonwealth	Time of entry onto the BU Bridge	Well-defined
Arrive MIT	Arrival at MIT parking area	Actual parking in the lot or entry to the garage

When I first started to collect data in September 1980, I was generally departing for work at about 830am. I was able to get a large number of observations over the 3-5 week period when traffic was difficult and people were adjusting their routes and their departure times (which is what "equilibration" requires). After that, I kept recording times in order to get data for a more normal period. Then, with a notebook already available in the car, and with plenty of congestion delays providing time to jot down times, recording travel times became a habit - one that has lasted my entire career. For the past 25 years, when I depart before 9:00, I almost always keep track of my travel time; if I depart between 9:00 and 9:30, I often record my travel time.

RESULTS

Exhibit 4 shows the travel times for the entire 25-year period for the journey to work on typical weekdays. In addition to one point for each day, the exhibit shows the running average trip time and the running average of the trip time plus 2 standard deviations. The average trip time indicates the amount of time that is consumed in commuting; the trip time plus 2 standard deviations suggests the minimum amount of time that I would like to allow to get to a class or a meeting.

Running averages are calculated for 30 to 70 observations centered on the departure time for each trip; more observations per time interval were used near the peak of rush hour where I had more data points. The running averages generally cover a period of about 20 minutes. It was necessary to vary the number of observations in the interval in order to keep the width of the interval close to 20 minutes.

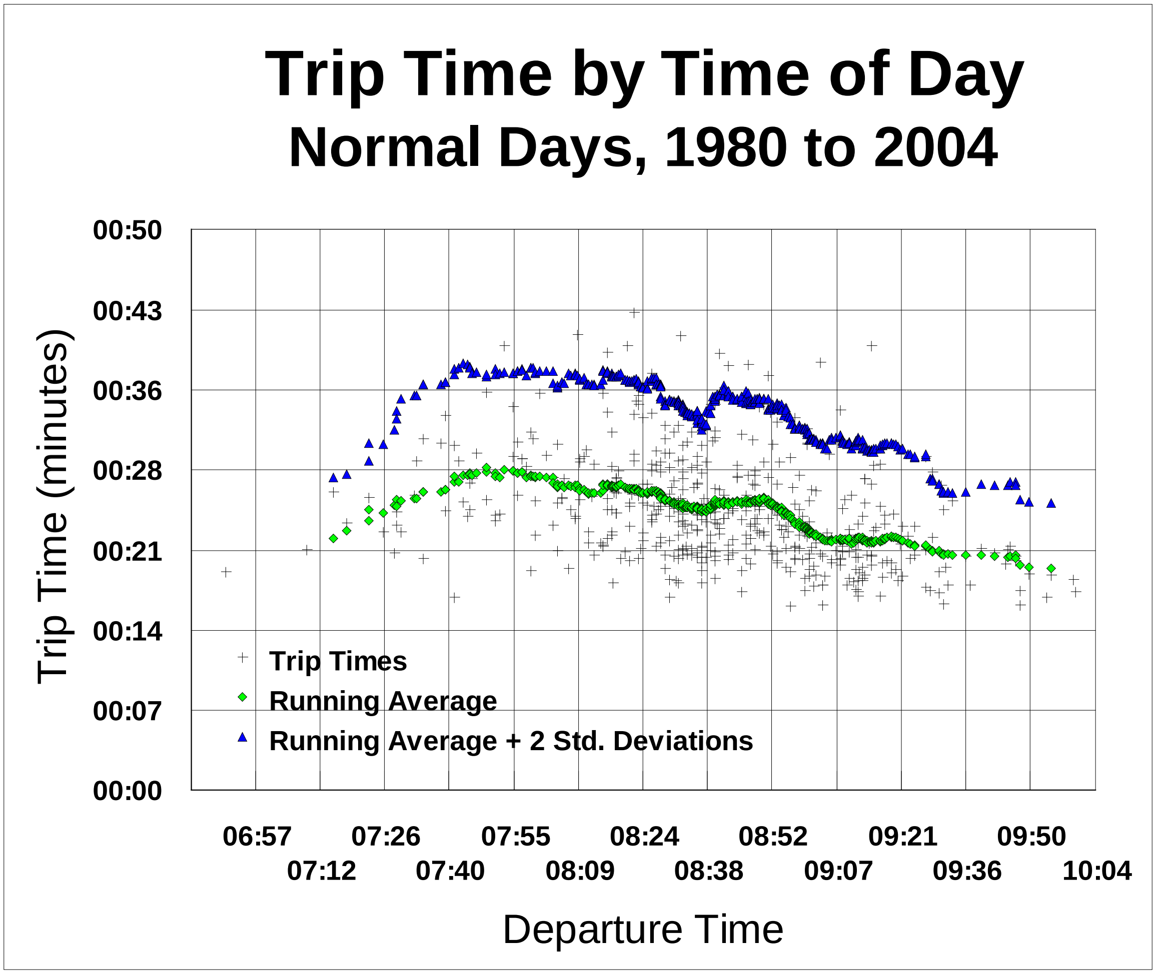
The data does not include summer days (June – August), weekends, school vacations, holidays, days with bad weather, or days when there was an extremely unusual event that caused trip times in excess of 45 minutes. On days with bad weather, all commuters know to expect somewhat longer trip times; in snowstorms, commuters stay at home, prepare for the worst, or assume that snow delays will excuse a late arrival. It was necessary to exclude the very longest trip times in order to get reasonably smooth running averages for the standard deviation. The very worst day in 25 years was a 73-minute commute on the second day after torrential rains caused the Muddy River to overflow into the Boston streets and eventually into the tunnel for the Green Line; the previous day I had left for work after noon and missed the even more horrendous delays. One of the other very bad days was associated with road work that restricted access to the BU Bridge, and the two other commutes in excess of 45-minutes were associated with grid-lock in the medical area that caused traffic to back up more than two miles along the Jamaicaway. These 4 very bad days represented about 0.5% of the days in the sample; I excluded them primarily in order to avoid strange breaks in the plot of the trip time plus 2 standard deviations.

The plot covers the full 25 years, so there is somewhat more variation in the data than is observed in most of the shorter intervals. However, as will be seen below, the year-to-year variation in performance is not excessive, so that this plot does seem to me to be a good representation of the performance that I expect when I head off to work. The advantage of using the entire interval is that it is possible to get many more data points and therefore to get better estimates of both the expected travel time and the reliability of the journey-to-work.

The exhibit clearly illustrates several key features of the journey-to-work:

- If you leave early enough, you can travel at off-peak speeds and reliability (before 715 or so in this case)
- However, congestion builds up rapidly, so if you are just a little late, you can suffer extensive delays (the longest and least reliable performance is for departures between 745 and 800 am)
- There is a limit as to what people endure – performance is relatively constant over a fairly wide period at the peak (e.g. performance is worst for departures between 745 and 830 on this route, and performance is pretty bad for the wider interval from 730 to 900)

Exhibit 4: Journey-to-Work Travel Times, 1980 –2004
Source: data collection and analysis by the author



- Due to the vagaries of demand and geography, there may be minor lulls in congestion; commuters can learn about these sweet spots and adjust their behavior accordingly. The dip in both the mean and the variability of trips times shown in the exhibit are real, not artifacts of the data. I learned decades ago that it was best for me to leave a little after 830 – I suspect that this is because businesses, hospitals and schools along my route have start times of 800, 830 or 900 – so leaving slightly after the half-hour allows me to slip between two local peaks in demand. (When I commented on this to my wife, she immediately responded that traffic is best – on her route to work - if she leaves at about a quarter to nine.)
- The standard deviation of travel time is increasing for quite a while after the expected travel time declines, i.e. variability increases the further you go into rush hour (between 745 and 830).
- The end of rush hour is not as sharply defined as the beginning; expected travel times and variability decline more slowly than they rose.

These observations will not provide much of a surprise to any commuter. We all know the vagaries of our routes, and we usually figure out when to leave if we really want to get to work on time. However, it is useful for planners and traffic engineers to see some actual statistics from the perspective of a commuter. It is especially useful for researchers, especially grad students who may never have owned a car or driven at rush hour on a regular basis.

It is interesting to compare what is shown in Exhibit 4 with my estimates of performance given above. Eliminating the walking time, those estimates could be restated as:

- Off-peak: 15-17 minutes (plus 5 minutes walking)
- Near-peak: 19 - 25 minutes (plus 5 minutes walking)
- Peak: 25 – 40 minutes (plus 5 minutes walking)

The actual performance shown in Exhibit 4 is not far from this, especially for the expected time. Departing at 10 am has an expected travel time of 20 minutes with a standard deviation of 3 minutes. The best travel times on commuting days were about 17 minutes; 15 minutes is possible late at night or on Sunday mornings when there is little or no traffic. Departing at 910, the expected travel time is 22.5 minutes with a standard deviation of 4.5 minutes. The mean is about what I suspected, but the variability is higher. Departing during the peak, the mean reaches 29 minutes with a standard deviation of 5 minutes.

Is Congestion Increasing?

The number of observations per year was too sparse to support more exhibits with the detail shown in Exhibit 4 for the entire period. Exhibits 5-10 simply show the distribution of travel times for each of six periods. The travel time and departure time scales are the same in each chart, so that it is possible to see at a glance some interesting differences that have occurred over the years. The first chart (Exhibit 5) covers two years from 1980 to 1982; during this time, I frequently walked or drove my son to his bus stop, then went to work. Hence, my departures are tightly clustered around an 830 departure. Note that the trip time is almost always less than 21 minutes if the departure is after 9:05; the longest trip times are close to 40 minutes. This chart is, not unexpectedly, closer to the performance that I described to my class in 1979. Aside from documenting my lack of discipline in departing for work, Exhibit 6 shows pretty much the same performance for the longer period from 1988 to 1994. I only bothered to take times for a few days when I departed after 9am, presumably because this was clearly after the end of rush hour.

Between 1995 and 1999, rush hour was spreading (Exhibit 7). Performance had deteriorated both early and late, although the peak does not appear worse than in the earlier years. The flattening of the peak continued between 1999 and 2001 – trip times at times were close to 30 minutes even with a 930 departure. Still, the very worst days remained less than 40 minutes.

After 2001, performance was seriously affected by the “Big Dig”. As construction caused delays in the corridors to the east of my corridor, commuters seemed to be shifting to new routes. Hence traffic volumes seemed higher, and performance clearly deteriorated. Between September 2001 and May 2003, there were many days with 40-minute commutes, and there continued to be problems for departures between 9 and 930.

In 2003/04, significant portions of the new routes were opened, and the “Big Dig” seemed to become a positive factor. Travel times dropped, especially before 9am. Travel after 9am was still hampered by congested conditions within the medical area.

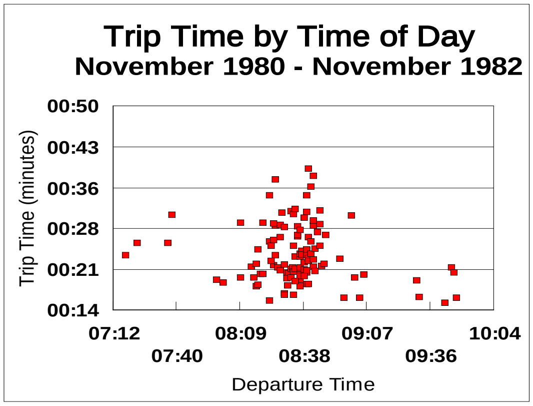
With the relatively sparse data shown in Exhibits 5-10, it would not be meaningful to show running averages, as getting a reliable estimate of the standard deviation would require too wide a range of departure times. Instead, I computed statistics for each 15-minute interval of departure times. My predilection toward later departures means that I did not have many observations for the earlier periods, so I cannot compare performance across the entire peak.

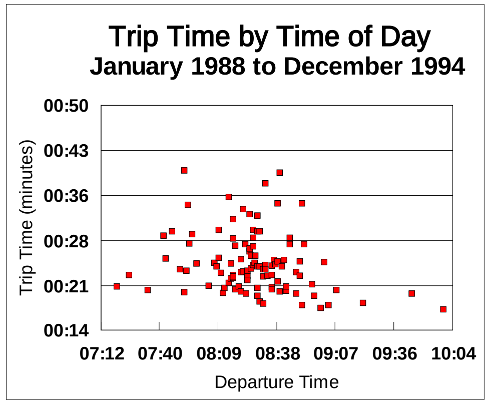
Trip Times for Major Trip Components

Exhibits 11 and 12 show the mean and standard deviation for the total trip time and for the major components of the trip. These charts are based upon the performance summarized for the eight 15-minute intervals between 730 and 930am. Where data were insufficient to compute an average or a standard deviation, estimates were made based upon the data that were available or upon patterns that were observed over the entire period. If data were unavailable for one 15-minute period, the first option would be to use the average of the prior and succeeding periods. If data were unavailable for the first or second period, then I estimated the missing value as a percentage of the 800-815 interval (80% of the peak for the 730-745 interval and 90% of the peak for the 745-800 interval). The averages shown in Exhibits 11 and 12 therefore are not weighted by the number of actual observations that were available. Instead, they reflect the expected performance over this two-hour period. It might be argued that the averages should be weighted by the number of travelers during each period, but that data is not available – and it is not clear that the weights would be the same for each trip components. The statistics shown here have the merit of being readily computed and easily compared. Most importantly, they provide an excellent insight into trends in performance on this route over the past 25 years.

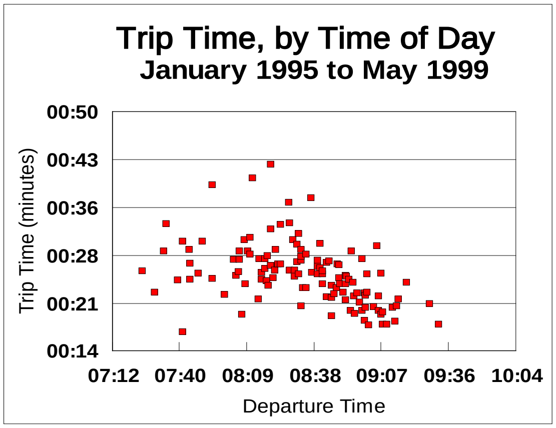
One fact is striking. For most of this 25-year period, the overall mean trip time was 25-27 minutes with a standard deviation of 3-4 minutes. If the poor performance for the 2001-3 period is disregarded as being unduly affected by the Big Dig, then there hasn’t been much change over the entire period. In fact, if we consider the mean plus 2 standard deviations, the best performance was in the most recent period! It appears that we may be receiving some real benefits from the Big Dig.

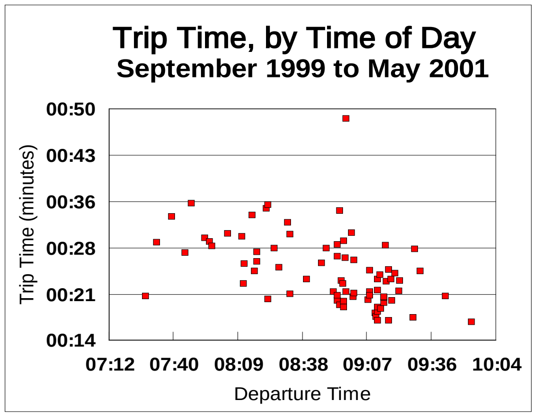
Exhibits 5 & 6



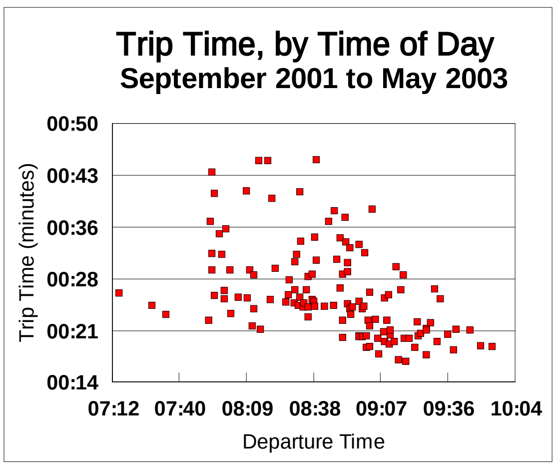


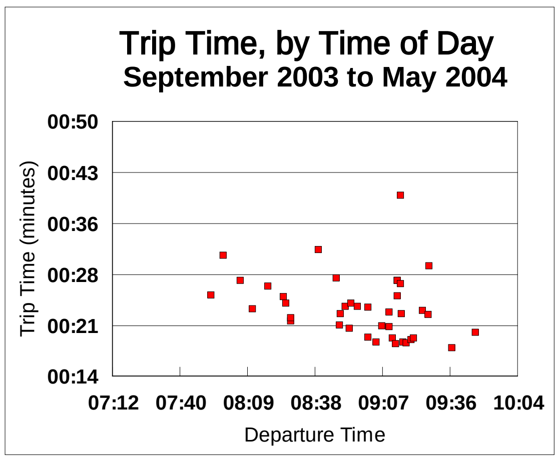
Exhibits 7 & 8





Exhibits 9 & 10





Exhibt 11: Average Times for Journey-to-Work and for Major Trip Components

	Trip Time	1st Leg	1st Brookline	2nd Leg	BU Bridge	3rd Leg	N
1980 Sep-Oct	00:25:57	00:08:46	00:04:12	00:06:02	00:02:48	00:03:56	23
1980-82	00:25:43	00:09:22	00:03:21	00:06:01	00:02:45	00:04:14	102
1984-86	00:26:42	00:11:13	00:03:56	00:06:23	00:01:41	00:03:28	28
1988-94	00:24:11	00:09:55	00:02:49	00:06:34	00:01:53	00:03:00	103
1995-99	00:25:57	00:10:23	00:04:12	00:06:25	00:01:43	00:03:22	123
1999-2001	00:26:55	00:11:06	00:04:23	00:06:19	00:01:43	00:03:17	77
2001-03	00:28:16	00:11:42	00:04:02	00:06:40	00:02:33	00:03:17	124
2003-04	00:26:06	00:11:04	00:02:58	00:07:23	00:01:40	00:03:00	40

Exhibit 12: Standard Deviation for Trip Time and for Major Trip Components

	Trip Time	1st Leg	1st Brookline	2nd Leg	BU Bridge	3rd Leg	N
1980 Sep-Oct	00:03:58	00:01:02	00:04:05	00:01:48	00:00:33	00:00:47	23
1980-82	00:04:38	00:01:08	00:01:54	00:01:56	00:01:44	00:01:18	102
1984-86	00:03:20	00:03:25	00:03:00	00:01:42	00:00:24	00:00:29	28
1988-94	00:03:55	00:01:19	00:03:01	00:02:19	00:01:06	00:00:40	103
1995-99	00:03:48	00:01:49	00:02:49	00:01:17	00:00:33	00:00:41	123
1999-2001	00:03:55	00:02:10	00:02:57	00:01:24	00:00:41	00:00:37	77
2001-03	00:05:27	00:02:25	00:03:39	00:01:17	00:02:11	00:00:52	124
2003-04	00:02:49	00:01:08	00:01:24	00:01:27	00:00:24	00:00:16	40

DISCUSSION

To summarize, there are various approaches to studying congestion. Highly publicized studies of commuting times tend to emphasize the increasing delays in commuting and the alarming trends if nothing is done to overcome the problem. Economists respond to calls for more highways with their own calls for tolls; and they also note that there can be substantial congestion even in an optimal system. Highway engineers delve into the minutiae of delays, while network modelers devise elegant frameworks for predicting equilibrium traffic flows. While each perspective undoubtedly has its strengths for some purposes, it is striking that none of them (i.e. none of the dozens of exhibits in the works cited) shows any data about how service actually varies over rush hour for any specific commute. It apparently is not necessary to observe the phenomena of congestion in order to write about how bad it is or how to deal with it.

The purpose of this paper is to provide some insight into congestion by documenting one commuter's long-time experience in driving to work. While this is merely one commute out of many millions in the United States, it is at least an in-depth analysis of the actual performance of that route as perceived by a real commuter. The nature of this commute is believed to be representative of the nature of millions of commutes, so that the insights gained by looking at this one commute may be broadly applicable. At the least, understanding one real commute will prevent researchers from grievous errors in trying to model rush hour performance.

The key findings can be summarized as follows:

- For any particular route, travel times and travel time variability vary predictably over the rush-hour period. Rush performance can be viewed as a steady-state cyclical queuing phenomena: every day may start afresh, but conditions on next Tuesday are likely to be similar to conditions last Tuesday.
- We can expect commuters to understand their options regarding both routes and departure times. They know that peak conditions are not a constant, and they can act accordingly. Modeling or imagining the peak as having a single level of performance (as is commonly done in network models or in traffic capacity analysis) will not give correct results. Traffic engineering models may not deal well with the length of delays that actually may occur at key intersections – delays that average 2-5 minutes are dramatically different from delays of 40 to 60 seconds that may be termed to be "unacceptable" by traffic engineers. The commuter doesn't mind the 2-5 minutes, but is really upset on the days when these are double or triple that because of a signal malfunction or the lack of a policeman to prevent gridlock.
- As more people use a route, the peak travel conditions may not be appreciably different, but these conditions will be observed over a wider peak.
- There may be lulls at predicable times within the rush hour, reflecting highly localized commuting habits and routes.
- The trip time and variability for a route may depend upon just a few key intersections. Modeling a relatively small number of key intersections may therefore provide a new way to model performance for a metropolitan area.
- It takes about a month after Labor Day for commuting times to settle down into what will become "normal" performance for the rest of the fall.

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