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The employment of smartphone technology in the calibration and validation of microsimulation models for road safety analysis

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Abstract

The main objective of this paper is to verify the capability of microsimulation to be employed in road safety analysis purposes. In particular, two different microsimulation tools (VISSIM and TRITONE) are used to analyse road safety performance of a two-way undivided highway under car-following conditions. The calibration/validation framework of microsimulation models makes use of vehicle tracking data obtained through smartphones with an embedded GPSchip. Observed vehicles' interactions are compared to those simulated, in terms of safety performance indicators, determining how a microsimulation approach fits the real conditions.

Keywords: Microsimulation, smartphones, road safety, safety performance measures.

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1. Introduction

The traditional approach for road safety studies is based on crash statistics as main data source (Hauer, 1997). However, the problem of consistency and availability of accident data and the random nature of crashes, have encouraged researches to develop complementary approaches (Davis et al., 2011). Over the last decade, computer traffic microsimulation has been widely considered as a useful tool for the analysis of users' behaviour and their impacts on transportation systems. In particular, traffic microsimulation, by analysing the complex interactions among vehicles of the traffic stream, enables to evaluate safety performance surrogate measures on the simulated road system (Souza et al., 2011). Nevertheless, microscopic simulation models require a detailed calibration process of input parameters on the basis of observed data, in order to ensure a good reproduction of real phenomena.

Some criticism has been raised in (Essa et al.,2015)on VISSIM ability to replicate traffic conflicts adequately. For this reason, to provide a more detailed analysis and in order to generalize results, the procedure presented in (Guido et al., 2014) has been

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extended by developing a specific microsimulation model "TRITONE" (Astarita et al., 2012) and applying the proposed calibration procedure to both VISSIM and TRITONE. This paper therefore presents an advancement of the previous work of the authors (Guido et al., 2014).

In this paper, in fact, the two different microsimulation packages (VISSIM® 5.4 and TRITONE) have been calibrated and validated, with a road safety analysis approach, on a rural highway reproducing vehicles interactions according to a car-following regime.

In both microsimulation tools, a car-following model (Wiedemann 99) is calibrated with vehicle trajectories data acquired from smartphones positioned on a sample of vehicles traversing the road test segment. The calibration process is based on the Deceleration Rate to Avoid a Crash (DRAC) that represents one of the most employed safety performance indicator. The calibration framework involves the following steps: selection of initial model inputs, statistical screening of inputs and determination of the best configuration of model inputs through a genetic algorithm. Once both VISSIM and TRITONE are calibrated, a validation framework is performed allowing the identification of potentially unsafe vehicle interactions scenarios. Observed DRAC values are compared to simulated DRAC, determining to what measure simulated safety performances reflect real vehicular interactions and, consequently, to what measure microsimulation can be applied to road safety analysis.

The paper is organized according to the following structure: the next section provides a literature review on the applications of computer simulation to road safety; section three introduces the adopted methodology; section four provides a description of the observed vehicle trajectory sample employed into the calibration and validation procedure; section five introduces the safety performance indicator (DRAC) adopted to assess the safety analysis; in the next section a calibration/validation framework is presented and applied to a case study for obtaining best estimates of model inputs; finally, the paper concludes with a summary of results and a discussion of the implications for future researches.

2. Literature Review

The earliest applications of microsimulation models looked at the relationship between conflicts and traffic flow at intersections (Darzentas et al., 1980; McDowell et al., 1983), giving a simplistic model for driver safety. An important step forward in road safety simulation was the determination of safety performance measures that represent a measure of the 'risk of collision' of vehicles in the traffic stream (Guido et al., 2011a; Guido et al., 2011b; Lee and Park, 2012; Astarita et al., 2014; Young et al., 2014; So et al., 2015). In particular, among safety performance measures, the deceleration rate to avoid a crash (DRAC), introduced by Archer in 2005, offers a clear view of the severity of the conflict (Cunto and Saccomanno, 2008; Astarita et al., 2011; Astarita et al., 2012).

The calibration of microsimulation input parameters necessitates a data collection process of real vehicles' trajectories and maneuvers. The technologies employed for the acquisition of vehicles' trajectories consist of dedicated equipment, such as video cameras, loop detectors and microwave radar sensors that can ensure the acquisition of vehicles' cinematic data only in certain road sections, with consequent high costs of installation and maintenance. Recently, the popularity of Assisted-GPS equipped smartphones has provided a potentially low-cost means to acquire instantaneous vehicle kinematic data (Herrera et al., 2010) overcoming the limitations of other technologies currently in use to detect the vehicles' trajectories, observing full tracks without losing consistent parts of users' trips. Smartphone devices, in addition to traditional phone features, provide a multitude of other services, including internet, positioning data, accelerometers and other sensors (Herrera et al., 2008).

In the literature there are several researches based on the application of smartphone mobile technology. GPS positioning data from smartphones were employed by Chen et al. in 2010 for estimating route choice models achieving good results. Magliocchetti et al. in 2011 encouraged the use of public transport developing an application for smartphone and tablets that guide users towards the best travel option in a multimodal transport network. Guido et al. in 2012 applied smartphone technology to a road safety problem acquiring, vehicles' speed and acceleration.

3. Methodology

Briefly, we introduce a description of the methodology adopted to determine how simulated traffic flows interactions fit real conditions in terms of safety performance measures. The steps involved in the methodology mainly refer to the acquisition of the vehicle trajectories data, the estimation of the safety performance measures, the calibration of the behavioural models, and the validation of the procedure. Figure 1 shows the flow-chart illustrating the above-mentioned steps. The following sections explain each single step of the methodology.

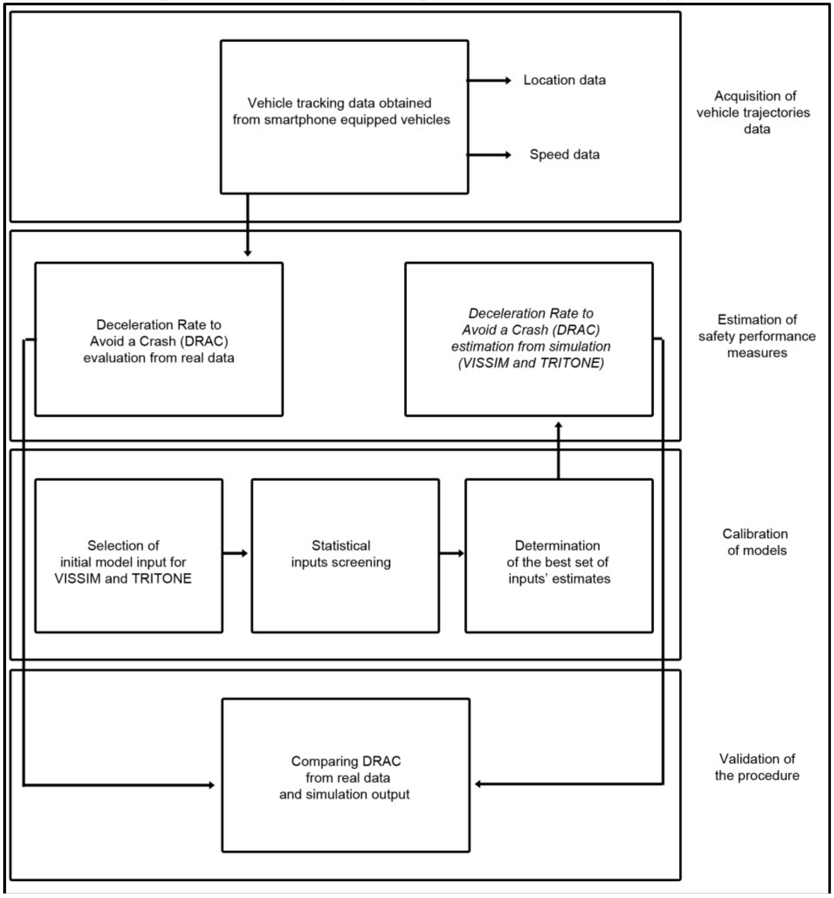

Figure 1: Flow-chart of methodology

4. Vehicle trajectories data acquisition

The observed vehicle trajectories data used in the calibration and validation procedures were collected on a segment of a rural highway (SS 106) through the use of smartphones. The test segment has a length of 1.5 kilometers and is characterized by a geometric configuration that causes a high level of risk for drivers (according national census database (Istat-ACI, 2015), considering the mortality index value for the SS106, it is 8.5 compared to the average national value of 4.9. For this survey, 23 vehicles with a Samsung Galaxy S-Plus smartphone on board with embedded GPS traversed the road test segment in southbound direction (Guido et al., 2013). The 23 vehicles generate about 250 total interaction with the other vehicles of the traffic stream. Location- and speed-based data obtained from the GPS probe sample were used to track vehicles and to estimate safety performance as discussed in the next section.

The participants in the survey were not part of the research group. In particular the drivers were chosen with a random sampling into different age classes:

- 18-25: 6 drivers.
- 26-36: 6 drivers.
- 37-50: 6 drivers.
- 51-65: 5 drivers.

The drivers were not informed on details of the experiment, they were simply instructed to drive in a natural way along a pre-established route. With the purpose to obtain two independent data samples to be employed in the calibration/validation procedure, the experiment was conducted on 27 and 28 June 2012, from 9:15 to 9:30 a.m.. In order to identify lead and following vehicles couples (for gap measurement) in addition to GPS data external, video cameras were used. Moreover, video imaging processing was used to extract values for interactions involving non-instrumented vehicles. According to both Archer (2005)and the car-following interval suggested by the Highway Capacity Manual (2010),a 3-second threshold was applied to establish whether two vehicles are interacting.

5. Estimating safety performance measures

The safety analysis on the road test segment was carried out considering the surrogate safety measures approach (Hayword, 1971; Minderhoud and Bovy, 2001; Huguenin et al., 2005) that, respect to statistical models based on historical crash data, allow a preventive safety analysis without having to wait for a crash to occur and that would give some advantages (Caliendo and Guida, 2012).

The safety indicator considered is the Deceleration Rate to Avoid a Crash (DRAC).

DRAC was defined by Almquist et al. in 1991 as the ratio between speed differential of a couple of vehicles (Following Vehicle (FV) and Lead Vehicle (LV)) and their closing time. Taking into account rear-end interactions, DRAC can be expressed as:

$$DRAC_{FV}^{REAR} = \frac{(V_{FV,t} - V_{LV,t})^2}{2 \cdot [(X_{LV,t} - X_{FV,t}) - L_{LV,t}]} \qquad (1)$$

In the expression (1) V is the speed (m/s), X is the vehicle (m), L is the vehicle length (m) and t is the time interval (s).

Arche defined a vehicle in conflict when its DRAC exceeds a braking value threshold of 3.35 m/s^2.

5.1 Measures from the field

The direct estimation of DRAC using smartphone technology necessitates determining the Lead Vehicle (LV) and the Following Vehicle (FV) along each trajectory.

The GPS chip of the smartphones provides position information and speed values for each equipped vehicle (Georgiadou et al., 2001). Instantaneous speed values were directly provided by the GPS unit (through NMEA protocol) and can be directly used in the DRAC function.

Table 1 shows the observed average DRAC values.

Table 1: Observe daverage DRAC values

Sample	*Average (m/s^2)*	*Minimum (m/s^2)*	*Maximum (m/s^2)*	*St. Deviation (m/s^2)*
1 - 27 June 2013	-3.27	-0.49	-6.15	0.35
2 - 28 June 2013	-2.32	-0.33	-5.33	0.25

5.2 Measures from simulation

The road test segment under study segment was simulated with two different microsimulation packages: TRITONE and VISSIM. In both microscopic simulators traffic volume values are set on the basis of those observed during the survey.

The startup time interval of each simulation is 15 minutes to assign traffic volumes on each link of simulated network according to a Poisson distribution.

TRITONE is a free license microsimulation tool, developed according a modular structure. The road safety analysis module in TRITONE is user friendly and provides traffic safety performance through a series of indicators (Crash Potential Index, Deceleration Rate to Avoid Crash, Available Maximum Deceleration Rate, Time to Collision, etc.).

VISSIM, on the contrary, does not contain a specific module for the computation of safety performance indicators. Therefore this software generates an output (a ".trj" file) containing data about vehicles' trajectories that can be analysed with a Surrogate Safety Assessment Model (SSAM) (FHWA, 2008). SSAM is a software that, analysing vehicle trajectories, provides several safety performance measures based on conflicts identified.

In order to compare simulated DRAC values correctly with those observed, a calibration and a validation framework are carried out for both microsimulation tools.

6. Calibration and Validation procedures

Calibration is a basic process to evaluate the model accuracy by comparing, in this specific case, DRAC values obtained in simulation to those measured in the field.

Three steps are involved in this process: selection of initial model inputs, statistical screening of inputs and determination of the best set of inputs' estimates.

6.1 Selection of initial model input

Both TRITONE and VISSIM packages need the definition of several parameters to be used as input for the behavioural models. Nevertheless, the case study segment is an undivided highway segment where no overtaking is observed, therefore vehicles move on the road in the prevailing conditions of the car-following model. The car-following model applied in the study for both microsimulator is Wiedemann 99. Thirteen parameters were chosen to model the interactions among the vehicles in car-following protocol to better explain potential for rear-end conflicts. Table 2 summarizes the thirteen parameters of Wiedemann 99 used as input both in TRITONE and VISSIM simulations (Park and Schneeberger, 2003; Lownes and Machemehl, 2006; Duan et al., 2013).

Table 2: Input parameters and range values

Factor	*Parameter*	*Low level (-1)*	*High level (+1)*	*Description*
A	Desired Speed (average)	45	90	Individual free flow speed (Km/h)
B	Desired Speed (standard deviation)	2.9	8.7	Standard deviation of the desired speed (Km/h)
C	Desired Deceleration	-4.5	-1.3	Maximum desired deceleration (m/s^2)
D	Observed vehicles ahead	1	4	Number of lead vehicles influencing drivers' ability to adjust their speed/distance
E	CC0	0.5	3	Standstill distance (m)
F	CC1	0.7	1.78	Headway time (s.
G	CC2	3.9	23	Following variation (m)
H	CC3	-15	-4	Threshold for the entering "following"
I	CC5	0.1	2	Positive "following" threshold
J	CC6	2	20	Speed dependency of oscillation
K	CC7	0.1	0.3	Oscillation acceleration (m/s^2)
L	CC8	0.5	3.5	Standstill acceleration (m/s^2)
M	CC9	0.5	1.5	Desired acceleration at 80 km/h (m/s^2)

6.2 Statistical inputs' screening

As suggested by Montgomery in 2005, a statistical screening of inputs was used to evaluate interactions among inputs themselves, and determine which inputs are statistically significant for the evaluation of safety performance. A Plackett–Burnman via fold over design was applied to test the main factors effects with the least number of simulations. Therefore, thirty-six scenarios with three replicates (Plackett–Burnmandesign) were simulated for a total of 108 simulations, in which replicates were used to account for the random nature of each simulation. The ANOVA test has permitted the weight and the significance of each input (factor) to be determined as illustrated in Tables 3 and 4.

Table 3:ANOVA test forf actors in TRITONE

Factor	*Coeff.*	*Effect*	*SS*	*D.F.*	*F*	*p*
Constant	-4.147					
A	-0.253	-0.507	6.860	1	14.910	0.000
B	-0.001	-0.001	0.000	1	0.005	0.994
C	-0.077	-0.153	0.628	1	1.360	0.246
D	0.288	0.576	8.864	1	19.270	0.000
E	-0.353	-0.707	13.338	1	29.000	0.000
F	0.595	1.191	37.884	1	82.360	0.000
G	0.161	0.322	2.773	1	6.030	0.016
H	-0.258	-0.515	7.093	1	15.420	0.000
I	-0.079	-0.158	0.668	1	1.450	0.232
J	0.006	0.012	0.004	1	0.010	0.930
K	0.031	0.062	0.101	1	0.220	0.640
L	-0.156	-0.311	2.591	1	5.630	0.020
M	-0.028	-0.056	0.085	1	0.180	0.668

Table 4:ANOVA test for factors in VISSIM

Factor	*Coeff.*	*Effect*	*SS*	*D.F.*	*F*	*p*
Constant	-4.134					
A	-0.270	-0.539	7.772	1	21.90	0.000
B	-0.001	-0.002	0.000	1	0.00	0.988
C	-0.057	-0.113	0.343	1	0.97	0.328
D	0.282	0.564	8.504	1	23.97	0.000
E	-0.359	-0.718	13.788	1	38.86	0.000
F	0.578	1.157	35.749	1	100.75	0.000
G	0.136	0.271	1.962	1	5.53	0.021
H	-0.237	-0.474	5.998	1	16.96	0.000
I	-0.071	-0.142	0.541	1	1.53	0.220
J	0.013	0.026	0.018	1	0.05	0.824
K	0.051	0.102	0.276	1	0.78	0.380
L	-0.149	-0.297	2.361	1	6.65	0.011
M	-0.039	-0.078	0.162	1	0.46	0.501

Results from the analysis highlight that average desired speed, observed vehicles ahead, CC0, CC1, CC2, CC3 and CC8 factors are statistically significant at the 5% level. Based on the results' analysis, a linear expression of these seven factors has been defined for DRAC measure of safety performance as for TRITONE and VISSIM models:

$$\begin{aligned} DRAC_{TRITONE} = {} & -5.266 - 0.011 * (average\ desired\ speed) + 0.192 \\ & * (observed\ vehicles\ ahead) - 0.282 * CC0 + 1.10 \\ & * CC1 + 0.017 * CC2 - 0.047 * CC3 - 0.103 * CC8 \end{aligned} \tag{2}$$

$$\begin{aligned} DRAC_{VISSIM} = {} & -5.083 - 0.011 * (average\ desired\ speed\ ) + 0.188 \\ & * (observed\ vehicles\ ahead) - 0.287 * CC0 + 1.071 \\ & * CC1 + 0.014 * CC2 - 0.043 * CC3 - 0.099 * CC8 \end{aligned} \tag{3}$$

In the following table the R-square and the sum of squared errors (SSE) for the above expressions are reported.

Table 5: R-squared and SSE for DRAC expressions

	R-square	*SSE*	*SSE (pure errors)*	*SSE (lack of fit errors)*
$DRAC_{TRITONE}$	0.65	42.778	18.243	24.535
$DRAC_{VISSIM}$	0.70	32.998	13.458	19.540

6.3 Determination of the best set of inputs' estimates

The best set of inputs' values in Equations 2 and 3 are obtained applying a generational genetic algorithm, which requires the definition of two constraints: 1) the genetic representation of the solution domain and 2) the fitness function to assess it.

In this paper, the linear expressions for DRAC (Equations 2 and 3) constitute the genetic solution domain (safety performance measure); while, the fitness function corresponds to the residual sum of squares. Three operators (selection, cross-over and mutation) are repetitively applied by the generational genetic algorithm to generate a new population from the previous one. For both simulators fifty genetic algorithm runs were performed in order to obtain the best set of inputs' estimates. Table 6 shows the estimate values corresponding to the best solution, which provide a simulated average DRAC of -3.32 m/s^2 (TRITONE) and -3.27 m/s^2 (VISSIM), matching very well to the observed one (-3.26 m/s^2).

Table 6: Genetic algorithm results

Factor	*Best estimate for TRITONE*	*Best estimate forVISSIM*
Average desired speed	51.00	64.00
Observed vehicles ahead	4.00	1.00
CC0	1.41	0.52
CC1	1.22	1.74
CC2	15.20	9.85
CC3	-14.75	-14.44
CC8	1.11	0.88

6.4 Validation process

For the validation process we used the best set of inputs coming from the calibration stage for both microsimulation tools. In Table 7 mean and standard deviation of observed and simulated DRAC are reported together with the root mean square percentage error (RMSPE) both for TRITONE and VISSIM.

Table 7:Validation results for DRAC

	TRITONE	*VISSIM*	*Observation*
Mean (m/s^2)	-2.48	-2.21	-2.32
Standard deviation (m/s^2)	0.32	0.22	0.25
Number of simulations (#)	10	10	-
RMSPE (%)	11.20	10.16	-

The average values of simulated DRACs, as in TRITONE and VISSIM, are very close to the average value of the observed safety performance measure in the experimental context; the root mean square percentage error ranges from 10.16% (VISSIM) to 11.20% (TRITONE).

As highlighted by the estimated DRAC for VISSIM and TRITONE, whose average values (-2.48 m/s^2 and -2.21 m/s^2) do not exceed a critical DRAC threshold generally adopted for rear-end conflicts, no unsafe conditions were reproduced by both simulators for the case study. Simulated traffic interactions closely match with those observed from the field, in which drivers adopt homogeneous speed profiles and no potential conflicts are associated with the car-following mode.

7. Conclusions

Results obtained from the analysis highlighted that microscopic simulation provides a useful tool for evaluating a potential gap in safety conditions on the road network; however, the more calibration and validation process are rigorous the more simulation output are reliable.

A calibration/validation framework for microsimulation packages has been presented in this paper in which accuracy is assessed in terms of safety performance measure for rear-end conflicts (DRAC). Traffic data to be used in the calibration/validation framework have been collected for a case study segment of a two-lane rural highway in Southern Italy by using a GPS smartphone probe sample.

In order to test the proposed calibration/validation framework two microsimulation packages were chosen, TRITONE and VISSIM, in which the best set of car-following model parameters based on Wiedemann theory was assessed. Even if TRITONE and VISSIM are based on different behavioural models (car following, lane changing, gap acceptance, etc.), results obtained through the validation framework for both tools demonstrate a good capability of microsimulation approach to replicate the observed DRAC values (RMSPE of 11.20% and10.16% respectively for TRITONE and VISSIM).

This paper is focused on the assessment of the simulation output in terms of surrogate safety measures of driver behaviour, but no relationship has been investigated between these indices and the historical crashes data. Despite the good results achieved for the analysed case study, more efforts have to be spent to address research towards the acquisition of observational data from other sources and for different contexts improving the transferability of the calibration results. Furthermore, it could be useful to adopt the real-time smartphone technology in a co-operative platform for traffic control and real-time simulation.

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