Identification of Temporal Variations in Speed Patterns for Urban Arterials Using Floating Car Data (FCD)

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Abstract

In addition to many data collection methods have been widely used such as; magnetic loops, pneumatic road tube counters, radars, to estimate the speed and the traffic states of a corridor, Floating Car Data (FCD) has become a major data collection method, additionally. FCD is collected from a set of vehicles equipped with GPS that provide speed and/or travel time data in a corridor. Collecting FCD for a long term enable us to examine the speed patterns of highway corridor which is the focus of this study. For a case study, speed profiles for a 4.5 km segment of Dumlupınar Boulevard are studied. The study corridor is a major arterial in the form of a multilane urban highway corridor (4 lanes in each direction) in Ankara and covers the segment from Hacettepe University interchange to Middle East Technical University entrance. FCD data provided real-time average speed archived at every 5 minute for each segment (at most 50-m length) during July-August and November, 2015. This large data is analyzed to identify localities in speed patterns, such as speed change due to network topology, temporal/seasonal variations, etc.

Keywords: *Floating Car Data; Speed Estimation; Speed Profiles*

1 Introduction

Accurate and reliable estimation of the traffic speed in urban arterials is an essential task for better traffic management and control. Traffic information collected from magnetic loops, road tube counters, radars, Bluetooth are used to estimate the link occupancy, average speed or density of a corridor, traditionally. More recently, Floating Car Data (FCD) has become another important traffic data source and has an increasing usage due to its lower cost and higher coverage area despite its reliability problems. Speed and position data of floating cars can be obtained periodically (e.g.,1 min or 5 min), then processed to estimate traffic information for each road segment at regular time intervals (Xu et al., 2013). Long term collection of this data enables identification of traffic patterns, such as the recurrent/non-recurrent congestion or bottleneck locations of a corridor. However, in order to identify traffic patterns, it is crucial to examine the speed profiles of each road segments.

The principle of FCD is to collect real-time traffic data by locating the vehicle via mobile phones or GPS over the entire road network. Data, such as car location, speed and direction of travel, is sent anonymously to a central processing center. Then, this information is processed to derive travel time and/or average speeds of road segments. Basically, FCD data can be taken from cellular or GPS probe data. Even though GPS is becoming more and more used and affordable, so far only a limited number of cars are equipped with this system such as taxis, trucks operating with fleet management services (Leduc, 2008). While traffic data obtained from private vehicles or trucks are more suitable for motorways and rural areas, taxi fleets are particularly useful due to their high number density and their on-board communication systems in urban regions. Currently, GPS probe data are widely used as a source of real-time information by many service providers but it suffers from lack of sufficient data flow due to the limited number of GPS-equipped vehicles (Leduc, 2008).

Demir et al. (2003) stated that at least 1.5% penetration is required for a reliable estimation of travel times and average speeds of the road segments. In Turkey, FCD is collected from 600,000 GPS-equipped vehicles (among the total 19 million vehicles), which corresponds to approximately 3% penetration rate. This penetration rate provides an opportunity to determine traffic segment variations, which is the focus of this study. For this purpose, 3-month FCD were utilized to examine the speed profiles variations in a 4.5 km segment of Dumlupınar Boulevard which is a major arterial in the form of a multilane urban highway corridor (4 lanes in each direction) in Ankara and covers the region starting from Hacettepe University interchange to the Middle East Technical University entrance. In particular, morning rush hour speed profiles are examined to determine temporal and seasonal variations in speed profiles as well as spatial variations along the corridor. The structure of the paper is as follows: a brief literature review is presented in Section 2, followed by the methodology section including the structure of the FCD and the selected corridor characteristics. Section 3. In Section 4, speed profiles during morning rush hour are compared as a function of time between 7:30-9:00 for two different periods of the year (July/August and November) which are expected to have significantly distinct behaviors.

2 Literature Review

The potential use of the FCD in traffic engineering studies is summarized by Leduc (2008) as follows:

- Detection focused: Congestion detection, traffic state estimation, traffic queue detection, incident detection, origin-destination matrix determination for commuter trips.
- Application focused: i) Optimization of existing infrastructures through a better use of the current road network, ii) dynamic network traffic control, iii) improved information services e.g. traffic information, dynamic route guidance, road message signs, etc., iv) improved vehicle fleet management especially for cargo companies, and v) shorten driving times to reduce costs.
- Planning and Policy related: Plan for future investments, new perspectives in transport modelling: real-time data could be used to set up dynamic transport models capable to provide forecasts in a very short period of time.

Within the scope of the study, literature relevant to speed pattern analysis by FCD is reviewed first. Traffic speed evaluation studies are generally focused on i) the combination of the FCD data with the other data types, such as, Remote Traffic Microwave Sensor Data (RTMS), inductive loops, video cameras, Automated Vehicle İdentification systems etc., to compare and measure the strength of the FCD or b) using only FCD data to derive the speed profiles and identify the congestion locations. Zhao et al. (2009) used FCD and Remote Traffic Microwave Sensor Data (RTMS) to compare the average speed values. Their results showed that RTMS speed values were generally 6% higher than the FCD speed values. Later, authors conducted regression analysis to investigate the relation between average speeds obtained from RTMS data and FCD. Another study conducted by Chase et al. (2012) evaluated the reported speeds obtained from 3 different kinds of traffic data. FCD was obtained from Inrix that 5-minute aggregation speed data were collected from GPS probe vehicles for 20 study weekdays.

Inrix reported the travel time, speed, average speed and reference speed. The second data was obtained from microwave radar sensors that 5-min aggregation speed data, volume and occupancy values were collected from the same corridor for the same study period. The last data type was obtained from radar sensors that only speed values were obtained. Speed profiles showed that all data type had similar pattern and the speed differences obtained from Inrix and microwave radar sensor data were compared and the differences was found normally distributed. Haghani (2010) analyzed the reliability of the average speed of the road segments obtained from FCD using the Bluetooth data. Statistical evaluation has been performed for 4 speed categories as; i) speed below 30mph, ii) 30-45 mph, iii) 45 and 60 mph and iv) speed above the 60 mph. Results showed that the Bluetooth mean speeds are not significantly different from the FCD speeds for each speed bin. Similar to these studies, Quayle et al. (2010) compared the FCD speed data from Bluetooth data. They indicated average speed values obtained from FCD is 6% less than the average speeds obtained from Bluetooth data. Pan et al. (2011) obtained average speeds from different transportation modes (private car, taxi, bus and truck) and investigated significant differences between the average speeds statistically. They indicated that the average speeds obtained from taxi fleets is more efficient to derive traffic state patterns.

For the congestion detection studies, Xu et al. (2013) discussed the difficulties of the dealing with the massive historical data set to find a meaningful traffic and congestion patterns. They obtained FCD from 12000 GPS equipped taxi fleets in Wuhan city, China. They proposed a statistical method to deal with the big data (name as data cube management) to faster analyze the data. Li et al. (2012) used three months historical FCD to examine the variabilities of the average speeds and they tried to determine the congestion locations depending on the sudden drops in average speeds among consecutive road segments. Fabritiis et al. (2008) proposed neural network based model to estimate the average speed of the links and to determine the congestion locations of the two selected corridors. Kong et al. (2015) developed a fuzzy comprehensive evaluation method to identify the congestion locations for every 5 minutes. Different than these studies, Adu-Gyamfi and Sharma (2015) explored the reliability of the probe speed data for detecting the congestion trends. The study focused on the pattern recognition and time series data analysis to identify the similarities and dissimilarities of the probe-based speed data. Reinthaler et al. (2010) used FCD from both taxi fleets and public transports for Dusseldorf city in Germany. Their findings revealed that public transportation based data provided more accurate results for speed and travel time values. Furthermore, they developed a model to integrate these two data sources to estimate the traffic states to identify the most congested locations.

3 Methodology

Speed pattern detection using FCD requires a series of analyses with different scopes and perspectives. To display the use of FCD in this attempt, first a brief summary of FCD format and the segmentation of the study corridor is discussed below, which are essential to understand and evaluate the FCD data analyses in the following chapter.

3.1 FCD Format

FCD data used in this study is provided by Be-Mobile, a Belgium-based traffic information provider, which delivers real-time average speed data in even at one-minute intervals for road segments of lengths shorter than 50 m (see Figure 1 for example road segments on Dumlupınar Boulevard). Static and dynamic tables were taken from raw FCD. While static table included the static characteristics of the road segments (such as, segment id, length, road class type, speed limit, average speed, and the coordinates), dynamic tables included dynamic attributes of the road segments (such as, segment id, day, time based average speed values, travel time, # of probe vehicle passed at a given time etc.) Example static and dynamic tables are shown in Table 1 and Table 2, respectively. In this study, average speed values for each segment are sampled at every 5-minute while archiving due to storage limitations

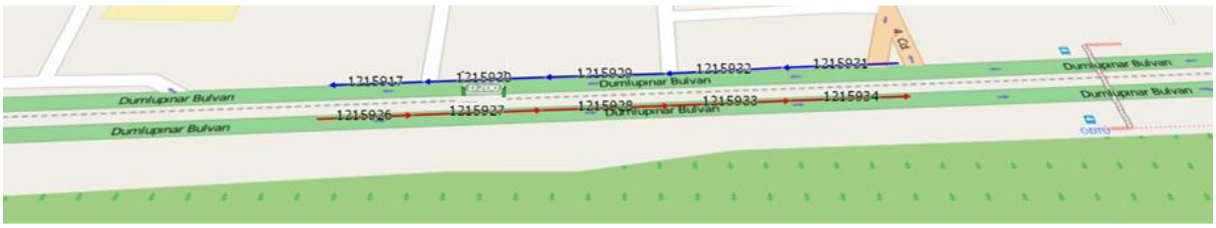

Figure 1. Bi-directional location of some of the road segments in Dumlıpınar Boulevard.

Table 1. Static information of sample road segments located in the study corridor.

Segment Id	Length (m)	Road Class	Average Speed	Speed Limit	Start Coordinate	End Coordinate	Local Id
1215926	49.24	5	70	90	32.813454 , 39.918419	32.813469, 39.917976	1
1215927	49.24	5	70	90	32.813469 , 39.917976	32.813501, 39.917533	2
1215928	49.24	5	70	90	32.813501 , 39.917533	32.813532, 39.917091	3
1215933	48.01	5	70	90	32.813532 , 39.917091	32.813542, 39.916655	4
1215934	48.01	5	70	90	32.813542 , 39.916655	32.813112, 39.916359	5

Table 2. Sample dynamic attributes for the “1215928” road segment.

Segment Id	Day	Time	Travel Time (s)	Speed	# of probed veh.
1215928	01.07.2015	8:00	2.48	70.00	10
1215928	01.07.2015	8:05	2.48	70.00	8
…					
1215928	01.07.2015	8:55	2.54	69.79	10
1215928	01.07.2015	9:00	2.89	61.34	10
…					

3.2 Study Area Selection

As a case study, a 4.5 km corridor on Dumlupınar Boulevard (from Hacettepe University interchange to Middle East Technical University entrance), which is a major arterial in the form of a multilane urban highway corridor (4 lanes in each direction) in Ankara, is selected as shown in Figure 2. The study period included the data archived from July-August and November 2015 for the morning peak hour period (between 07:30-09:00) including weekdays, only. The study corridor consists of 134 segments in one direction. For these segments, local numbering has been assigned in a consecutive way instead of the Be-mobile's segment numbering (see Table 1). Be-mobile produces average speed data for road segments, however, publishes the results as truncated at the road speed limits. Though the speed limit of the study corridor is 82 km/hr (and 90 km/hr in practice for speeding tickets) by the municipality, speed data obtained from Be-mobile was truncated at previous limit of 70 km/hr.

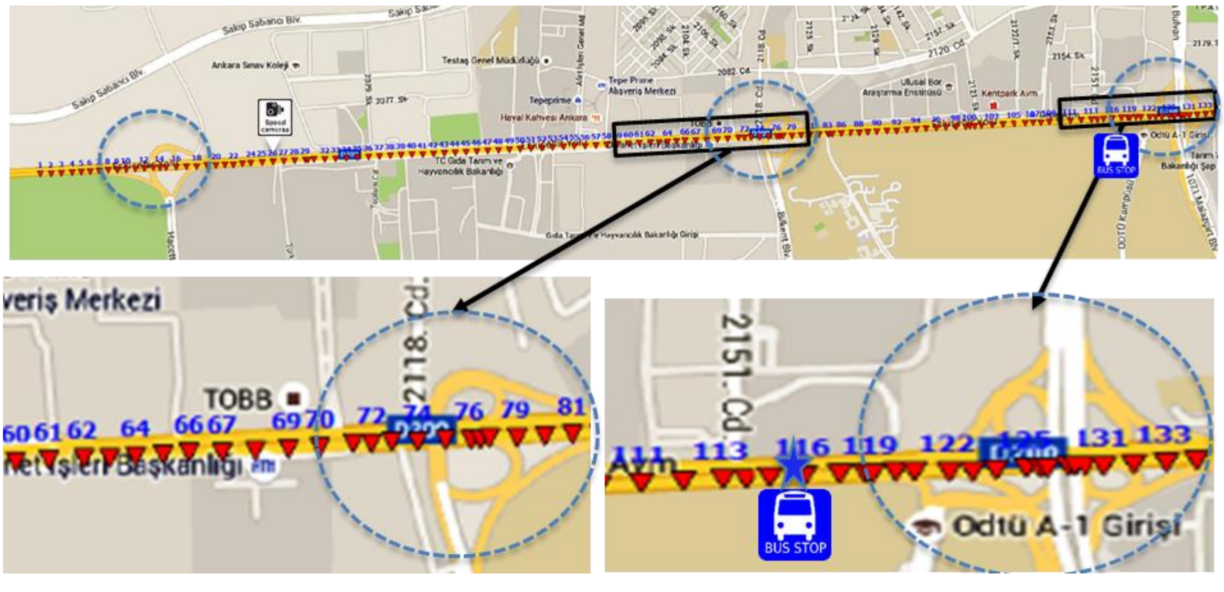

Figure 2. a) The study corridor and the locations of the 134 road segments and close-up view of b) Bilkent interchange and c) ODTÜ Interchange.

Study area includes one section with electronic speed enforcement point (spot speed enforcement located around the road Segment ID 27), and 3 major grade-separated interchanges (Hacettepe, Bilkent and ODTU) and a major bus stop near ODTU interchange (Segment ID 116) as shown in Figure 2.

4 Profiling Speed along the Study Corridor

The set of analyses of the archived data for the study corridor within different scopes and perspectives included i) evaluation of existence of seasonal effect and ii) day-of-the-week effect.

4.1 Seasonal Variations in Speed Profiles

In order to examine to what extent FCD can provide information on speed profiles and to see the seasonal effect on the speed profiles, we chose July/August period (low traffic demand), and November (high traffic demand) data. The minute based speed values recorded for every weekday (and archived at every 5-min intervals such as at 7:30, 7:45, …, 9:00) in July and August, were averaged during morning peak period. Temporal variations of these average speeds within the morning peak period during the summer (Figure 3) and during the winter (Figure 4) show significant differences in speed profiles. Whilst travel speeds are observed at a value much lower than free-flow levels at the Hacettepe interchange, this is most likely the impact of slowing down prior to electronic enforcement measures, located immediately after, at Segment 27. Traffic conditions at the Bilkent interchange improve along the segments within the interchange, whilst the main problems are observed in the upstream segments. Similarly, traffic is mostly free-flowing at the METU interchange, while severe congestion is observed at the segments immediately prior to the bus stop close to this interchange. The severity of the congestion progresses was more after 8:00 and variations in speed profiles showed degradation in traffic conditions continued until 09:00. In the corridor, sudden drops in averages speed were observed much earlier (between 07:30-08:30) after which the average speed started to increase (except for certain locations with persistent congestion); this suggests an earlier peak hour (thus congestion) occurrence during winter times. Further aggregation of the speed values for 30-minute periods and presentation of summer and winter conditions in Figure 5 revealed that the most congested time was at 08:00-08:30 in winter condition, whereas the most congested time was observed during 08:30-09:00 in summer.

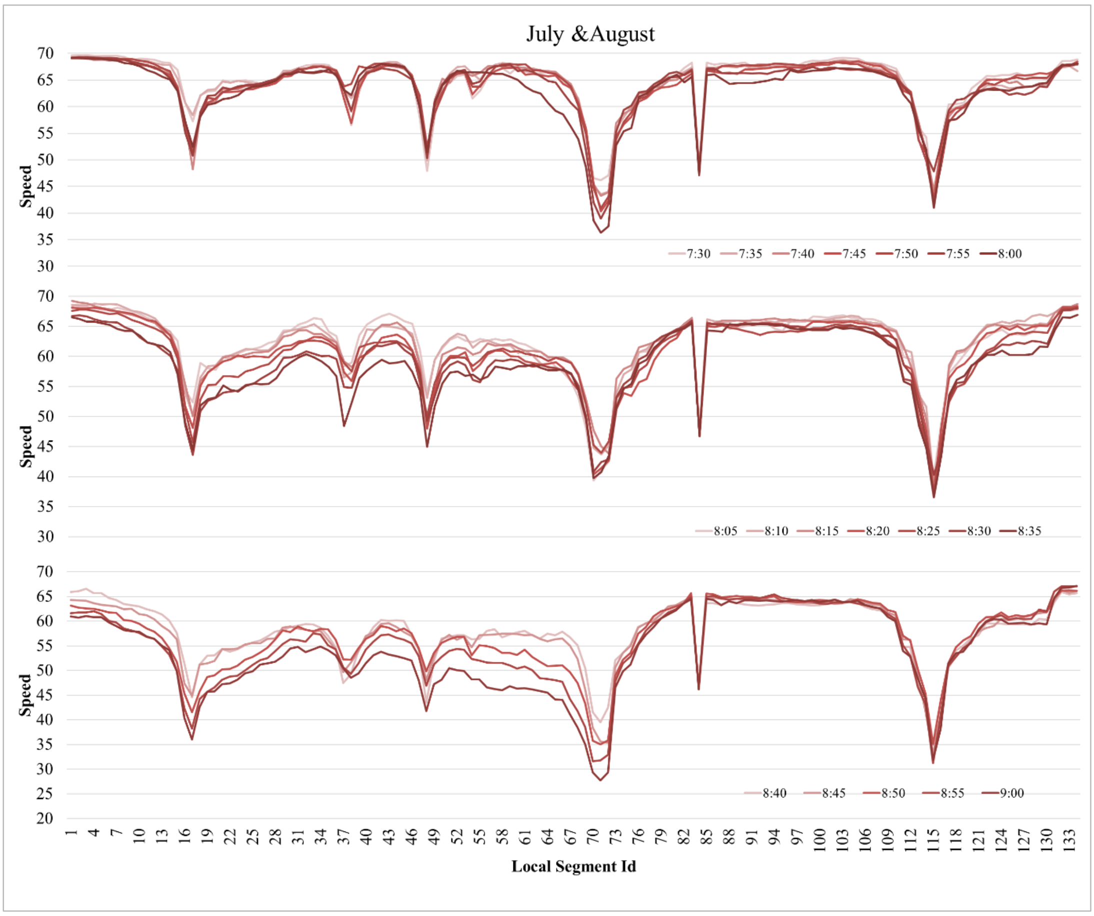

Figure 3. Temporal variation of average speed profiles at morning peak hours for the July and August data.

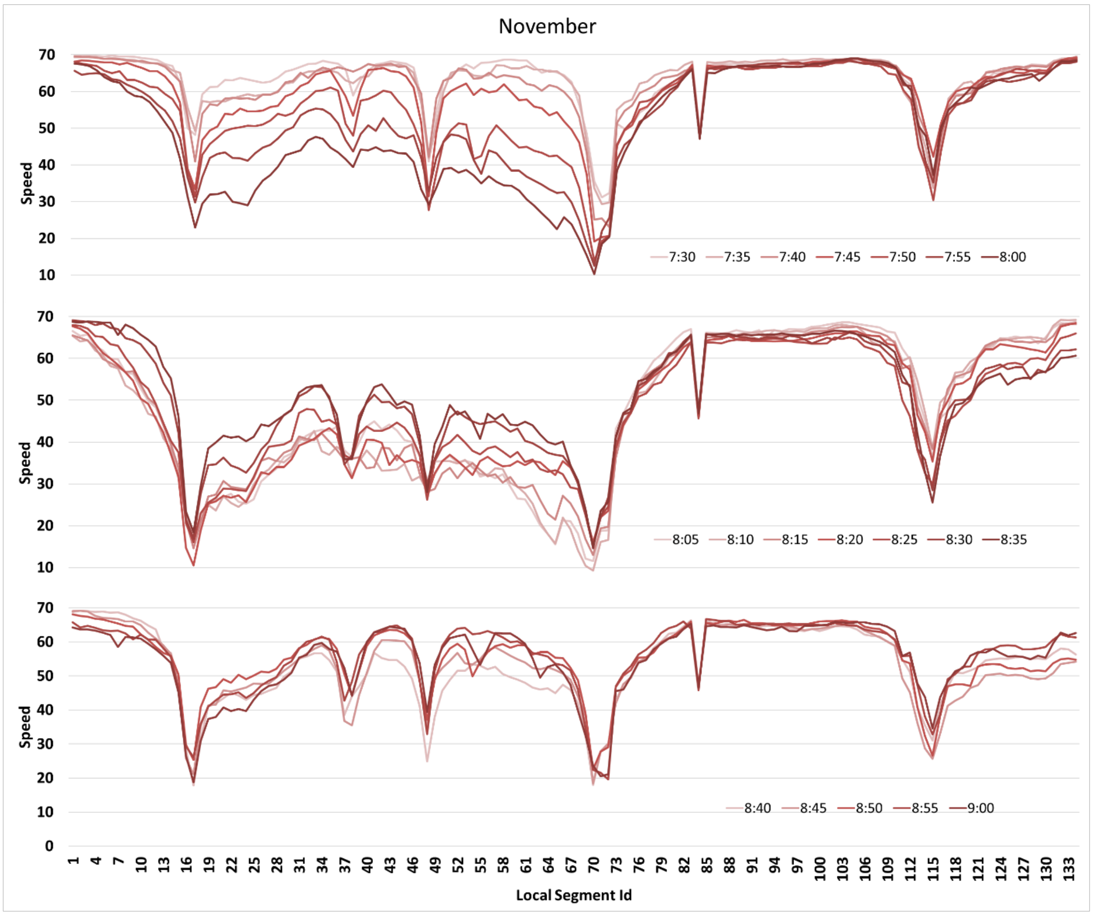

Figure 4. Temporal variation of average speed profiles at morning peak hours for the November data.

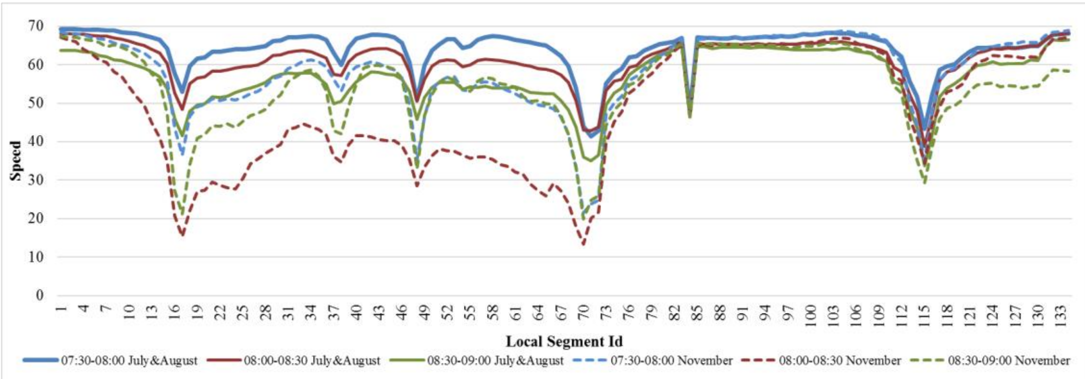

Figure 5. The average speed profiles of the July/August and November data for the 30-min time intervals

The variations in the standard deviations of the FCD speed values, are presented for the summer and winter periods separately in Figure 6, which showed smaller deviations during the higher average speed segments and time intervals (which are mostly free-flow conditions), standard deviations always increase at the congested segments and time intervals which means the congestion patterns and times show more randomness in time and lengths in this corridor.

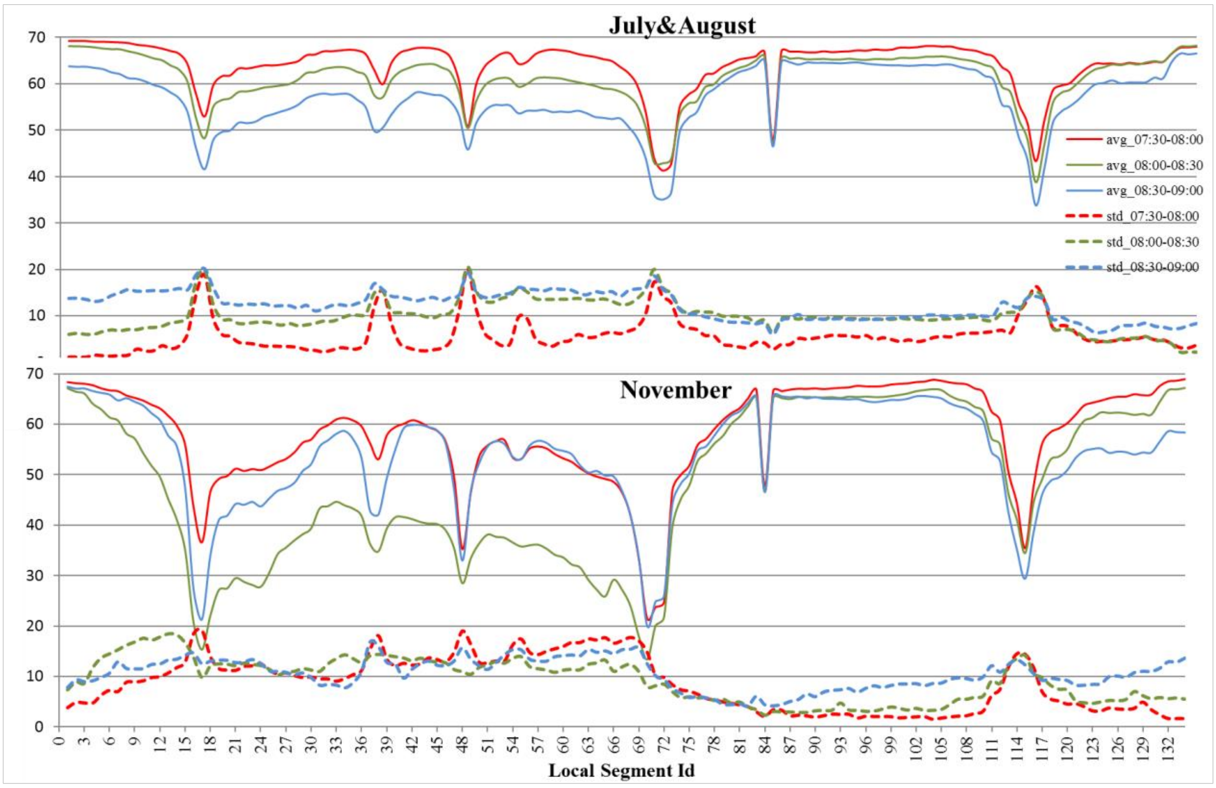

Figure 6. Average versus standard deviation values for the July&August and November data.

4.2 Weekday Speed Profiles

Similar to a seasonal effect, a possible variation can be seen between different days of the week, which are studied separately as shown in Figure 7. While there were not much variation between different days of the week during the early morning period (7:30-8:00) and late morning period (8:30-9:00), a slightly more recognizable speed profile variations are observed during the critical 8:00-8:30 time interval for different days: this is more visible at the first part of the corridor (segments up to 70 and especially up to 13) which means they are more susceptible to demand, thus congestion, changes based on the day of the week, while the second part of the corridor has more recurrent states, at either free-flow or congestion levels every week day.

5 Conclusions

The analyses of speed values for urban road segments obtained from FCD data revealed that there are certain spatial and temporal localities, which have to be determined, mainly because archiving FCD speed data as detailed as it is published (at every minute for every road segment shorter than 50m) is neither meaningful not practical in terms of data management. The case study from an urban corridor in Ankara showed significant variations between summer and winter time traffic conditions, but, the effect of the day-of-the week was observed only for the time period of 8:00-8:30. Any procedure to compress the FCD speeds for archival use as well as future estimation purposed has to address these locations in speed patterns in the corridor and FCD data.

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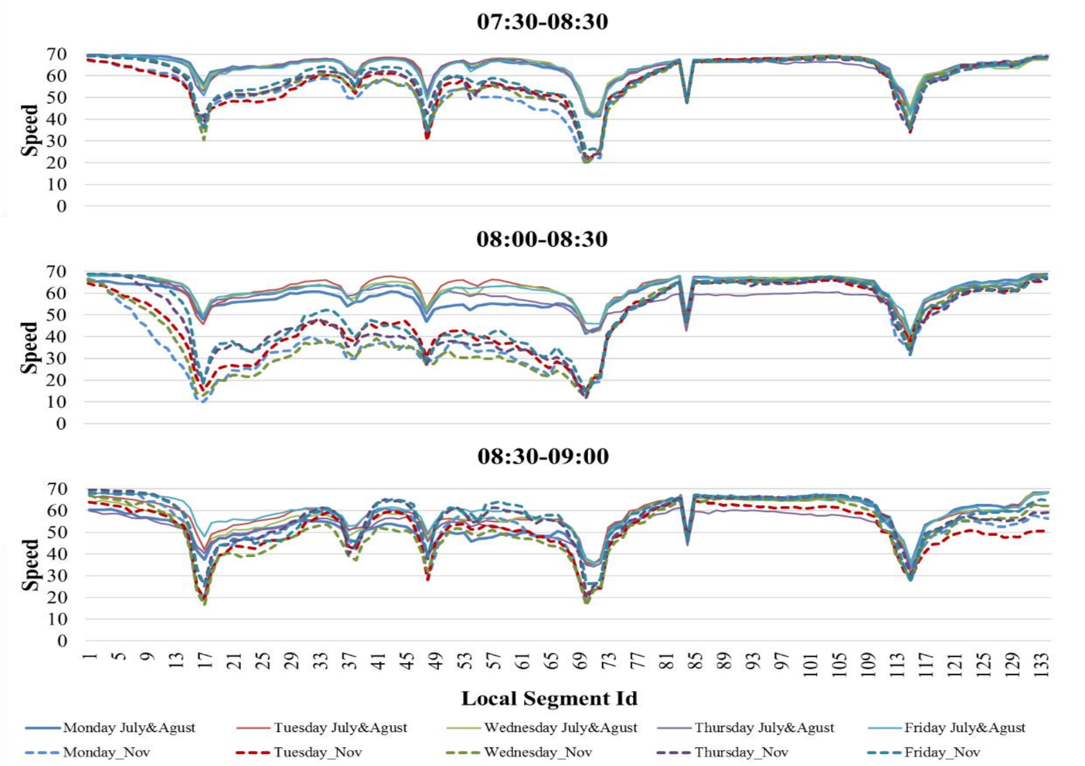

Figure 7. Weekday average speed profile of the selected corridor for the July&August and November data for 30-min time intervals.

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