PUBLIC BUS TRANSIT TRAVEL TIME VARIABILITY IN ANKARA (TURKEY)*

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ABSTRACT

This study aims to quantify and find out underlying causes of public bus transit travel time variability using data collected in the capital city of Turkey, Ankara. Public transit service in Ankara metropolitan area is mainly based on the bus system operated by both public and private sectors. Bus transit system is generally mixed with other traffic (Right-of-Way C); therefore, it is expected that travel times are subject to high degrees of variability. The system is organized in a hub-and-spoke fashion with the hub at one of the city centers (Ulus or Kizilay) and the spoke in the urban fringe. As regards travel time variability in public transit bus system, three models are developed to account for variation induced by operational regions, trunk roads, and individual lines. Besides, two different sub-models have been developed with respect to dependent variables used: Standard Deviation and Coefficient of Variation of travel times. Three main causes of travel time variability have been identified and tested in this study: temporal dimension, spatial dimension, and service characteristics. Model results indicate that all of these factors affect travel time variability. We generally conclude that uniform organization of the system has to be changed in order to control travel time variability.

Key Words: Travel Time Variability, Public Transit, Ankara Public Bus System

1. INTRODUCTION AND MOTIVATION

While there is already a large body of research on travel-time variability and its use as a policy variable in the domain of private transportation, relatively little has been investigated in terms of public transport, either theoretically or empirically. Indeed, the public transit system's reliability is a vital issue affecting its status as a desired alternative to private transportation. In other words, attracting ridership to public transit is based, inter alia, on its reliability and travel-time variability (Bowman and Turnquist, 1981). Contrary to private (automobile) transport, public (bus) transit has many designated points for passengers to board and alight. Therefore, public transit has a frequent cycle of decelerating, stopping (or idling), accelerating, and moving. Travel-time variability in public transit may be affected by a number of factors, including passenger volume and its distribution along the route, vehicle types and vehicle design, drivers and driving habits, transit administration and operations as well as network design. For example, travel-time variability for public rail transit, which uses exclusive rights of ways, is associated with punctuality in its operations (e.g., Olsson and Haugland, 2004). Conversely, for the public bus-transit system, which commingles with other traffic, changes in traffic conditions, traffic signals, etc., might easily induce variations in travel times—similar to private transport (Strathman and Hopper, 1993).

The nature of transit reliability may be divided into different study areas. One area is the punctuality of service operations at the dispatch unit, which primarily relates to administrative structure, operations in the field, vehicle fleet size, etc. (e.g., Furth and Muller, 2009). An analysis of this area might include physical models of allocating transit vehicles of a certain size to a number of dispatch units. Another study area may focus on the busses' timeliness at the point of departure and of arrival. Although closely related to the punctuality of service operations, a prompt arrival might also be subject to numerous other factors (El-Geneidy et al., 2009). Reliable punctuality may be valued differently with respect to the characteristics of the departure point, arrival point and their spatial separation. Waiting at an unsheltered bus stop, standing in an overcrowded bus, or sitting in an empty bus may be valued differently. Each of these scenarios has a well-established a-priori temporal affinity among users that is associated with the time of day, week, or year.

This study aims to quantify and identify the underlying determinants of public bus transit travel-time variability in the Ankara (Turkey) metropolitan area. In addition, we discuss possible remedies for alleviating travel-time variability. In this study, we draw upon data collected from five one-week periods of public bus transit operations from 2009 to 2010 in the Ankara metropolitan area[1]. Ankara is the capital city of Turkey with a metropolitan population of nearly 4.5 million people. The metropolitan area has an approximate radius of 50 km from its center.

The existing public transport system serving the Ankara metropolitan area is complex and heterogeneous in terms of operators, technologies, vehicles, and routes. Variation in any one of these factors requires a different organizational and administrative structure. The transit service in Ankara primarily relies on an extensive bus and minibus system, along with two metro-rail lines, namely Ankaray and Batikent Metro Rail Lines, and a suburban rail line running east-west[2]. The bus transit system is comprised of public buses operated by the Greater Municipality of Ankara and privately operated buses and minibuses (the number of privately run vehicles has remained stable for nearly 30 years). The entire public transit system is administered by the Public Transit Authority of the Greater Municipality of Ankara (abbreviated as EGO in Turkish). The routes, ticket prices and service levels of the entire transit system are regulated by a central council, the Transportation Coordination Center (abbreviated as UKOME in Turkish), which is headed by the metropolitan mayor.

Both publicly and privately operated transit buses may traverse parallel routes serving the same neighborhoods. Some routes are served only by public or private operators, but passenger volume on these routes tends to be either low or variable depending on the time of day or week. Thus, private operators, as small-business owners, hesitate to work on these routes; instead, they exert constant pressure on the UKOME to assign them to more lucrative routes. The bus transit system generally operates amidst other traffic (i.e., Right of Way C) in Ankara. As a result, it is subject to travel-time variability caused by traffic conditions. In this study, we focus on public bus transit service, which has market dominance in the metropolitan area.

To analyze travel-time variability, we rely on statistical measures of standard deviation

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[1] First Panel: December 14–20, 2009; Second Panel: March 15–21, 2010; Third Panel: July 19-25, 2010; Fourth Panel: October 11-17, 2010; Fifth Panel: December 20-26, 2010.

[2] The suburban rail line ceased its operations temporarily on August 1, 2011, because of new junctions and road construction that cross or run parallel to the railroad.

and coefficient of variation of bus transit travel time. We hypothesize that the travel-time variability of publicly operated bus transit is subject to three sources of variation: the temporal dimension, the spatial dimension, and service characteristics. Three groups of models have been devised for operational regions of public transit, trunk roads and individual transit lines, respectively, in the metropolitan area. Altogether, there are five operational regions that comprise the entire metropolitan area. In addition, three highways have been identified. Two of the highways, Eskisehir Road and Istanbul Road, connect residential areas in the west with the metropolitan center (see Map 1 below). The third, Ataturk Boulevard, crosses the metropolitan area in a north-south direction. The majority of the metropolitan area is served by these highways, where the traffic varies significantly with respect to the time of day and week. Seasonal variation (especially between the school year and the off-school season) is also evident on these highways.

This study is organized into six sections. The second section provides background information for the study. The third section elaborates upon the characteristics of the public transit system in the Ankara metropolitan area. The information derived from the five-week panel data collected over the course of one year is presented in the fourth section. The fifth section describes the model used in this study and its results. General conclusions and policy recommendations for the public bus transit system in the Ankara metropolitan area are presented in the final section.

2. BACKGROUND

Contrary to private transport, public transit imposes additional costs and inconveniences on their riders. Riders must cope with unfamiliar areas, crowds, the weather, walking, waiting, and sometimes transferring (Horowitz, 1981). Moreover, users attach different values to each of these components, thereby subjecting the public transit system to vast heterogeneity among its riders. Apart from total travel time, transit users are quite sensitive to arriving on time, travel-time reliability and variability (Nash and Hille, 1968; Hartgen and Tanner, 1970; Wachs, 1976; Jackson and Jucker, 1982; Taylor, 1982; Bell and Casser, 2000). Travel-time variability in public bus transit is affected by both internal and external factors. Internal factors are associated with features such as the vehicle type, passenger capacity, fare-collection process, and the number of bus stops on the route (Strathman and Hopper, 1993; Hensher, 2007). External factors of public transit travel time variability primarily relate to traffic conditions, characteristics of the service area, the route and the level of passenger demand. Traffic conditions may be associated with recurrent traffic congestion during certain times, such as peak hours, or non-recurrent incidences, such as traffic accidents, road maintenance, etc. (Noland and Polak, 2002).

Strathman and Hopper (1993) report that travel-time variability increases during the afternoon peak, with longer headways and high passenger demand. Bates et al. (2001) have developed a methodology for applying existing models of travel-time variability to scheduled transit services. In this setting, deviations from scheduled departures and arrivals are considered to be sources of disutility because such deviations may cause variations in expected travel times.

In a study conducted in US cities, it was observed that automobile speeds are 1.4 to 1.6 times faster than bus speeds (Levinson, 1983). In the same study, bus travel times and speeds were related to stop frequency, stop duration, and bus acceleration and deceleration times. The elimination of two stops per mile and a 5-second decrease in idling time (from 20 to 15 seconds) was found to produce a 4.30- to 6-minute time saving per mile, which is greater than the time saved by eliminating traffic congestion (Levinson, 1983). Restructuring and reorganizing transit services, especially by reducing the number of bus stops, changing the fare-collection method, and altering the door configurations and widths on high-density routes are important policy elements in reducing bus travel times (Levinson, 1983). By using components of bus travel time such as idling time, travel time, traffic-signal delay time, general traffic delay time, etc., another study found significant time variations in the bus services operating on differently configured routes in different regions of the city (Maloney and Boyle, 1999). According to Abkowitz and Engelstein (1983), travel time is strongly affected by trip distance, the number of passengers, boarding and alighting procedures, and intersections with traffic signals. More importantly, the same study reports that scheduling deviations at early points along the route propagate further deviations downstream. In addition to improved control and corrective actions on transit operations, shorter routes may well improve travel-time variability. Thus, it is also important to account for heterogeneity caused by different routes and the regions served by these routes.

According to Taylor (1982), metro-rail networks, which are generally free from the main causes of travel-time variability, offer more reliable and faster services to transit users than bus networks. Therefore, it is important to develop policies promoting metro-rail lines as the main transit mode that is supported by buses. Nonetheless, as bus transit systems are less costly and more flexible than rail transit in the short run, bus systems may be more appropriate in rapidly growing cities in developing countries. The bus system and its operators enjoy high patronage in developing countries; however, the development is not sustainable because urban traffic congestion is much worse in developing countries, where road length and density is much lower than in developed countries (Cervero, 1998; Gakenheimer, 1999; UITP, 2001; Gwilliam, 2003). Moreover, public transit riders suffer from uncomfortable conditions, and the buses comingle with the general traffic. In comparison, private cars appear to be a faster and more comfortable alternative. Accordingly, the ills of the public bus transit system accelerate automobile use in developing countries (Gakenheimer, 1999).

It is important to maintain current public-transportation services in developing countries while improving the transportation infrastructure and service quality. However, the existing operational status of the bus transit systems does not support this approach. Among the many necessary actions required to improve bus transit services in developing countries, an important task is to reduce bus transit travel-time variability, which negatively affects the reliability of public transit. Therefore, this study's primary aim is to analyze the causes of travel-time variability in the public bus transit systems of rapidly growing, motorized cities, as in Ankara, the capital of Turkey.

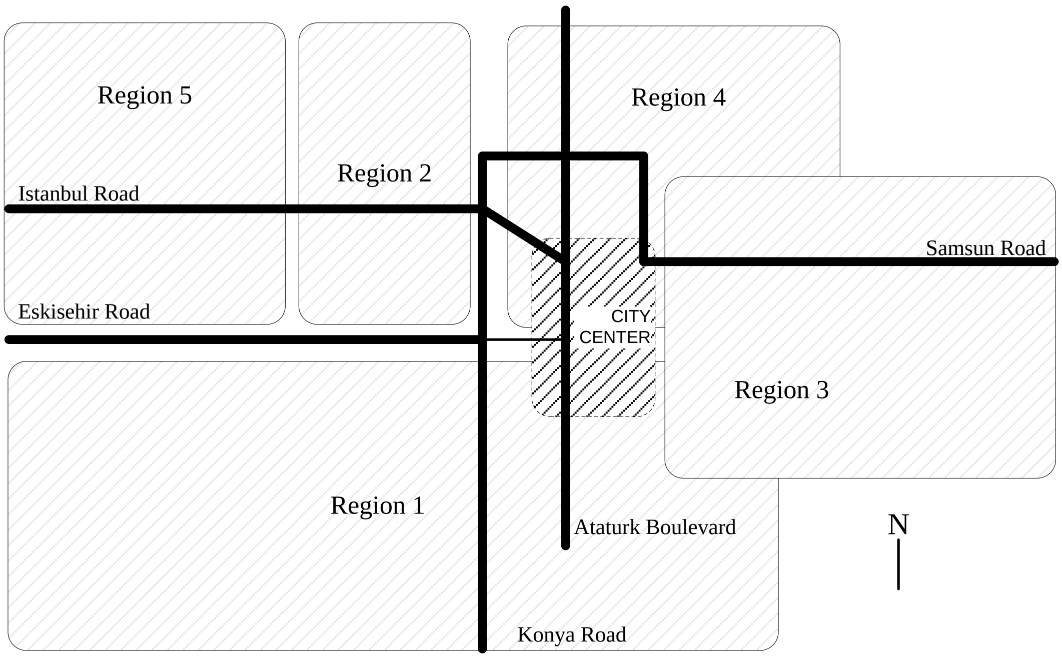
Within Turkey, Ankara is one of the fastest growing cities in terms of private vehicle ownership, which poses an important challenge for the city's public transportation system with its current and expected trends in the future. Although the public transit system represents a majority of motorized trips, 65 %, patronage of public transit is destined to decrease in the face of rapid motorization and urban sprawl. However, automobile transport is more costly than public transport because of high fuel prices[3]. Although the travel costs for public transit are lower than for private transport, public transportation has lost ridership for failing to be reliable and accessible, as the transit lines focus on the city center. Although three additional metro lines are currently under construction, and several other lines are planned for the next phase of rail network expansion, the future of public transit in Ankara is not promising if business continues as usual. In fact, metro rail-line projects had been stalled for approximately ten years because of insufficient public funds in the Greater Municipality's budget. Recently, the legislation regarding

[3] In 2008, Turkey ranked first in retail fuel prices in Europe (http://www.gtz.de/de/dokumente/gtz2009-en-ifp-part-2.pdf, Accessed on February 12, 2012).

roles in urban transportation projects has been modified to enable the central government's involvement in metro rail-line projects. It is expected that these lines under construction will become operational within 5-10 years.

3. PUBLIC TRANSIT SYSTEM IN THE ANKARA METROPOLITAN AREA

The Public Transit Authority of the Greater Municipality of Ankara maintains the public transit bus system in 5 operational regions (Map 1), which together account for the entire metropolitan region and have varying characteristics. The Greater Municipality of Ankara operates the public bus system along with two metro-rail lines. The suburban rail system is operated by the Turkish State Railways. The remainder of the public transit system is operated by small proprietors. Except for the suburban rail system, all of the transit fares are strictly regulated by the municipality. Public bus and metro-rail transit require pre-paid magnetic ticket cards to travel, while the privately operated buses and minibuses accept only cash. The fares for both systems are nearly identical and are fixed on all routes. However, there are some advantages of using multi-ride magnetic cards, such as fare reductions and lower fares for transfers, from which cash-based privately operated transit buses and minibuses are exempt. As the data are collected from magnetic card readers, the scope of this study is limited to the public bus transit service only.



Map 1

In sum, there are nearly 400 public bus transit lines operated in five regions. Nearly all of the buses execute a u-turn to complete their journeys, which end at the point of departure. A bus terminal is where the buses idle, as well as the point of departure and return. While different bus lines follow different paths through the neighborhoods near the bus terminals, their routes often converge outside of their respective neighborhoods, and nearly all of them meet at the metropolitan center. Therefore, the transit system emulates a hub-and-spoke network with the metropolitan center typically serving as the hub and the bus terminals as spokes. Passengers travelling between regions must transfer at the hub, the metropolitan center.

Although the entire metropolitan area is equipped with bus stops for transit access, the proportion of sheltered bus stops is small, and few are equipped with a timetable or route information. However, one can be certain before going to a bus station that an arriving bus travels to the city center. There are no rules governing the location of bus stops. The Transit Authority applies ad hoc criteria for establishing bus stops, taking into account the location and density of residential areas as well as activity centers. Bus stops are typically placed every 300 meters along a route. However, the location of a bus stop or the route of a line is subject to change when a certain number of local residents sign a petition requesting a bus stop or transit service near their homes. Therefore, bus lines and bus stops are often subject to change without any reference to generally accepted principles of transit operations (e.g., Vuchic, 2005). This practice often causes disruptions to bus transit service in terms of speed, comfort, etc. In addition, the unnecessary elongation of bus lines in neighborhoods inevitably increases the travel times of public bus transit.

The hub-and-spoke type of network exhibits limited flexibility and sensitivity to variations in demand in both time and space. All public transit lines connect the residential areas of the metropolitan area with the city center. Therefore, one must change buses in the city center to reach another destination. Transfers in the city center entail a 5-10 minute walk as well as additional monetary costs and wait times. If reaching a destination requires transfers, one may prefer to utilize privately run minibuses that stop for passengers to board or alight at any point on their routes, thereby decreasing walking times. Some of the main public-transportation routes are thus privately operated and include no fare reduction.

4. DATA

The data set used in this study was collected by the Public Transit Authority (EGO) of the Greater Municipality of Ankara in five one-week panels: December 14-20, 2009 (the first panel), March 15-21, 2010 (the second panel), July 19-25, 2010 (the third panel), October 11-17, 2010 (the fourth panel), and December 20-26, 2010 (the fifth panel). Each line in the data set contains information regarding the bus line number, the bus identity, the driver's identity (not associated with a single person), the departure/return times to the bus terminal, along with the number of passengers carried.

A trip begins with the insertion of the driver's card into the reader machine at the bus terminal; it ends with the card's insertion upon returning to the same terminal. The times of departure and return are recorded by the reader machine when the driver's card is inserted at the start and end of the trip. Passengers are counted by the reader machines, as each passenger inserts a magnetic card into the machine when boarding the bus (note that free passengers—police officers, postal-delivery staff, etc.—and senior card holders do not use a magnetic card; thus, they are exempt from the tally). However, we expect similar numbers of these unaccounted for passengers on all of the bus lines.

For the first panel, there were 369 public bus transit lines, while the total number of lines for the second, third, fourth and the fifth panel were 370, 350, 385 and 388, respectively. The service frequencies by day of the week are shown in Figure 1. Service frequency is at its lowest during the summer season, which is primarily due to the school holiday season.

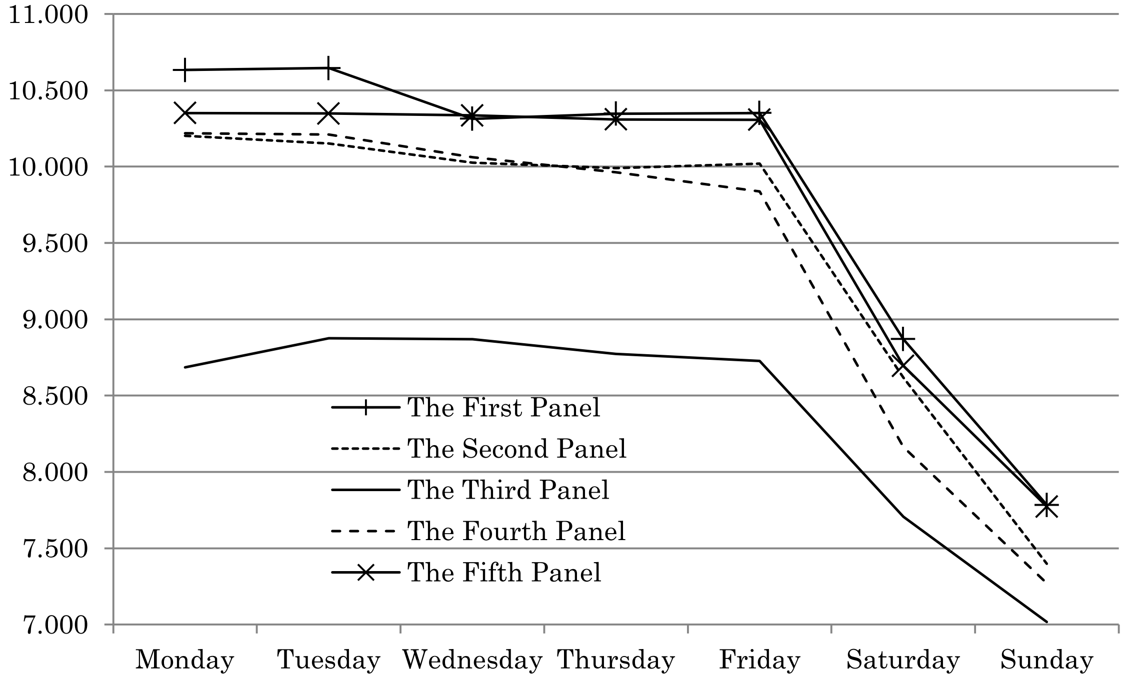


Figure 1 Service frequencies by time of week.

The average number of passengers per bus and the total number of passengers carried per day of the week for each panel are displayed in Table 1. If we assume that an average bus has a capacity of 80 persons, for all panels except for the third, the bus load is at approximately 80 % capacity during the weekdays; weekends reveal a consistency of approximately 60 % of capacity for the first, fourth and fifth panels. When the total numbers of passengers carried are compared for each panel, a consistent decrease in the total passenger number is observed. This decrease implies that metropolitan residents' preferred transportation mode is changing: they prefer to commute using their own (likely newly purchased) cars or switch to privately operated buses or minibuses, which run more frequently and flexibly. As expected, passenger demand is at its lowest in the summer season (except for Sunday in the second panel). Other sources of variation may include activities that occur in diverse locations around the city, seasonal cycles and changes in consumer preferences regarding modes of transportation.

Table 1. Average number of passengers per bus and total number of passengers carried

Time of Week	First Panel		Second Panel		Third Panel		Fourth Panel		Fifth Panel	
	1	2	1	2	1	2	1	2	1	2
Monday	62.23	661,687	60.55	617,816	53.67	466,097	60.79	621,213	61.87	640,436
Tuesday	64.51	665,371	62.23	624,021	52.20	463,024	59.68	600,426	62.57	646,728
Wednesday	63.06	671,310	61.58	625,119	52.80	468,622	60.40	616,653	62.75	649,289
Thursday	65.00	672,509	60.86	608,036	52.75	462,810	59.95	597,348	62.50	644,310
Friday	64.38	666,411	60.56	606,787	51.96	453,420	61.85	608,509	62.86	647,856
Saturday	59.44	527,202	41.31	356,056	47.90	369,173	56.02	457,321	57.82	502,707
Sunday	46.40	361,163	21.24	157,170	36.85	258,640	45.90	333,661	46.00	357,580

1: Average number of passengers per bus
2: Total number of passengers carried

Table 2 displays the distribution of average travel times according to day of the week. The average round-trip travel time is 73 to 85 minutes. The summer season (i.e., the third panel) and Sundays are associated with the shortest travel times (the average travel time is 73 minutes on Sundays in the summer) due to low traffic levels in the summer and on Sundays. During the summer season, many individuals travel outside of Ankara, and the remaining residents spend Sundays at home, in nearby locations or in non-central areas.

Table 2. Distribution of average travel times by time of week

Time of Week	The First Panel		The Second Panel		The Third Panel		The Fourth Panel		The Fifth Panel	
	1	2	1	2	1	2	1	2	1	2
Monday	80.66	35.42	81.78	36.76	78.86	34.71	83.20	38.12	82.92	37.89
Tuesday	81.47	36.54	80.53	35.53	78.12	34.19	82.73	37.18	83.30	38.66
Wednesday	85.13	39.08	81.33	36.17	78.21	34.08	83.41	37.33	82.66	38.54
Thursday	84.27	37.85	80.72	35.98	78.08	34.27	84.12	38.29	82.64	38.74
Friday	82.88	37.68	81.86	36.50	78.12	34.49	86.45	41.22	83.38	39.23
Saturday	81.07	34.31	79.78	33.87	77.47	33.79	84.29	40.18	80.98	37.73
Sunday	75.16	32.05	74.61	32.22	73.67	31.72	76.74	33.60	75.68	35.47

1: Average travel time
2: Standard devition of travel time

As displayed in Figure 2, the temporal distribution of travel times points to a two-peaked diurnal distribution. The earlier peak, which falls between 7:00 AM and 9:00 AM, is sharper, while the later peak covers nearly the entire afternoon and evening and is higher. All panels have a decreasing trend in terms of travel times after evening hours. Although one can detect seasonal differences in both average travel times and their standard deviations, they generally follow similar trends throughout the day.

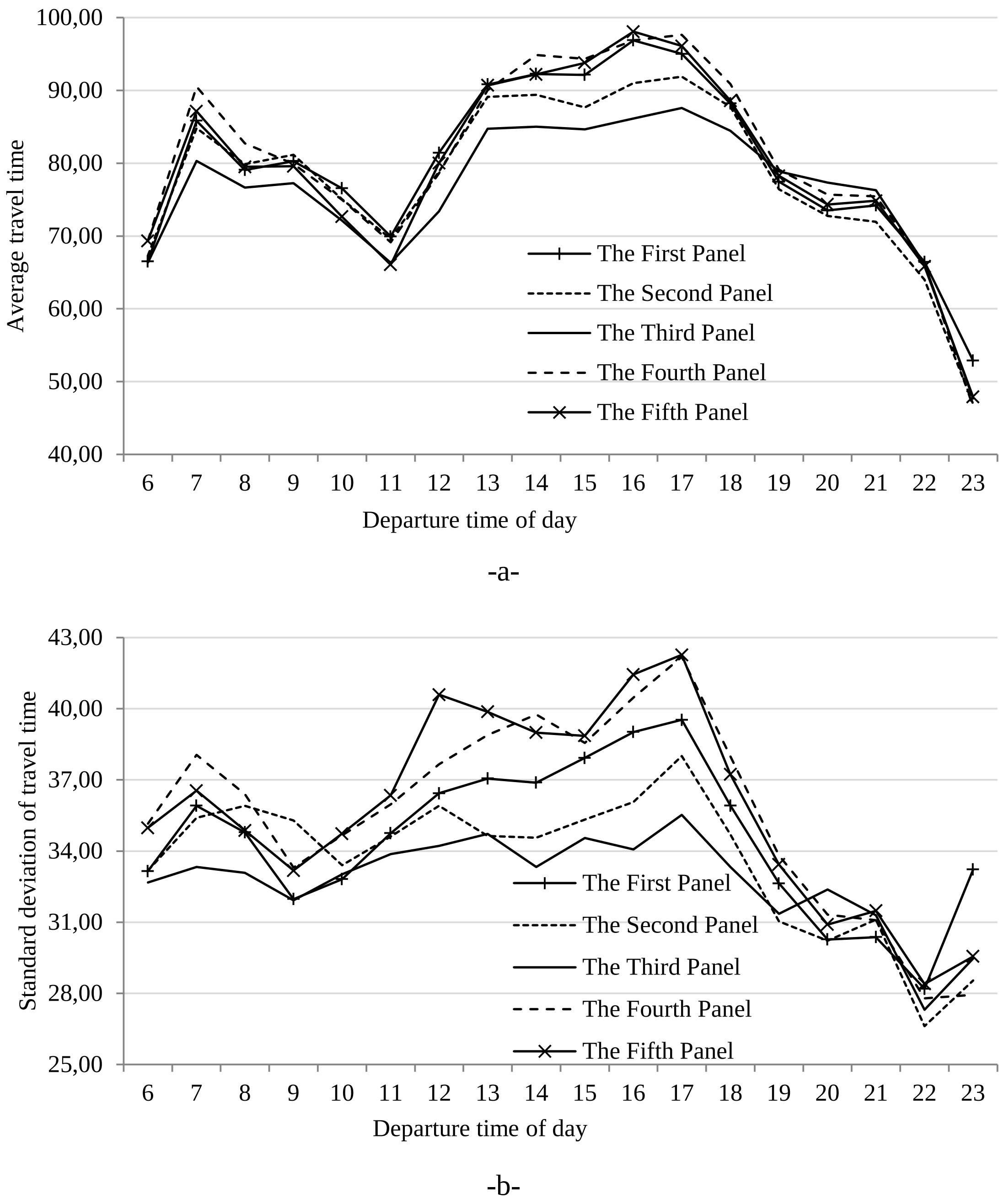


Figure 2 Distribution of travel times by time of day.

As noted above, the bus transit system in the metropolitan area is organized within five operational regions. Trips between a region and the city center normally produce travel times in accordance with the distance of that region from the city center. For example, Region 5 is the remotest region from the city center (see Map 1 above) and therefore has the highest travel time, ranging from 106 to 113 minutes. In terms of travel-time variability, two measures used in this study are associated with the statistical measures of standard deviation and the coefficient of variation. While standard deviation measures the deviance of travel times from the average travel time, the coefficient of variation divides standard deviation by the average travel time (the computation of these measures is given below).

We detect different levels of travel-time variation in different regions, which might be due to geographical, road-network features and the number of bus stops in these regions. Generally, Region 1 and Region 3 reveal the highest and lowest levels of travel time variability, respectively. Region 1 is elongated along the east-west axis, with the north-eastern part close to the city center. Therefore, it is probable that the travel times of bus lines serving the western area are significantly longer than the travel times of those serving the eastern past. This geographic variation may produce additional variation in travel times. Among all regions, Region 3 is the closest to the city center and thereby exhibits the lowest levels of travel time variability. When we change the statistical measure from standard deviation to the coefficient of variation, the ranking changes at the high end. The highest degree of travel time variability is found in Region 2, which has a shorter travel time. This difference is primarily due to a low level of variation among the standard deviation of travel times across regions.

5. MODEL DEVELOPMENT AND ESTIMATION

In this section, we disentangle the sources of travel-time variation of the bus transit system in Ankara. Three main sources of variation are accounted for in the models. The first source of variation is expected to lie in the temporal dimension. Time of day and time of week are two of the temporal variables present in the data set. Data analysis reveals that both of the variables cause variations in travel times. In the longer term, there is also seasonal variation, the most significant of which occurs during the school season. From September until June, with a short winter holiday in February, the school year is one of the main causes of traffic congestion in Ankara, as there are too many inter-zonal school trips along with commute trips within a similar window. Return trips from work or school create congestion in the opposite direction as well. All panels except the third fall in the school season; therefore, we expect significant differences in variation between the third panel and the others.

The second source of variation is expected to lie in the spatial dimension, as the public bus transit system is operated in five different regions with unique physical characteristics. Almost all of the bus lines connect the neighborhoods in operational regions with the city center; out of its local neighborhood area, a bus line shares the same route (usually a highway) with other lines of the same region or neighboring regions. Therefore, differences in travel-time variability might also be affected by a highway that serves a region. The existence of a highway might increase the operational speed, which in turn might compensate for delays caused by passenger boardings in the local neighborhood. There are significant differences in the lengths of the regional highways, a fact that may cause variation in travel times with respect to operational regions.

The third source of variation analyzed in the models is service characteristics. The number of bus stops on a line and the types of bus are expected to be the two significant sources of travel-time variation caused by service characteristics. The number of bus stops, especially in the populous neighborhoods, may result in variation due to the time devoted to passenger boarding and alighting at each stop. Regarding the latter, bus types are generally differentiated according to age. Although the vehicle fleet is relatively new and is composed of similar types of vehicles, vehicle age is expected to cause variations in travel time.

This study utilizes three groups of models to investigate the sources of travel-time variation. Each group includes two individual models with different dependent variables, i.e., statistical measures of standard deviation and the coefficient of variation of travel times. For each group of models, dependent variables have been computed by using average travel times according to the time of day, time of week and time of year with respect to five operational regions (*Model 1*), three main highways (*Model 2*) and individuals bus lines (*Model 3*).

The average travel time according to time of day, d, time of week, w, and time of year, y, is denoted by ${}^{dwy}t_a$. The standard deviation, sd_{dwy}, of bus transit travel times is computed as the square root of the average of the total squared deviations of travel times, ${}^{dwy}t$, from their respective averages, ${}^{dwy}t_a$, i.e., $sd_{dwy} = [(1/N)\times\sum^N({}^{dwy}t - {}^{dwy}t_a)^2]^{1/2}$, where N is the number of bus dispatches during a time of day, and the time of day represents one-hour intervals between 06:00 and 24:00. The coefficient of variation, cv_{dwy}, is calculated by dividing the standard deviation of bus transit travel times, sd_{dwy}, by the average travel time, ${}^{dwy}t_a$, i.e., $cv_{dwy} = sd_{dwy}/\,{}^{dwy}t_a$. Two of the statistical measures used in the models bear different meanings: whereas the standard deviation provides a measure of dispersion around average travel times, the coefficient of variation is a normalized measure of travel-time variation with respect to average travel times.

The first group of models (*Model 1*) has been designed to reveal variation in each region using aggregated variables for each region. The second group (*Model 2*) focuses on three of the highways along with surface streets using aggregated variables for each highway. Running in an east-west direction, Eskisehir and Istanbul Roads connect vast residential areas in the west with the metropolitan center (see Map 1 above). The final highway, Ataturk Boulevard, combines the northern and southern parts of the metropolitan area while crossing the metropolitan center; therefore, it is congested throughout the day. The last group of models (*Model 3*) focuses on the individual bus lines to determine differences that are not considered in the previous model groups.

Table 3 presents the descriptive statistics of the continuous variables used in the models. The first two models differ from *Model 3* in terms of dependent-variable calculation. In *Model 3*, the standard deviation and the coefficient of variation of travel times have been calculated using the whole day to compute travel-time variability measures. In addition, we have trimmed the data for *Model 3* by eliminating the lines that have service frequencies below 10 (36 % of the sample is excluded, leaving us with a data set of 7,424 cases). For all of the models except for *Model 3*, we have included temporal variables that account for hourly changes in travel-time variability.

Table 3. Model variables

Model 1: Region based model *Number of Cases: 3150*	Min	Max	Average	Std. Dev.
Time of Day Standard Deviation	8.81	60.31	28.74	6.66
Time of Day Coefficient of Variation	0.17	0.69	0.38	0.12
Ratio of New Busses in The Fleet	0.45	1.00	0.81	0.14
Average Number of Bus Stops per Line	27.17	107.20	65.70	19.77
Average Number of Passengers	0.00	112.61	53.42	23.31
Model 2: Route based model *Number of Cases: 2481*	Min	Max	Average	Std. Dev.
Time of Day Standard Deviation	5.18	61.34	23.21	9.57
Time of Day Coefficient of Variation	0.04	0.87	0.26	0.15
Ratio of New Busses in The Fleet	0.41	1.00	0.87	0.12
Average Number of Bus Stops per Line	41.98	111.10	83.14	22.34
Average Number of Passengers	1.07	255.20	68.15	34.73
Model 3: Line based model *Number of Cases: 7424*	Min	Max	Average	Std. Dev.

Within Day Standard Deviation	5.01	60.69	19.58	8.81
Within Day Coefficient of Variation	0.05	1.44	0.24	0.10
Ratio of New Busses in The Fleet	0	1.00	0.77	0.28
Average Number of Bus Stops per Line	4.00	144.00	64.62	29.70
Average Number of Passengers	0	173.80	57.94	25.31
Number of Daily Service Frequencies	10	152	39.40	22.33

Models have been estimated using generalized linear model routines of PASW Statistics R18 using the maximum likelihood estimation method. We have analyzed the model estimation results with respect to temporal and spatial dimensions followed by service characteristics, as displayed in Table 4.

Temporal Dimension

All of the models reveal significant variation with respect to time of year. Moreover, travel-time variation increased over the course of one year. As the bus transit system does not have exclusive rights of way, it can be concluded that traffic conditions worsened in one year from 2009 to 2010. This finding also implies the positive effects of motorization, urban sprawl, and inadequate transportation infrastructure on travel-time variability. Among the days of the week, Wednesday generally exhibits the highest source of variation across all models. Wednesday marks the weekly peak in terms of passenger demand; therefore, the additional number of passengers may increase the total passenger boarding and alighting time, which in turn increases the variation in travel times. During boarding, each passenger must insert a magnetic card into the card reader that subtracts one fare and prints the relevant information on the back of the card (a picture of the machine is provided in Picture 1). This process takes 5-15 seconds per person (233 measurements carried out by the authors of this study show that 95 % fall in this range).

Picture 1. The magnetic card machine installed in public transit buses.

Hourly variation is significant for nearly all of the hours included in the standard-deviation based *Model 1*. According to this model, the greatest variation occurs during the evening peak hour between 17:00 and 17:59 hours. However, in Model 1, which is based on the coefficient of variation, travel-time variation is increased during mid-day hours (Figure 3). According to Figure 3 above, one may conclude that longer travel times in the morning and afternoon are more reliable than shorter travel times during other times. Recurrent traffic congestion has been consistently observed during peak hours, as there is constant passenger demand in the peak hours. However, off-peak hours are subject to greater changes in passenger demand, a fact that is primarily due to the passengers who do not use magnetic cards, such as public servants or senior citizens, and non-recurrent congestion caused by traffic accidents, road maintenance, etc. As most of the trips include the city center in their routes, the effects of traffic and unexpected events are more evident during mid-day hours.

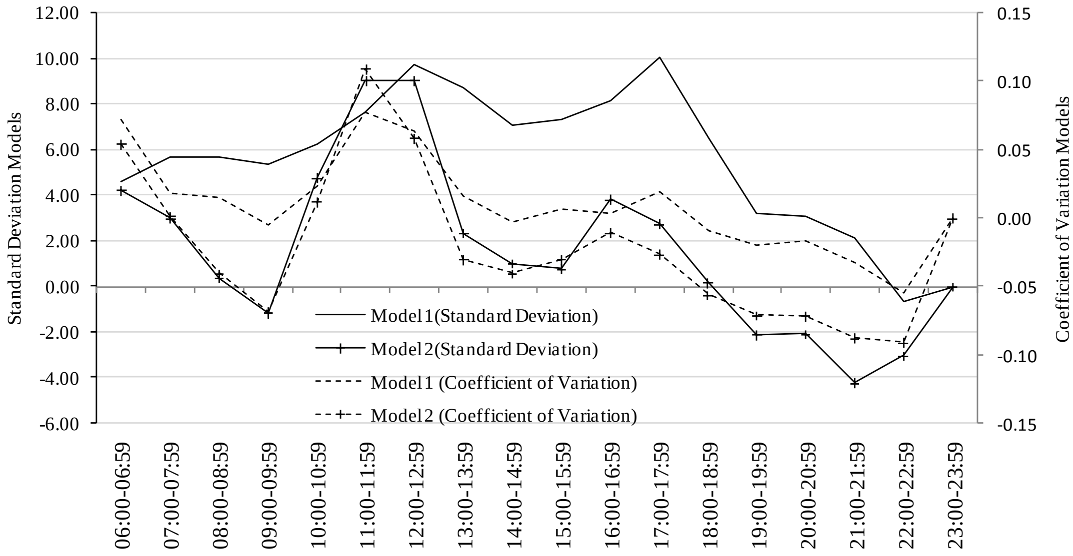


Figure 3. Time of Day coefficient estimates for *Model 1* and *Model 2*.

Spatial Dimension

Aggregation at each respective region, i.e., *Model 1*, points to Region 3 as the most reliable region and Region 1 as the least reliable region in both the standard-deviation and coefficient-of-variation models. Considering the characteristics of these regions, the results are not surprising. While Region 3 is close to the city center, has the smallest area, shortest total road length and highest road density, Region 1 has the largest area, longest road length but one of the lowest road densities among all operational regions. Moreover, Region 1 is modest and heterogeneous in terms of land use and covers part of the city center where government offices and universities are located. Upper- and middle-income Ankara residents generally live in Region 1. Therefore, higher car-ownership levels along with worse traffic conditions are expected in Region 1. There are also differences between the urban patterns of the regions that affect the travel-time variability in bus operations. The suburban districts of Regions 1 and 5, recently developed, have modern but scattered residential areas; hence, bus lines generally transverse of the streets. Conversely, Regions 2, 3 and 4 include traditional homes and informal (i.e., squatter) houses, along with residential areas with narrow and steep streets that limit the bus operations to the main streets. These characteristics of the operational regions affect travel-time variability in these regions.

Table 4. Model Estimation Results

Independent Variables	*Model 1: Region Based Model*				*Model 2: Route Based Model*				*Model 3: Line Based Model*			
	Standard Dev. Model		Coeff. of Var. Model		Standard Dev. Model		Coeff. of Var. Model		Standard Dev. Model		Coeff. of Var. Model	
	Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.
Constant	33.47	0.00	0.38	0.00	44.59	0.00	0.87	0.00	-4.26	0.00	0.15	0.00
Time of Year: December, 2009	-2.29	0.00	-0.02	0.00	-2.75	0.01	-0.04	0.00	-1.68	0.01	-0.02	0.00
Time of Year: March, 2010	-0.94	0.11	-0.04	0.00	-3.17	0.00	-0.05	0.00	0.15	0.83	-0.04	0.00
Time of Year: June, 2010	-1.67	0.00	-0.02	0.00	-2.86	0.01	-0.04	0.00	-2.44	0.00	-0.04	0.00
Time of Year: October, 2010	-1.37	0.01	-0.02	0.00	-0.48	0.65	-0.01	0.53	-0.52	0.46	-0.02	0.07
Time of Year: December, 2010	0.00	.	0.00	.	0.00	.	0.00	.	0.00	.	0.00	.
Eskisehir Road					-3.89	0.27	-0.01	0.80	1.52	0.00	0.01	0.05
Istanbul Road					-11.82	0.00	-0.10	0.02	-1.32	0.01	-0.02	0.00
Ataturk Boulevard					-5.26	0.00	-0.02	0.06	1.56	0.07	0.02	0.04
Other surface streets (Normalized to Zero)					0.00	.	0.00	.	0.00	.	0.00	.
Region 1	0.55	0.56	0.13	0.00					11.26	0.00	0.12	0.00
Region 2	-0.55	0.68	0.27	0.00					8.18	0.00	0.10	0.00
Region 3	-10.61	0.00	-0.01	0.42					8.14	0.00	0.08	0.00
Region 4	-1.26	0.10	0.13	0.00					13.03	0.00	0.17	0.00
Region 5 (Normalized to Zero)	0.00	.	0.00	.					0.00	.	0.00	.
Time of Week: Monday	0.63	0.27	0.00	0.92	2.79	0.01	0.02	0.05	2.44	0.00	0.02	0.06
Time of Week: Tuesday	1.45	0.01	0.01	0.14	3.38	0.00	0.03	0.02	2.83	0.00	0.02	0.02
Time of Week: Wednesday	1.52	0.01	0.01	0.07	3.55	0.00	0.04	0.00	3.19	0.00	0.03	0.00
Time of Week: Thursday	1.78	0.00	0.02	0.01	2.99	0.01	0.03	0.01	2.47	0.00	0.02	0.05
Time of Week: Friday	1.81	0.00	0.01	0.06	2.35	0.03	0.02	0.07	2.93	0.00	0.02	0.01
Time of Week: Saturday	0.81	0.15	0.00	0.68	1.12	0.28	0.01	0.27	1.68	0.01	0.01	0.07
Time of Week: Sunday (Normalized to Zero)	0.00	.	0.00	.	0.00	.	0.00	.	0.00	.	0.00	.
Time of Day: 0600-0659	4.58	0.00	0.07	0.00	4.23	0.00	0.05	0.00				
Time of Day: 0700-0759	5.66	0.00	0.02	0.03	3.00	0.01	0.00	0.90				
Time of Day: 0800-0859	5.69	0.00	0.01	0.04	0.38	0.72	-0.04	0.00				
Time of Day: 0900-0959	5.34	0.00	0.00	0.44	-1.17	0.24	-0.07	0.00				
Time of Day: 1000-1059	6.23	0.00	0.02	0.00	4.79	0.00	0.01	0.27				
Time of Day: 1100-1159	7.62	0.00	0.08	0.00	9.06	0.00	0.11	0.00				
Time of Day: 1200-1259	9.76	0.00	0.06	0.00	9.06	0.00	0.06	0.00				
Time of Day: 1300-1359	8.71	0.00	0.02	0.03	2.35	0.03	-0.03	0.01				
Time of Day: 1400-1459	7.08	0.00	0.00	0.71	1.02	0.36	-0.04	0.00				
Time of Day: 1500-1559	7.31	0.00	0.01	0.42	0.78	0.51	-0.03	0.03				
Time of Day: 1600-1659	8.14	0.00	0.00	0.63	3.83	0.00	-0.01	0.43				
Time of Day: 1700-1759	10.04	0.00	0.02	0.01	2.75	0.02	-0.03	0.05				
Time of Day: 1800-1859	6.52	0.00	-0.01	0.20	0.17	0.88	-0.06	0.00				
Time of Day: 1900-1959	3.22	0.00	-0.02	0.00	-2.11	0.04	-0.07	0.00				
Time of Day: 2000-2059	3.09	0.00	-0.02	0.01	-2.09	0.03	-0.07	0.00				
Time of Day: 2100-2159	2.13	0.00	-0.03	0.00	-4.23	0.00	-0.09	0.00				
Time of Day: 2200-2259	-0.65	0.14	-0.05	0.00	-3.05	0.00	-0.09	0.00				
Time of Day: 2300-2359 (Normalized to Zero)	0.00	.	0.00	.	0.00	.	0.00	.				
Ratio of New Busses in The Fleet	-6.60	0.00	-0.06	0.00	-9.83	0.00	-0.11	0.00	1.59	0.00	-0.01	0.03
Average Number of Bus Stops per Line	-0.07	0.00	0.00	0.34	-0.08	0.27	0.00	0.00	0.14	0.00	0.00	0.01
Average Number of Passengers	0.04	0.00	0.00	0.00	-0.05	0.00	0.00	0.00	0.06	0.00	0.00	0.00
Number of Daily Service Frequencies									0.00	0.60	0.00	0.00
Scale Parameter	14.19		0.00		38.42		0.00		43.92		0.01	
d.f.	58		58		57		57		45		45	
Likelihood Ratio Chi-Square	3584.93		6050.53		2156.94		3844.78		4174.21		2567.57	

Highway-based models include the bus lines on one of the three highways. According to the model results, we have found that the most reliable highway is Istanbul Road. It is also the fastest road in the Ankara metropolitan area, according to our inquiries at the Public Transit Authority. Istanbul Road, which crosses Region 5 and 2 in an east-west direction, has fewer bottlenecks than Eskisehir Road, which crosses Region 1 in an east-west direction. Region 1 was found to be the least reliable region in *Model 1*. Therefore, the results of the model establishing Eskisehir Road as the least reliable road are as expected. One of the reasons for this finding lies in the characteristics of Eskisehir Road and the areas it serves. Most of the public offices and major universities, as well as newly established central business districts, are in the areas served by Eskisehir Road.

The final group of models, bus-line based models, analyzes the differences on each line throughout the day. According to the estimation results, the most reliable lines are found on Istanbul Road, which has fewer intersections. Notably, there are different results in parameter values between the region-based and line-based models. As the focus switches to individual lines in the line-based model, regional variances appear to be nullified by daily line-based operations. The line-based models do not take hourly variation during the day into account; nonetheless, all of the hourly variations might be captured by the regional variations.

Service Characteristics

Among service characteristics, the ratio of new buses in the fleet is the most effective variable in decreasing travel-time variability in both *Model 1* and *Model 2*. The reason for this finding likely lies in the technical characteristics of the new vehicles. First, these vehicles are installed with automatic gears, which prevent possible time losses in acceleration and deceleration. Second, these vehicles are more reliable and easily maneuverable on surface streets, where older vehicles without anti-lock breaking systems are unable to maintain a constant speed.

In terms of service characteristics, another anticipated result pertains to the number of bus stops in the line-based model. As the number of bus stops per line increases, travel time variability tends to increase, a finding that supports previous studies of travel-time variability. Furthermore, the estimation results regarding the relationship between the number of passengers and travel-time variability are not surprising: as the number of passengers increases, travel-time variability increases. The fastest time periods during the day are generally off-peak hours in the early morning, late evening and at night, when there are fewer passengers. Other times typically experience 70 to 110 % of total bus capacity.

Picture 2 Transit bus used by EGO with alias 07-141 which signifies the vehicle is in the fleet in 2007 for Region 1.

6. CONCLUSIONS

Three variations of travel-time variability prevalent in the Ankara metropolitan area have been investigated in this study: spatial (i.e., operational region), route (i.e., highway), and bus-line based travel-time variability. Spatial travel-time variability is computed by aggregating variables of interest over five operational regions in Ankara. Similar aggregations have been carried out separately for route and line-based models. Each operational region differs in various respects, including street length, existence of highways, a suburban or inner-city character, and the distribution of activity centers. This heterogeneity results in travel-time variability particular to each region. Highway-based models are expected to capture differences in travel-time variability among buses operating on three different highways and surface streets. Line-based models reveal individual differences between individual bus lines.

As expected, we have identified significant regional differences in Ankara, a city typical of developing countries characterized by a dual nature. In urban sectors of developing countries, traditional and modern areas are located side-by-side. In general, modern areas are more apt to be located on the urban fringe, as modern residential areas can easily be established in these expanding areas. As modern areas are associated with topographical advantages and networks of broad streets, bus lines tend to be longer in these areas. Especially in the westernmost portions of Ankara, Regions 1 and 5 include modern residential areas that feature wide streets. Bus lines tend more to cover all of the residential districts that have wide streets, whereas this level of service is not observed in more traditional regions, i.e., Regions 2, 3 and 4. This finding suggests policies that re-organize bus operations with respect to regional differences in an urban area. Because the densities of traditional regions are higher than the densities of the modernized regions, bus-stop spacing standards should be established according to the neighborhood density. The implementation of such an approach in the Portland, Oregon, metropolitan area has demonstrated that bus-stop consolidation improves bus transit times (El-Geneidy et al., 2006).

Highway-based travel-time variability has narrowed our focus to four different routes with different characteristics. Two of these, Eskisehir Road and Istanbul Road, connect the modern residential areas in the west with the metropolitan core. The two roads differ with respect to various characteristics, including the right of way (Eskisehir Road has quasi-transit lanes in some sections), speed (Istanbul Road is generally faster than Eskisehir Road), signaled intersections (Istanbul Road has more signaled intersections), and bottlenecks (Eskisehir Road has more bottlenecks than Istanbul Road). Ataturk Boulevard is the main highway that connects the northern and southern parts of the metropolitan area, traversing the city center (see Map 1 above). All of the lines on these highways perform better than those on the surface streets. El-Geneidy et al. (2009) also lend support to bus-only shoulder policies, bus-stop consolidation, serving major streets with fewer stop signs and the implementation of smart transit signals. Highway-based models call for lane privileges and signal priorities in the inner city to improve the travel-time variability of bus transit services. Moreover, by reducing the number of bus stops on some of the transit lines, the transit time along Eskisehir and Istanbul Roads may decrease travel delays caused by unnecessary stops. All transit lines on the east-west corridors, which connect different suburban neighborhoods to the city center, coincide on Eskisehir or Istanbul Roads. However, because they have bus stops at different locations along these roads, bus-stop consolidation may improve the performance of public-transit services on these roads.

Bus-line based models further narrow the models to individual lines. The variable results obtained through these models indicate heterogeneity among the bus lines. Regions with high travel-time variability in particular point to the existence of bottlenecks and the inadequacy of the street layout for individual lines. Notably, the regions with high travel-time variability are either traditional or informal neighborhoods, where the transportation network requires significant improvements.

In fact, the current bus transit operating system provides the entire metropolitan area with identical transit service without regard to variation induced by regional, temporal or line-based characteristics. A high degree of heterogeneity reported in the models calls for a more flexible organization of transit services. The model results suggest different policy implications. For example, highways may be used to pool all of the passengers traveling to the city center. Passengers might be transferred to high-capacity buses at certain points where most of the bus lines converge. This tactic may be helpful in alleviating regional variations in bus-line operations and increasing speed and reliability on the highways. Moreover, this change would significantly shorten the bus lines and restrict them to surface streets in the neighborhoods where bus terminals are established. Regions 1 and 5 are well-suited to this type of structural and operational change.

The results of line-based models also support the idea that the existing point-to-point bus-line operations must be changed, as there is significant variation among the regions that are connected to the city center using the same type of vehicle. The establishment of transit-only lanes may also alleviate travel time variability in certain respects. Reserved lanes in the city center at noon and during the evening hours would increase travel-time variability.

This study has produced valuable results regarding the macro-organization of the bus transit system: that is, reorganizing the transit system based on the characteristics of operational regions, highways, time of day and time of week will produce significant gains in transit reliability. Further research calls for a close monitoring of a sample of transit-vehicle operations based on the bus design, distribution of passengers on the route, driver behavior as well as detailed land-use and route characteristics.

7. REFERENCES

Abkowitz, M. D. and Engelstein, I., 1983. Factors affecting running time on transit routes. Transportation Research A, 17, pp. 107-113.

Bates, A., Polak, J., Jones, P., Cook, A., 2001. The valuation of reliability for personal travel. Transportation Research E, 37, pp. 191–227.

Bell, M. G. H. and Cassir, C., eds., 2000. Reliability of transport networks. Research Studies, Baldock, Herts.

Bowman, L.A. and Turnquist, M. A., 1981. Service frequency, schedule reliability and passenger wait times at transit stops. Transportation Research-A, 15(6), pp. 465–471.

Cervero, R., 1998. The Transit Metropolis: A Global Inquiry. Island Press, Washington D.C.

El-Geneidy, A. M., Strathman, J. G., Thomas J. K. and Crout D. T., 2006. Effects of Bus Stop Consolidation on passenger Activity and Transit Operations. Journal of the Transportation Research Record, No. 1971, pp. 32–41.

El-Geneidy, A. M., Hourdos, J. and Horning, J., 2009. Bus Transit Service Planning and Operations in a Competitive Environment. Journal of Public Transportation, 12-(3), pp. 39–59.

Furth, P. G., Muller, T. H. J., 2009. Optimality conditions for public transport with time-point holding. Public Transport, 1, pp. 87-102.

Gakenheimer, R., 1999. Urban mobility in the developing world. Transportation Research A, 33, pp. 671–689.

Gwilliam, K., 2003. Urban transport in developing countries. Transport Reviews, 23, pp. 197–216.

Hartgen, D. T. and Tanner G. H., 1970. Individual attitudes and family activities: a behavioral model of modal choice. High Speed Ground Transportation Journal, 4, pp. 439–467.

Hensher, D., 2007. Bus transport: Economics, policy and planning. Research in Transport Economics, 18, pp. 1–507.

Horowitz, A. J., 1981. Subjective Value of Time in Bus Transit Travel. Transportation, 10, pp. 149-164.

Jackson, W. B. and Jucker, J. W., 1982. An Empirical Study of Travel Time Variability and Travel Choice Behavior. Transportation Science, 16, pp. 460–475.

International Union of Public Transport (UITP), 2001. Millennium Cities Database for Sustainable Mobility. CD-ROM.

Levinson, D., 1983. Analyzing Transit Travel Time Performance. Transportation Research Record, 915, pp. 1–6.

Maloney, M. and Boyle, D., 1999. Components of Travel Time on the Glendale Beeline Bus Network. Transportation Research Record, 1666, pp. 23-27.

Nash, Allan N. and Hille, J. S., 1968. Public attitudes toward transport modes: a summary of two pilot studies. Highway Research Record, 233, pp 33–46.

Noland, R. B. and Polak, J. W., 2002. Travel time variability: A review of theoretical and empirical issues. Transport Reviews, 22, pp. 39–54.

Olsson, N. O. E. and Haugland, H., 2004. Influencing factors on train punctuality—results from some Norwegian studies. Transport Policy, 11, pp. 387–397.

Polak, J.W., 1987. Travel time variability and departure time choice. Discussion Paper 15, Transport Studies Group, University of Westminster.

Strathman, J.G. and Hopper, J.R., 1993. Empirical analysis of bus transit on-time performance. Transportation Research A, 27(2), pp. 93–100

Taylor, M. A. P., 1982. Travel time variability—the case of two public modes. Transportation Science, 16, pp. 507–521.

Vuchic, V., 2005. Urban Transit: Operations, Planning, and Economics. John Wiley and Sons, New Jersey.

Wachs, M., 1976. Consumer Attitudes Toward Transit Service: An Interpretive Review. Journal of American Institute of Planners, 42, pp. 96–104.