Vehicle Data Collection for Predicting Driving Behavior on Interchanges

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Abstract

Interchanges act as roadways where marginal speed transitions between motorways and local arterials are reported. In many cases, vehicles are required to negotiate a sequence of curves that can be relatively sharp and unexpected (e.g. trumpet interchanges). As driving behavior differs among drivers, some vehicles may enter a ramp at a higher speed than the posted one for the designed curve [1]. Therefore, accurate vehicle data collection on interchange ramps is of utter importance in order to assess driving behavior aspects as well as deliver accurate safety margins in terms of vehicle speeds. This paper evaluates the consistency of the results for two vehicle data collection methods on interchange ramps; namely, floating vehicle data collection apps that utilize the GPS receiver of drivers' smartphones [2], and, direct field measurements. The authors intend to assess the reliability of such data collection environments in terms of their accuracy to record various driving behaviors, with special emphasis on ramps with varying curvature. Moreover, the outputs from the vehicles' speed analysis can be compared to the maximum constant speeds (safe speeds) as imposed from retention requirements during vehicles' motion on curved paths [3], [4] and, thus, quantify the resulting safety margins. Despite the fact that data collected through the app-oriented methodology reduces time and cost, in general, it was found that the results under both approaches are of relatively similar accuracy. Nevertheless, in certain parameters, there seems to be a number of inconsistencies. For example, the relation of the 85th percentile speed to the radius of the interchange seems to differ between the two examined methodologies, where further investigation seems necessary for various interchange types and for additional vehicle types (SUV's etc.).

Keywords: Interchange, speed, vehicle data collection, driving behavior

1. Introduction

Interchanges are key components of motorways due to their significant role in the entrance and exit of traffic volumes. In particular, vehicles enter and exit the interchange ramps at relatively high speeds and in certain interchange configurations they are required to follow a horizontal alignment with sharp curves and/or a longitudinal alignment with steep gradients. The aforementioned high speeds combined with steep gradients and sharp turns in an interchange, may result in vehicle skidding regarding passenger cars, especially under wet pavement conditions, and rollover of heavy vehicles (e.g. commercial trucks), on dry pavements.

Based on experience, drivers tend to increase or decrease their speeds during on-ramp entrance and exit maneuvers respectively. In addition many interchange ramps designed in the past (40 or more years ago), do not meet the requirements of more recent research, such as provision of decision sight distance or road perspective in 3D. Such cases are common in Greece, where at that time there were no official design guidelines for interchanges and as a result, areas of potential safety violations may exist.

It is obvious that in order to properly assess the safety of an interchange ramp, the necessary data includes, but is not limited to, the horizontal and vertical alignment of the ramp itself, as well as the speed data of the vehicles using it. Although the design elements of the interchange ramp can be easily obtained either from its original drawings or by on-site measurements, the speed data collection presents a challenge. That challenge lies in the fact that in order to properly assess the safety of an interchange ramp, a large amount of vehicular speed data is necessary throughout a significant period of time. This process of on-site measurements, using Automated Traffic Counters (ATC) is expensive and finite in the sense that the ATC's cannot be installed indefinitely in each ramp of the interchange. Therefore it is clear that this method can provide important vehicular speed data but only for a short period of time.

Alternatively, by utilizing the GPS receiver of drivers' smartphones, the necessary speed data can be provided indefinitely as long as vehicles keep using the interchange. This method is significantly cheaper than manually installing ATC's in each interchange ramp and the recorded data can be used for many purposes including safety assessment, real time traffic control, predicting drivers' behavior through machine learning algorithms, neural networks etc.

This paper evaluates the consistency of the results for two vehicle data collection methods on interchange ramps; namely, the results of floating vehicle data collection apps that utilize the GPS receiver of drivers' smartphones [2] and direct field measurements are compared. This paper also intends to assess the reliability of such data collection environments in terms of their accuracy to record various driving behaviors, with special emphasis on speed choice on ramps with varying curvature. The outputs from the vehicles' speed analysis can then further be compared to the maximum constant speeds (safe speeds) as imposed from retention requirements during vehicles' motion on curved paths and, thus quantify the resulting safety margins, using already developed vehicle dynamics models [3],[4].

2. Methodology

In order to compare the result consistency of the two methods, a study interchange with a variety of curve radii was selected for the on-site measurements. The assessment, implemented on the ramps of a trumpet interchange, is based on the comparison of the data collected via the app-oriented methodology, capable of recording speed and position data in one-second intervals, against field measurements utilizing automatic traffic counters positioned on critical points along the ramp.

Study Interchange Selection

The study interchange was selected based on the thought that an interchange that is heavily used by passenger vehicles as well as commercial trucks, and is unfavorably designed, has increased possibility of accidents occurring. This renders such an interchange as a perfect candidate for vehicles speed analysis, in order to determine its safety margins. Following this thought, the Schistou interchange was selected as a study interchange, which is located in the area of Skaramagkas and connects Athens Avenue with Schistou-Skaramagkas Avenue. The selection of this particular interchange was done because it is a trumpet type interchange and it is the most common form of three-legged interchange in Greece. A wide variety of vehicles utilize this interchange due to the fact that Skaramagkas is an industrial area and thus traffic consists of both passenger vehicles and commercial trucks alike. Moreover this interchange is a reverse trumpet type interchange, which means that the small radius loop of the interchange is used by vehicles entering the main motorway rather than vehicles exiting the main motorway. The selected study interchange as well as the respective ramp radii are presented in Figure 1.

Figure 1: Schistou interchange.

Interchange characteristics

The characteristics of the study interchange were obtained through an official drawing providing the horizontal and vertical alignment of the interchange. In total, 5 spots were selected in order to measure the speed of the vehicles and traffic data of the interchange. The width of the road is 3.75m and the design characteristics of the interchange at the measurement spots are shown in Table 1.

Measurement spot	Curve radius	Road gradient	Superelevation
ATC-1	110 m	-1.57 %	2.00 %
ATC-2a	65 m	2.48 %	200 %
ATC-2b	30 m	-3.80 %	3.50 %
ATC-3 (Pir)	220 m	-4.00 %	-2.00 %
ATC-3 (Kor)	220 m	4.00 %	2.00 %

Table 1: Geometrical characteristics of the study interchange at measurement spots

Speed and traffic data collection

For the purposes of this analysis, traffic data and speed data of vehicles using the interchange for a period of three consecutive days were collected through automatic traffic counters in the form of rubber tubes. The equipment used was the MetroCount MC5600 portable traffic classifier, using pneumatic tubes laid across the road. The basic work principle of this type of traffic counters is as follows: One set of at least two rubber tubes are placed across traffic lanes and when a set of wheels passes over the first tube, the air pressure changes and activates a recording device noting the time of the event. The moment the vehicle passes over the second tube the device records the time stamp of this event and with the distance between the two rubber tubes known, the supplied software easily calculates the speed of the vehicle. The software also categorizes the vehicle by comparing the length of the two axles (or more) of the vehicles passing over the pneumatic tubes with a standard vehicle classification system that relies on wheelbase length. The passenger cars are the only vehicle category that is examined in this paper.

This data collection was performed for 5 days, starting on the 5th of July, 2018 (12:00 local time) and ending on the 9th of July, 2018 (9:00 local time). The first and the last day of the measurements were not taken into account because only a part of the daily traffic was measured. Three consecutive days (6th July, 7th July, 8th July) were studied in full, as 24 hours of traffic recordings were available, thus giving a better idea of the speed and traffic conditions occurring on the interchange.

Meteorological data

The speed of a vehicle is influenced by present weather conditions and so it is necessary to obtain the meteorological data at the study interchange for the study period. The meteorological data for the region were used for the three days of the measurements. Due to the fact that the meteorological data could not be recorded in real time during the measurements, the website www.wunderground.com was used, which allows users to search and find meteorological data for any area of the world in the past year. The meteorological station of Elefsina was selected with coordinates 38.07 oN, 23.55 oE, is 27 m above sea level and less than 8 km from the study junction. The meteorological data was collected for the dates 6th July 2018, 7th July 2018, 8th July 2018 and 21st October 2018.

Generally the weather conditions can be described as mild with the exception of Sunday 8th of July, where heavy rainfall was recorded in the afternoon. These data were collected in order to correlate them with the velocity and geometrical characteristics of the intersection in order to compare the results with relevant investigations [2].

3. Analysis and Results

The raw data collected from the automatic traffic counters were processed through a spreadsheet software in order to firstly determine the traffic volume at the interchange. From this it was determined that the number of vehicles travelling with direction to Korinthos is higher compared to vehicles travelling to Piraeus which further strengthens the assumption that this particular interchange is potentially dangerous as the higher volume traffic is occurring on the loop ramp of the interchange.

As stated before this paper aims to assess the consistency of the results for two different vehicle data collection methods on interchange ramps. The reliability of such data collection environments, in terms of their ability to accurately record various driving behaviors will be examined by the outputs from the vehicles' speed analysis. This can later be compared to the maximum constant speeds (safe speeds) as imposed from retention requirements during vehicles' motion on curved paths and, thus, quantify the resulting safety margins [3], [4].

The most important speed characteristic that will be compared in this paper is the 85th percentile speed. This is defined as the speed that is not exceeded by 85% of all vehicles travelling in free-flow conditions in wet but clean road surface. Road surface conditions are shown by research to not greatly impact the 85th percentile speed of car, so in this paper the speed difference in dry versus wet surface will not be the main subject of examination, however the results from the obtained data can be easily examined in this regard. In order to calculate the 85th percentile speed, the raw data were converted so that every measured vehicle has at least 6 seconds of head space from the leading vehicle, meaning that it travels in free-flow conditions [5], [6].

85th percentile speed analysis

The 85th percentile speed was extracted from the measured speed data, for each different radii of the horizontal curves that measurements took place, for all 3 days. The ATC-3 measuring spot was largely ignored during the analysis due to the fact that there are traffic lights less than 150m away meaning that the results are heavily affected by them, thus rendering the results somewhat unreliable. For all other measuring spots the results are presented in Table 2.

85th percentile speed (km/h)				
Measurement spot	**6/7/2018**	**7/7/2018**	**8/7/2018**	**Average**
ATC-1 (R=110 m)	64.43	68.84	65.94	66.40
ATC-2a (R=65 m)	54.78	56.51	54.93	55.41
ATC-2b (R=30 m)	37.24	38.53	37.97	37.91

Table 2: 85th percentile speed measured at the study interchange

The calculated 85th percentile speed was then graphed depending on the radius of the ramp and compared to the findings of the GPS data collection method [2] as well as the Federal Highway Administration [7] graphs for longitudinal slopes ranging from 0% to +4%. The produced graph is presented in Figure 2.

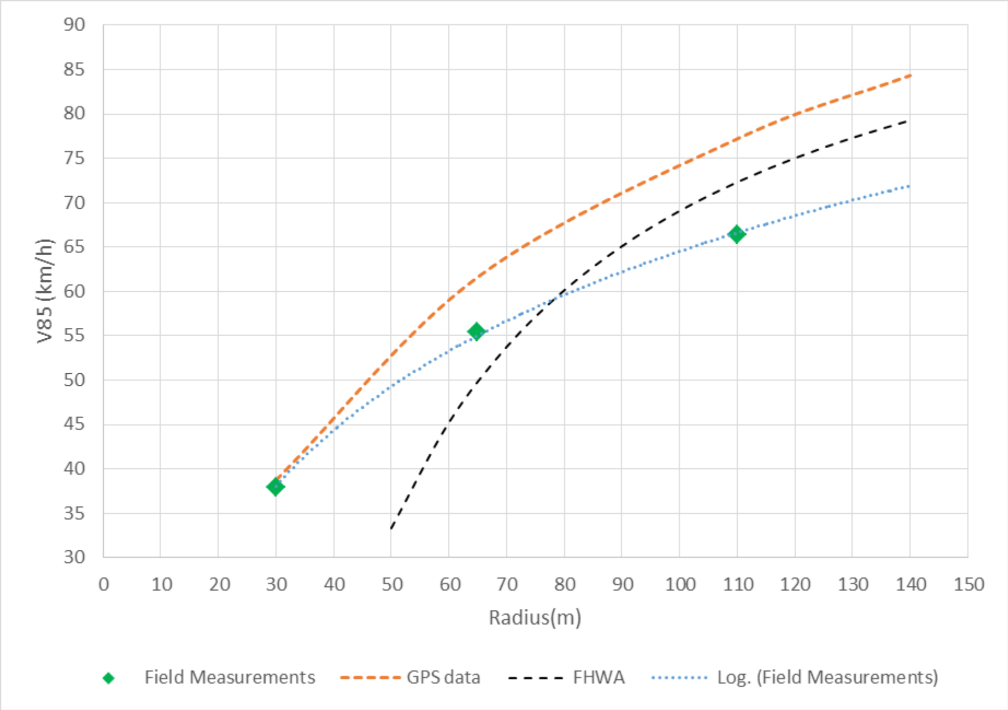

Figure 2: 85th percentile speed to radius graph

It is clear the 85th percentile speeds suggested by the FHWA does not correlate to the findings of neither the on-site measurements nor the GPS measurements. This suggests general differences between the speeds that vehicles travel on interchanges and on suburban roads, despite the similarities in the radius of the curve.
The on-site measurements appear to be correlated to the GPS measurements for curves up to 50m. However curves with radius greater than 50m appear to have a deviation when using different measurement methods, despite showing a similarly formed graph. This deviation is most likely caused due to the abnormally small superelevation rate (2,00%) in the larger radii curves at the studied interchange compared to the interchanges measured using the GPS data, which are designed with superelevation rates of approximately 6,00% [2].

Day and night 50th percentile speed comparison

According to research [2] the 50th percentile speed of vehicles is dependent on the time of the day. In particular, at night there is a speed reduction of approximately 3% compared to daylight hours. However, this reduction does not seem to correlate to the geometric design elements of the interchange ramps.
In the study interchange a similar analysis was conducted in order to determine how the time of the day affects the average speed at which vehicles travel on the interchange ramps. Data measured between 06:00 and 21:00 were considered daytime measurements and the remaining time was considered nighttime measurements. The speed analysis is conducted for the total of the 3 days and not for each day individually, in order to better calculate the average speed during daytime and nighttime. The results of this analysis are presented in Table 3.

50th percentile speed (km/h)			
Measurement spot	**V_{50} day**	**V_{50} night**	**Difference**
ATC-1 (R=110 m)	57.22	56.66	-1.0 %
ATC-2a (R=65 m)	48.98	48.20	-1.6 %
ATC-2b (R=30 m)	30.39	33.84	+11.4 %

Table 3: 50th percentile speed, difference between day and night

According to the results of the performed analysis it is concluded that the speed reduction between day and night is not related to the geometric design of the interchange ramps, mainly due to the small sample size and the uneven speed deviation in the various radii of the interchange. It is worth noting that the on-site measurements of the interchange loop (R=30m) suggest an increase in speeds at nighttime which could potentially increase the possibility of accidents occurring.

Speed variation and weather conditions

The GPS data measurements for the speed analysis concluded that meteorological data affect vehicle speeds and in particular, the speeds are reduced depending on the curve of the interchange ramps when raining [2]. The weather conditions in the aforementioned study were categorized according to the amount of the precipitation per 5 minutes. More specifically the weather conditions were considered as: A) Dry (precipitation 0mm/5min), B) Rain (precipitation >0mm/5min) and C) Heavy Rain (precipitation >0.5mm/5min). It is noted that the third class is a subcategory of the second class and helps in the examination of the effect that different raining conditions have on vehicle speeds.
In the studied Schistou – interchange a similar approach was followed. The meteorological data were obtained for each one of the days and it was found that on August 8 of 2018, a sudden rainfall occurred at approximately 19:20 and lasted for more than 3 hours. This provided a perfect opportunity to assess the weather effect on measured speeds and further help determine the reliability and comparability of the two measurement methods. The available meteorological data did not provide any precipitation height measurements. However, a classification of the weather conditions was readily available as follows: A) Fair , B) Light Rain / Light Rain with Thunder, C) Heavy T – Storm, D) Partly Cloudy and E) Mostly Cloudy. The classification between the two methods were correlated for the purpose of this assessment as follows: A) Dry = Fair, B) Rain = Light Rain / Light Rain with Thunder, C) Heavy Rain = Heavy T – Storm. In addition to this classification, the 85th percentile speed of the vehicles traveling on the interchange ramps after the end of the rainfall was calculated as "Wet pavement" speed. The results of this analysis are summarized in the following Table 4.

Measurement spot	85th percentile speed (km/h) Dry	Heavy Rain	Light Rain	Wet Pavement
ATC-1 (R=110 m)	64.55	42.57	53.48	58.91
ATC-2a (R=65 m)	54.15	42.75	44.83	48.75
ATC-2b (R=30 m)	38.94	30.71	31.75	35.36
ATC-3 Kor (R=220 m)	59.72	47.50	51.36	56.36
ATC-3 Pir (R=220 m)	59.04	47.73	52.30	56.82

Table 4: 85th percentile speed depending on weather conditions

In order to more accurately compare the results of the two methods, by using similar radii of interchange ramps, only a portion of the data from the GPS method were included. More specifically, the following interchanges from similar studies [2] were taken into consideration: 1) Holendrecht (R=90m), 2) Noordhoek (R=70m), 3) Sabina (R=120m) and 4) Azelo (R=140m).
In the study interchange, the rainfall event took place during nighttime, so the reduction of speed that is affected by nighttime was also taken into account while examining the reduction due to rainfall. In Figure 3, the results from the two methods are presented.

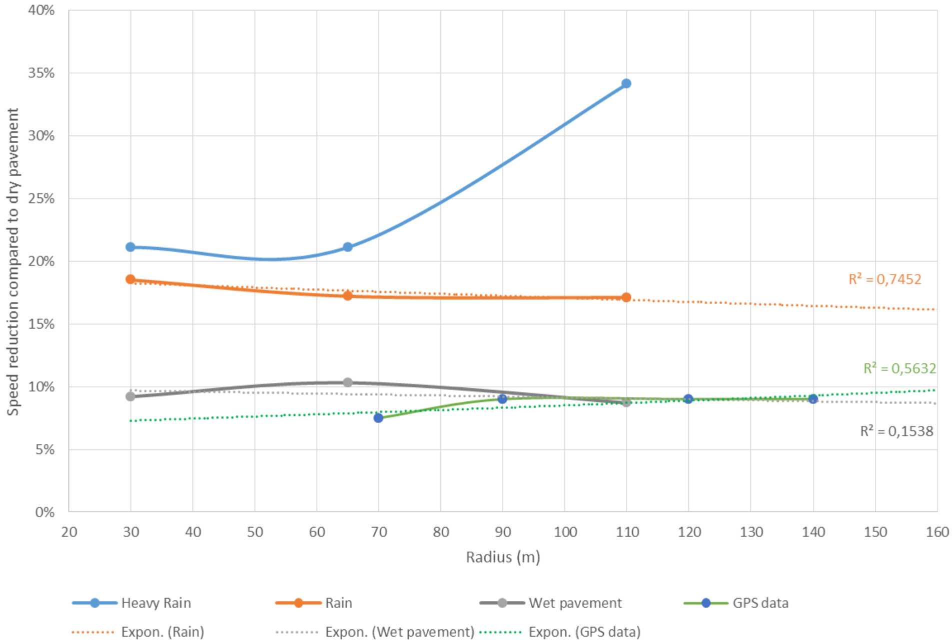

Figure 3: 85th percentile speed reduction depending on rainfall

It is worth noting that the 85th percentile speed of vehicles traveling at the study interchange ramps, show greater reduction when heavy rainfall conditions are prevalent, as opposed to the reduction that is calculated through the GPS method [2]. That could be explained by the fact that during heavy rainfall conditions, the stopping sight distance is heavily affected. In addition to that, the rainfall event occured while the sun was setting, which also affects speeds on its own. Finally, the psychological factor must also be considered, as drivers tend to drive more carefully and are hesitant to develop high speeds when it's raining.
The results from the GPS data method [2], suggest an 85th percentile speed reduction in the range of 3%-8%. At this paper's studied interchange and the on-site measurements, the calculated speed reduction is around 8.7%-10.2%, which despite being a little increased compared to the GPS method, are in agreement with the previous findings. The small variations in the reduction percentage is likely caused by the design elements of the studied interchange, namely the small supelevation rates at 2,00% compared to 6,00% on the ramps of the GPS measured interchanges.

4. Discussion and Conclusions

This paper aimed to assess the reliability of the two methods for measuring traffic data, namely on-site measurements using ATC's and an app-driven GPS data collection method used on previous research.
Specifically the assessment was carried out by comparing the result from the app driven method with the results of vehicle data travelling on a study interchange, namely the Schistou trumpet type interchange in Attica. Traffic data and speed data of vehicles using the interchange for a period of three consecutive days were collected through automatic traffic counters in the form of rubber tubes. By examining the passenger cars that were more than 6 seconds away from the leading vehicle, meaning they were travelling at free-flow speeds, the 85th percentile speed was determined.
Meteorological data collected were also used in order to correlate the effect of weather conditions on the speeds of the vehicles.
Based on the above analysis, the results of the recorded speeds, namely the 85th percentile speed of passenger cars, were compared to the calculated speed from the app-driven method [2]. This analaysis was also performed in regards to weather conditions and lighting condition to better assess the reliability of the two methods. By the above analysis it was concluded that:

- The 85th percentile speeds measured with the two methods are in agreement when examining curves with small radii, but appear to have a deviation as the studied radius grows, despite simarly formed graphs. This could be caused by the fact that the superelevation rate of the studied interchange is very small at 2,00%, as compared to the GPS measured interchanges which were designed with superelevation rates of 6,00%.
- Both methods concluded that the speed reduction between day and night is not related to the geometric design of the interchange ramps.
- Both methods suggest an 85th percentile speed reduction during rainfall. In the GPS data collection method, this reduction was in the range of 3%-8% compared to the study interchange and the on-site measurements in which the measured speed reduction is around 8.7%-10.2%

The present analysis suggests that despite small deviations of the findings, the two examined methods yield similar results, suggesting that the two methods could be used interchangeably to provide accurate results. However this analysis needs to be further performed on more interchange types in order to solidify the findings of this paper and better examine the reliability of each method's findings.

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