Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 69 (2023) 711–718

Transportation Research Procedia

www.elsevier.com/locate/procedia

AIIT 3rd International Conference on Transport Infrastructure and Systems (TIS ROMA 2022), 15th-16th September 2022, Rome, Italy

Road Infrastructure Safety Management: Proactive Safety Tools to Evaluate Potential Conditions of Risk

Giulia Del Serrone[a]*, Giuseppe Cantisani[a], Paolo Peluso[a], Ilaria Coppa[b], Maurizio Mancinetti[b], Barbara Bianchini[b]

[a]Sapienza University of Rome, Via Eudossiana 18, 00184 Rome, Italy
[b]Anas S.p.A., Direzione Operation e Coordinamento Territoriale, Pianificazione Trasportistica Aggiornamento e Classificazione Rete, Via Pianciani 16, 00184 Rome Italy

Abstract

The identification of highly critical sections in a road network is possible by examining the network operation, with the goal of determining the risk factors and observe the critical issues, in order to better plan possible improvements.
Therefore, this study proposes a method to evaluate the coherence of existing road layouts, through the analysis of the geometric characteristics, theoretical speeds and drivers operating speeds, under different environmental and flow conditions.
The analysis focuses on the road network managed by ANAS SpA in the Veneto Region, for which the reconstruction of the road axes geometry, the curvature graph and the theoretical design speed profile have been obtained, according to the indications of the Italian Ministerial Decree 05/11/2001. The theoretical design speed profile has then been compared with the information relating to the road users' mobility, in terms of the 85th percentile speeds, obtained from the extraction and analysis of the Floating Car Data (FCD). The data were processed by reconstructing the continuous profile of operating speeds with a specific regression function known as "smoothing cubic spline". The comparison with the theoretical design speeds allows to observe whether the users assume a behavior close to or distant from what is expected, based on the technical and geometrical characteristics of the road layout.
The proposed methodology can contribute to the implementation of a proactive road safety check, aimed at recognizing and assessing the potential risk conditions for road traffic, with particular attention to the point of view of the road user.

Keywords: Road safety management; Proactive safety tool; Floating car data; Comparison of operating and theoretical speeds.

* Corresponding author. Tel.: +39 06 44585 124; fax: +39 06 44585 121.
E-mail address: giulia.delserrone@uniroma1.it

2352-1465
10.1016/j.trpro.2023.02.227

1. Introduction

Directive (EU) 2019/1936 of the European Parliament and of the Council of October 23rd, 2019 introduced a proactive approach to road safety assessment at network level (Consiglio 2019). The new approach is aimed to evaluate the integrated safety of roads based on their design characteristics, regardless of the number of accidents recorded, through an “ex ante” observation. Therefore, the technical, geometric and functional characteristics of the infrastructures that can result in accidents are first identified (Wang, Quddus, and Ison 2013) and, subsequently, the strategies for the mitigation or elimination of these negative factors are detected.

In this context, the analysis of operating speeds can be an important tool for the management and monitoring of the real traffic conditions over a road network (Esposito et al. 2012; Hossain and Medina 2020; Park et al. 2021). Operating speeds, which are generally identified as the 85th percentile (%-ile) of the users’ current speed distribution, are useful to observe the actual drivers’ behavior and to investigate the causes of driving defects. The scientific literature proposes different predictive operating speed models, depending on the available speed data sample (Praticò and Giunta 2012). In case of data acquired in pre-defined sections, as in the center of the circular arcs or in the midpoint of the straights, it is assumed (Lamm et al. 1990; Watters and O’Mahony 1981) that the user travels along the elements with constant curvature at a regular speed, while he/she accelerates and decelerates along the transition elements. Instead, through the information extracted from traffic surveys it is possible to observe the actual driving behavior along the road and, consequently, to develop more detailed speed models, able to better represent the real phenomenon and consequently evaluate the design consistency of the road infrastructure. (Cafiso and Cerni 2012; Cafiso, Di Graziano, and La Cava 2005; Cvitanić and Maljković 2017; Fabrizi and Ragona 2014; Ibrahim H. Hashim, Abdel-Wahed, and Moustafa 2016; Javier and Torregrosa 2013; Silva, Almeida, and Vasconcelos 2017; Zuriaga et al. 2010).

The need to have reliable data source for vehicular speeds’ surveys has meant that the applications of Information and Communication Technologies (ICT) in this field have significantly increased in recent years. ICT have simplified and improved the acquisition of georeferenced information (Verma, Varghese, and Jana 2021), generating a large and complex set of data, known as Big Data, for which it has become necessary to define data mining models (Fusco, Colombaroni, and Isaenko 2016; Joe Grengs, Xiaoguang Wang 2009; Leduc 2008; Valenti, Liberto, and Mastroianni 2016; Wu et al. 2014). This is how, in addition to the classic static traffic detection devices such as detection stations, automatic traffic counters, video cameras, radar and laser guns, traffic sensors, such as microwave radars and acoustic sensors (Bassani et al. 2016; Cantisani, Del Serrone, and Di Biagio 2018; Cantisani, Del Serrone, and Di Biagio 2020; Dell’Acqua 2012; Ibrahim Hassan Hashim 2011; Lobo, Rodrigues, and Couto 2013; De Luca, Lamberti, and Dell’Acqua 2012; Ottesen and Krammes 2000), an innovative source of data, known as Floating Car Data (FCD), has been proposed for these aims. FCD come from probe vehicles equipped with black boxes installed mainly for insurance purposes; they are geo-localized through GPS technology and record a wide range of information such as position, speed, travel direction, date and time of issue, which are subsequently sent to data collection and processing centers. Although to date the FCD sample has a penetration rate of 2-5%, its representativeness has been demonstrated by means of statistical analyses in comparison with traditional data sources, which have found values of the coefficient of determination R^2 greater than 0.9 (Giuseppe Cantisani, Del Serrone, and Peluso 2022). Therefore, compared to the static devices which sample the entire traffic flow but only in the points where they are installed, FCD currently represent an effective monitoring tool as they are georeferenced and acquired along the entire road layout; on this sample basis, accurate assessments can be made and methods for estimating travel times, traffic forecasts and circulation methods can be pursued. (Ajmar et al. 2019; Fusco, Colombaroni, and Isaenko 2016; Wagner 2009).

In this study, starting from a sample of FCD, the continuous operating speed profiles have been reconstructed by means of an algorithm that uses the specific regression function “smoothing cubic spline” (G Cantisani et al. 2004; Dyer and Dyer 2001). This allowed providing a representative trend of the actual driving behavior along various infrastructure belonging to the road network. The knowledge of the operating conditions will allow defining a methodology, from which it will be possible to identify any risk posture that the user could encounter while traveling on existing roads.

2. Data and Methods

The assessment about the coherence between the technical features and the operating conditions of existing roads - through the analysis of their geometric characteristics, theoretical speeds and operating speeds, under different environmental and traffic conditions - was carried out on the entire road network administered by the company ANAS in the Veneto region. The examined roads, on the basis of their construction, technical and functional characteristics, are recognizable as rural roads Type C in accordance with the Italian Highway Code (Ministero delle Infrastrutture e dei Trasporti 1992).

The geometric reconstruction of the layouts was carried out by applying an original procedure for road axes planimetric elements recognition (Giuseppe Cantisani and Del Serrone 2021), starting from the georeferenced vertices of the road graph. The process returned all the descriptive parameters of the various planimetric elements of the road layout, from which it was possible to create the curvature diagram. Conventionally, in the graphical representation, the direction of the right-hand curves has been assumed with a positive value of the curvatures, while that of the left-hand curves with a negative value. The sections that have not been classified either as straight or as circular arcs, have been considered as variable curvature elements, having the function of transition between different constant curvature elements. The described preliminary analysis ended with the reconstruction of the theoretical speed diagram, following the indications of the Ministerial Decree 2001 (Ministero delle Infrastrutture e dei Trasporti 2001) for the calculation of the design speed; therefore, the speed profile was obtained through the implementation of a calculation code, which extracts the trend of theoretical speeds as a function of the curvilinear abscissa, based solely on the planimetric trend and with the application of analytical formulas.

The information relating to the road users' driving behavior was obtained from the analysis and processing of the Floating Car Data (FCD) provided by a commercial Company; however, since the extraction of the speeds actually assumed by users did not take place in real time, it is more correct to refer to the definition of Historical Car Data (HCD). The data used date back to three previous monthly periods: August 2018, February 2019, and May 2019, and they are geolocated within the Veneto region. The total number of data in the sample amounts to a value greater than 900 million, distributed over the three months of observation as shown in the following Table 1:

Table 1. An example of a table.

Total HCD	**927'733'936.00**
August 2018	309'060'029.00
February 2019	315'978'826.00
May 2019	302'695'081.00

The preliminary operations for the management and treatment of the HCD took place using the MySQL Workbench software (Oracle Corporation 2016), an open source SQL relational database management system developed and supported by Oracle. Subsequently, the HCD were processed and filtered through other calculation codes, which first allowed to extract from the GPS database the data emitted along each examined road; then, with a map matching procedure, the geographical coordinates of the vehicles' positioning were combined to the graph of each street (Chen, Shen, and Tang 2011; Miwa et al. 2012; Xi et al. 2007). Finally, through the vehicle direction information, the HCD were divided into the two main travel directions: AB and BA. Vehicles with a direction of travel in total disagreement with the layout of the road were excluded, since these vehicles were probably located at intersections, underpasses, overpasses or entrances, and, albeit near the examined road, they were performing different and independent maneuvers.

The analysis of the operating conditions was carried out with the aim of obtaining the profile of 85th %-ile of operating speeds, in order to compare them with the theoretical speeds obtained from the reconstruction of the speed diagram, and with the posted speed limits. The speed data from the probe vehicles was filtered to obtain a smaller sample of data referred to the ideal weather and flow conditions. The identification of the time slots corresponding to the constrained and unconstrained traffic conditions took place with the study of the traffic surveys obtained by the inductive-loop detectors and microwave radar sensors; for this aim, the ANAS Company has made available the data acquired from the control units installed along the network under consideration.

The observation of the fundamental diagrams of traffic flow (N,v) allowed to determine that the flows were always unconstrained: as the flow increases, the travel speeds assumed a constant trend, not falling back. Therefore, other external factors have been investigated to understand their influence on user behavior. A division of the HCD into the two macro-time slots of daytime and nighttime was therefore carried out, by reading the sunrise and sunset hours from the weather reports. Two speed profiles were thus created, respectively representing day and night conditions, which can allow highlighting the relative differences and the different behaviors assumed by the users, when compared. The search for ideal driving conditions also from a meteorological point of view was conducted considering the time of the rainfalls, based on the data acquired by the rain gauge stations located near the roads under considerations, and subsequently eliminating the data recorded in adverse weather conditions. More specifically, through the implementation of a calculation code, it was possible to proceed with an automated filtering operation of HCD, to collect and exclude from the data sample the ones recorded during the hours affected by heavy rain. So, finally, a set of data representative of operating conditions corresponding to ideal weather and flow conditions was obtained.

As a result of the operations described above, precise information referred to the curvilinear abscissa of each road has been therefore obtained, from which a continuous profile of the operating speeds has been realized with the use of a particular regression function known as “smoothing cubic spline”. A third degree polynomial regression has been used to interpolate the data, which creates a curve that approximates the trend of the input data through a least squares fitting. For each road segment different speeds have been calculated, specifically the average, the minimum, the maximum, and the 85th %-ile, and also the root mean square and the number of data falling within the segment itself.

The representation of the different speed profiles, overlapped by the diagram of the theoretical speeds, the posted speed limits, and the position of the various inventory and monitoring data (such as intersections, accesses, bridges, viaducts and tunnels), allows an immediate comparison between the theoretical model and the actual speeds. In this way, the identification of the causes that led users to adopt a certain behavior and the recognition of road sections potentially critical for drivers will be more easily performed.

3. Results

The search for ideal driving conditions made it possible to analyze the trends in operating speeds, for various scenarios, showing the effects of some of the main interactions between environment, infrastructure and road user that can influence the correct operation of the road system.

For example, Figure 1 shows the comparison of the operating speeds (85th %-ile) in the two day-time and night-time bands: it can be observed that the speed profile at nighttime is generally above the corresponding speed profile at daytime.

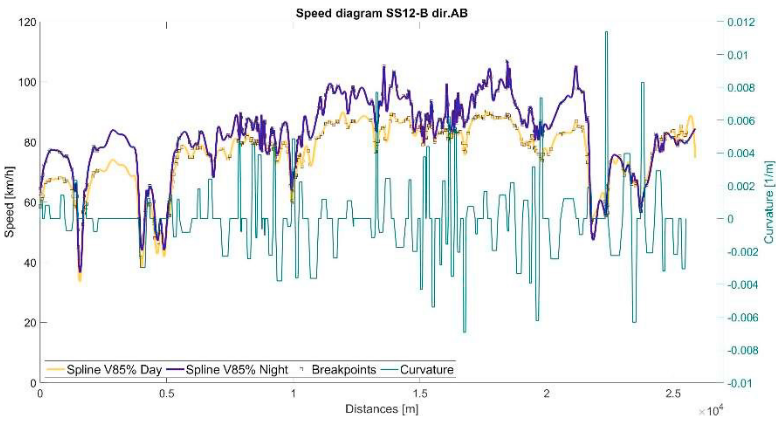

Fig. 1. Comparison of the operating speeds in the two day time and night time bands.

The graphs therefore show a tendency of users to assume higher speeds at night than during the day, along the analyzed roads, with the exception of some sections characterized by a more binding geometry or by factors related to the infrastructure and territorial context, regardless of the brightness and visibility present.

As for the conditioning due to meteorological factors, in Figure 2 the trends of the operating speeds evaluated in the two different conditions of dry and wet road are shown. It is immediately noticeable, in agreement with the literature (Kyte et al. 2001; Procedure 1954; Yeo, Lee, and Jang 2021), how in adverse weather conditions marked by a wet pavement, the speeds assumed by drivers are lower than those reached in good weather conditions characterized by dry pavements. The difference between the two profiles shows a much more precautionary driver behavior during rainy hours, since these conditions induce drivers to reduce speed due to a limited visibility, the effect of rain on the vehicles, and the reduced friction coefficients of wet pavements.

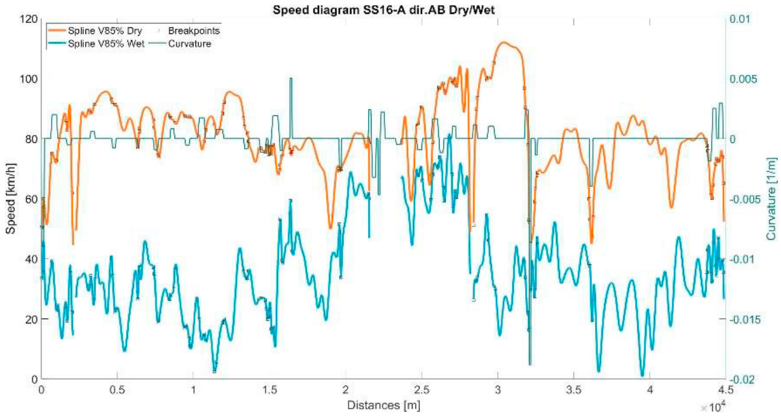

Fig. 2. Comparison of the operating speeds on dry and wet pavement.

From the observation of the graphs, it is also evident that the behavior assumed by the drivers does not depend exclusively on the geometry of the road layout. Other factors related to the anthropization of the territory in which the road is located, like the density of accesses, intersections and structures along the route, as well as the characteristics of the vehicular flow and the road management policies can affect the driving styles.

In particular, to investigate the effects of speed regulation, the graph in Figure 3 has been created, which directly represents the comparison between the actual speeds practiced along a road with the theoretical speeds of the same section and the posted speed limits. The practiced speeds are distinguished in the two day and night time bands, represented by cubic spline interpolations of the speed data.

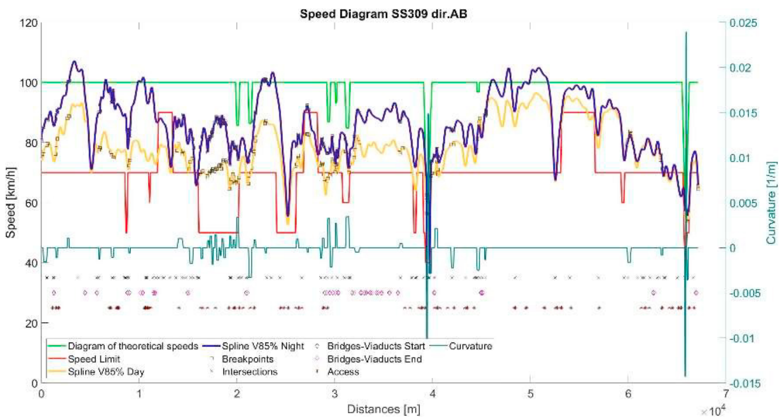

Fig. 3. Comparison of actual speeds, theoretical speeds, and speed limits imposed.

By means of a global observation of the entire graph, it can be seen how the trend of operating speeds generally extends within a range identified above by the design speed and below by the imposed limits. To evaluate the influence of the road geometry (Praticò and Giunta 2011), it was decided to show overlapped in the same graph the curvature diagram, to evaluate the conditioning induced by the presence of geometrically binding elements. At the same time, to evaluate the anthropization of the territory, the graph shows the positions along the curvilinear abscissa of various elements such as intersections, accesses to private and public areas and the points corresponding to the start and end sections of overpasses and bridges along the infrastructure. This additional information makes it possible to observe how in case of a dense concentration of accesses or intersections the operating speeds reach minimum values, maintaining an almost constant speed as users are prevented from accelerating. On the contrary, in the sections where the interaction of the infrastructure with the surrounding environment is apparently low, users tend to increase their speeds, with the consequent failure to comply with the limits imposed. It can also be noted how the operating speeds tend to reach and exceed the design speeds only at night, especially in the rural sections having road platform consistent with the standards, good visibility, and where the density of intersections and accesses to private areas is low. It is interesting to notice how along these sections the operating speeds, defined with the identification of ideal conditions, and tends towards the theoretical ones. Instead, during daytime in industrialized areas, with the presence of warehouses, companies or factories, with high percentage of heavy vehicles in the traffic flow, operating speeds are lower than theoretical speeds. In addition, there are sudden huge drops in speeds near intersections, mainly at roundabouts, where the geometry requires a reduction in travel speed in order to allow the deflection of vehicular trajectory.

Since the sample of the examined roads includes layouts that unroll in both flat and mountainous environments, the analysis has also aimed to assess how the territorial context in which the infrastructure is embedded can influence the driving behavior. It has been observed that with the same type and road classification, along the sections where it is low or absent the anthropization of the territory the operational speeds tend to the theoretical ones, although the geometry of the road axis of a mountain road may be more binding in terms of travel speed than in a flat environment. On the other hand, when crossing urban centers and sections characterized by high density of accesses and intersections, the differences between theoretical and operating speeds are amplified.

Coincident minimum points in the two night and day speed profiles correspond to specific sections where speed control devices are installed, which induce drivers to respect the posted speed limits, regardless of time of day.

The comparison of speed limits with actual speeds allows to know if they are respected or not by drivers and to consider the possible causes of these behaviors. In particular, in the view of a proactive approach to road safety it is necessary to remind that if the road users consider the speed limit proper for the infrastructure characteristics, then a respectful behavior of the limit imposed can be expected, while the failure to recognize the limit can sometimes be attributed to an imposition perceived as excessively restrictive.

In conclusion, the speed diagrams extracted from the analyses show an operating speeds trend sometimes at odds with the theoretical model and difficult to predict, as it depends on various factors. The survey carried out shows how driver behavior is influenced by the various information and conditioning provided by the entire road system and by the environment, consequently noting those critical sections where the lack of the coherence between various components can evolve into a potentially risk condition.

4. Conclusions

The recent proactive approach to road safety ask network managers to identify and mitigate the significant risk factors for drivers, especially evaluating the critical issues related to the consistency of the road layouts. This research provides an input into the “ex ante” road safety assessment, before accidents occur or in the case of the impossibility to analyze the accident data. The proposed methodology identifies potential risk conditions along an infrastructure, with particular attention to the road user point of view: the driver, indeed, interprets the information from the environment-vehicle-infrastructure system and behaves accordingly, in terms of operating speeds and maneuvers performed.

The case study involved the road network managed by ANAS SpA in the Veneto Region. The proposed methodology requires the preliminary use of an innovative procedure for reconstructing the horizontal alignment of the road axes, so allowing graphing their curvatures and deducing the theoretical speed profiles. These last can be then compared with the operating speeds, considered as the 85th %-ile of the distribution of actual vehicular speeds. The data source adopted was that of the Historical Car Data (HCD), which reveals itself as a reliable data sample, well representative of the entire traffic stream, despite to date the penetration rate of the instrumented probe vehicles is still relatively low. Speed data were processed to reconstruct a continuous profile of the operating speeds (85th %-ile of the users' speed distribution) with a specific regression function, known as "smoothing cubic spline".

The comparison of operating speeds with theoretical design speeds is useful to observe whether users assume a behavior close to or far from the theoretically expected one. In this study, various road sections characterized by a large deviation between the operational and theoretical speeds have been found; they should be considered as potentially hazardous to safe driving and further investigation will be focused on them. Furthermore, it has been shown that the operating speeds are not constant within elements with constant curvature, contrary to what is stated by some theoretical models, but rather they have trends characterized by a frequent succession of acceleration and deceleration phases. This last result highlights how the user can assume behaviors that differs from the expected ones, also because the trend of the actual speeds does not depend only on the geometric characteristics of the alignment but on the entire vehicle-environment-infrastructure system. In fact, the study found that the operational speeds are influenced by both the characteristics and conditions of the infrastructure and by the territory, highlighting how the context and the anthropization play a key role for driving behaviors.

The proposed methodology can contribute to the implementation of a proactive approach to road safety, aimed at recognizing and assessing the potential risk conditions for road traffic, identifying in a first phase the sections that can be classified as potentially more exposed to risk of accidents. Subsequently, by planning on-site inspection activities, it will be possible to focus and evaluate the specific risk factors, observing their issues, to eliminate or mitigate their effects through the planning of the actions for infrastructure improvements.

References

Ajmar, A., E. Arco, P. Boccardo, and F. Perez. 2019. "Floating Car Data (Fcd) for Mobility Applications." *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives* 42(2/W13): 1517–23.

Bassani, Marco, Cinzia Cirillo, Serena Molinari, and Jean Michel Tremblay. 2016. "Random Effect Models to Predict Operating Speed Distribution on Rural Two-Lane Highways." *Journal of Transportation Engineering* 142(6): 1–11.

Cafiso, Salvatore, and Gianluca Cerni. 2012. "New Approach to Defining Continuous Speed Profile Models for Two-Lane Rural Roads." *Transportation Research Record* (2309): 157–67.

Cafiso, Salvatore, Alessandro Di Graziano, and Grazia La Cava. 2005. "Actual Driving Data Analysis for Design Consistency Evaluation." *Transportation Research Record* (1912): 19–30.

Cantisani, G, D Dondi, G Loprencipe, and A Ranzo. 2004. "Spline Curves for Geometric Modeling of Highway Design." In *Proc., 2nd Int. Congress New Technologies and Modelling Tools for Road Applications to Design and Management, Societe Italiana Di Infrastrutture Viarie, Ancona, Italy*,.

Cantisani, Giuseppe, and Giulia Del Serrone. 2021. "Procedure for the Identification of Existing Roads Alignment from Georeferenced Points Database." *Infrastructures* 6(1): 1–16.

Cantisani, Giuseppe, Giulia Del Serrone, and Giorgia Di Biagio. 2018. "Calibration and Validation of and Results from a Micro-Simulation Model to Explore Drivers' Actual Use of Acceleration Lanes." *Simulation Modelling Practice and Theory* 89(May): 82–99. https://doi.org/10.1016/j.simpat.2018.09.007.

Cantisani, Giuseppe, Giulia Del Serrone, and Giorgia Di Biagio. 2020. "Results of Micro-Simulation Model for Exploring Drivers' Behavior on Acceleration Lanes." *European Transport - Trasporti Europei* (77): 1–10.

Cantisani, Giuseppe, Giulia Del Serrone, and Paolo Peluso. 2022. "Reliability of Historical Car Data for Operating Speed Analysis along Road Networks." *Sci* 4(2). https://www.mdpi.com/2413-4155/4/2/18.

Chen, Feng, Mingyu Shen, and Yongning Tang. 2011. "Local Path Searching Based Map Matching Algorithm for Floating Car Data." *Procedia Environmental Sciences* 10(PART A): 576–82. http://dx.doi.org/10.1016/j.proenv.2011.09.093.

Consiglio, Parlamento europeo e. 2019. "Direttiva 2019/1936/EC." *Gazzetta ufficiale dell'Unione europea* 2019.

Cvitanic´ , D., Maljkovic´ , B., 2017. Operating speed models of two-lane rural state roads developed on continuous speed data. Tehnicki vjesnik/Technical 620 Gazette 24 (6).

Dell'Acqua, Gianluca. 2012. "European Speed Environment Model for Highway Design-Consistency." *Modern Applied Science* 6(9): 1–10.

Dyer, S A, and J S Dyer. 2001. "Cubic-Spline Interpolation. 1." *IEEE Instrumentation Measurement Magazine* 4(1): 44–46.

Esposito, Tommaso, Raffaele Mauro, Francesca Russo, and Gianluca Dell'Acqua. 2012. "Operating Speed Prediction Models for Sustainable Road Safety Management." *ICSDC 2011: Integrating Sustainability Practices in the Construction Industry - Proceedings of the International Conference on Sustainable Design and Construction 2011*: 712–21.

Fabrizi, V., and R. Ragona. 2014. "A Pattern Matching Approach to Speed Forecasting of Traffic Networks." *European Transport Research Review* 6(3): 333–42.

Fusco, Gaetano, Chiara Colombaroni, and Natalia Isaenko. 2016. “Short-Term Speed Predictions Exploiting Big Data on Large Urban Road Networks.” *Transportation Research Part C: Emerging Technologies* 73: 183–201. http://dx.doi.org/10.1016/j.trc.2016.10.019.

Hashim, Ibrahim H., Talaat A. Abdel-Wahed, and Yasser Moustafa. 2016. “Toward an Operating Speed Profile Model for Rural Two-Lane Roads in Egypt.” *Journal of Traffic and Transportation Engineering (English Edition)* 3(1): 82–88.

Hashim, Ibrahim Hassan. 2011. “Analysis of Speed Characteristics for Rural Two-Lane Roads: A Field Study from Minoufiya Governorate, Egypt.” *Ain Shams Engineering Journal* 2(1): 43–52. http://dx.doi.org/10.1016/j.asej.2011.05.005.

Hossain, Fahmid, and Juan C Medina. 2020. “Effects of Operating Speed and Traffic Flow on Severe and Fatal Crashes Using the U.S. Road Assessment Program Methodology and Field Data Verification.” *Transportation Research Record* 2674(11): 30–41.

Javier, Francisco, and Camacho Torregrosa. 2013. “New Geometric Design Consistency Model Based On.” *Accident Analysis & Prevention* 61: 33–42.

Joe Grengs, Xiaoguang Wang, Lidia Kostyniuk. 2009. “Using GPS Data to Understand Driving Behavior.”

Kyte, Michael, Zaher Khatib, Patrick Shannon, and Fred Kitchener. 2001. “Effect of Weather on Free-Flow Speed.” *Transportation Research Record* (1776): 60–68.

Lamm, Ruediger, E.M Choueiri, Theodor Mailaender, and T Unger V Sandner. 1990. “Comparison of Operating Speed on Dry and Wet Pavement of Two Lane Rural Highways.” *Transportation Research Record* 1280(1122): 68–78.

Leduc, Guillaume. 2008. “Road Traffic Data : Collection Methods and Applications.” *EUR Number: Technical Note: JRC 47967* JRC 47967: 55. http://ftp.jrc.es/EURdoc/EURdoc/JRC47967.TN.pdf.

Lobo, António, Carlos Rodrigues, and António Couto. 2013. “Free-Flow Speed Model Based on Portuguese Roadway Design Features for Two-Lane Highways.” *Transportation Research Record* (2348): 12–18.

De Luca, Mario, Renato Lamberti, and Gianluca Dell’Acqua. 2012. “Freeway Free Flow Speed: A Case Study in Italy.” *Procedia - Social and Behavioral Sciences* 54(2011): 628–36. http://dx.doi.org/10.1016/j.sbspro.2012.09.780.

Ministero delle Infrastrutture e dei Trasporti. 1992. “Nuovo Codice Della Strada.” 2001. “Norme Funzionali Geometriche per La Costruzione Delle Strade.” 285: 90.

Miwa, Tomio, Daisuke Kiuchi, Toshiyuki Yamamoto, and Takayuki Morikawa. 2012. “Development of Map Matching Algorithm for Low Frequency Probe Data.” *Transportation Research Part C: Emerging Technologies* 22: 132–45. http://dx.doi.org/10.1016/j.trc.2012.01.005

Oracle Corporation. 2016. “Oracle Corporation, MySQL™ Workbench Reference Manual, Revision: 47148, 2016 - Http://Dev.Mysql.Com/Doc/Workbench/En/.”

Ottesen, Jeffery L, and Raymond A Krammes. 2000. “Speed-Profile Model for a Design-Consistency Evaluation Procedure in the United States.” *Transportation Research Record* 1701(00): 76–85. http://trrjournalonline.trb.org/doi/pdf/10.3141/1701-10.

Park, Eun Sug, Kay Fitzpatrick, Subasish Das, and Raul Avelar. 2021. “Exploration of the Relationship among Roadway Characteristics, Operating Speed, and Crashes for City Streets Using Path Analysis.” *Accident Analysis and Prevention* 150(November 2020): 105896. https://doi.org/10.1016/j.aap.2020.105896.

Praticò, F.G., Giunta, M., 2012. Quantifying the effect of present, past and oncoming alignment on the operating speeds of a two-lane rural road. The Baltic Journal of Road and Bridge Engineering, vol. 7(3): 181-190. (DOI: 10.3846/bjrbe.2012.25).

Praticò, F. G., Giunta, M., 2011. Speed Distribution on Low-Volume Roads in Italy: From Inferences to Rehabilitation Design Criteria. Transportation Research Record, 2203(1), 79–84. https://doi.org/10.3141/2203-10.

Procedure, Study. 1954. “Speeds of Passenger Cars on Wet and Dry Pavements.” : 79–84.

Silva, Ana Bastos, Raul Almeida, and Luís Vasconcelos. 2017. “A Speed Model for Curves of Two-Lane Rural Highways Based on Continuous Speed Data.” *Transport Infrastructure and Systems - Proceedings of the AIIT International Congress on Transport Infrastructure and Systems, TIS 2017*: 177–83.

Valenti, Gaetano, Carlo Liberto, and Pierpaolo Mastroianni. 2016. “L’importanza Dei Big Data Sulla Mobilità Urbana.” : 42–47.

Verma, Deepank, Varun Varghese, and Arnab Jana. 2021. “Applicability of Big Data for Transportation Planning and Management.” *Advances in Urban Planning in Developing Nations*: 99–110.

Wagner, Peter. 2009. “How Many Floating Car Data (FCD) Are Needed for Traffic Management?” (November): 1–29. http://elib.dlr.de/60552/1/FOVUS-FCD4VM.pdf.

Wang, Chao, Mohammed A. Quddus, and Stephen G. Ison. 2013. “The Effect of Traffic and Road Characteristics on Road Safety: A Review and Future Research Direction.” *Safety Science* 57: 264–75. http://dx.doi.org/10.1016/j.ssci.2013.02.012.

Watters, Paul, and Margaret O’Mahony. 1981. “The Relationship Between Geometric Design Consistency and Safety on Rural Single Carriageways in Ireland.” *Journal of Chemical Information and Modeling* 53(9): 1689–99.

Wu, Xindong, Xingquan Zhu, Gong Qing Wu, and Wei Ding. 2014. “Data Mining with Big Data.” *IEEE Transactions on Knowledge and Data Engineering* 26(1): 97–107.

Xi, Lianxia, Quan Liu, Minghua Li, and Zhong Liu. 2007. “Map Matching Algorithm and Its Application.”

Yeo, Jiho, Jooyoung Lee, and Kitae Jang. 2021. “The Effects of Rainfall on Driving Behaviors Based on Driving Volatility.” *International Journal of Sustainable Transportation* 15(6): 435–43. https://doi.org/10.1080/15568318.2020.1756543.

Zuriaga, Ana Maria Pérez, Alfredo García García, Francisco Javier Camacho Torregrosa, and Pierangelo D’Attoma. 2010. “Modeling Operating Speed and Deceleration on Two-Lane Rural Roads with Global Positioning System Data.” *Transportation Research Record* (2171): 11–20.