Validation of a Low-Cost Driving Simulator Based on Continuous Speed Profles

Corresponding Author:
David Llopis-Castelló
Ph.D. Student
Highway Engineering Research Group (HERG), Universitat Politècnica de València
Camino de Vera, s/n. 46022 – Valencia. Spain
Tel: (34) 96 3877374; Fax: (34) 96 3877379; E-mail: dallocas@doctor.upv.es

Other Authors:
Francisco Javier Camacho-Torregrosa
Assistant Professor
HERG, Universitat Politècnica de València
E-mail: fracator@tra.upv.es

Javier Marín-Morales
Research Assistant
LabHuman, Universitat Politècnica de València
Camino de Vera, s/n. 46022 – Valencia. Spain
Tel: (34) 96 3877000; E-mail: jamarmo@cam.upv.es

Ana María Pérez-Zuriaga
Assistant Professor
HERG, Universitat Politècnica de València
E-mail: anpezu@tra.upv.es

Alfredo García
Professor
HERG, Universitat Politècnica de València
E-mail: agarciag@tra.upv.es

Juan F. Dols
Associate Professor
Institute of Design and Manufacture, Universitat Politècnica de València
Camino de Vera, s/n. 46022 – Valencia. Spain
Tel: (34) 96 3877000; Fax: (34) 96 3877629; E-mail: jdols@mcm.upv.es

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ABSTRACT

The amount of road safety studies based on driving simulators is significantly growing. The Universitat Politècnica de València (UPV) has developed a low-cost driving simulator: SE^2RCO (Simulator for the Assessment, Training and Rehabilitation of Drivers, in Spanish).

The main objective of this research is the validation of the SE^2RCO driving simulator in order to perform studies about road safety and highway geometric design considering human factor. Its validation is based on continuous speed profiles collected from 28 volunteers on a 30 km two-lane rural road section. The same volunteers drove through the same road section built in SE^2RCO. Speed data of 79 curves and 52 tangents were selected for the analysis. The comparison of the real and simulated speeds ensured the objective validity according to average and operating speeds. Two models were developed to predict field speeds from simulated speeds. Results show that a simulated average speed lower than 90 km/h approximately is linked to a similar real average speed. For higher simulated speeds, the average speed in the real environment is lower than the simulated one. In addition, the actual operating speed is around 5 km/h lower than the operating speed in the driving simulator. Most volunteers assessed the quality and similarity of the virtual environment to the real world as medium or high, as well as for the driving tasks, thus achieving the subjective validation.

INTRODUCTION

Road accidents may be caused by several concurrent factors, being infrastructure, vehicle and human factor the most important ones. Human factor is estimated to be behind over 90% of all road accidents. Thus, the importance of its inclusion in the highway geometric design process. However, analyzing the human factor may become a very difficult task.

Driving simulators may become an interesting and effective tool to include human factor in road safety. They can be loaded with scenarios where drivers provide similar responses than on a real situation. Under this controlled environment, researchers can monitor several more parameters, but without the physical risk of driving through an actual road. Thus, simulators are a flexible tool for research, since they allow performing studies that otherwise would be unaffordable.

Currently, most studies about road safety and geometric design use operating speed as a surrogate measure of driver behavior. This speed is defined by the AASHTO as "the speed at which drivers are observed operating their vehicles during free-flow conditions" (*1*). It is usually considered as the 85^{th} percentile of the speed distribution for passenger cars under free-flow conditions with no environmental restrictions (V_{85}).

Many researchers have used driving simulators to study the influence of the road geometric design in the driver behavior. Their research lines can be grouped into the following topics: coordination of the horizontal and vertical alignment (*2-4*); passing maneuvers (*5, 6*); acceleration and deceleration lanes (*7*); intersections design (*8-10*); cross section (*11-13*); speed analysis (*14, 15*); assessment of traffic signs (*16, 17*). The wide variety of topics gives an insight about the extensive use of driving simulators in road safety and highway engineering. Note that the validation of the driving simulator is different depending on the objective of the research.

Simulators must provide a close-to-reality environment in order to allow the researchers to obtain valid results. Validity is achieved by means of the validation process, which consists on determining how similar drivers' behaviors under simulated and real conditions are.

In 1982, Blaauw carried out a research proposing two levels of validity: physical and behavioral (*18*). The first one is the physical correspondence of the simulated vehicle components and its dynamics with a real car; while the second one tries to establish a correspondence between the simulator and reality according to drivers' behavior. The last one presents two dimensions: absolute and relative validity. Absolute validity is the numerical correspondence between behavior in the driving simulator and in the real road, while relative validity is the correspondence between the different variations in the driving situation and the variations in the real situation.

Later, Törnros (*19*) indicated that relative validity is of a major importance for determining the usefulness of a simulator, while absolute validity is not required. This is why most validation efforts have not been focused on determining how accurate the simulator is in absolute terms, but on establishing partial validations for specific fields of research.

The validation process is usually divided into:

- Objective validation based on comparison of the observed measures in the simulator with those collected in field study.
- Subjective validation through the driver's perception.

In the literature, there are many studies about how simulators are validated (*20 21*). Driving simulators present the following issues compared to real world, which might bias the results:

- The user does not perceive a homogeneous sensory answer
- The sampling rate may be unconsciously perceived by drivers
- Lack of risk

- Lack of knowledge of the vehicle, as well as errors in the sensory feedback

Despite of these issues, previous research indicate that drivers operate more similarly to the real environment when using advanced simulators with high quality graphics.

On the other hand, one of the most important advantages of using driving simulation is the ability to collect continuous speed data, which is very difficult in field. This is why most previous validation studies have used spot-speed data. Pérez-Zuriaga et al. (*22*) introduced a new methodology for obtaining continuous operating speed profiles in field conditions.

This paper presents how SE^2RCO simulator has been validated. After a first exploratory analysis, some models to estimate the field speed as a function of the simulated speed have been obtained. Both the mean speed and the operating speed have been considered.

OBJECTIVES AND HYPOTHESES

The main objective of this research is the validation of SE^2RCO driving simulator at the Universitat Politècnica de València to perform studies about road safety and highway geometric design.

The validation process considers two dimensions: objective and subjective validity. The first one is achieved by means of a comparison between field (V_f) and simulated (V_s) speeds. The subjective validity is performed considering drivers' perception, obtained through surveys. It has also enabled the study of the symptoms of adaptation to the simulation (SAS), which is always an issue when a driving simulator is used.

The underlying hypothesis is that there is a correlation between V_s and V_f, which allows the validation of a driving simulator. According to Bittner et al. (*23*) and Bella et al. (*14*), the difference between the simulated speed (V_s) and the field speed (V_f) increases when V_s increases. In addition, according to Bittner et al., a lower simulated speed is expected for hard-controlled geometric features.

METHODOLOGY

Two-lane Road Section

The researchers proposed a 30 km long two-lane rural road section of the CV-35 road for the analysis, from Losa del Obispo (PS 53+500) to Titaguas (PS 83+700). This road section is located in the Valencian Region (Spain). It presents a lane width of 3.25 m, and a shoulder width of 0.25 m. The AADT is 2012 vpd.

This road section has been selected since it is composed by three homogeneous road segments with different features, covering a wide range of geometric features. The first one extends from Losa del Obispo to Chelva (PS 67+800) and it is basically composed of isolated smooth curves, low longitudinal grades and long tangents. The second segment is located between Chelva and Tuéjar (PS 73+100) and it is characterized by successive sharp curves, moderate longitudinal grades and short tangents. The last one includes sharp curves, large grades and diverse tangents (TABLE 1).

The total length is 30.185 km. However, the effective length is 28.877 km because there is 1.308 km of urban road between segments 1 and 2. As a result, a total amount of 79 isolated horizontal curves and 52 tangents longer than 120 m were selected for the study.

Volunteers

Twenty-eight volunteers took part in the experiment. The age ranged from 27 to 61 years-old, while the men/women ratio was 80/20. Participants were students, faculties and staff of the

University, as well as non-university-related volunteers. All participants drove their own vehicle for the field tests. None of the volunteers was directly involved in the research or was aware about its final objective.

The age and gender distributions of the drivers were representative of the actual drivers of this region, according to the naturalistic data collected by Pérez-Zuriaga et al. (*22*). In their study, age and gender distributions from more than 80 actual drivers (not volunteers) along the same road were obtained in 2008 for a different research, where continuous individual speed profiles were also collected. García et al. (*24*) compared how mean and operating speed profiles of volunteers and actual drivers matched, validating the use of data from volunteers as a surrogate measurement of actual drivers.

Field Study

Data Collection

The quasi-naturalistic methodology of this study was presented by García et al. (*24*). Each one of the 28 volunteers performed one forward and backward trip, driving their own vehicle (passenger cars in all cases). The tests were carried out between March and April 2014 under daylight and favorable weather conditions.

Every vehicle was equipped with three VIRB Elite cameras, which include a GPS unit. These cameras record a HD video of the road, as well as the position (1 Hz), speed and accelerations (10 Hz). Two of these cameras were centered in the windshield, facing towards the front of the vehicle. The third one was also in the windshield, pointing towards the interior of the vehicle in order to record driver' expressions (FIGURE 1).

Collected data was used for developing continuous operating speed profiles for every driver. In addition, driving experience, road familiarity, dizziness and workload demand were also asked to participants before or after the test (*24*).

Data Reduction

Once data were collected, a computer program developed by the research group was used to transform the original time-based data to a station-based one. In addition, the horizontal alignment was recreated according to the procedure proposed by Camacho-Torregrosa et al. (*25*).

Drivers not performing at free-flow conditions were removed, using the methodology proposed by Pérez-Zuriaga et al. (*26*). This procedure states that drivers experience a sudden variation of their corresponding operating speed percentile under non-free-flow conditions. After this step, 66% of curve data and 68% of tangent data performed under free-flow conditions. Considering each element separately, the amount of valid data ranges from 43% to 79% in curves and from 50% to 75% in tangents.

Driving simulator study

The SE^{2}RCO Driving Simulator

The SE^{2}RCO is an interactive fixed-base driving simulator (FIGURE 2). It consists of a simulation computer, which provides the graphics performance required for the implementation of the simulation software; data collection in real time; wireless router; three-screen-display monitors 1.80x0.34 m with 120º of the field of view; Matrox TripleHead2Go, which is the intermediary between the graphics card of the simulation computer and the three screens; sound stereo system; steering wheel, pedals and gear shift of a Citroen Saxo; and generic adjustable seat.

In addition, the simulator has sensoring brake pedal by load cell to measure forces; sensoring displacement in the three pedals by potentiometers; sensoring of gear changes by microswitch; sensoring the steering wheel by encoder; and sensoring the torque on the wheel by torque sensor.

That provides a view of the road and the environment very close to the real conditions. The equipment of the simulator offers very close-to-reality driving conditions and allows to collect many variables, such as longitudinal and lateral speed, location and heading direction, with a frequency of 10 Hz. After data collection, all these variables are transformed into a station-based reference system using a software developed by the HERG.

Development of the virtual scenario

The first step to undertake data collection in the driving simulator was to build the road segment and its environment in a virtual reality. It was necessary to dispose of:

- Horizontal and vertical alignments of the road segment
- Surface model of the area
- Orthophotography of the area
- Inventory of road and environmental elements

The horizontal alignment was obtained according to the methodology proposed by Camacho-Torregrosa et al. (*25*). The vertical alignment was extracted from GPS data of the tests, using the same methodology. All different road and environmental elements, such as trees, traffic signs or safety barriers, were located in a CAD file and uploaded to the simulator. The SE^2RCO driving simulator was able to merge all elements, providing a very accurate recreation of the actual infrastructure and environment (FIGURE 2).

Data Collection

The scope of the driving simulator study was the same as in the field study. In order to ensure the validity of the collected data, it consisted of the following steps:

1. Drivers are informed about how they should perform. No information about the research project is given.
2. Drivers fill out the first survey
3. Training segment
4. Test
5. Drivers fill out the second survey

The first survey collected personal information, such as driving experience or road knowledge. The second one asked about test-related topics, such as:

- Dizziness (nothing/low/medium/high)
- Sickness (yes/no)
- Eyestrain (yes/no)
- Headache (yes/no)
- Sleepiness (yes/no)
- Reality of the virtual environment (low/medium/high)
- Similarity between driving task in the simulator and the reality (low/medium/high)
- Natural driving (nothing/low/medium/very natural)
- Workload demand (nothing/low/medium/high)

- Familiarity with the road segment (no/little/medium/a lot)

This information was collected in order to analyze the symptoms of adaptation to the simulation (SAS) and to complement the driving simulator validation through drivers' perception.

The training session was needed to ensure that drivers do adapt to the simulator controls and environment. It consisted of driving through a road segment that presented similar characteristics than the road segment under study. The duration of the training session was 10 minutes at least.

In order to prevent dizziness, every participant had to stand up and walk for several minutes between the training stage and the beginning of the test, as well as between the forward and backward trips. In this regard, the researchers wrote down whether the driver had shown symptoms of dizziness along the test or not.

The driving simulator test was performed by 24 out of 28 volunteers who participated in the field test.

ANALYSIS

An exploratory and statistical analysis comparing the simulated speed (V_s) and the field speed (V_f) is presented. Drivers' perception and reaction to the simulator were also analyzed.

Speed

Exploratory Analysis

Before analyzing the relationship between field and simulated speeds, it was necessary to validate the operating speed profiles obtained from the real environment. This was achieved by comparing the field speed distribution of the 28 participants to the speed distribution observed by Pérez-Zuriaga et al. (*22*) in the same road section. The operating speed profiles for several speed percentiles were very similar, so it was concluded that volunteers were not biased. This process was deeply explained by Garcia et al. (*24*), using the same data set. In addition, the surveys results showed that all drivers performed in a natural (or quasi-natural) way in the field test, with a low workload demand.

Three volunteers reported dizziness and sickness problems and could not finish the driving simulator test. Hence, data of 21 drivers were processed. However, 87.5% of the volunteers indicated that they performed in a natural or quasi-natural way.

The next step was to compare the operating speed distributions of the simulated and the real environments. Percentiles 15^{th}, 30^{th}, 50^{th}, 70^{th} and 85^{th} of the simulated speed (V_s) were compared to the same field speed (V_f) percentiles. FIGURE 3 shows that these speed percentiles were quite similar in road features that presented a strong geometric control, i.e., the difference between V_s and V_f was found to be lower on curves than on tangents. This meets the conclusions provided by Bella (*14*) and Bittner et al. (*23*), who reported a higher speed variability in simulators.

Average and operating speed were also analyzed in all curves and tangents separately. Curves were analyzed using the minimum observed speed, while the maximum speed was used on tangents. The identification of these speed data was possible thanks to availability of continuous operating speed profiles in both cases.

Horizontal curves impose a geometric control, so the minimum speed was selected in order to determine how strong this control was. On the contrary, tangents are not geometric controls, so higher speeds can be reached. Thus, maximum speeds were selected.

The difference between the speed observed in the driving simulator and the speed developed in the field study (V_s-V_f) was also analyzed according to geometric features. On curves, the difference between average speeds (V_{ms}-V_{mf}) ranged from -9.92 km/h to +8.65 km/h, whereas the difference between 85th percentiles (V_{85s}-V_{85f}) ranged from -8.57 km/h to +15.70 km/h. Attending to tangents, the difference (V_{ms}-V_{mf}) ranged from -7.12 km/h to +16.14 km/h, whereas the difference (V_{85s}-V_{85f}) ranged from -8.76 km/h to +27.84 km/h.

Statistical Analysis

A hypothesis test was performed to determine whether the speed observed in the driving simulator could be considered similar to the speed observed in the field study or not. For each element, the following hypotheses were formulated: (a) Null hypothesis H_0: $V_{ms}=V_{mf}$; (b) Alternative hypothesis H_1: $V_{ms} \neq V_{mf}$. The level of significance considered in the analysis was 95%.

A first analysis was performed only for curves (TABLE 2a). The null hypothesis was checked for all curves except seven, where speeds were influenced by external factors, such as the relative proximity to important intersections and some issues related to the simulated scenario.

The same analysis was carried out for tangents (TABLE 2b). The null hypothesis was only rejected for six tangents. Three of them can be explained due to the presence of important intersections nearby, while the others are more related to the accuracy of the driving scenario.

All anomalous data were discarded from further analyses.

Drivers' perception and adaptation to the simulator

The driving simulator should also be validated from drivers' perception. This was performed by analyzing the results obtained from surveys.

The results showed that 62.5% and 33.33% of the drivers assessed the quality of the virtual environment as medium and high, respectively.

In addition, 80% of all volunteers indicated that the similarity of the driving task between the simulator and the real world was medium or high. As expected, drivers who suffered dizziness evaluated this similarity as low.

Finally, it is worth to highlight that only 16.67% of the users reported that the test presented a high workload demand. These drivers were mainly who suffered dizziness. Hence, most volunteers indicated a mid-workload demand, similar to the field test.

Regarding the symptoms of adaptation to the simulation (SAS), the drivers who suffered dizziness performed in the simulator much slower than in the field study. In addition, drivers older than 45 drove faster in the reality than in the simulator. The speed in the backward trip was lower than the speed in the forward one, probably due to the influence of the training session. On the other hand, the driving experience did not have any influence in the average speed of the volunteers who participated in the simulation test, although in the real world those users with greater experience often drive faster. Also notice that the problems related to dizziness and nauseas were presented in drivers older than 50.

DISCUSSION

The operating and average speeds were analyzed in field and simulated conditions, for curves and tangents separately.

FIGURE 4b shows the 85th percentile of the simulated speed distribution (V_{85s}) versus the 85th percentile of the field speed distribution (V_{85f}) on curves. A close relationship between both parameters can be observed, being the simulated speed higher (V_{85s}) than the field one (V_{85f}). This conclusion meets most previous research (*14*), and is mainly due to the lack of lateral acceleration and lack of risk provided by the simulator.

Conversely, the average simulated speed (V_{ms}) is very similar to the average field speed (V_{mf}) (FIRURE 4a), which is remarkable. This could be explained taking into account how an average driver performs. In this condition, drivers experience a lower lateral acceleration than those driving at an 85th percentile speed, so the difference compared to the simulated environment is lower or even negligible.

The analysis of average and operating speed for tangents is shown in FIGURE 5. In this case, the relationships are weaker than for horizontal curves, probably due to the higher speed magnitude and dispersion on tangents. In addition, both the average simulated speed (V_{ms}) and the simulated operating speed (V_{85s}) were greater than the field ones (V_{mf} and V_{85f}, respectively).

Considering both curves and tangents, it can be concluded that the more complex an alignment layout, the lower the difference between the field and simulated average speeds, which is consistent with the research of Bella (*14*) and Bittner et al. (*23*). In other words: the higher the speed, the higher the difference between simulated and field speed.

As stated by Bella (*14*), this phenomenon may be due to a lower perception of risk in the simulated road. According to Fuller's driver behavior theory (*27*), drivers continuously make comparisons between their capability and the risk perception, trying to keep a constant level of perceived risk. In the simulator, the perceived risk on tangents or smooth curves is very low, thus enabling drivers to reach higher speeds.

Considering the behavior of speed data, two regression models were calibrated in order to predict field speeds as a function of the simulated ones (FIGURE 6a). They will allow designers to estimate actual speed from simulator speed in the road design phase. These analyses were performed merging curve and tangent data, since the relationship between simulated and field speeds could be performed in terms of speed or geometric constraint.

Although the first analysis showed that the mean field speed was statistically equal to the simulated one, a slight change in the tendency has been observed when simulated speed is higher than approximately 90 km/h (FIGURE 6a). A composite linear model was proposed accordingly. For simulated speeds lower than 87.66 km/h, field average speeds are very similar to simulated ones. For higher simulated average speeds, field speeds are a bit lower than simulated ones.

In addition, another model was calibrated for operating speeds (FIGURE 6b). This is a simpler unique model that estimates the field operating speed to be 4.86 km/h lower than the simulated operating speed.

This analysis can also be performed determining the speed difference as a function of geometry. The difference between the speed observed in the driving simulator and the speed developed in the field study (V_s-V_f) was analyzed according to curve radius and tangent length (FIGURE 7).

As the geometric constraint becomes stronger, (V_{ms}-V_{mf}) is lower, and viceversa. In this regard, sharp curves (radii lower than 300 m) and short tangents (length lower than 300 m) presented very low values -even negative in some cases-, whereas smooth curves and long tangents presented higher simulated speeds. Nevertheless, the tendency of the difference between mean speeds in curves was constant and equal to 0 km/h approximately. Finally, the negative difference observed in some short tangents might be due to the preceding and/or following curve.

Considering (V_{85s}-V_{85f}), a higher tangent length produces a higher operating speed difference. On the other hand, this difference was around 5 km/h in curves, being slightly higher for sharp curves.

The objective validation for the SE^2RCO driving simulator has been achieved, considering both the exploratory and statistical analyses.

The subjective validity was also achieved by means of drivers' perception. Most drivers assessed the quality of the virtual environment and the similarity of driving task between the simulator and the real world as medium or high.

All drivers suffering dizziness showed a great difference between the average simulated speed and the average field speed. Hence, these drivers were not considered in the study. Another important aspect is training time. In the driving simulator test, the average speed in the backward trip was a bit lower than in the forward one. This may be due to driver's adaptation, i.e., in the backward trip the volunteers already handled the system control of the simulator properly, whereas a section of forward trip could have been used as training. However, this fact might also be caused by tiredness accumulated by volunteers, since the simulator test lasted for one hour.

CONCLUSIONS

The validation of the SE^2RCO driving simulator has been carried out comparing the continuous speed profiles obtained in a field study and in a simulator. In this regard, the average and operating speed of 79 curves with a radius from 40 to 520 m and 52 tangents with lengths ranging from 120 to 1500 m were obtained. Both the average and operating speeds have been analyzed. This analysis showed that:

- 118 geometric configurations were used for validating the driving simulator. The field operating speed was 4.86 km/h lower than the simulated one. For average simulated speeds lower than 87.66 km/h, the average speed in the driving simulator and in the actual road were similar. However, for simulated speeds greater than 87.66 km/h the field speed was lower. This indicates that simpler geometries produce greater simulated-field differences attending to average speeds. One possible explanation is the difference of perceived risk.
- Drivers' perception supported the validity derived from speed analysis, so most volunteers assessed the quality of the virtual environment and the similarity of driving tasks between the simulator and the real world as medium or high. Only drivers who suffered dizziness evaluated the simulator features negatively.

As a result, the SE^2RCO is a useful tool for driving speed behavior research, since there is a high correlation between the driver behavior in the simulator and the real road. A closer relationship between the speeds developed in the driving simulator and in field might be achieved by means of implementing motion to the simulator. In addition, training time and the symptoms of adaptation to the simulation (SAS) should also be studied in further research. The main objective would be to identify the optimum training time and assess the SAS taking into account social features and drive experience.

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TABLE 1 Geometric Features of the Road Segment

Road segment	R_{min}	R_{max}	AR	AG	G_{max}	L_{max}	AL
Losa del Obispo-Chelva	73	603	260	±2.13 %	±6.70 %	664	175
Chelva-Tuéjar	56	840	250	±3.54 %	±7.81 %	358	56
Tuéjar-Titaguas	37	483	145	±4.33 %	±10.28 %	1511	150

R_{min}=minimum radius (m); R_{max}=maximum radius (m); AR=average radius (m); AG=average longitudinal grade (%); G_{max}=maximum longitudinal grade (%); L_{max}=maximum length of tangent (m); AL=average length of tangent (m)

TABLE 2 Statistical Analysis

Curves													
Forward							Backward						
Id	V_{mf}	σ_f	V_{ms}	σ_s	t	P-Val	Id	V_{mf}	σ_f	V_{ms}	σ_s	t	P-Val
1	58.22	6.33	60.60	10.74	-0.8553	0.3990	1	59.77	5.67	55.73	9.15	1.5451	0.1341
2	61.98	6.27	63.99	12.76	-0.6340	0.5313	2	67.03	6.18	62.58	10.46	1.5946	0.1216
3	81.56	7.09	81.97	13.91	-0.1154	0.9090	3	80.66	7.14	84.79	11.21	-1.3206	0.1970
4	82.27	8.09	84.72	14.21	0.6695	0.5083	4	83.04	7.20	85.81	13.42	-0.7912	0.4356
5	84.48	6.92	89.45	12.45	-1.5602	0.1293	5	83.70	6.24	84.22	12.41	-0.1294	0.8986
6	62.84	6.31	64.16	12.03	-0.4250	0.6742	6	63.36	5.59	65.66	11.98	-0.7187	0.4797
7	71.23	5.48	70.08	11.34	0.3982	0.6938	7	65.31	4.75	64.48	10.58	0.2961	0.7699
8	78.44	7.58	77.73	13.21	0.2042	0.8397	8	80.42	7.86	79.77	10.50	0.1975	0.8448
9	69.95	6.14	69.87	11.64	0.0257	0.9797	9	72.66	6.95	68.76	9.42	1.3747	0.1796
10	68.99	6.98	70.12	14.09	-0.2892	0.7751	10	71.02	6.68	68.34	10.03	0.9165	0.3673
11	70.53	8.22	70.36	13.42	0.0403	0.9683	11	62.20	6.19	59.63	9.89	0.8825	0.3858
12	65.24	7.07	63.25	12.30	0.5623	0.5791	12	71.80	6.47	69.30	10.16	0.8807	0.3858
13	68.68	6.14	73.72	12.36	-1.4579	0.1590	13	77.86	7.75	67.94	13.34	2.6503	0.0136
14	78.01	6.12	74.34	14.64	0.9535	0.3510	14	92.51	9.06	87.92	16.45	0.9472	0.3539
15	89.45	10.32	90.43	18.68	-0.1713	0.8657	15	90.94	8.31	89.73	16.27	0.2488	0.8061
16	93.79	9.23	92.72	18.06	0.1984	0.8448	16	87.59	7.31	80.01	12.84	1.8488	0.0801
17	82.43	8.62	81.05	13.53	0.3089	0.7606	17	73.48	8.33	69.46	11.09	1.1572	0.2570
18	57.93	6.02	63.17	9.78	-1.8248	0.8003	18	59.47	5.22	62.39	10.74	-1.0370	0.3098
19	61.83	5.92	66.70	13.18	-1.3903	0.1782	19	61.17	4.82	60.66	9.91	0.1962	0.8461
20	73.49	7.99	74.80	13.94	-0.3663	0.7167	20	75.80	6.39	76.59	11.93	-0.2545	0.8010
21	56.97	6.52	62.57	12.41	-1.6485	0.1122	21	74.29	7.31	76.95	12.66	-0.8126	0.4228
22	53.15	4.76	54.42	9.41	-0.5100	0.6145	22	57.28	7.28	72.96	12.01	-4.9928	0.0000
23	74.96	8.43	81.21	18.59	-1.2978	0.2068	23	70.73	5.30	70.24	12.73	0.1554	0.8778
24	67.04	10.27	75.69	13.43	-2.1094	0.0434	24	59.59	4.76	61.02	10.32	-1.3206	0.1970
25	65.55	6.83	65.18	13.55	0.1085	0.9144	25	83.31	8.54	80.51	12.55	0.8038	0.4275
26	60.12	5.26	61.87	10.78	-0.6512	0.5203	26	79.52	7.62	80.13	15.25	-0.1642	0.8707
27	76.96	7.78	74.74	13.72	0.6140	0.5441	27	76.28	7.65	71.47	12.20	1.5295	0.1355
28	77.99	8.66	78.07	13.13	-0.0233	0.9815	28	59.98	6.22	58.63	10.49	0.4936	0.6251
29	76.88	7.95	78.43	13.21	-0.4479	0.6573	29	50.12	3.52	44.77	9.64	2.3314	0.0285
30	60.16	5.55	60.95	12.42	-0.2678	0.7908	30	57.59	5.23	56.06	11.03	0.5740	0.5704
31	56.76	5.44	61.83	12.40	-1.7158	0.0975	31	67.92	4.47	65.82	11.10	0.8041	0.4285
32	53.51	4.71	51.84	8.91	0.7261	0.4740	32	84.12	9.18	81.56	14.85	0.6728	0.5057
33	48.38	3.78	48.65	9.85	-0.1128	0.9112	33	62.28	6.19	58.43	10.13	1.4879	0.1462
34	54.88	4.56	57.02	11.21	-0.7926	0.4354	34	65.10	6.43	59.24	9.38	2.3613	0.0238
35	79.70	6.74	75.67	13.33	1.2060	0.2379	35	68.11	5.18	59.34	11.36	3.2167	0.0033
36	57.31	6.87	56.89	9.68	0.1607	0.8733	36	75.54	6.55	77.23	12.36	-0.5548	0.5931
37	68.66	5.43	66.31	12.11	0.7712	0.4478	37	68.11	7.32	66.52	13.75	0.4459	0.6592
38	68.65	5.52	63.18	15.81	1.4235	0.1684	38	71.52	7.54	69.06	12.57	0.7339	0.4688
39	69.88	7.53	62.68	12.92	2.2074	0.0345							
40	68.75	7.10	70.32	12.37	-0.5075	0.6153							
41	74.56	7.01	76.32	13.50	-0.4892	0.6289							
Tangents													
Forward							Backward						
Id	V_{mf}	σ_f	V_{ms}	σ_s	t	P-Val	Id	V_{mf}	σ_f	V_{ms}	σ_s	t	P-Val
1	85.44	7.25	96.01	15.35	-2.8511	0.0080	1	93.49	10.20	98.51	14.22	-1.2176	0.2326
2	78.98	7.13	84.31	13.24	-1.6244	0.1145	2	89.90	8.38	89.30	15.15	0.1524	0.8800

3	94.63	7.53	100.90	15.86	-1.5968	0.1219	3	95.74	8.38	101.42	12.19	-1.7171	0.0952
4	92.24	7.75	94.05	15.00	-0.4784	0.6360	4	93.50	8.41	94.32	11.67	-0.2536	0.8013
5	92.74	7.57	97.48	14.50	-1.2948	0.2057	5	97.01	9.48	99.09	16.97	-0.4676	0.6437
6	92.44	7.08	94.85	14.36	-0.6735	0.5062	6	96.72	9.34	96.05	16.12	0.1512	0.8809
7	88.95	7.60	95.16	16.26	-1.5466	0.1336	7	94.29	7.96	88.27	11.50	1.8275	0.0775
8	89.67	9.14	91.80	14.73	-0.5505	0.5858	8	94.88	9.33	96.38	14.01	-0.3771	0.7088
9	85.60	7.60	84.10	14.04	0.3878	0.7015	9	90.30	8.64	84.53	10.92	1.8062	0.0797
10	98.61	13.37	101.55	15.76	-0.5492	0.5873	10	101.2	9.04	96.79	18.01	0.8630	0.3980
11	100.6	11.91	113.85	16.47	-2.4264	0.0232	11	99.41	9.28	100.87	17.90	-0.2902	0.7743
12	75.63	10.02	91.77	24.29	-2.4574	0.0233	12	72.00	7.51	78.89	16.06	-1.6472	0.1125
13	84.59	7.62	86.87	16.63	-0.5279	0.6025	13	84.68	8.22	83.46	13.27	0.3483	0.7299
14	87.96	7.41	96.83	17.32	-1.9422	0.0652	14	83.40	7.91	93.52	15.89	-2.5504	0.0165
15	90.10	10.28	96.52	18.35	-1.3291	0.1944	15	90.52	10.72	97.93	20.27	-1.4452	0.1592
16	102.2	10.93	114.54	21.94	-2.2909	0.0293	16	105.2	9.81	107.73	17.92	-0.5340	0.5974
17	88.34	10.28	87.97	14.39	0.0963	0.9238	17	89.27	8.02	88.78	14.51	0.1287	0.0898
18	80.85	7.76	77.43	13.10	1.0024	0.3240	18	89.58	9.21	84.88	12.36	1.3973	0.1706
19	83.65	8.10	82.23	13.60	0.3894	0.6998	19	89.08	9.63	84.81	13.63	1.1750	0.2477
20	90.66	9.56	85.38	14.09	1.3860	0.1749	20	88.34	9.78	87.33	17.16	0.2332	0.8171
21	83.95	8.99	85.58	14.03	-0.4483	0.6568	21	84.36	8.34	77.24	13.92	-1.3949	0.1725
22	72.96	7.34	77.31	12.25	-1.3949	0.1725	22	83.65	8.02	79.37	15.44	1.1257	0.2692
23	85.45	7.91	85.85	15.74	-0.1021	0.9194	23	92.73	10.18	87.18	14.92	1.4073	0.1681
24	88.23	9.04	88.32	15.51	-0.0236	0.9813	24	89.81	10.09	82.68	12.96	1.9871	0.0542
25	82.00	7.12	76.98	14.29	1.3700	0.1822	25	75.19	6.15	69.09	10.68	2.2662	0.0304
26	93.01	9.46	91.94	17.56	0.2463	0.8071	26	85.01	8.84	85.55	12.84	-0.1604	0.8735

FIGURE 1 Location of the VIRB Elite cameras in the volunteers' car.

FIGURE 2 SE^{2}RCO driving simulator.

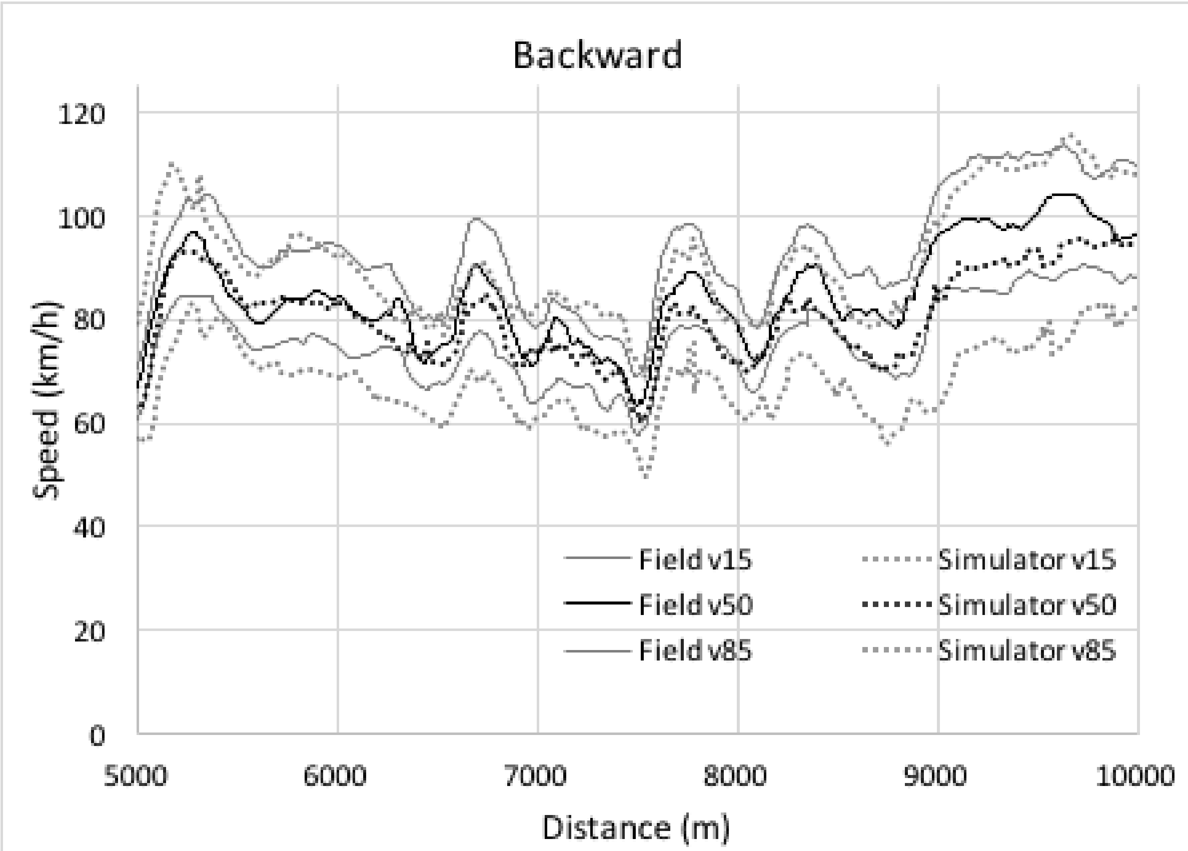

FIGURE 3 Comparison between V_s and V_f.

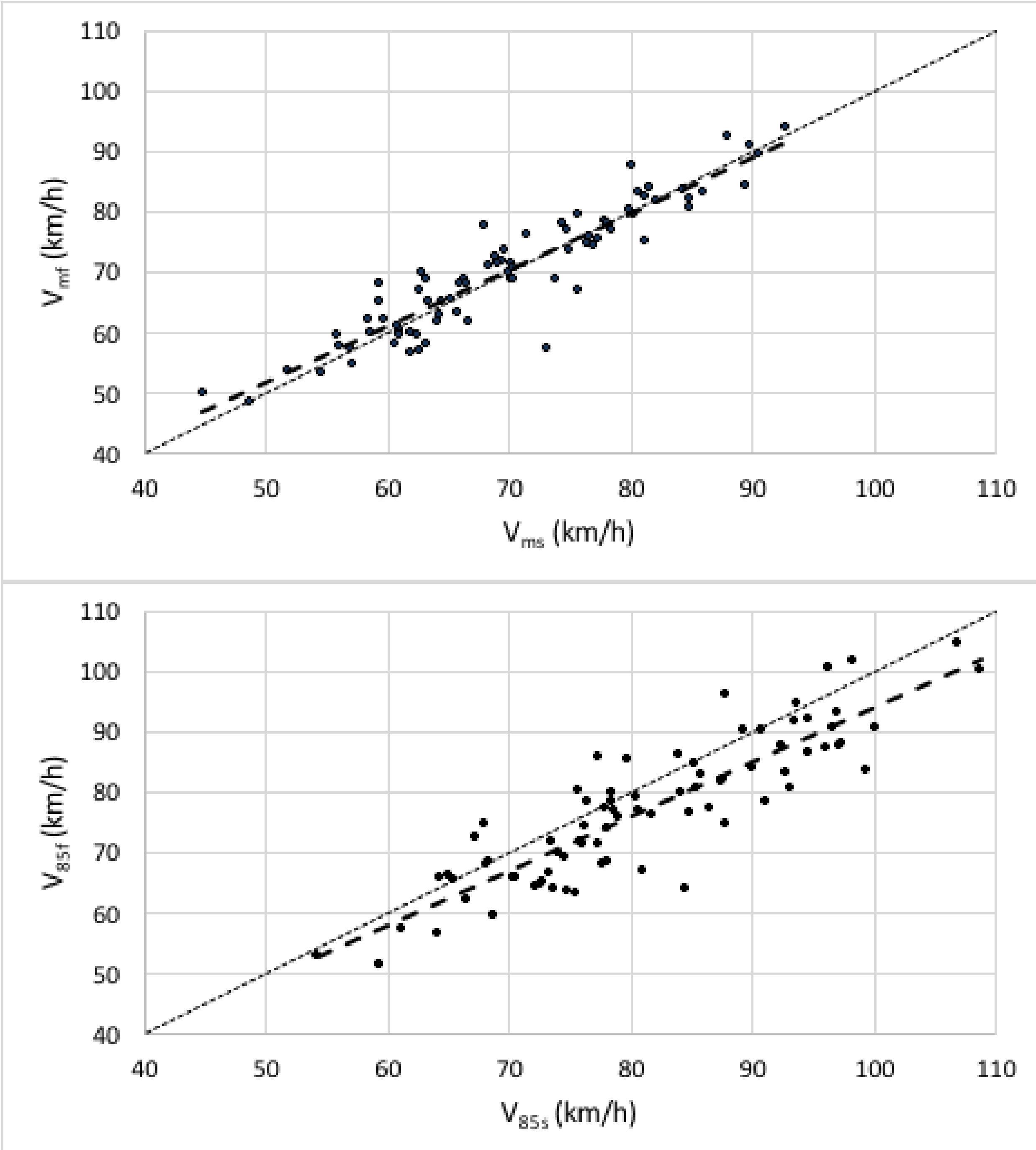

FIGURE 4 Average speed and operating speed on curves.

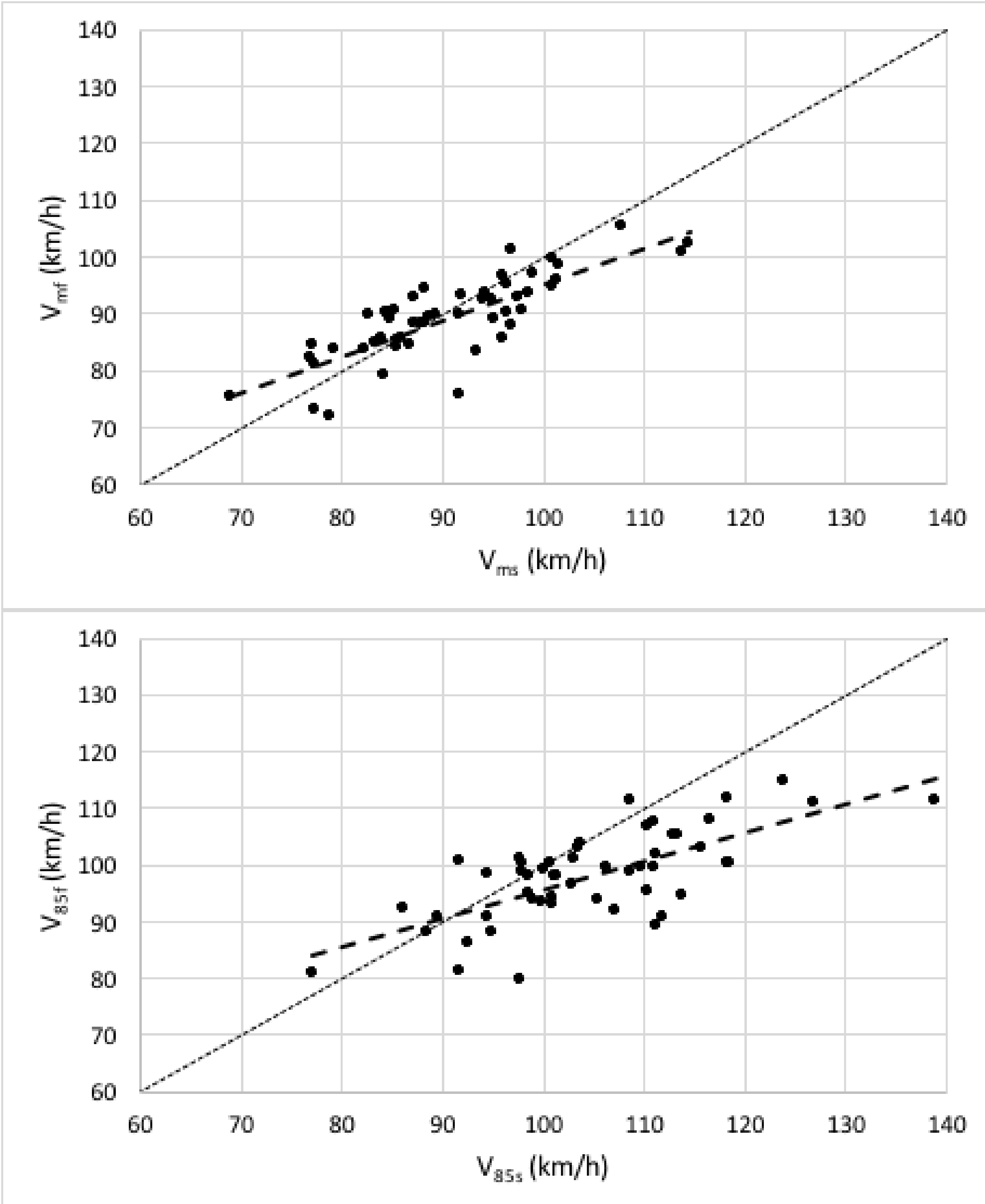

FIGURE 5 Average and 85th percentile of the speed distributions on tangents.

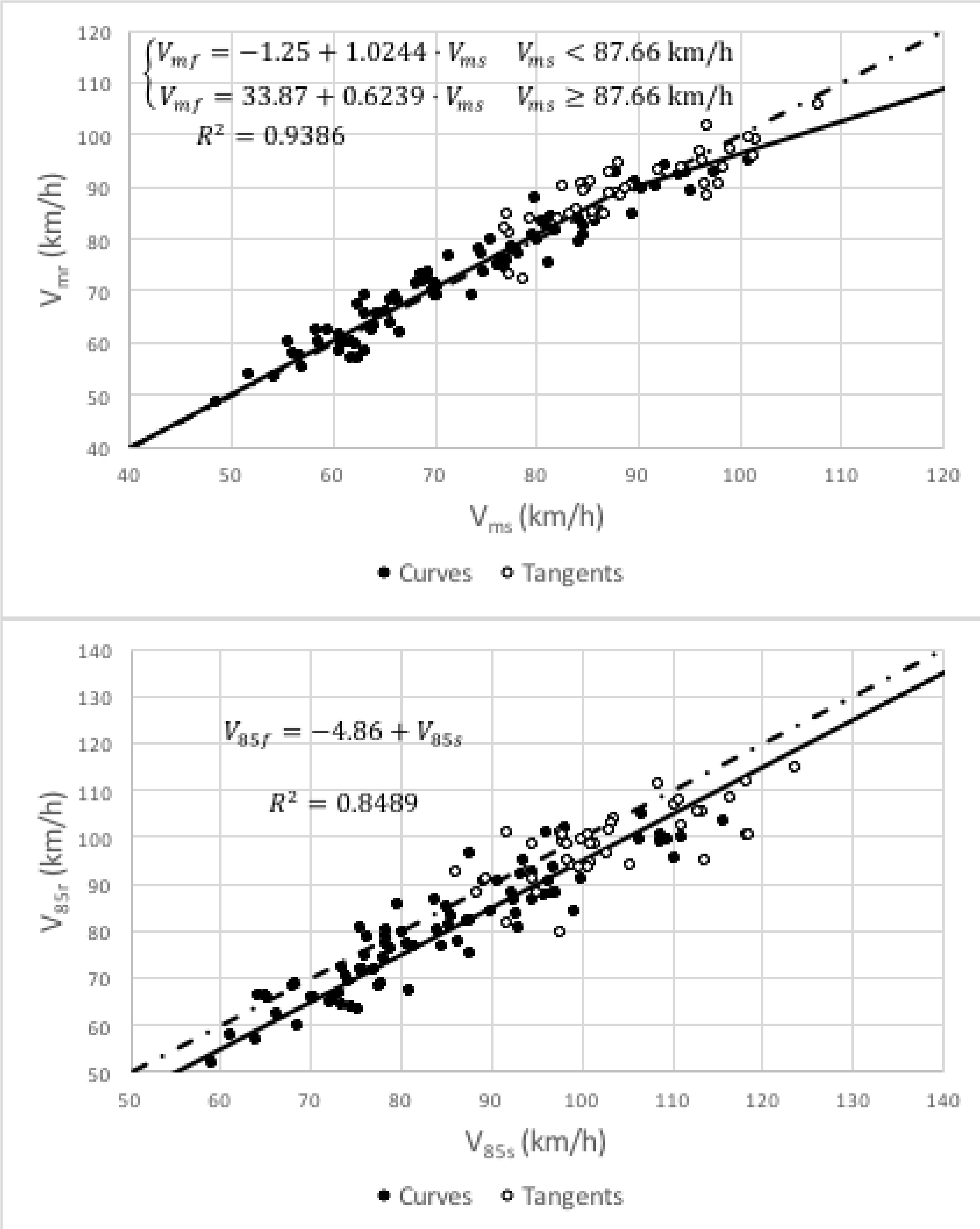

FIGURE 6 Average and operating speed models.

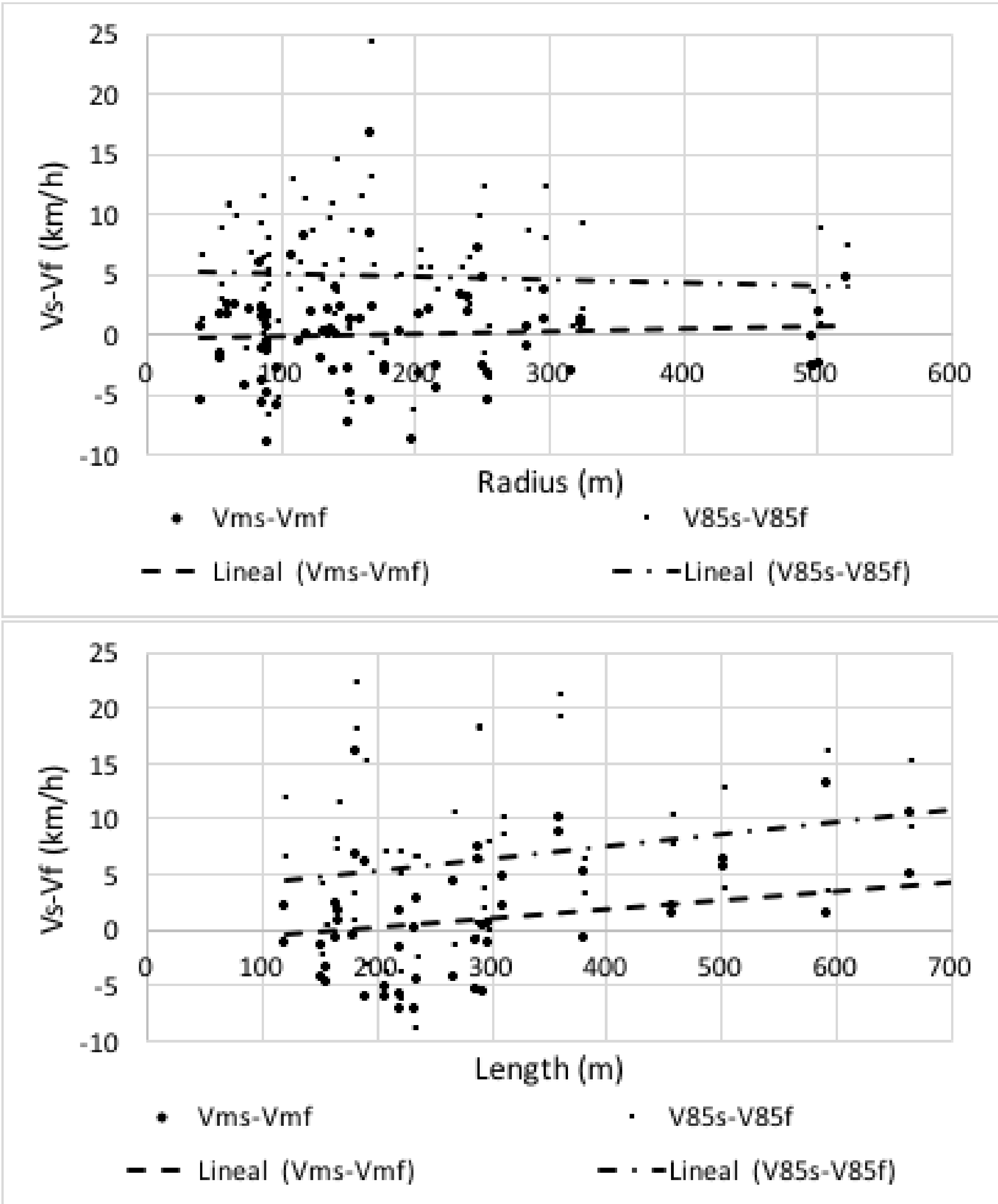

FIGURE 7 Speed difference vs Geometric features.