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Gap-acceptance behavior at roundabouts: validation of a driving simulator environment using field observations

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Abstract

A general procedure for the validation of a driving simulation environment for the analysis of gap-acceptance behavior was developed in this study. It allows to test whether a synthetic indicator of gap-acceptance behavior (the mean critical gap) shows significant differences when computed on the basis of field observations versus observations collected in the simulated environment. If such differences are not significant, driver behavior can be considered similar in the two contexts, thus supporting validation of the driving simulation environment. In order to demonstrate its effectiveness, the proposed procedure is applied to the case of a three-leg roundabout located in the Veneto region (Italy). The results show that the mean critical gap estimated in the field and the mean critical gap estimated in the virtual environment are not significantly different. The proposed procedure can be applied in various contexts in which gap-acceptance behavior is a central element in terms of safety and operational performance of the traffic system under analysis.

Keywords: gap-acceptance; driving simulator; roundabout

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1. Introduction

The analysis of gap-acceptance behavior is an important field of investigation for its implications for intersection safety and level of service. Several studies have been conducted on gap-acceptance at unsignalized intersections, using both classical probabilistic models (Rossi et al., 2013; Maze, 1981; Teply et al., 1997a, 1997b) and fuzzy system theory (Rossi & Meneguzzer, 2002; Rossi et al., 2011a; Rossi et al., 2014a; Gastaldi et al., 2015); calibration and validation of these models is usually based on data collected during field observations at real intersections. In

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general terms, the use of a driving simulator (DS) allows to record variables describing drivers' behavior in different situations (easily and economically) and to measure the effects of variables that are not detectable in real traffic contexts. With reference to the study of gap-acceptance behavior, the set of observations that can be collected during a DS experiment makes it possible to carry out statistical analyses on the effect of speed, type and arrival time distribution of on-coming vehicles, size of gap, delay, viewing distance, driver age and gender, etc. on the drivers propensity to accept a gap (Yan et al., 2007; Adebisi & Sama, 1989; Ashworth, 1970; Kittelson & Vandehey, 1991; Cassidy et al., 1995; Wennel & Cooper, 1981; Rossi et al., 2012; Rossi et al., 2018). However, it is not clear whether phenomena and data recorded within simulated scenarios can be directly used in the analysis of real-life behaviors in on-road conditions : situations occurring in a DS could be different from those that occur in real contexts, primarily because of the lack of risk in the simulated environment. The validity of a DS as a reliable tool to measure drivers' behavior has been extensively debated within the research community, and the general indication is that simulators, after appropriate validation, can be used for investigating drivers' behavior (Espié et al., 2005; National Highway Administration, 2010; Bella, 2008; Godley et al., 2002; Milleville-Pennel & Charron, 2015; Farah et al., 2007; Bella, 2005; Blana, 1996; Staplin, 1995; Kaptein et al., 1996; Bittner et al., 2002; Alexander et al., 2002; Klee et al., 1999; Rossi et al., 2011b).

The main aim of our work is to develop a complete procedure for validating a virtual scenario to be used for analyzing driver gap-acceptance behavior at unsignalized intersections, and to test its application on a case study. The paper is organized as follows. Section 2 illustrates in general terms the procedure proposed for the validation of a DS environment, describing the various activities required for its implementation and the relationships among them. Section 3 presents the application of the procedure to a specific case study and the results obtained. Concluding remarks and possible developments of this research are presented in Section 4.

2. Procedure components

This work presents a complete procedure for designing, developing and validating unsignalized intersections in virtual environments starting from gap-acceptance behavior observations in real contexts (Figure 1). The first activity consists of an on-field traffic survey at the intersection chosen for the study. Data collection is mainly focused on headways between vehicles in the main stream and on the gap selection process of vehicles moving through the intersection from a given approach. Real gap-acceptance data are used for estimating the mean critical gap of drivers observed in the survey.

On the other hand, the field observations are used to extract information about headways between vehicles in the main stream, in particular by identifying trendless samples used to determine the probability density function that best describes the distribution of headways. The fitted distribution is then applied to generate sequences of headways in the DS gap-acceptance experiment. The latter produces a set of gap-acceptance data that are used for estimating the mean critical gap through the same method adopted for the treatment of data collected on field.

Finally, the values of mean critical gap estimated on the basis of field and simulated observations are compared using an appropriate statistical test of hypotheses. If the results of this test indicate that there is no statistically significant difference between the two values, the driving simulation environment can be considered to be a valid representation of the phenomenon under analysis with reference to the chosen case study.

2.1. Gap-acceptance data treatment (on field observation)

The primary objective of field observations is to collect information on drivers' gap-acceptance decisions (acceptances and rejections). The observations relate to the minor stream entry movement, and are usually collected using video camera recording systems. The videos are then processed using application software that allows the user to record the vehicle arrival and departure at the yield line (YL) of the minor approach and the main stream vehicle arrival at the conflict point (CP) together with the vehicle category (car, van, truck, etc.). The data are organized in a database and then processed using a software procedure that extracts the following gap-acceptance information for each driver decision: type of time interval (lag or gap); interval time size; entering vehicle waiting time at stop line (zero in case of lag acceptance); category of minor approach vehicle; category of main stream vehicle closing the interval; driver decision (interval acceptance or rejection).

Even if we use the term gap because it is more common in the literature on this topic, the variable that was measured in the field is the time headway (TH) between vehicles in the main stream.

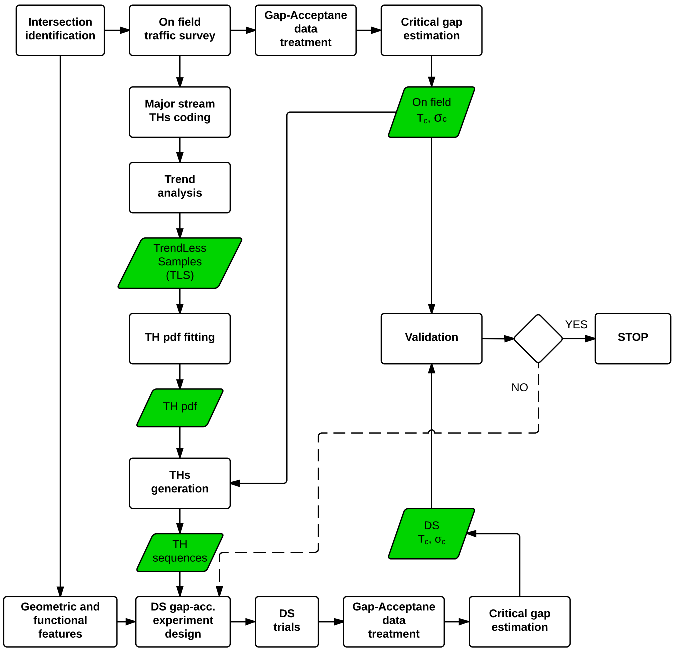

Figure 1. Functional components of proposed procedure.

2.2. Mean Critical Gap Estimation (on-field and DS gap-acceptance data)

Mean critical gap is one of the most significant parameters used in capacity assessment of maneuvers at priority intersections (including roundabouts). It depends both on geometric characteristics of the intersection and on driver characteristics (age, gender, driving experience, driving style, etc.). Several methods for estimating mean critical gap over a population of drivers have been proposed in the literature since the 1960's. Among these methods, the well-known maximum likelihood technique seems to be the most accurate (Rodegerdts et al., 2007; Tian et al., 1999); this method, which requires information about the accepted gap and the largest rejected gap for each driver, has been used to process the gap-acceptance data available for both on-field and laboratory situations The output of this step is the mean critical gap (t_c) with the corresponding standard deviation (σ_c).

2.3. Trend analysis

Trend analysis is an essential step in fitting probability density functions representing TH distributions, because the real properties of this variable can only be inspected with stationary data (at least in time). In our procedure, trend analysis was implemented in R language, following Luttinen (1996). In order to obtain stationary datasets, each sample of time headways at the entry-main stream CP is submitted to trend analysis by the "exponential ordered scores trend test" of Cox and Lewis (1966), applied by Luttinen (1992) and slightly modified by Rossi et al. (2014b). The output of this task is a set of TrendLess Samples (TLSs) observed at the CP.

2.4. Time headway distribution fitting process and sequences generation

The aim of the fitting process is to identify the best theoretical model to describe TH empirical distributions answering criteria of reasonability, applicability and validity (Luttinen, 1996). Since we are interested in having a good approximation of empirical TH distributions, field validity is our main objective. First, the goodness-of-fit (GOF) of the model has to be graphically checked: the empirical distribution in the form of histograms or kernel density functions (Luttinen, 1996; Rossi et al., 2014b) is compared with the fitted model curve. Among the GOF tests that can be used to evaluate the adherence of the model to the data, the best is believed to be that of Kolmogorov-Smirnov, which is always applicable, valid, and provides an immediate and reliable response. The output of this step is a set of TH pdfs, each of them associated to TLSs characterized by specific flow rates.

The output of this step is a set of TH sequences to be used in the DS experiment. Each sequence is generated using the estimated TH distribution. In order to exclude from the DS experiment gap acceptance decisions that can be considered "certain" (occurring when time headways are much larger than any reasonable value of critical gap), the distribution used in the generation of TH sequences is truncated with a threshold that is identified based on observed gap-acceptance data (see the feedback in the diagram of Figure 1).

2.5. Driving simulator gap-acceptance experiment and critical gap estimation

The virtual scenario representing the system under analysis for the DS experiment is developed on the basis of the observation of the geometric and functional features of the real intersection and of the way drivers actually use it. Software commonly used for the development of the virtual environment allows to control both the geometry of the intersection and the parameters determining the motion of the vehicles (called "agents") interacting with the driver under observation. TH sequences generated in the previous step of the procedure are used to simulate the arrival of agents at the CP.

During the DS trials, gap-acceptance data are collected and recorded in order to provide, for each decision of each test driver, the following information: interval time size; entering vehicle waiting time at stop line (zero in case of lag acceptance); category of main stream vehicle closing the interval; driver decision (interval acceptance or rejection). These data are then used for the estimation of the mean value and standard deviation of the critical gap, based on the same procedure described in section 2.2 with reference to the on-field observation of the phenomenon.

2.6. Validation

In the specific case of unsignalized intersections, a direct comparison between the value of mean critical gap estimated in the field and the value of the same parameter determined in the DS trials is considered an appropriate approach for the validation of the virtual environment. In case of a successful validation, the virtual environment can be considered as a reliable tool for performing both safety studies and operational analyses, because mean critical gap implicitly provides a measure of the level of risk that drivers are willing to accept when performing the desired maneuver, and has a considerable effect on the capacity of minor approaches to unsignalized intersections. In our procedure, we use a test of hypotheses based on the t-statistic as a way to identify the existence of significant differences between the values of mean critical gap estimated in the field and in the simulation. If statistically significant differences do not emerge from this test, then the virtual environment can be considered to be validated; otherwise, it is necessary to modify the DS experiment design in order to obtain the desired validation (see the dashed feedback in the diagram of Figure 1).

3. Application of the procedure

3.1. Description of study site

The study site is a three-leg roundabout located in the urban area of Noventa Padovana, in the province of Padova, Italy. Basic roundabout characteristics are reported in Table 1. The primary objective of our field observations was to collect information on drivers' gap-acceptance decisions (acceptances and rejections). The observations relate to the entry movement from the North and West approaches.

3.2. On field traffic survey, gap acceptance data treatment and mean critical gap estimation

The experimental observations were collected during peak-hour periods (7:00 am– 10:00 am and 5:00 pm – 8:00 pm) in weekdays through a video camera recorder. The entire dataset obtained from the field survey consisted of 13,895 entry maneuvers. For each maneuver, the accepted interval and the largest rejected interval were identified. Within this dataset, we selected the subset of maneuvers corresponding to the TLSs on which we had calibrated the distributions used for the generation of TH in the circulating stream. For the North approach, the resulting sample consisted of 299 maneuvers and the estimated t_c was equal to 2.3756 s, with a σ_c of 0.1053 s; for the West approach, the resulting sample consisted of 4380 maneuvers and the estimated t_c was equal to 2.7158 s, with a σ_c of 0.5116 s.

3.3. Circulating flow Time Headways: coding, fitting and generation

A trend analysis was carried out on the set of circulating flow TH coded with reference to the CP for the North approach. The result was a set of TLSs corresponding to stationary conditions (at least in time). Among these, we selected two TLSs having an average Flow Rate (FR) of about 470 vehicles/hour (see Table 2). Using the StatFit software, we fitted a Lognormal distribution to the distribution of TH (Rossi et al., 2015). In the TH generation carried out for the DS experiments, we used the Lognormal distribution obtained from the calibration based on the union of the two samples (Table 2).

As explained before, the TH sequences generated for the DS experiments were extracted from a truncated distribution excluding all headways larger than 6 seconds. Moreover, the TH sequences so obtained were randomized in order to avoid the presentation of the same sequence to the same subject more than once.

Table 1. Roundabout characteristics

General characteristics		**Approach characteristics**	**North**	**East**	**West**
Inscribed circle diameter (m)	32	Number of entering lanes	1	1	1
Central island diameter (m)	15	Number of exiting lanes	1	1	1
Circulatory roadway width, included apron (m)	8.5	Splitter island width (m)	4.40	6.80	6.00
Number of lanes of circulatory roadway	1	Entry width (m)	4.50	4.70	5.00

Table 2. Main characteristics of TLS used for TH pdf fitting and Lognormal parameters estimated

Duration (minutes)	# of elements	FR (vehicles/hour)	K-S statistic	p-value	Minimum (sec)	Mean (sec)	Standard deviation (sec)
60.00	471	471	0.0366	0.537	0.907	1.38	1.09

3.4. DS experiments

The simulation system used in this study is a fixed-base driving simulator produced by STSoftware®, comprising a cockpit, composed by an adjustable car seat, a gaming dynamic force feedback steering wheel with a 900 degrees turn-angle and gas, brake and clutch pedals. The system also comprises three networked computers, and five full high-definition screens creating a 330° (horizontal) by 45° (vertical) field of view. It is also equipped with a Dolby Surround® sound system, the whole producing realistic virtual views of the road and the surrounding environment.

Following Blana (1996) and Rossi et al. (2011b), a simulated scenario was designed to match the real environment in terms of both simulated traffic and landscape (trees, buildings, roads, etc.) and was reproduced in the DS, using a 3D rendering software. Simulated gap acceptance data were retrieved from trials on the scenario, which reproduces the conditions of the real situation. The basic roundabout, with the same geometric features as the real-life roundabout, was repeated eight times, in order to obtain a circuit. Circulating traffic in front of the North and West approaches was modeled according to the TH distribution fitted (see section 3.3) and drivers were not constrained by vehicles ahead. Daytime and good weather conditions were adopted to allow good visibility.

Vehicles circulating in front of North and West approaches traveled at constant speed (34.2 km/h), so that the gaps between them remained constant once vehicles were created.

The test drivers were recruited from students and staff at the University of Padova; they had regular driving licenses and did not have any previous experience with DS. Gender and age information regarding the test drivers is reported in Table 3.

Each driver had to complete 4 laps (during each lap the same roundabout was approached 8 times). The entry approach of the roundabout was thus presented 32 times to each participant. Among the many parameters characterizing driver behavior provided by the simulator, only circulating stream vehicles arrival time at the conflict point and test driver's arrival and departure time at/from the yield line were considered for the purpose of this study.

The dataset obtained from the DS observations contained 344 completed entry maneuvers for experiment #1 and 545 completed entry maneuvers for experiment #2. A total of 38 maneuvers for experiment #1 and 31 for experiment #2 were excluded because of accidents or other events that prevented the execution of the maneuver.

Table 3. Basic characteristics of test drivers in DS experiments #1 and #2.

Experiment	Total number of participants	Male	Female	Average age	Min. age	Max. age
#1 (North approach)	47	35	12	23	19	29
#2 (West approach)	18	11	7	22	19	26

3.5. Validation of Driving Simulator for Gap-Acceptance Experiments

The main aim of the study was to verify if the gap-acceptance behavior observed at the case study roundabout, built in virtual reality, can be considered similar to that observed at the corresponding real intersection. The simulator of our Transportation Laboratory has already been validated for priority intersections (Rossi et al., 2011b); however, a new validation study was needed in order to test the proposed procedure, also because of the operational differences between roundabouts and priority intersections.

In order to determine if the DS can be considered as a valid tool for the analysis of gap-acceptance behavior with reference to the chosen case study, the t-statistic was used to test the null hypothesis of no significant difference between the mean values of critical gap estimated in the field and with the DS. The results of this analysis, in which all tests of hypothesis are two-sided, are presented in Table 4. For each of the two approaches, the table shows, separately for the field observations and for the DS experiment, the number of completed entry maneuvers (N), the mean value and standard deviation of the estimated critical gap (t_c and σ_c), the value of the t statistic used for testing the significance of the differences of means, and the corresponding p-value. Note that the sequences of circulating stream headways used in the DS experiment #2 (West approach) were generated from the same distribution fitted on the field data collected for the North approach.

The results in Table 4 indicate that, for both experiments, the null hypothesis of no difference between observed and simulated mean critical gaps cannot be rejected at the 5% significance level. Based on the calculated p-values, this conclusion appears to be stronger for experiment #2 (West approach). Therefore, we conclude that the DS environment can be considered to be validated with reference to the chosen case study.

Table 4. t-statistics and corresponding p-values for the comparison between on-field and DS mean critical gaps in experiments #1 and #2.

Experiment	On-field			Driving Simulator				
	N	t_C	σ_c	N	t_C	σ_c	t stat	p-value
#1 (North approach)	299	2.3756	0.1053	344	2.4532	0.7567	1.7584	0.0851
#2 (West approach)	4380	2.7158	0.5116	545	2.7319	0.5859	0.6791	0.3168

4. Concluding remarks and future developments

A complete procedure for the validation of a DS environment for the analysis of gap-acceptance behavior has been presented in this paper. The final aim of the procedure is to test whether a synthetic indicator of gap-acceptance behavior (the mean critical gap) shows significant differences when computed on the basis of field observations versus observations collected in the DS environment. The absence of such differences can be considered as sufficient evidence that driver behavior is similar in the two contexts, and therefore provides adequate support in favor of DS validation. A central element of the procedure is the analysis of the distribution of headways between vehicles of the main traffic stream, because of its considerable impact on the gap selection process. Headways observed in the field experiment are used as input to a fitting process that determines the form of the probability density function which best describes the real phenomenon. The selected distribution is then applied in order to generate headways in the DS experiment. In order to test the applicability and the effectiveness of the procedure, we applied it to the case of a three-leg roundabout located in the Veneto region (Italy). The results of this application show that the mean critical gap estimated in the field and the mean critical gap estimated in the virtual environment are not significantly different, confirming the results obtained in a previous study (Rossi et al., 2011b) for priority intersections. In addition to this finding, two main conclusions can be drawn from this study. First, the proposed procedure is sufficiently general to allow applications in different contexts in which gap-acceptance behavior plays a central role such as, for example, lane changing, merging, overtaking, etc. Second, in case of a successful validation the simulated environment can be considered as a reliable tool to perform both safety and operational analyses in which mean critical gap implicitly provides a measure of risk accepted by drivers in the presence of traffic conflicts and has a considerable effect on the capacity of minor traffic streams involved in priority situations.

Possible developments of the research described in this paper include the extension of the sample used in the driving simulation in terms of size and composition, and the application of the proposed procedure to gap-acceptance contexts different from intersections (merging, lane changing etc.).

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References

Adebisi O. and Sama G. N. (1989). Influence of stopped delay on driver gap acceptance behavior. *Journal of Transportation Engineering*. ASCE, Vol. 115 No 3, pp.305-315.

Alexander J., Barham P., Black I. (2002). Factors influencing the probability of an incident at a junction: results from an interactive driving simulator. *Accident Analysis and Prevention* Vol. 34, No. 6, pp. 779-792.

Ashworth R. (1970). The analysis and interpretation of gap acceptance data. *Transportation Science*, Vol.4, No 3, pp. 270-280.

Bella F. (2005). Validation of a Driving Simulator for Work Zone Design. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1937, Transportation Research Board, Washington D.C., pp. 136-144.

Bella F. (2008). Driving simulator for speed research on two-lane rural roads. *Accident Analysis and Prevention*, Vol. 40, No 3, pp.1078-1087.

Bittner Jr. A.C., Simsek O., Levison W.H., and Campbell J.L. (2002). On-road versus simulator data in driver model development driver performance model experience. *Transportation Research Record: Journal of the Transportation Research Board,* No. 1803, Transportation Research Board, Washington D.C., pp. 38-44.

Blana E. (1996). Driving simulator validation studies: a literature review. *Institute of Transport Studies, University of Leeds, Working Paper 480*.

Cassidy M. J., Madanat S. M., Wang M. H., and Yang F. (1995). Unsignalized intersection capacity and level of service: revisiting critical gap. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1484, Transportation Research Board, Washington, D.C., pp. 16-22.

Cox, D. R., P. A. W. Lewis (1966). *The Statistical Analysis of Series of Events*. Methuen & Co Ltd., London.

Espié, S., P. Gauriat, and M. Duraz. (2005). Driving Simulators Validation: The Issue of Transferability of Results Acquired on Simulator. Presented at the Driving Simulation Conference, Orlando, USA, pp. 149–156.

Farah H., Polus A., Bekhor S., and Toledo, T. (2007). Study of passing gap acceptance behavior using a driving simulator. *Advances in Transportation Studies*, No. 13, pp. 9-16.

Gastaldi M., Meneguzzer C., Gecchele G., Rossi R. (2015). Comparing Direct Transferability of Logit and Fuzzy Logic Models of Gap Acceptance at Unsignalized Intersections. Transportation Research Procedia, 5, 95-102, doi: 10.1016/j.trpro.2015.01.010.

Godley S.T., Triggs T.J. and Fildes B. (2002). Driving simulator validation for speed research. *Accident Analysis and Prevention* , Vol. 34, No 5, pp. 589-600.

Kaptein N.A., Theeuwes J., and van der Horst R. (1996). Driving Simulator Validity: Some Considerations. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1550, Transportation Research Board, Washington D.C., pp. 30-36.

Kittelson W. K. and Vandehey M. A. (1991). Delay effects on driver gap acceptance characteristics at two-way stop-controlled intersections. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1320, Transportation Research Board, Washington, D.C., pp. 154-159.

Klee H., Bauer C., Radwan E., and Al-Deek H. (1999). Preliminary Validation of Driving Simulator Based on Forward Speed. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1689, Transportation Research Board, Washington D.C., pp. 33-39.

Luttinen, R. T. (1992). Statistical properties of vehicle time headways. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1365, Transportation Research Board, Washington, D.C., pp. 92-98.

Luttinen, R. T. (1996). *Statistical analysis of vehicle time headways*. Publication 87, Helsinki University of Technology, Transportation Engineering, Otaniemi.

Maze T.H. A probabilistic model of gap acceptance behavior (1981). *Transportation Research Record: Journal of the Transportation Research Board*, No.795, Transportation Research Board, Washington, D.C., pp. 8-13.

Milleville-Pennel, I., and Charron, C. (2015). Driving for Real or on a Fixed-Base Simulator: Is It so Different? An Explorative Study. *Presence: Teleoperators and Virtual Environments*, 24(1), 74–91.

National Highway Administration (2010). Driving Simulation Forward. Making Driving Simulators More Useful for Behavioral Research.

Rodegerdts, L., M. Blogg, E. Wemple, E. Myers, M. Kyte, M. Dixon, G. List, A. Flannery, R. Troutbeck, W. Brilon, N. Wu, B. Persaud, C. Lyon, D. Harkey, and D. Carter (2007). Roundabouts in the United States. NCHRP Report 572. Transportation Research Board, Washington, DC..

Rossi R., and Meneguzzer C. (2002). The effect of crisp variables on fuzzy models of gap-acceptance behavior. In *Proceedings of the 13-th Mini-EURO Conference "Handling Uncertainty in the Analysis of Traffic and Transportation Systems"*, Bari, Italy, pp.240-246.

Rossi, R., Gastaldi, M., Gecchele, G., Meneguzzer, C. (2011a). Transferability of Fuzzy Models of Gap-Acceptance Behavior. In: A. Gaspar-Cunha, R. Takahashi, G. Schaefer and L. Costa. Advances in Intelligent and Soft Computing - Soft Computing in Industrial Applications, Vol. 96, 379-390, Springer, Berlin.

Rossi, R., M. Gastaldi, C. Meneguzzer, and G. Gecchele (2011b). Gap-acceptance behavior at a priority intersection: field observation versus experiments of a driving simulator. Presented at 90th Annual Meeting of the Transportation Research Board, Washington, D.C.

Rossi, R., Gastaldi, M., Gecchele, G., Meneguzzer, C. (2012). Comparative Analysis of Random Utility Models and Fuzzy Logic Models for Representing Gap-Acceptance Behavior Using Data from Driving Simulator Experiments. Procedia: Social & Behavioral Sciences 54, 834-844.

Rossi R., Meneguzzer C., Gastaldi M. (2013). Transfer and Updating of Logit Models of Gap-Acceptance and their Operational Implications. Transportation Research Part C, Emerging Technologies, 28, 142-154, doi: 10.1016/j.trc.2011.05.019.

Rossi, R., Gastaldi, M., Gecchele, G., Meneguzzer, C. (2014a). Fuzzy Logic Models of Gap-Acceptance Behavior at Roundabouts. In: J. Freire de Sousa, R. Rossi. Advances in Intelligent System and computing - Computer-based Modelling and Optimization in Transportation. Vol 262 (p. 281-291). Cham (Switzerland): Springer International Publishing. ISSN: 2194-5357, DOI: 10.1007/978-3-319-04630-3_21.

Rossi, R., M. Gastaldi and F. Pascucci (2014b). Gamma-GQM time headway model: endogenous effects in rural two-lane two-way roads. *Procedia Social and Behavioral Sciences*, Vol. 111, pp. 859-868, doi:10.1016/j.sbspro.2014.01.120.

Rossi, R., M. Gastaldi and F. Pascucci (2015). Fitting Time Headway–Vehicle Speed Bivariate Distributions. Operational Procedure for Two-Way Two-Lane Roads. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2490, Transportation Research Board, Washington, D.C., pp. 94-105.

Rossi, R., Gastaldi, M., Meneguzzer, C. (2018). Headway distribution effect on gap-acceptance behavior at roundabouts: driving simulator experiments in a case study. Advances in Transportation Studies 46, 97-110.

Staplin L. (1995). Simulator and Field Measures of Driver Age Differences in Left-Turn Gap Judgments. *Transportation Research Record: Journal of the Transportation Research Board*, No.1485, Transportation Research Board, Washington D.C., pp. 49-55.

Teply S., Abou-Henaidy M. I., and Hunt J. D. (1997a). Gap acceptance behaviour – aggregate and Logit perspectives: Part 1. *Traffic Engineering and Control*, Vol. 9, pp. 474-482.

Teply S., Abou-Henaidy M. I., and Hunt J. D. (1997b). Gap acceptance behaviour – aggregate and Logit perspectives: Part 2. *Traffic Engineering and Control*, Vol. 10, pp. 540-544.

Tian Z., Vandehey M., Robinson B.W., Kittelson W., Kyte M., Troutbeck R., Brilon W., and Wu N. (1999). Implementing the maximum likelihood methodology to measure a driver's critical gap. *Transportation Research A*, Vol. 33, No. 3-4, pp. 187-197.

Wennel J., and Cooper D. F. (1981). Vehicle and driver effects on junction gap acceptance. *Traffic Engineering and Control*, Vol. 22, No 12, pp.628-632.

Yan X., Radwan E., and Guo D. (2007). Effects of major-road vehicle speed and driver age and gender on left-turn gap acceptance. *Accident Analysis & Prevention*, Vol. 39, No. 4, pp. 843-852.