Highway versus Urban Roads: Analysis of Travel Time and Variability Patterns Based on Facility Type

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ABSTRACT

In this paper, the differences in travel time variability patterns between urban roads and highways are analyzed. For urban roads, a GPS dataset which includes all taxi trips in New York City is used. For highways, New Jersey Turnpike (NJTP) Automatic Vehicle Location data is employed. Moreover, NJTP is divided into two sections as urban and suburban highway based on urbanization level, time of day demands, and physical roadway features. Hence, the analysis does not only compare the travel time patterns between highways and urban roads, but also investigates the travel time characteristics along the same highway facility. First, the temporal variation of travel times at both facility types are calculated and compared. Second, the travel time distributions are extracted for different time periods and compared visually to determine the distributional patterns. Last, the relationship between the average travel time and variability is investigated. Travel time patterns not only differ between urban roads and highways, but major differences in travel time characteristics can also be observed along the same highway. Higher travel times correspond to lower reliability at the highways, yet correspond to higher reliability at the urban roads. Overall, the findings suggest that attributing travel time variability patterns to facility type may actually be an oversimplification of the phenomenon.

INTRODUCTION

In recent years, there have been an increasing number of travel time variability studies due to an increased market penetration of technologies such as GPS, smart phones, and Bluetooth devices. With the help of these technologies, equipped vehicles in a transportation network may be utilized as probe vehicles, and the travel time characteristics can be calculated even in real time. Researchers employ value of travel time (VOT) and value of travel time variability/reliability (VOR) as a measure for evaluating transportation planning, policy and investment decisions.

On one hand, many studies agree that the travel time variability fluctuates mainly with respect to the time period (e.g. peak hours vs. off-peak, weekdays vs. weekends). Other factors such as weather, traffic incidents, roadways geometry, traffic signals, and traffic demand level are also considered to have influence on variability. However, the magnitude and the sign of identified impacts are not consistent among the studies. For instance, the impact of weather has been found to both increase and decrease variability (also with varying levels of impact) based on different studies (1). Similarly, the facility type (highway vs. urban roads, freeway vs. arterial) has also been recognized as an important distinction. Peer et al. (2) studies travel time variability on Dutch highways and question some of their results’ divergence from previous urban road studies. They conclude that travel time variability in urban networks is already high due to factors such as traffic lights, and an increase in mean delay may not be fully reflected on the travel time variability. Likewise, (1, 2, 3, 4) identify conflicting variability patterns for urban roads compared to highways.

So far, the discrepancy between highways’ and urban roads’ travel time variability has been identified through several studies and datasets that do not necessarily belong to the same city or even region. Meanwhile, the characteristics and dynamics of each urban area may lead to
different travel times. In this respect, the current study aims to investigate the facility related
discrepancy based on travel time datasets gathered from the same metropolitan area. For this
purpose a GPS dataset which includes taxi trips in New York City (NYC) is used to calculate
urban road travel times. For calculation of highway travel times, New Jersey Turnpike (NJTP)
Automatic Vehicle Location (AVL) data is employed.

NJTP is a toll road that stretches in South-North direction along the state of New Jersey.
NJTP connects to major NJ-NY passages such as Holland and Lincoln tunnels, and George
Washington Bridge, Outer Bridge Crossing and Verrazano-Narrows Bridge. NJTP also functions
as one of the main highways that New Jersey commuters use to get to their workplace in and
around NYC. However NJTP is not a homogeneous facility regarding the road geometry,
utilization of the road network and traffic conditions. Southern New Jersey is relatively less
developed and more suburban whereas Northern New Jersey is highly urbanized with close
proximity to NYC. More, NJTP has “dual-dual” lane sections where inner lanes are for cars only.
In this respect, a cutoff point is defined on NJTP which separates the facility into two sections as
suburban and urban highway.

The current paper does not only compare the travel time patterns between highways and
urban roads, but also investigates the travel time characteristics along the same highway facility.
Overall, the paper aims to answer the following questions:
1. How do the average travel times and variability patterns compare between highways and
urban roads?
2. How similar or different are travel time distributions on highways and urban roads?
3. Is there any consistent relationship between the travel time variation and the average travel
time?

The paper is organized as follows. First, a literature review on travel time variability is
provided, followed by a detailed description of the datasets used for analysis. Second, the
average travel time and travel time variation for specified road facilities are extracted for 24/7.
Travel time patterns are identified and discussed in terms of similarities and differences. Then,
the travel time distributions for highways and urban roads are compared, and the relationship
between average travel time and variability is investigated. Finally, conclusion and discussion
are provided.

LITERATURE REVIEW
Travel time variability can be defined as the random variation in travel time (5), or as the
uncertainty in journey trip times (6). Travel time variability is used almost interchangeably with
travel time reliability (7, 8) although these two concepts are not necessarily comparable. Travel
time variation is a statistical characteristic of travel time distribution. “Reliability” is based on
variability, but requires a system failure as a part of its definition. Nevertheless, the same set of
factors affects both reliability and variability. Researchers employ probe vehicles, Bluetooth,
GPS and similar technology to analyze the aforementioned randomness in travel time (9, 3, 10,
11, 12, 2, 13). Studies agree that average travel times as well as travel time variability fluctuate
with respect to various factors such as time-of-day and day-of-week, weather, incidents, traffic
demand, roadway geometry, existence of traffic signals, and facility type (freeway vs. arterials).
Hojati et al. (14) conducts a study of factors affecting freeway reliability, summarizes the sources
of congestion and their relationship with travel time reliability. Although a set of factors are
identified, many studies report varying degrees of magnitude for each factors contribution to
variability. Sometimes the same factor is shown to have opposite impacts depending on the study
area. Li et al. (15) find that demand contributes more than half of the variability in AM-peak and
one quarter of the variability during PM-peak. They also argue that incident and weather
contribute more to PM peak variability. Kwon et al. (16) agree that incidents contribute more
during PM-periods but they identify relatively little weather impact on variability. As a matter of
fact, the impact of weather on travel time variability has been discussed more than many other
factors. However, there is no consensus on the sign and magnitude of the weather impacts (1). Peer et al. (2) investigates the relationship between the mean duration and the variability
(represented by standard deviation) for highways. They find that a unit increase in mean travel
time is associated with a larger increase in variability during free-flow conditions than the
periods with hyper-congested traffic. This finding contradicts previous knowledge that travel
time variability is higher during congested conditions. They question their findings and conclude
that travel time variability on highways and urban roads have different characteristics. Urban
networks travel time variability is already high due to factors such as traffic lights at
intersections, thus, an increase in the mean delay may not be fully reflected on the travel time
variability. Franklin and Kalstrom (3) also argue the differences between freeway and urban
travel time characteristics based on data from Stockholm.

Studies focusing on a specific road facility or network also provide hints regarding the
possible sources of discrepancy between urban roads and highways. Liu et al. (17) develop a
prediction model for urban travel time variability using only cruising times and intersection
delays. Their model with high prediction accuracy suggests a high impact of traffic signals. Similarly, Graves et al. (18) find that vehicle volume and traffic signals have the highest
influence on urban arterial’s travel time variability. Nevertheless, there can still be contradicting
findings for the same type of roadway facility. For instance, for the urban roads in London and
Leeds, the coefficient of variation is found to be the highest for AM and PM peaks (1), whereas
peak periods are found to have lowest coefficient of variation (CoV – standard deviation
normalized by the mean) in NYC (10). Hence, comparable dense urban road network do not
necessarily produce same patterns of travel time variability. On the highway side, the roadway
geometry such as the number of ramps and weaving sections per unit length are found to affect
the travel time variability (20). In another study, Tu et al. (21) also calculate critical inflow levels
(with respect to the roadway capacity), which are found to have an impact on freeway travel time
variability. In these studies, demand levels, capacity and physical roadway characteristics stand
out to be important factors for travel time variability. The analysis presented in the current paper
also takes these factors into account while categorizing the sections in NJTP.
DATA

For analyzing the travel time statistics on urban roads, taxi GPS data obtained from the NYC Taxi and Limousine Commission (TLC) is used. There are more than 13,000 taxis with a GPS device in NYC working 24/7. The dataset has more than 370 million taxi trips covering the period from January 1, 2009 to November 28, 2010. The vast majority of trips originates from and ends in NYC, particularly in Manhattan. Each trip record includes the pick-up and drop-off time as well as the metered trip distance. The taxi trip durations vary based on the trip distance. Unlike a corridor travel time analysis with a fixed length, trip durations cannot be compared directly. Hence, for each taxi trip, “travel rate” (in minutes per mile) is used as a length-neutral surrogate for trip time variation (8). This conversion makes it possible to analyze the system-wide travel times and to avoid using particular origin-destination pairs or a representative trip length. For the variability analysis, the trips are aggregated for each hourly period during the day based on the pick-up time. Although the origin and destination coordinates are recorded, the dataset do not include the chosen path among multiple alternatives in NYC grid network. More, the taxi trips can occur between any two points in the city, not necessarily in north-south, or east-west alignment. In these respects, no directional attribute is considered for NYC travel times.

In an effort to clean the data, taxi records with obvious errors (e.g. trip with zero travel time or zero distance) and records with practically unreasonable travel times (e.g., average speed in multiples of the free flow speed or of the speed limit) or unreasonably slow travel speeds (e.g., average vehicle speeds that were fractions of the average walking speed) were removed from the dataset. Specifically, any record with an average speed higher than 1 minute per mile (or 60 mph) and ones with a speed lower than 40 minutes per mile (half of the average human walking speed of 3 mph) are deleted.

For travel time statistics on highways, Automatic Vehicle Location (AVL) records in NJTP were used. NJTP is a 122-mile long toll road with controlled access through entry/exits points along the highway. The NJTP AVL dataset covers all days in 2011, and provides travel time information between the locations where vehicle passes through a card reader location and the vehicle leaves the roadway. OD travel times with respect to exits can be calculated as the average travel time of vehicles travelling between that particular OD exit pair. Other vehicles that do not belong to the set of this same OD pair but that cross the corresponding path are not taken into account. AVL data may include unrealistically short and long observations due to factors, such as spending time in a rest area, missing AVL records either at the entry or exit, extra time spent at toll plaza. Such records are filtered out from the data. More, similar to taxi travel time records, the travel rate is calculated by dividing the travel time between each entry/exit location by the corresponding distance. Using travel rate for both datasets helps avoid using particular origin-destination pairs or a representative trip length for both datasets. Similar to taxi data, NJTP trips are also aggregated for each hourly period throughout the days. Since commuting patterns affect the traffic conditions, the NJTP travel times are analyzed with respect to the direction of travel as well, e.g. southbound and northbound.
Urban vs. Suburban Highway

As shown in FIGURE 1, NJTP is a major roadway facility in New Jersey that provides access to many localities in New Jersey as well as and New York, Delaware and Pennsylvania. It passes through both urban and suburban regions, but no straightforward delineation line can be drawn between suburban and urban parts. In order to extract the region that exhibits similar urban travel dynamics around NYC, major network connections within NJ, and between NY and NJ were considered. For instance, the Garden State Parkway (GSP) is another major highway (a toll road as well) in NJ which aligns also in South-North direction, and serves in between the coastal and Northern NJ. GSP connects with the turnpike at Exit-11. Exit-10, which is less than 3 miles south from Exit-11, connects to the Outer Bridge Crossing to Staten Island, which leads the way to Brooklyn and Queens through the Verrazano-Narrows Bridge. Other major NYC connections (Holland and Lincoln Tunnel, George Washington and Goethals Bridge) are on the North of Exit-11. The average distance between consecutive exits also becomes shorter after Exit-11 due to the need for providing connection the urban centers. On the other hand, around Exit 8A (North of Exit-8) NJTP splits into “dual-dual” lane structure where inner lanes are for cars only and the outer lanes are open to all types of vehicles including trucks. In order to incorporate this geometrical change, Exit-8 is selected to be the border of suburban highway. Hence, north of Exit-11 is assigned as urban highway, and south of Exit-8 is assigned as suburban highway. The section between Exit-8 and Exit-11 exhibits unique travel delay patterns due to the road geometry transition, and makes the comparison with the other sections problematic. In this respect, this section is excluded from the analysis.
FIGURE 1 Map of NJTP and illustration of urban-suburban highway boundaries
ANALYSIS
In this paper, three types of analysis and comparison are made to identify the differences in travel time variability between urban roads and highways. First, the temporal variation of travel times at both facility types are calculated and compared. Second, the travel time distributions are extracted for different time periods and compared visually to determine the distributional patterns. Last, the relationship between the average travel time and variability is investigated.

Temporal Variations in Travel Time
FIGURE 2 shows the temporal changes in average travel time for the urban and suburban highways, and NYC urban roads. The highway travel times are also categorized for northbound (NB) and southbound (SB) travel. Please note that, due to different speed limits and actual travel speeds, highway and urban road travel times cannot be compared directly. The highway travel time figures are based on the same color scale whereas NYC urban roads have a separate color scale.
FIGURE 2 Temporal variation in mean travel times at NJTP and NYC
As shown in FIGURE 2, the suburban highway has lower travel times almost at all times compared to the urban highway. Based on the literature, possible reasons are the higher demand and more frequent exit/entry points at sections of the urban highway. The urban highway travel times are higher during AM and PM peak, whereas the suburban highway does not exhibit any peak travel pattern. On the contrary, the suburban highway has its lowest average travel times around the AM peak hours. Suburban travel times are higher during Friday PM peak for both directions, and Sunday PM peak for northbound direction. The reason of this weekend peak is most likely the return of weekend leisure trips. Meanwhile, the urban highway southbound PM peak is distinctly higher than any other peak period. PM southbound travel is supposedly the return trip (Northbound AM peak) of commuters working in the NYC metropolitan area. However, the magnitude of the average travel times is not symmetric between AM and PM peaks. This may suggest that travelers are more likely to re-schedule departure times during AM peak to avoid congestion compared to PM peak. It can be also argued that PM peak period involves more activities and possible trip chains (e.g. shopping, picking kids from school, running errands etc.). Thus PM peak traffic volumes can be higher than AM peak. The bottleneck (due to reduction in the number of lanes) around Exit-8A should also be mentioned. The queue back-up might affect upstream traffic up to Exit-11 (southern border of urban highway as defined in the current paper). Unfortunately, there is no data to prove these arguments and a definite explanation for the finding cannot be provided.

Travel times during early AM periods (12AM thru ~5AM) are slightly higher than the following morning hours (6AM-9AM). This could be due to several reasons. Lane closures for roadway maintenance in NJTP are performed during night when there is relatively less traffic. The roadway capacity losses during nights may result in higher travel times. More, NJTP is a popular route for trucks, and truck drivers usually prefer night travel. Higher truck volumes during the night might be a factor for slowing down the NJTP traffic. Investigating the validity of these reasons is out of the scope of this study, and reserved for future research.

A comparison of travel times between the urban roads and urban highways shows considerably different patterns. In NYC, there is no distinct AM or PM peak. There is a spread-out peak period that starts with conventional AM peak and ends with PM peak. As a matter of fact, the highest travel times are observed during midday (~12PM). This fact is also acknowledged by NYC officials and commercial deliveries are mentioned as a possible reason (24). Heavy pedestrian traffic during lunchtime can also be a contributor to the slow roadway traffic. The lowest travel time values, on the other hand, are observed between 4AM to 6AM. In other words, the overall average travel time patterns in urban roads draw a completely different picture compared to highway patterns. It should be noted that NYC has a dense, signalized grid network. On the other hand, few roadways (e.g. West Side Highway, East River Drive on two sides of Manhattan) may offer routes without signal delays for certain origin destination pairs. The dataset does not include path/route information; hence detection of such trips is not possible. Nevertheless, NYC taxis mainly operate on the grid network. Consequently, the findings are assumed to represent the travel times for the signalized grid network.
FIGURE 3 shows the northbound average travel times in the first row, standard deviations in the second row, and coefficient of variation (CoV) in the third row. The columns refer to suburban highways, urban highways, and NYC urban roads, respectively from left to right. Similar to FIGURE 2, NYC travel times and standard deviations are plotted on a separate color. Since CoV is a normalized measure (i.e. standard deviation normalized by the mean), all three CoV figures are based on the same color scale. In other words, CoV values can be used to directly compare the variation with respect to facility type.
FIGURE 3 Standard deviation and coefficient of variation patterns at NJTP northbound and NYC urban roads
Midday (12PM to 2PM) has the largest travel time variability in NYC, where urban highways have the largest variation during the AM or PM peak periods. Suburban highways have the largest variability during Sunday between 4PM-7PM, on Friday between 4PM and 5PM. More, suburban highway has relatively larger weekday variability during early AM periods (12AM to 5AM) compared to other weekday time periods.

CoV values point out the main differences between the facility types. Wenjing (22) investigates several travel time reliability measures and suggests CoV as a good proxy for several other reliability measures. Lower CoV implies higher reliability. In this sense, NYC network has the lowest travel time reliability among all facility types. Urban highways, overall, have higher travel time reliability compared to rural highways. In NYC, the travel variability measured by standard deviation is larger during the day, but CoV is lower. Thus, NYC urban roads have the large variance during day time hours but also the highest reliability (indicated by lower CoV) at these periods. Low reliability periods for suburban travel are early AM periods (12AM-5AM). Urban highway, on the opposite, exhibits relatively high reliability during early AM periods. In other words, difference in travel time variability and reliability exists not only between urban roads and highways, but also among the different sections of the same highway facility. Hence a traveler commuting from Southern NJ to NYC during AM peak period may experience different travel patterns along the way. For instance, in the beginning of her/his journey, the traveler may experience low travel time (or faster travel) and high reliability on the suburban highway. When s/he is at close proximity to NYC (reaching urban highway sections), s/he may face considerably higher travel time and lower travel time reliability (compared to suburban highway) for this section of her/his trip. Once s/he reaches NYC, the reliability level may be the relatively high for NYC urban network, but still lower than highway reliability. The overall travel time reliability of a commute through multiple types of facility types poses an interesting future research direction.

**Travel Time Distributions**

Besides the temporal variations in travel time statistics, analysis of travel time distributions can provide additional insights for the comparison. FIGURE 4 compares the travel time distributions in NJTP with respect to selected time periods on Wednesday (as a representative of a weekday). Columns in FIGURE 4 show the distributions based on urban-suburban highway, and the direction of travel. FIGURE 5 compares the distributions for northbound travel in NJTP and NYC for the same selected day and time periods. The time periods are selected to represent the conditions for varying traffic conditions, e.g. very early morning (4AM-5AM), AM-peak (9AM-9AM), midday (1PM-2PM), PM-peak (5PM-6PM), and evening/night (8PM-9PM) travel.
FIGURE 4 Travel time distributions at urban-suburban sections on NJTP (Wednesday)
As shown in FIGURE 4, the travel time distributions at suburban highway are relatively more skewed than urban highway. The skewness of the suburban travel time distributions is not dramatically affected at different time periods. They mostly shift right or left depending on the time period with no distinctly visible peak hour impact. On the other hand, urban highway distributions are strongly affected by the time period. They exhibit lower skewness and higher dispersion during peak periods. Midday (1PM-2PM) period also has high dispersion but still has lower dispersion than peak periods. Overall, the findings show that the travel time distributions at urban and suburban parts of the same highway may exhibit considerably different characteristics. Based on FIGURE 5, NYC travel time distributions are also affected by the time of day similar to urban highways. The travel time distribution is highly left skewed at early morning (4AM-5AM) and exhibits higher dispersion but less skewness during the day.
FIGURE 5 Comparison of NJTP northbound and NYC travel time distributions (Wednesday)
Average Travel Time vs. Variability

FIGURE 6 shows the standard deviation of the travel time vs. the average travel time for all 7/24 hourly intervals. Each data point represents the average travel time-standard deviation data calculated for each hourly period. Thus the figure contains 168 data points (i.e. 24 hours x 7 days). Again, NYC travel times are not directly comparable to NJTP, so they cannot be plotted on the same axes. As seen in FIGURE 6, suburban highways have a higher variance than urban highways for the same average travel times. The trend shows that the suburban highway travelers are exposed to higher variation compared to urban highway’s travelers as the average travel time increases. Similarly, higher average travel times correspond to higher variation in NYC as well. However, the absolute variation may not tell the whole story as the variation with respect to the average travel time (represented by CoV, shown in FIGURE 7) gives more insights to the issue of reliability.

FIGURE 6 Average travel time versus standard deviation
As shown in FIGURE 7, CoV ranges between ~0.45 and ~0.65 at NYC urban roads. For both types of highways, CoV varies between ~0.1 and ~0.5. Hence, a certain level of variation always exists at NYC urban roads at all times. This consistent presence of high variation can be attributed to the existence of traffic signals which affect the traffic flow at all times regardless of the time period or the demand levels. CoV increases as travel time increases for highway travel. Interestingly, the opposite case is observed for NYC urban roads. The CoV values, overall, decrease as the travel time increases. That being said, CoV values in NYC remain about the same after 6min/mile and exhibit a slightly increasing trend after 7 min/mile. CoV values for urban highways also stay about the same after ~95 sec/mile. Unfortunately, the travel time records do not provide additional points at higher ranges so that the trend can be fully understood. These conflicting CoV trends at urban roads and highways stand out as an interesting future research topic.

CONCLUSIONS
This paper focuses on the travel time and variability patterns with respect facility type (urban road vs. highway). Different from the past literature, the current study is based on the datasets from facilities within the same metropolitan road network, which function under similar regional travel patterns. For the urban roads, taxi GPS data obtained from NYC Taxi and Limousine Commission is used. For the highway, AVL data for the New Jersey Turnpike (NJTP) is employed. Due to the varying proximity to urban centers, different demand levels, travel patterns and roadway geometry, NJTP is divided into two parts, categorized as urban and suburban highways. For all defined roadway types, the average travel times for all hourly periods in a
week are calculated to investigate the overall travel time patterns. In order to discuss the travel
time variability and reliability, the standard deviation and coefficient of variation of travel times
are calculated. Besides the average travel time and variability measures, the travel time
distributions for different periods and facility types are also compared.

The suburban highway travel is found to be free of any peak travel time period, in
contrast, the lowest travel times were observed around the morning peak. Urban highways
exhibited higher average travel times for both AM and PM periods. However, the magnitudes of
average travel times at AM peak (NJ to NYC) and PM peak (NYC to NJ) (in reverse directions)
are found to be asymmetric. The possible reasons of this discrepancy are discussed in the paper;
however none of the arguments can be backed up with hard evidence. Hence, it stands as a future
research topic.

NYC average travel times, on the other hand, increases around AM-peak and stays at
high levels all day long until the end of the PM peak. Hence no distinct AM-PM peak pattern is
found, instead, an all-day-long peak is observed. As a matter of fact, the highest average travel
times are found to be at midday (around noon). Possible explanations of this observation can be
the increase in commercial midday deliveries and lunchtime pedestrian traffic; however, again,
no hard evidence can be offered based on the available data.

In terms of average travel time patterns, two sections of the same highways and urban
roads show completely different characteristics although these facilities are highly connected and
served the same metropolitan area. The analysis of travel time distributions agreed with the
heterogeneity of travel time among different facilities. Time period has a minor impact on
suburban travel time distributions, whereas for urban highways and urban roads, the peak periods
exhibit a less skewed but considerably higher dispersed travel times compared to off-peak
periods.

Regarding the travel time variability, it was found that variability (represented by the
standard deviation) increases as the average travel time increases. However, the magnitude of the
increase differs between urban roads and highways, as well as between suburban and urban
highways. Meanwhile, an interesting relationship is observed between the average travel time
and the travel time reliability (represented by CoV). The CoV values at the highways exhibit an
increasing trend (but with varying magnitudes at suburban and urban highway sections) as
average travel time increases. On the contrary, the CoV values decrease for the urban roads as
average travel time increases. In other words, higher travel times correspond to lower reliability
(=higher CoV) at the highways, yet correspond to higher reliability at the urban roads. All these
findings show that a trip from southern NJ to NYC may include roadway sections with varying
(sometimes conflicting) travel time characteristics, which makes it a challenge to calculate trip
travel time variability/reliability for the whole trip

Overall, the study findings suggest that the travel time patterns not only differ between
urban roads and highways, but major differences in travel time characteristics are observed along
the different sections of the same highway as well. Hence, the findings point out to the need for
more research on spatial impacts along the same facility as well as investigation of activity patterns, traffic flow levels, vehicle mix (e.g. truck volume) on travel time variability.

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