Car Drivers Do Not Choose Their Speed in Urban Environments: Speed Models in Tangent Streets

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Keywords: GPS Equipment, Roundabout Intersections, Signal-controlled Intersections, Speed Model, Stop-controlled Intersections, Urban Tangent Streets.

Abstract: The performance-based design approach is one way to deal with speeding in the streets. Under this approach, the geometric elements of roadways can influence on the desired operating speeds. Thus, several studies have investigated the relationship between geometric elements and light vehicle speeds; however, no conclusive results have been reached at this stage. In this context, this article aims to investigate the influence of several characteristics from urban street tangents, car driver, and vehicle on their speed in free-flow conditions. Three tangents scenarios were set out: before stop-controlled intersections, before signal-controlled intersections, and before roundabout intersections. Speeds of light vehicles were measured at 34 streets. Speeds were collected with in-vehicle GPS equipment. Thirty-five car drivers participated in the study with their vehicles. Street geometric characteristics, street environment variables, driver and vehicle characteristics were also collected. As a result, 15 regression models were calibrated and validated. Street length and objects density were the most influential variables in those models, and not the driver and vehicle characteristics as would suppose. This comprehensive research extends the knowledge of the most influential variables on speed in several urban scenarios, offering useful information for urban planners and street designers.

1 INTRODUCTION

Performance-based design is one approach to deal with speeding in the streets, where the street geometrics and its environment elements are selected based on their influence on the desired driving speeds, especially in tangents. This approach presents a more active and efficient alternative to reduce speed vehicles (Fitzpatrick et al., 2003; Harwood et al., 2000; Ray et al., 2014). The success of this approach is finding the relationship between driving speeds and street features. Several studies have developed operating or free-flow speed models for urban streets in order to understand this relationship. These investigations were focused especially on tangents before stop-controlled intersections and tangents before roundabout intersections.

In general, five principle parameters influencing the free flow speed: driver, vehicle, roadway, environment, traffic operation and control (Sekhar et al., 2016). Those variables also may influence acceleration and deceleration choice. Speed choice is influenced by driver characteristics, such as personality traits (García-Ramírez, 2014; Gargoum et al., 2016; Roidl et al., 2014), driver age (Keay et al., 2013; Thompson et al., 2012), driver reliability (Gstaltera and Fastenmeier, 2010), conversation and texting tasks (Choudhary and Velaga, 2017), gender and driving experience (Goralzik and Vollrath, 2017), speeding intention (Dinh and Kubota, 2013b), threat-related feelings and arousal (Schmidt-Daffy, 2013), among others (Tarris et al., 1996).

Vehicle characteristics also impact on speed choice, such as vehicle class (Dhamaniya & Chandra, 2013; Gargoum et al., 2016; Jevtić et al., 2015; Wang, 2006) vehicle age (Gargoum et al., 2016) or vehicle length (Giles, 2004).

Roadway also influence on speed choice, such as street length (Dinh and Kubota, 2013a; Wang, 2006), number of lanes (Dinh and Kubota, 2013a; Eluru et

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García-Ramírez, Y., Paladines, L., Verdesoto, C. and Torres, P.
Car Drivers Do Not Choose Their Speed in Urban Environments: Speed Models in Tangent Streets.
DOI: 10.5220/0010435904210428
In *Proceedings of the 7th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS 2021)*, pages 421-428
ISBN: 978-989-758-513-5

al., 2013; Wang, 2006), shoulders (Eluru et al., 2013; Gargoum and El-Basyouny, 2016), longitudinal slope (Ding et al., 2015), roadway width (Bassani and Sacchi, 2012; Dinh & Kubota, 2013a), lane width (Bassani and Sacchi, 2012; Poe and Mason, 2000), pavement markings (Ding et al., 2015; Guo et al., 2016), pavement condition (Eluru et al., 2013; Sekhar et al., 2016; Wang, 2006). In roundabouts, speed choice were related to entry width (Al-Omari et al., 2014; Gallelli et al., 2014), internal circle diameter (Al-Omari et al., 2014; Gallelli et al., 2014), drive curve (Al-Omari et al., 2014), entry deviation angle (Al-Omari et al., 2014) and approach/exit speed (Gallelli et al., 2014).

Street environment impacts on driver speed choice too, specially sidewalk presence (Dinh & Kubota, 2013a; Eluru et al., 2013; Wang, 2006), access density (Wang, 2006), roadside objects density including trees, utility poles, traffic signs, etc. (Antonson et al., 2014; Dinh and Kubota, 2013a; Wang, 2006), parking presence (Eluru et al., 2013; Gargoum et al., 2016; Wang, 2006), crash barriers (Antonson et al., 2014), bus stop (Antonson et al., 2014), adjacent land uses (Galin, 1981; Gargoum et al., 2016; Giles, 2004; Wang, 2006) or open landscape and broad road (Antonson et al., 2014). On the other hand, speeds are also significantly affected by changes in lighting conditions, such as: sunny, cloudy, and dark (Bassani et al., 2016; Hjelkrem & Ryeng, 2016) as well as weather conditions (Rahman & Lownes, 2012). Likewise, the day of the week (Eluru et al., 2013) or nighttime and daytime (Tarko et al., 2016) also would affect driver speed choice.

Traffic operation and control could affect speed choice, for example, speed limits (Gargoum & El-Basyouny, 2016; Goralzik and Vollrath, 2017), point-to-point speed enforcement system (Montella et al., 2015), speed cameras (Schechtman et al., 2016), speed publicity campaigns (Schagen et al., 2016), perceived posted speed (Schechtman et al., 2016) or photo-radar presence (Chen et al., 2000). It should be mentioned that given the scope of the investigation, this parameter will not be included in the analysis.

In summary, there is no doubt that driver speed choice is affected by a range of different attributes of driver, vehicle, roadway, environment, traffic operation and control. However, some of those attributes were not statically significant in all the studies, for example, lane width (Wang, 2006) or pavement condition (Bassani and Sacchi, 2012) did not influence on speed choice; which means that more research is needed.

In this context, the aim of this research is to investigate the influence of several characteristics of urban tangent streets, car driver, and its vehicle on the driver speed choice in free-flow conditions. Fifteen regression models were calibrated and validated and three different scenarios. To show these findings, the rest of the article is organized as follows. Section 2 gives an overview of the materials and methods. This section describes the sample size, road test section, measurement equipment, the selection of car drivers, and the selection of the test vehicles. Also, this section details the data collection, data processing, and speed pattern analysis. Later, the results section presents the speed model calibration process and its validation. And the principal conclusions are highlighted at the end of the article.

2 MATERIALS AND METHODS

2.1 Sample Size

The speed sample size was calculated based on equation 1 (Pignataro, 1973). This equation includes several speed percentiles, the speed standard deviation, a level of confidence and an admissible error. For this investigation, a standard deviation of 13 km/h was assumed (Bennett, 1994) and an error of 5 km/h.

$$n = \frac{K^2 * \sigma^2 * (2 + U^2)}{2 * el^2} \qquad (1)$$

Where n: simple size, K: constant related to the confidence level, σ: standard deviation, U: normal deviation related to the percentile of speed, el: maximum admissible error. With a level of confidence of 95% (K = 1.96) and value of U = 1.04 (for the worst-case scenario: 85th percentile speed), a minimum number of 40 observations are obtained with that equation. In this study, in just the yellow signal, that value could not be reached (only 13 observations were collected).

2.2 Road Test Section

Streets for this study were selected based on the following criteria: a) urban streets, b) tangents before stop-controlled intersections, tangents before signal-controlled intersections or tangents before roundabout intersections, c) longitudinal slope less than 3%, d) pavement surface in good condition, e) speed limit of 60 km/h, and f) allow free-flow condition. Based on those criteria, 34 streets were selected in Loja city (Ecuador), where 13 streets were tangents before stop-controlled intersections, 12 were tangents before signal-controlled intersections, and 9 were tangents before roundabout intersections. In order to optimize resources, all those streets were part of a single circuit of 9.8 km.

Regarding the characteristics of the tangents before stop-controlled intersections, the length of tangents before stop-controlled intersections was between 47-226 m, up to 2 lanes, roadway width between 7 to 9 m, and up to traffic directions. In tangents before signal-controlled intersections, the length of the streets was between 94 and 121 m, up to 3 lanes, roadway width between 7 to 10 m, and up to traffic directions. In tangents before roundabout intersections, the length of the streets was between 63 and 830 m, up to 3 lanes, the roadway width between 7 and 13 m, the traveled length within the roundabout was between 17 and 118 m, the internal diameter was between 11.5 and 25 m, the external diameter was between 26 and 61 m, the width of entry and exit of the roundabout was between 7 and 11 m, and the roadway width inside the circle was between 9 and 14 m.

2.3 Measurement Tool

Video VBOX Lite was selected to collect vehicle speeds. This device was placed inside the light vehicle. It allows recording geo-referenced digital images, its speed, and its height, among others. The Video VBOX Lite has an accuracy of 0.05% for distance travelled, 0.2 km/h for speed, and ± 10 m for height. The device, in movement, receives information every 0.1 s from 8 satellites. The geo-referenced digital images helped with the data analysis. Independent variables, such as street length, were collecting using traditional measures.

2.4 Driver and Car Selection

Car drivers who participated in this investigation were selected from a non-probabilistic sampling. They had to meet the following requirements: a) have a driver's license, b) have a light vehicle, c) know the streets of the study, and d) have driven frequently in the last two months. Based on these restrictions, 23 men and 22 women were chosen. This distribution was proportional to the last population census in the country (INEC, 2010). All car drivers had an average age of 30.5 years (min = 21, max = 60) and driving experience of 9.3 years (min = 1, max = 40). At the end of the trip, drivers answered two surveys: MDSI-S (Taubman-Ben-Ari et al., 2004) and ZKPQ-50-cc (Aluja et al., 2006) to estimate their personality traits and driving style, respectively. This information was used to analyse their influence on their speed choice. A previous research found a statistical relationship between maximum speed and certain personality traits and driving styles on rural roads (García-Ramírez, 2014).

Vehicles in this research were mostly Chevrolet and Hyundai (62%). From all vehicle study, 78% were cars and 22% pickup trucks. Average manufacturing year was 2008 (min = 1994, max = 2015), average cylinder capacity was 1850 cm^3 (min = 1000, max = 3700) and average last mechanical check-up was 52 days (min = 15, max = 140) before the day of data collection.

2.5 Speed Data Collection

Speeds were collected in good weather conditions, dry pavement and during daylight. It selected the weekends and outside of peak hours (2:00 a.m. to 6:00 p.m.) as study time, to ensure that streets were in a free-flow condition. Video VBOX Lite was discretely installed in each vehicle, with the precaution of not interfering with the driving task. The device has a GPS antenna and a camera. GPS antenna was placed in the central part of the vehicle roof and the camera was placed on the front windshield, facing the street. During the device installation, the driver was briefly explained about the circuit and the academic use of the speed data.

2.6 Data Processing

After the collection data, position data, distance travelled, accumulated distance and speed were exported every second. Every speed profile, o part of it, which was not in free-flow condition, was eliminated. In tangents before stop-controlled intersections, there were 21 free-flow speed profiles for every street. In tangents before signal-controlled intersections there were 67 free-flow speed profiles when the traffic light was green, 45 in red light and 13 in yellow light. Free-flow speed profiles tangents before roundabout intersections were 90, while the free-flow speed profiles within the roundabout were 125. In each street, in its middle, the operating speed or the 85th percentile speed, mean free-flow speed, and free-flow speed standard deviation were calculated, as well as considered in the previous literature.

At the end of the trip, car drivers were asked to answer two surveys: ZQPK-50-cc, and MDSI-S. The ZQPK-50-cc survey has 50 questions related to the five traits of personality: aggression - hostility, impulsive sensation seeking, neuroticism - anxiety, sociability, and activity. MDSI-S survey (41 questions) estimates the driving style that prevails in the driver: risky and high-velocity style, dissociative style, angry style, careful and patient styles, anxious style, or distress reduction style. According to the results, the majority of the drivers had the following predominant personality traits: impulsive sensation seeking (44.4%) and activity (42.2%). Likewise, most of the drivers were careful and patient style (53.3%) or risky and high-velocity style (26.7%).

2.7 Pattern Analysis

After data processing, this section analyses the patterns of the independent variables related to the speed, in order to detect the most influential variables. All statistical analyses were performed using the R program (R Core Team, 2013). In this software, a linear regression analysis was performed at 95% level of confidence. The variables statistically significant from this process will use in the equation calibration process.

The variables analysed in this process were: street length (m), roadway width (m), lane width (m), land use, objects density (n°/100 m), trees density (n°/100 m), access density (n°/100 m), number of lanes, and parking and sidewalk presence. In tangents before stop-controlled intersections the street length influences the operating speed (v_{85}), mean free-flow speed (v_{AVG}), free-flow speed standard deviation (v_{SD}). Also, the parking presence affected the v_{AVG}. On the other hand, in the tangents before signal-controlled intersections, the lane width influences the v_{85} in the green light, and the objects density (n°/100 m) affects the v_{85} in the red light. No variable was statistically significant in the yellow light. In tangents before roundabouts intersections, the street length influences the operating speed (v_{85}), and the mean free-flow speed (v_{AVG}). Variables related to the driver and to the vehicle were not statistically significant.

3 RESULTS

Speed model calibration was performed based on the most influential variables. In this calibration, a linear regression analysis was performed with a 95% level of confidence. When there were not any statistically significant variables, fixed values were assumed. After the calibration, models were validated with data in another test circuit, which had similar characteristics to the initial one. This validation was carried out by analyzing the prediction errors.

3.1 Models Calibration

It calibrated a linear regression analysis with the street length (see table 1).

Table 1: Proposed models for tangents before stop-controlled intersections.

Condition	Equation	R^2 adj.	#
Speed in the middle of the tangent	v_{85} = 22.4 + 0.114 L	0.94	(2)
	v_{AVG} = 20.1 + 0.105 L	0.95	(3)
	v_{SD} = 1.99 + 0.0146 L	0.79	(4)

v_{85} = operating speed in km/h, v_{AVG} = mean free-flow speed in km/h, v_{SD} = free-flow speed standard deviation in km/h, L = street length between 47 and 226 m, $R^2 adj.$ = adjusted coefficient of determination.

Vehicle speed in table 1 increases with the length of the street when the driver perceives a long distance to travel. Conversely, in shorter paths, drivers will have smaller speeds because they do not have “the physical space” to do both speed up in the tangent and speed down before to reach the intersection.

In tangents before signal-controlled intersections are more complex than the previous tangents because traffic lights increase driver mental workload. The calibrated models shown in table 2 are also consistent with actual driving. In green light, vehicles are slower than in yellow light, which makes sense, because many drivers tend to speed up to pass the yellow traffic light, especially when they are in the dilemma zone (Bar-Gera et al., 2016).

Table 2: Proposed models for tangents before signal-controlled intersections.

Condition	Equation	R^2 adj.	#
Speed in the middle of the tangent in green light	v_{85} = 52.72 km/h	NA	(5)
	v_{AVG} = 43.55 km/h	NA	(6)
	v_{SD} = 4.34 km/h	NA	(7)
Speed in the middle of the tangent in yellow light	v_{85} = 56.28 km/h	NA	(8)
	v_{AVG} = 43.31 km/h	NA	(9)
	v_{SD} = 9.82 km/h	NA	(10)
Speed in the middle of the tangent in red light	v_{85} = 33.4+0.53OD	0.49	(11)
	v_{AVG} = 39.71 km/h	NA	(12)
	v_{SD} = 4.45 km/h	NA	(13)

v_{85} = operating speed in km/h, v_{AVG} = mean free-flow speed in km/h, v_{SD} = free-flow speed standard deviation in km/h, L = street length between 94 and 122 m, OD = object density between 5.3 and 29.1 units per each 100 m , $R^2 adj.$ = adjusted coefficient of determination, NA: not available.

In this dilemma zone can also see high-speed data dispersion because other drivers decelerate with high rates in order to stop in yellow light. When the light is green, drivers have already decided that they will pass the intersection, so the speed data dispersion is lower than in yellow light. In the red light, speeds are lower than the two previous conditions, because drivers already know that they must stop before the red light. In this condition, speed data dispersion should be the lowest.

Models in roundabouts (see in table 3) are applicable for tangent lengths between 63 to 312 m. In longer tangents (> 312 m) could be assumed that drivers have reached their desired speed. In this study, the average desired speed was 44.80 km/h with a standard deviation of 5.90 km/h. This average value is similar to the result of the equation 16, using a street length value of 312 m (45.46 km/h). This double check strengthens confidence in the equations developed.

The speed values from table 3 are higher than those found in the previous scenarios (stop-controlled and signal-controlled); because in tangents before roundabouts, the driver has a less mental workload. Speed data dispersion is higher than in green light and the red light cases, as what has been seen in the yellow light case. This is because roundabout could generate a dilemma zone, given that the driver may doubt if he/she continues or stops the vehicle when approaching vehicles inside the roundabout.

Street geometric and street operation variables were also analysed inside the roundabouts. However, there were not any variable statistically significant, so fixed values were adopted: an average speed of 28.60 km/h and a standard deviation of 4.66 km/h. This average speed was similar than in previous investigations: 30 km/h (Bassani & Sacchi, 2011), 17-26 km/h (Gallelli et al., 2014), as well as its standard deviation 4.13-5.21 km/h (Gallelli et al., 2014).

Table 3: Proposed models for tangents before roundabouts.

Condition	Equation	R^2 adj.	#
Speed in the middle of the tangent	$v_{85} = 28.3 + 0.091\ L$	0.98	(14)
	$v_{AVG} = 20.5 + 0.080\ L$	0.90	(15)
	$v_{SD} = 5.38$ km/h	NA	(16)

v_{85} = operating speed in km/h, v_{AVG} = mean free-flow speed in km/h, v_{SD} =free-flow speed standard deviation in km/h, L = street length between 63 and 312 m, $R^2 adj.$ = adjusted coefficient of determination, NA: not available.

3.2 Models Validation

A validation process was performed to evaluate the calibrated models from tables 1 to 3. For this validation, another circuit was collected in the same city, with similar street characteristics. Information was collected from 8 streets with a length between 47 m and 112 m for tangents before stop-controlled intersections, 12 streets with a length between 94 to 120 m for tangents before signal-controlled intersections, and 6 streets with a length between 66 to 287 m for tangents before the roundabout.

Six car drivers (3 were men and 3 were women) drove through the validation circuit. The drivers had an average age of 26.3 years (min = 25, max = 28) and an average driving experience of 7.2 years (min = 5, max = 9). Chevrolet or Hyundai brands (67%) were the vehicles that participated in the calibration circuit. Cars were 67% and pickup trucks were 33%. The average manufacturing year was 2007 (min = 2004, max = 2011), the average cylinder capacity was 2000 cm3 (min = 1400, max = 2700), and the average last mechanical check-up was 53 days before the collection day (min = 30, max = 90). Both the measurement equipment and the time data collection were the same in the initial circuit. Also, the same data processing from the calibration process was used for the calibration process.

Prediction errors were calculated in order to validate the previous calibrated speed models. Those errors were: mean squared error (MSE), mean absolute error (MAE), mean absolute percentage (MAPE), and Chi-square test (see table 4). Table 4 did not include the constant values models because is not possible to get prediction errors, however, in those cases, an analysis of variance (ANOVA) was carried out, comparing values from the constant value models with the collected values from validation. And those values should not differ at 95% level of confidence.

The highest values from table 4 are MSE and MAE. Those errors are obtained by the model of operating speed and the mean free-flow speed for the tangents before roundabouts. When these equations are used, caution should be taken because prediction error was around 5 km/h.

The highest values of the MAPE is given by the equations of the free-flow speed standard deviation, so caution is also suggested when will be used. Despite the values of those errors, these equations and the other is table 4, equations are valid because the chi-calculated did not pass the chi-critical value. Regarding to the fixed models, the p-value from ANOVA is more than the level of significance (α=0.05), which means that the differences between the means are not statistically significant, so also those fixed models are valid.

Table 4: Prediction errors and chi-square values for speed, acceleration, and deceleration equations for the intersections in this study.

# equation	Prediction errors					p value (ANOVA)
	MSE (km/h)²	MAE (km/h)	MAPE (%)	χ^2 calculated	χ^2 critic	
(2)	3.83	1.27	4.04	0.95	14.07	-
(3)	5.85	2.13	7.69	1.68	14.07	-
(4)	0.82	0.70	22.84	2.11	14.07	-
(5)	-	-	-	-	-	0.804
(6)	-	-	-	-	-	-
(7)	-	-	-	-	-	-
(8)	-	-	-	-	-	0.321
(9)	-	-	-	-	-	-
(10)	-	-	-	-	-	-
(11)	8.77	2.44	5.70	1.41	12.59	-
(12)	-	-	-	-	-	0.245
(13)	-	-	-	-	-	-
(14)	36.79	5.44	11.60	4.54	11.07	-
(15)	26.60	5.11	14.39	4.44	11.07	-
(16)	-	-	-	-	-	0.560

MSE= mean squared error, MAE=mean absolute error, MAPE=mean absolute percentage error,χ^2 calculated =Chi -square calculated, χ^2 critic = Chi-square critic. P value: results from ANOVA. -: Not performed o not possible to calculate.

It is worth mentioning that a standard deviation of 13 km/h was adopted for the calculation of the sample size, while the standard deviation in this study was 5.7 km/h. With this standard deviation, the sample size will be 8 observations, less the minimum used in this study. So, the sample size of this study has more than 95% level of confidence.

4 CONCLUSIONS

This article aimed to investigate the influence of several characteristics from urban street tangents, car driver, and vehicle on their speed in free-flow conditions. After analyzing the results, the following conclusions are presented:

In tangents before stop-controlled intersections, the street length was the most influential variable on speed. In tangents before signal-controlled intersections, object density was the only variable that influenced the speed in red light. In roundabout intersection and tangents before the roundabout, the street length influenced the speed. The average desired speed in tangents was 44.80 km/h, and the average speed within the roundabouts was 28.60 km/h. The calibrated and validated models are consistent with what happens in real driving condition. Considering this finding, apparently car drivers do not choose their speed; nevertheless, the car driver is indirectly influenced by the street length. If they perceive that the urban street is long they will speed up, and in short streets, they will do the opposite or the will keep their initial speed.

This study has several limitations. First, Video VBOX Lite was used based on the assumption that this device gives accurate speed data; which should be studied in the future. Also, all speed models are valid for speeds in the middle of the tangent, thus, other points in the street speed profile should be analyzed. Also, the calibrated speed models are valid in a specific range, so it should be used in those ranges. The circuits were located in an Andean city, which could differ from other cities.

Despite these limitations, the present study helps to extend the knowledge on urban speeds and their relationship with street variables, offering useful information for urban planners and street designers. It studied three different scenarios and several variables related to car driver characteristics, vehicle characteristics, roadway, and street environment. It showed that the street length is the main variable that affects the speed in urban tangents and not the variables related to the vehicle and driver. This outcome suggests that the government, especially in developing countries, should put more emphasis on street infrastructure than on the driver or vehicle.

ACKNOWLEDGEMENTS

The authors acknowledge the support of the National Secretariat of Higher Education, Science, Technology and Innovation (SENESCYT) and Universidad Técnica Particular de Loja from the Republic of Ecuador.

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