EXAMINING THE FREE-FLOW SPEED DISTRIBUTION ON TWO-LANE RURAL ROADS

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ABSTRACT

Free-flow speed variation of passenger vehicles along a road segment is one of the most used factors in road safety studies, as a surrogate measure to evaluate road design consistency. Free-flow speed may be measured when a road segment is already built, but it must be estimated during design phase. Several studies have been carried out in order to calibrate models to estimate free-flow speed, using geometric features as explanatory variables.

Currently, most free-flow speed models only focus on mean speed or in particular percentiles, such as 85th, or 95th. Moreover, most of these studies assume normality in their free-flow speed distribution without checking this hypothesis.

The main objective of this paper is to analyze the free-flow speed distribution on two-lane rural road curves and tangents. The research focuses on two main issues: determining whether speed data are normally distributed at a specific site, and analyzing the behavior of the mean and standard deviation of speed on both curves and tangents.

This study is based on continuous operating speed profiles, obtained from a database of more than 16,000 veh-km collected by the same authors. A total amount of 63 horizontal curves and 78 tangents has been analyzed. According to the results, normal distribution is not the best distribution in most cases for describing free-flow speeds. In fact, in 46 of the curves and in 64 of the tangents, free-flow speed cannot be assumed to be normally distributed. Therefore, some other distributions should be tested in further research.

Keywords: speed distribution, free-flow, operating speed, two-lane rural road

INTRODUCTION

One of the most concerned aspects of transportation engineers is highway safety. The main concurrent factors are human, vehicle, and infrastructure. Many studies have revealed the importance of the interaction between infrastructure and human factors. In order to analyze this interaction, research has usually been focused on operating speed, which is defined as the speed at which drivers are observed operating their vehicles under free-flow conditions *(1)*. This speed is not a fixed value since it presents transversal variability (different drivers develop different speeds in a road section) and longitudinal variation along the corridor (every driver develops different speeds in different road sections). The 85th percentile of the distribution of observed speeds in free-flow conditions is the most frequently used measure of the operating speed associated with a particular location or geometric feature *(1)*.

The 85th percentile of the free-flow speed distribution is very useful for road geometric design. However, several studies have highlighted the importance of considering the entire speed distribution, instead of focusing on a particular percentile speed in designing and operating roadways *(2)*. In fact, it is possible that a road with a high mean speed and low speed variability presents the same 85th percentile than a road with a much lower mean speed but higher speed variability *(3, 4)*.

Garber and Gabiraju *(5)* found that the accident rate on a highway does not necessarily increase with the average speed but with the speed variance. Besides, it is well known that locations with geometric features showing higher values of speed variability may be locations associated with driver errors. Significant changes in speed distribution measures may also suggest that design inconsistencies are present between alignment features *(6)*.

These findings confirm the importance of considering the entire free-flow speed distribution instead of a single percentile. There are two main ways of addressing the problem of estimating the speed distribution: calibrating models for each speed percentile *(7, 8)*, and calibrating models for speed average and variance *(6, 9, 10)*.

The main limitation of the first kind of models is that they cannot predict any other percentile than the one they were developed for. On the contrary, models based on mean and variance can estimate any speed percentile, as long as the speed distribution is known. A common hypothesis is that free-flow speeds are normally distributed (11), thus enabling an easy calculation of any operating speed percentile.

The studies whose objective is the calibration of models for different speed percentile estimation are normally focused on main percentiles, such as mean speed, 85th and 95th percentiles. An important concern is which parameters should be considered in the models. In most cases, independent variables are different for each percentile. For instance, Schurr et al. (7) calibrated an equation for mean speed depending on deflection angle, arc length of the curve and posted speed, but the equation calibrated for 85th percentile speed estimation depended on deflection angle, arc length of curve and approaching grade.

Some researchers suggest that standard deviation of speed increases as the radius of the horizontal curve does for sharp curves, and it remains constant for flatter ones. Since deviation becomes greater as the radius increases, it also does with increasing speed (6, 9). Besides, Jacob and Anjaneyulu (10) found that there are changes in the speed distribution of vehicles between tangent and mid-curve. There was a speed reduction from tangent to mid-curve, and the mid-curve speed variability was lower than on tangent. Their models indicated that both mean speed and standard deviation increased as radius did, decreasing as the curve length increased.

Collins et al. (6) also found that higher posted speed limits generally result in a higher standard deviation.

A variation of this methodology is the calibration of an equation to estimate all percentiles. Figueroa and Tarko (3) developed a model to estimate tangent speed including eleven parameters affecting mean, and five parameters related to the standard deviation. Their model for curves includes four different variables. The first intercept and the following five terms apply to the mean speed, while the second intercept and the two variables, whose names start with Zp, apply to the standard deviation.

Lobo et al. (12) calibrated a free-flow speed frontier model. This model allows the estimation of the fastest free-flow driver speed as a function of local geometric features of the road. Based on this speed, every single speed percentile may be estimated through the cumulative function of the one-sided disturbance.

As mentioned above, these studies have to be based on the hypothesis that speeds are normally distributed at a specific site. However, normality tests are hardly ever included in papers.

Lindeman and Ranft (9) documented skewness and kurtosis of the speed distribution observed at 10 curves. Their values indicated that speeds were normal distributed.

Fitzpatrick et al. (13) also checked speed data normality using the Shapiro-Wilk test. Also, stem-and-leaf plots and normal probability plots were created to check the normality of the speed data. The normality test results indicated that most locations presented normally distributed speeds. All sites failing the test were checked by observing the normal probability plots. In most cases, the plots indicated a normal distribution, so speeds were assumed to be normal.

In the same way, Fazio et al. (14) conducted a chi-square goodness-of-fit for each site to determine whether observed speed distributions followed a Gaussian distribution or not. The results showed that only six out of ten locations presented normally distributed speeds.

Despite of previous research, normality is widespread assumed as hypothesis even without checking it (3, 12). Moreover, most research do assume it as a basis for the statistical analysis, but no mention is given about data distribution. The authors have not found any previous research trying to fit alternative distributions to free-flow speed.

OBJECTIVES AND HYPOTHESES

The main objective of this paper is to analyze free-flow speed distribution in curves and tangents, with a special focus on average and standard deviation. The free-flow speed distribution will also be analyzed, in order to determine whether a normal distribution accurately fits the actual speed distribution at a specific site or not. Considering the free-flow distribution instead of only the operating speed will be of a major importance for road safety studies due to the relationship between speed variability and crash occurrence.

The main hypothesis is that both mean and standard deviation are highly correlated with geometric features. Besides, although free-flow speed was traditionally assumed to be normal, other distributions may better reflect drivers' behavior.

METHODOLOGY

This research is based on a database of more than 16,000 veh-km collected in 2008 in Spain. Speed data were always collected in working days between 8:30 a.m. and 2:00 p.m. and under dry weather conditions. The data collection methodology was developed by Pérez-Zuriaga et al. *(15)*.

Ten two-lane rural road sections between 5 and 20 km long were selected, with an AADT ranging from 850 to 7,000 vpd *(15)*. AADT should not be too high in order to ensure free-flow conditions, as well as to avoid safety risks. On the other hand, it was necessary to collect a significant sample size of drivers *(16)*.

Two checkpoints were located at the beginning and at the end of each road section. Every incoming vehicle was stopped, and drivers were asked to participate in the study. If the driver agreed, a 1Hz pocket-sized GPS was placed onto the vehicle. The accuracy of these GPS devices was 2.5 m. However, this accuracy is mainly composed by a general bias (common to all measurements) and a minimum random error (millimeters). To check whether drivers were biased by the presence of the GPS device, a naturalistic test was carried out *(16)*. The test was based on comparing spot speeds of drivers who were carrying GPS devices and drivers who did not, one day before the experiment. These spot speeds were recorded by video cameras hidden from driver's vision. The results validated the methodology, since no statistical difference was found between both data sets.

Free-flow conditions were also checked *(16)*. The test is based on the hypothesis that every single driver behaves in a particular way, approaching their individual speed profile to a certain speed percentile. Therefore, for each individual speed profile, non-free-flow road sections were identified by means of comparing the individual speed profile with different percentiles of the speed. After removing non-free-flow sections for every single driver, the sample size ranged from 53 to 121 drivers, depending on the geometric element.

The geometry of the road sections used in the research was extracted using an algorithm based on the heading direction *(17)*.

63 single, isolated curves were selected for data analysis. Compound and broken-back curves were not considered, since their amount was not enough for obtaining conclusions. In the selected set of curves, it was checked that the minimum speed was statistically similar than the speed at the midpoint. Thus, the speed of each single driver was selected at the midpoint of the curves in order to analyze the free-flow speed distribution.

The analysis also included 78 tangents. All independent tangents were selected, as well as those non-independent tangents in which a constant speed was reached.

Table 1 summarizes the main characteristics of all geometric elements.

SPEED DISTRIBUTION

After the treatment of the speed data recorded during data collection, a database with drivers' individual speed, mean and standard deviation of speed distribution was prepared for every curve and tangent. Those data are the basis for the following analysis of free-flow speed distribution.

Speed distribution for curves

In order to analyze the free-flow speed distribution on curves, it is necessary to calibrate a speed model that estimates the average speed using a specific functional form. A model using the radius as explanatory variable was selected, since most models use it. Although this might not be the best model, different functional forms can be calibrated using the conclusions obtained in this paper.

Figure 1 shows how the mean free-flow speed varies according to the radius. As expected, sharper curves present lower speeds. In the same way, the relationship between mean speed and radius is not linear, since it approaches to a constant speed for larger radii. This is not surprising, since weaker geometric controls encourage drivers to perform faster, like in tangents. Most free-flow speed models include this behavior by means of hyperbolic or logarithmic functional forms.

Figure 2 shows the relationship between free-flow speed variability and radius. It can be observed that the speed variability increases with the radius, following a hyperbolic functional form. Like mean speed, values are stabilized for large radii, where the geometric control is very weak and drivers behave like in tangents.

Therefore, both mean and standard deviation of free-flow speed are highly correlated to curve radius. This may indicate that both parameters are also correlated. Figure 3 shows how free-flow speed variability varies according to the mean free-flow speed. The relationship seems to be linear, with a positive gradient (R^2=0.41). In this case, there is no stabilization for high mean speeds.

After studying the mean and the variability of the distribution, some normality tests were carried out. The aim of the tests was to check whether the normal distribution can be assumed for free-flow speeds. There are several tests to check the normality of a distribution. Since no one of them is definitely the best for this purpose, four tests have been considered: Chi-Square test, Shapiro–Wilk test, standardized bias and standardized kurtosis. A confidence level of 95% has been considered, where necessary.

- Chi-Square test checks normality contrasting the observed frequencies with the expected frequencies according to a normal distribution. A P-Value lower than 0.05 means that data do not fit a normal distribution.
- The Shapiro-Wilk test is maybe the most accurate test to check normality. This test assumes as null hypothesis a normal distribution of data. Like in the Chi-Square test, a p-value lower than 0.05 indicates a non-normal data distribution.
- The standardized bias measures the degree of asymmetry of a distribution. A standardized bias within [-2, 2] indicates a symmetric distribution, which is necessary – but not enough – for assuming a normal distribution.
- The standardized kurtosis measures the sharpness level of a distribution. Like in the previous test, a value within [-2, 2] is necessary for assuming a normal distribution, although some other distributions could meet this condition too.

Table 2 shows the results. Most curves do not follow a normal speed distribution, attending to the different normality tests. Hence, it cannot be assumed that the free-flow speed follows a normal distribution on curves, although in several cases it could be a close approximation. Summarizing, 46 out of 63 curves do not follow a normal distribution attending to the following tests: 36 due to Chi-square test, 30 because of Shapiro-Wilk test, 14 because of standardized bias test and 17 due to standardized kurtosis test.

Figure 4 depicts the speed distribution for some curves, supporting the lack of normality of the data.

A normal probability plot was also developed for each curve. Although all results cannot be shown in this paper, most curves presented a positive skewness.

The relationship between non-normality and geometry was also examined (Figure 5), concluding that the lack of normality is not associated to either sharp or flat curves.

Speed distribution for tangents

In order to analyze the tangent free-flow speed distribution, the individual operating speed profile for each driver was examined, selecting the maximum constant speed reached. From those data, mean and standard deviation were obtained.

The analysis of free-flow speed on tangents is more difficult than on curves since there is not a parameter that clearly affects the speed. As a result, researchers have used several different parameters to estimate it, but the variability is very high. In this study, free-flow speed mean value has been analyzed considering its relationship with tangent length (Figure 6).

Speed variability has been also studied focusing on its relationship with tangent length (Figure 7).

The relationship between the mean and the standard deviation of the free-flow speed and the corresponding tangent length shows that longer tangents are associated to higher mean speeds and standard deviations.

Figure 8 shows the free-flow speed variability as a function of the mean free-flow speed. Again, a higher variability is observed for higher mean speeds, although the relationship is not linear.

Finally, it has been analyzed whether a normal distribution can be assumed or not, considering the same tests than for curves (Table 3). 64 out of 78 tangents cannot be assumed to follow a normal speed distribution: 58 because of Chi-square test; 37 due to Shapiro-Wilk test; 22 because of standardized bias test; and 30 due to standardized kurtosis test. According to these results, the speed on tangents cannot be assumed to follow a normal distribution. This conclusion was also supported by the normal probability plot, which was developed for every tangent. The lack of normality is not linked to the tangent length (Figure 9).

DISCUSSION

Operating speed, as 85th percentile of the free-flow speed distribution, is one of the most used parameters in order to evaluate road design consistency. However, several studies have highlighted the importance of evaluating the effects of considering the entire speed distribution *(2)*. Speed distribution estimation may be carried out by models for each speed percentile *(7, 8)* or by models for mean and standard deviation of speed distribution *(6, 9, 10)*.

Previous studies stated that standard deviation of speed increases as the radius of the horizontal curve does for sharp curves, and then it remains constant for flatter curves. Since deviation becomes greater with increasing radius, it does also with increasing speed (6, 9). The findings of the present study confirm this statement. This occurs probably because curves impose a geometric control which weakens as the radius increases. In fact, drivers tend to perform similarly on flat curves and on tangents.

Results show that mean speed on curves increases with radius up to a certain value, which is similar to the speed reached on tangents. The same tendency happens on tangents, where drivers drive faster on longer tangents. This is due to the fact that long tangents allow drivers to reach their desired speed, not constrained by the preceding or following geometric control. Desired speed depends on driver characteristics more than on road geometric features. Thus, higher dispersion is achieved for weaker or even null geometric controls.

It was found that curves and tangents behave similarly attending to the relationship between speed dispersion and average speed. Thus, both relationships were plotted in the same graph (Figure 10). Two conclusions can be derived:

- Free-flow speed variability increases as the mean speed does.
- Horizontal curves and tangents seem to share the same tendency.

Both conclusions are very important for developing further free-flow speed models.

The comparison of the relationship between mean speed and standard deviation for curves and tangents shows that for both elements the standard deviation increases with the average speed. Both data sets overlap in the range between 65 km/h and 95 km/h.

The present research has also checked whether free-flow speed is normally distributed on curves and tangents. Results show that 73% of curves and 82% of tangents are not normally distributed, which disagrees with most previous research. Nevertheless, some previous research also found similar conclusions on some specific locations *(13, 14)*.

Considering the lack of normality in most geometric elements, a deeper analysis was performed considering social factors. These factors included social data, driving experience, type of vehicle, travel purpose and road and environment characteristics. All those factors were checked, but no significant differences were found between the geometric elements which met normality and those which did not. Further, road elements sharing similar geometries also differed in normality within the same road section.

Attending to the results obtained in this research, further analyses should be performed in order to determine which speed distribution fits free-flow speed best. Although a normal distribution cannot definitely be assumed for all cases, this assumption might be enough for most research, not invalidating its use.

CONCLUSIONS

This paper presents the analysis of the free-flow speed distribution on 63 horizontal curves and 78 tangents. The main scope of this research was to analyze mean speed and its variability, as well as to check whether free-flow speed is normally distributed.

Continuous free-flow speed data from actual drivers were registered using GPS devices, using the data collection methodology proposed by Pérez-Zuriaga et al. *(15)*. From these data, actual individual speed data were filtered for both curves and tangents.

The analysis of the curve free-flow speed distribution is based on the performance of the mean speed and standard deviation as a function of the radius. As expected, the mean free-flow speed on curves is highly correlated with their radius. This relationship is not linear, since it approaches to a constant speed for large radii. Speed variability also increases with the radius. Flat curves and tangents behave similarly.

Speed on tangents was analyzed considering the tangent length. This analysis shows that longer tangents are associated to a higher mean speed and a higher standard deviation, although the relationship is weaker than for curves, since tangents do not impose a geometric control.

A relationship between mean free-flow speed and free-flow speed variability was determined for curves and tangents. It was also found that both geometric elements shared a nearly linear relationship. Higher speed dispersions were associated to higher average speeds.

Finally, the free-flow speed normality assumption was checked for every single curve and tangent. Statistic tests like the standardized bias, the standardized kurtosis, the Chi-Square test and the Shapiro–Wilk test were used. Most elements were found to present free-flow speeds that do not follow a normal distribution (73% curves and 82% tangents). However, the lack of normality does not seem to be related to geometry.

Those are valuable findings compared to previous research. Although most free-flow speed models are focused on operating speed, in some cases it might be of interest to know how the entire free-flow speed distribution behaves. Therefore, a more accurate model might be developed by means of the free-flow speed of every single driver, i.e., with disaggregate data. This model will be able to incorporate the effect of speed variability and will allow the estimation of any speed percentile. Further research is proposed to identify which probability distribution fits free-flow speed data the best. This should also take into consideration a wider range of parameters, as well as additional functional forms.

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TABLE 1 Summary of curves and tangents characteristics

		Curves	Tangents
Number		63	78
Radius (m)	Minimum	52	-
	Maximum	645	-
Length (m)	Minimum	93	26
	Maximum	425	2543
Mean Speed (km/h)	Minimum	48	65
	Maximum	96	105
Standard Deviation (km/h)	Minimum	6	7
	Maximum	13	22

TABLE 2 Normality test

Curve	Chi-Square	P-Value	Shapir-Wilk	P-Value	Stand. Bias	P-Value	Stand. Kurtosis	P-Value
C01I01	46.14930	0.00028	0.97072	0.28464	0.70402	0.48142	-0.85670	0.39161
C01I02	11.63640	0.63548	0.95255	0.10565	1.40538	0.15991	1.28926	0.19731
C01I03	15.43280	0.63206	0.96234	0.10762	1.79787	0.07220	3.09282	0.00198
C01I04	20.42860	0.15610	0.98784	0.95234	0.23647	0.81307	-0.37737	0.70590
C01I05	21.07460	0.27567	0.96666	0.18137	0.90849	0.36362	-0.30375	0.76131
C01I06	13.55220	0.75778	0.97558	0.45577	0.90499	0.36547	-0.14474	0.88491
C01V01	27.29410	0.12719	0.96069	0.04478	0.18410	0.85393	-1.14748	0.25118
C01V02	44.87500	0.00001	0.88203	0.00198	0.10574	0.91579	1.02108	0.30722
C03I01	63.90530	0.00000	0.93722	0.00021	2.94361	0.00324	3.55024	0.00038
C03I02	51.27370	0.00024	0.92899	0.00003	2.99690	0.00273	3.10155	0.00193
C03V01	28.00000	0.10940	0.92252	0.00002	3.20850	0.00133	3.77064	0.00016
C03V02	57.21690	0.00001	0.92944	0.00015	2.73047	0.00632	3.04926	0.00229
C04I01	27.49060	0.19318	0.96363	0.03749	1.70871	0.08750	0.62985	0.52879
C04I02	43.18180	0.00448	0.95433	0.00395	1.89397	0.05823	0.96219	0.33595
C04I03	28.11110	0.17203	0.95380	0.00388	2.06317	0.03910	1.67478	0.09398
C04I04	51.88240	0.00020	0.95353	0.00510	1.70047	0.08904	1.38464	0.16616
C04V01	24.10260	0.19225	0.98430	0.79574	0.38866	0.69752	0.37088	0.71072
C04V02	32.30120	0.02890	0.97281	0.27551	0.01210	0.99034	-1.12822	0.25923
C04V03	59.76470	0.00001	0.96028	0.04184	1.73978	0.08190	1.69884	0.08935
C05I0	53.70270	0.00002	0.94784	0.00945	1.20732	0.22731	-1.26408	0.20620
C05I02	72.43240	0.00000	0.98228	0.71941	0.73160	0.46441	0.43888	0.66075
C05I03	16.84510	0.53378	0.96407	0.11794	1.38454	0.16619	1.10027	0.27121
C05I04	31.13040	0.02780	0.92215	0.00024	2.55730	0.01055	2.61874	0.00883
C05I05	27.73530	0.06620	0.94876	0.01609	2.11249	0.03464	2.14919	0.03162
C05V01	45.42720	0.00152	0.95313	0.00441	2.68189	0.00732	3.11997	0.00181
C05V02	52.25000	0.00029	0.96808	0.09228	1.62467	0.10423	0.69762	0.48541
C05V04	44.55770	0.00302	0.93335	0.00003	3.14839	0.00164	3.76226	0.00017
C05V05	40.38610	0.00667	0.93832	0.00015	2.90816	0.00364	3.14637	0.00165
C06V01	47.48280	0.00006	0.94338	0.01569	1.44589	0.14821	1.74532	0.08093
C06V02	54.18180	0.00005	0.94149	0.00103	2.48307	0.01303	3.03664	0.00239
C06I01	33.50000	0.02971	0.97835	0.46937	1.21879	0.22292	1.17276	0.24089
C07I02	14.43640	0.56624	0.94930	0.03930	1.70952	0.08735	1.25476	0.20957
C07I03	13.03850	0.66994	0.96878	0.32548	0.83540	0.40349	-0.45325	0.65037
C07I04	26.19230	0.05138	0.96230	0.18055	1.08431	0.27823	0.55368	0.57980
C07I05	26.92310	0.04235	0.94395	0.02650	1.86198	0.06261	1.85922	0.06300
C07I06	12.64000	0.63008	0.94011	0.02051	1.78552	0.07418	1.52259	0.12786
C07V01	52.13700	0.00004	0.95728	0.04281	1.51849	0.12889	0.71967	0.47172
C07V02	113.26800	0.00000	0.94700	0.01015	1.73162	0.08334	2.04343	0.04101
C07V04	31.42470	0.02569	0.95000	0.01420	1.69216	0.09062	0.85751	0.39116
C07V05	31.44120	0.02558	0.94216	0.00607	1.61075	0.10723	0.48982	0.62426
C07V06	24.02940	0.15407	0.96255	0.10676	1.13097	0.25807	0.15293	0.87845
C07V07	25.32430	0.11624	0.97344	0.33768	1.03606	0.30017	0.16115	0.87197
C07V08	39.21050	0.00415	0.98034	0.62320	0.72633	0.46764	1.55955	0.11887
C08I01	59.71430	0.00001	0.97424	0.27032	0.93549	0.34954	-0.40957	0.68212
C08I02	48.44900	0.00060	0.98525	0.79973	0.45354	0.65016	0.76237	0.44584
C08I03	31.56840	0.06470	0.98725	0.88301	1.06197	0.28825	1.25284	0.21026
C08I04	58.00000	0.00003	0.96923	0.13296	1.67031	0.09486	1.97151	0.04867
C08V01	46.50570	0.00069	0.97255	0.25129	1.36988	0.17073	0.88971	0.37362
C08V02	53.90800	0.00006	0.96936	0.16285	1.34912	0.17730	0.51241	0.60836
C08V03	27.47130	0.12252	0.97909	0.52270	0.18330	0.85456	0.44798	0.65416

Curve	Chi-Square	P-Value	Shapir-Wilk	P-Value	Stand. Bias	P-Value	Stand. Kurtosis	P-Value
C08V05	15.31030	0.75838	0.97149	0.21862	0.05398	0.95695	-0.81667	0.41412
C08V06	14.30590	0.81466	0.97604	0.39021	0.36238	0.71706	1.82303	0.06830
C09I01	96.59260	0.00000	0.96342	0.18786	0.05098	0.95933	-0.73310	0.46349
C09I02	13.74550	0.61767	0.97596	0.54345	1.14578	0.25189	2.38569	0.01705
C09V01	14.65960	0.47621	0.97648	0.61902	0.70177	0.48282	-0.49238	0.62245
C09V02	27.04000	0.02841	0.98158	0.78428	0.17906	0.85789	1.41388	0.15740
C10I01	12.29410	0.83169	0.95396	0.03381	1.96565	0.04934	2.13126	0.03307
C10I02	87.83330	0.00000	0.90207	0.00001	2.44000	0.01469	3.57206	0.00035
C10I03	57.95240	0.00000	0.95000	0.02611	0.68986	0.49028	1.56166	0.11837
C10I04	25.76920	0.07877	0.95981	0.08425	1.68534	0.09192	1.74485	0.08101
C10V01	35.05880	0.00390	0.93874	0.01621	1.95010	0.05116	3.27320	0.00106
C10V02	27.65380	0.03476	0.98638	0.91886	0.09018	0.92814	1.04645	0.29535
C10V03	16.24000	0.36628	0.97471	0.53245	0.74794	0.45449	-0.27550	0.78293

TABLE 3 Tangents normality hypothesis checked.

Tangent	Chi-Square	P-Value	Shapir-Wilk	P-Value	Stand. Bias	P-Value	Stand. Kurtosis	P-Value
R01I01	28.59700	0.05353	0.97384	0.38868	1.11750	0.26378	1.12294	0.26146
R01I02	16.05970	0.58838	0.97367	0.38265	0.90694	0.36444	-0.14954	0.88112
R01I03	33.39390	0.01004	0.97644	0.49615	1.00034	0.31715	2.07037	0.03842
R01I04	22.95520	0.19232	0.96731	0.19553	1.27109	0.20370	0.75459	0.45049
R01I05	24.83580	0.12951	0.98146	0.70794	0.24535	0.80618	0.67166	0.50180
R01I06	21.70150	0.24551	0.96463	0.14263	1.22048	0.22228	0.47470	0.63500
R01V01	66.25880	0.00000	0.93316	0.00025	1.02702	0.30441	-2.21274	0.02692
R01V02	37.57650	0.00997	0.96487	0.08755	0.20373	0.83856	-1.44836	0.14752
R01V03	82.49410	0.00000	0.90842	0.00000	0.28542	0.77532	-6.37318	0.00000
R02I01	93.29410	0.00000	0.94480	0.00067	2.81269	0.00491	3.33185	0.00086
R02I02	110.23500	0.00000	0.97566	0.31293	1.29483	0.19538	1.02204	0.30676
R02V01	132.05500	0.00000	0.98255	0.64287	0.07978	0.93641	0.26684	0.78959
R03I01	61.67350	0.00001	0.97953	0.50841	0.53968	0.58941	1.17579	0.23968
R03I02	46.93620	0.00096	0.90763	0.00000	3.50548	0.00046	3.96233	0.00007
R03I03	49.75790	0.00039	0.94903	0.00293	2.62772	0.00860	3.61339	0.00030
R03I04	71.00000	0.00000	0.93655	0.00024	2.37112	0.01773	2.14985	0.03157
R03V01	36.01270	0.01052	0.88147	0.00000	3.53276	0.00041	3.98848	0.00007
R03V02	54.96550	0.00004	0.94933	0.00525	2.18677	0.02876	1.94514	0.05176
R03V03	44.91950	0.00113	0.95309	0.01071	2.46372	0.01375	2.78478	0.00536
R03V04	24.78050	0.16790	0.97510	0.36404	1.55405	0.12017	1.59428	0.11087
R04I01	43.33330	0.00429	0.95853	0.01331	1.51284	0.13032	-0.03644	0.97093
R04I02	38.56070	0.01584	0.95063	0.00192	1.82911	0.06738	0.55775	0.57701
R04I03	62.83330	0.00001	0.94898	0.00119	2.18518	0.02888	1.51502	0.12977
R04I04	34.00000	0.03624	0.94313	0.00044	2.54282	0.01100	2.36933	0.01782
R04V01	22.75900	0.24812	0.98759	0.90577	0.36553	0.71471	0.44567	0.65583
R04V02	93.79520	0.00000	0.97975	0.56925	0.22310	0.82345	0.57364	0.56621
R04V03	38.62790	0.00741	0.95405	0.01349	2.32109	0.02028	2.61911	0.00882
R04V04	48.52380	0.00036	0.96266	0.06383	1.70816	0.08761	2.24718	0.02463
R04V05	31.62350	0.04748	0.97891	0.52136	0.17465	0.86135	-0.56397	0.57277
R05I01	49.40000	0.00009	0.94124	0.00448	0.61831	0.53637	-2.87622	0.00402
R05I02	40.63010	0.00171	0.97450	0.38216	1.05332	0.29219	0.26446	0.79142
R05I03	53.52110	0.00002	0.98407	0.80321	0.07538	0.93991	0.41437	0.67860
R05I04	29.26760	0.04521	0.93563	0.00168	2.00436	0.04503	1.14213	0.25340
R05I05	37.63640	0.00276	0.94899	0.01889	1.82283	0.06833	1.64222	0.10054
R05I06	18.47060	0.42508	0.93861	0.00355	2.40407	0.01621	2.62169	0.00875
R05V01	100.85700	0.00000	0.88973	0.00000	3.58761	0.00033	4.33636	0.00001
R05V02	54.65380	0.00013	0.96110	0.02392	2.25143	0.02436	3.86092	0.00011
R05V03	57.07770	0.00003	0.89602	0.00000	3.75253	0.00018	4.36191	0.00001
R05V04	85.50490	0.00000	0.97191	0.17910	1.83934	0.06586	2.05226	0.04014
R05V05	57.05770	0.00006	0.93849	0.00011	2.93963	0.00329	3.06240	0.00220
R06I01	54.64360	0.00008	0.96733	0.08669	2.36063	0.01824	3.17649	0.00149
R06V01	27.03370	0.13432	0.96267	0.05427	2.18397	0.02896	2.87407	0.00405
R06V02	39.95510	0.00506	0.95616	0.01710	1.68338	0.09230	1.51471	0.12985
R07I01	42.39290	0.00034	0.95707	0.08944	1.40561	0.15984	0.37529	0.70744
R07I02	21.29630	0.16740	0.96356	0.19058	0.78902	0.43010	-0.93085	0.35193
R07I03	31.33330	0.01220	0.95946	0.14260	1.07346	0.28307	0.23188	0.81663
R07I04	40.07690	0.00076	0.94009	0.01727	1.05960	0.28933	-0.96938	0.33235
R07I05	23.13730	0.11011	0.96613	0.26541	1.33013	0.18347	0.97676	0.32869
R07I06	23.88240	0.09211	0.94841	0.04606	1.63524	0.10200	1.14697	0.25139
R07V01	36.95770	0.00531	0.93623	0.00185	1.29317	0.19595	-1.16786	0.24286

Tangent	Chi-Square	P-Value	Shapir-Wilk	P-Value	Stand. Bias	P-Value	Stand. Kurtosis	P-Value
R07V02	51.08330	0.00005	0.95209	0.02077	1.72000	0.08543	1.01764	0.30885
R07V03	33.00000	0.01669	0.95396	0.02747	1.54270	0.12290	0.16319	0.87037
R07V04	30.08330	0.03664	0.96841	0.19773	0.79699	0.42546	-0.61882	0.53603
R07V05	36.31580	0.00965	0.98661	0.88438	0.59336	0.55294	1.21002	0.22627
R07V06	21.84210	0.29219	0.98686	0.89202	0.09568	0.92377	0.30473	0.76057
R08I01	49.42860	0.00044	0.98591	0.82849	0.88322	0.37712	2.26257	0.02366
R08I02	37.35050	0.01534	0.98872	0.92633	0.66431	0.50649	0.57486	0.56539
R08I03	45.00000	0.00173	0.98092	0.58707	1.09605	0.27306	0.83242	0.40517
R08V01	28.52870	0.09746	0.98243	0.68847	1.23877	0.21543	1.60259	0.10903
R08V02	42.80460	0.00217	0.95915	0.03194	1.02181	0.30687	0.66942	0.50322
R08V03	31.70110	0.04659	0.88277	0.00000	3.64676	0.00027	4.13029	0.00004
R08V04	40.23260	0.00467	0.94122	0.00116	2.69209	0.00710	3.21851	0.00129
R08V05	25.25580	0.19182	0.97923	0.53340	1.26512	0.20583	2.34961	0.01879
R08V06	31.67440	0.04689	0.94786	0.00424	2.53146	0.01136	2.93127	0.00338
R09I01	42.76360	0.00030	0.94438	0.02220	1.86961	0.06154	1.57379	0.11554
R09I02	46.62960	0.00008	0.96982	0.33997	0.90368	0.36616	1.07490	0.28242
R09I03	38.61540	0.00124	0.95373	0.07609	1.74848	0.08038	1.93601	0.05287
R09I0	18.48150	0.29647	0.97925	0.67772	0.56760	0.57030	-0.09764	0.92221
R09V01	27.75000	0.02319	0.92394	0.00457	1.87831	0.06034	1.37341	0.16962
R09V02	18.95650	0.21571	0.98372	0.86708	0.70767	0.47915	1.10845	0.26766
R10I01	28.35290	0.05688	0.96708	0.18567	1.02489	0.30542	0.17610	0.86021
R10I02	77.33330	0.00000	0.91748	0.00007	2.58153	0.00984	3.12140	0.00180
R10I03	44.89550	0.00043	0.96967	0.25434	1.55131	0.12083	1.53290	0.12530
R10I04	31.57580	0.01698	0.96251	0.11372	1.32749	0.18435	0.41718	0.67654
R10V01	30.58820	0.01518	0.94632	0.03688	1.80792	0.07062	2.66695	0.00765
R10V02	32.76920	0.00793	0.96003	0.14478	0.80587	0.42032	2.59282	0.00952
R10V03	22.39220	0.13098	0.96393	0.21764	0.22963	0.81838	2.50486	0.01225
R10V04	24.11110	0.08711	0.94441	0.02401	1.79692	0.07235	1.28423	0.19906

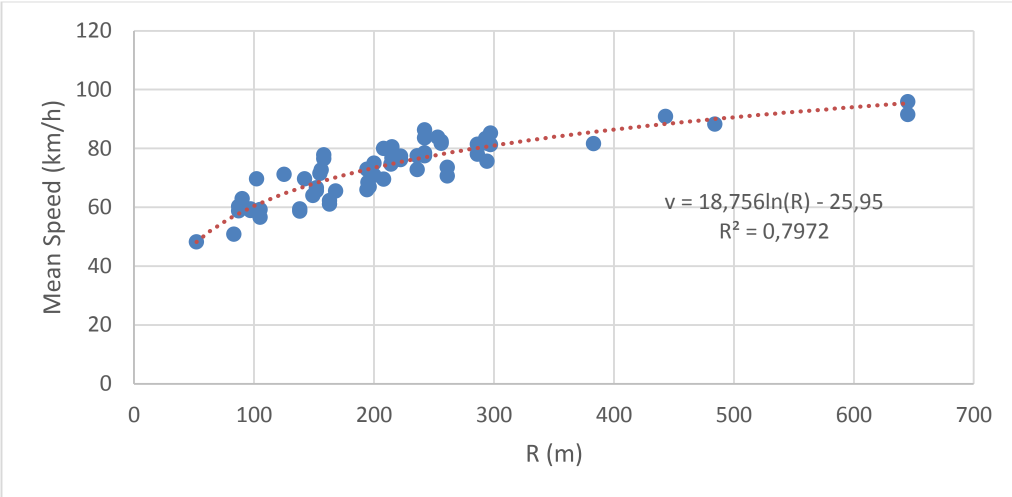

FIGURE 1 Mean speed vs radius in curves

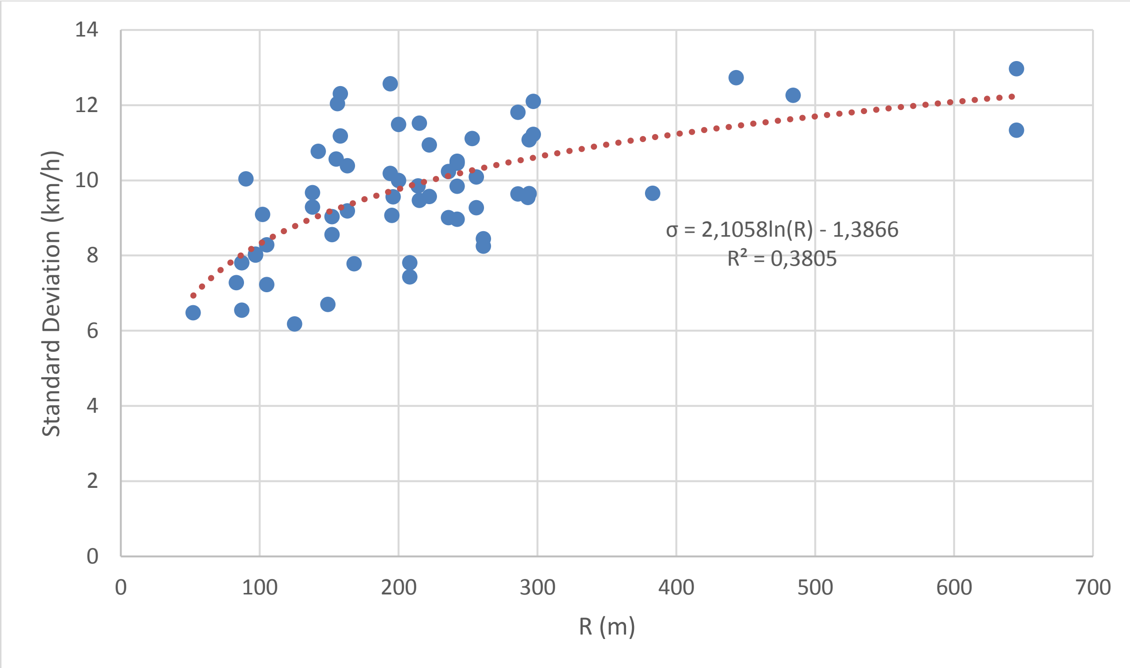

FIGURE 2 Standard deviation vs radius in curves

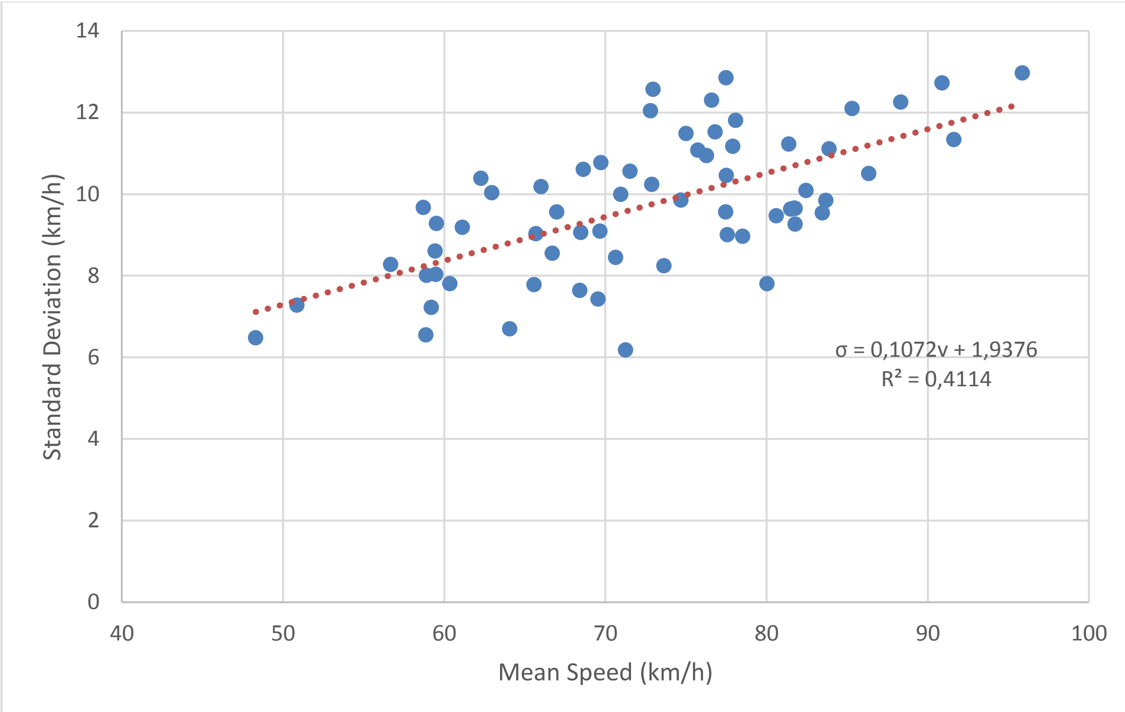

FIGURE 3 Mean speed vs standard deviation in curves

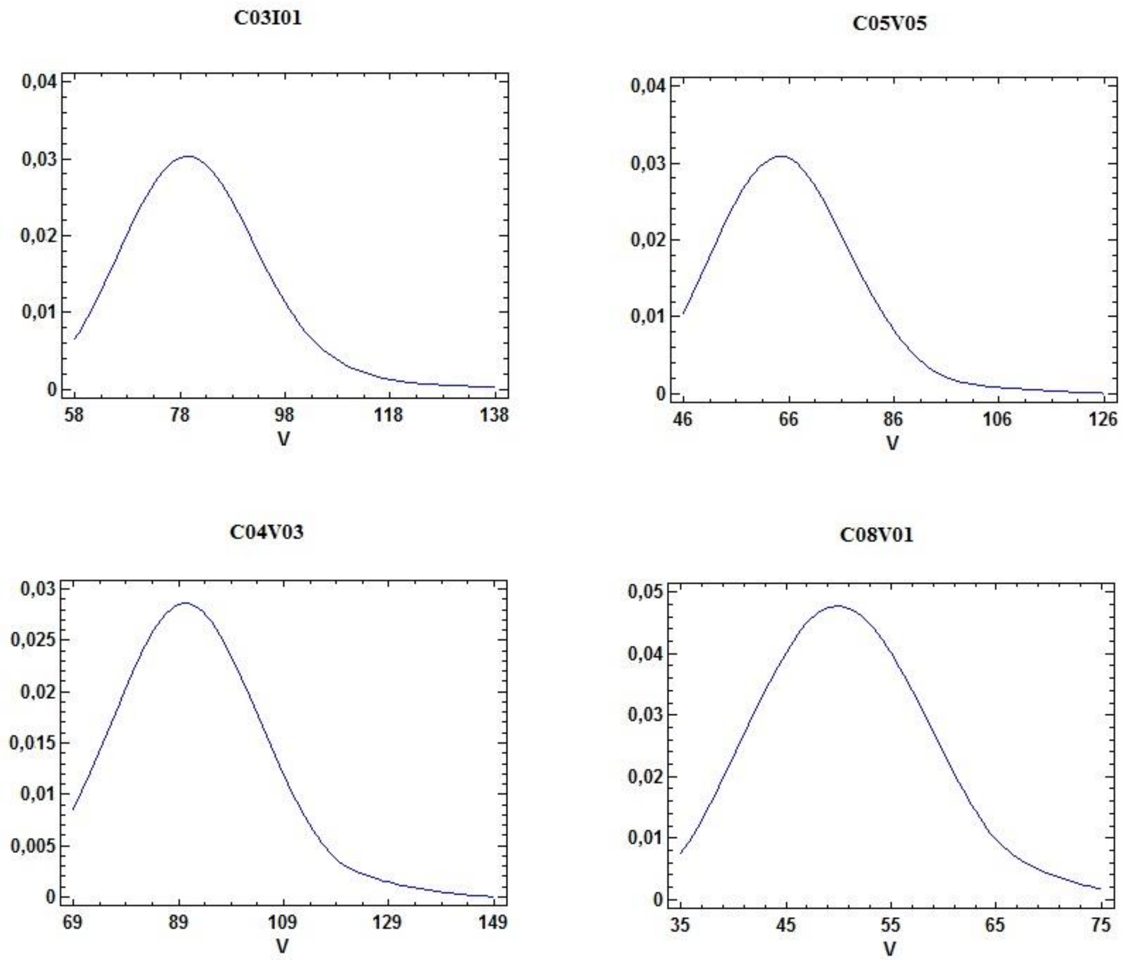

FIGURE 4 Probability density function

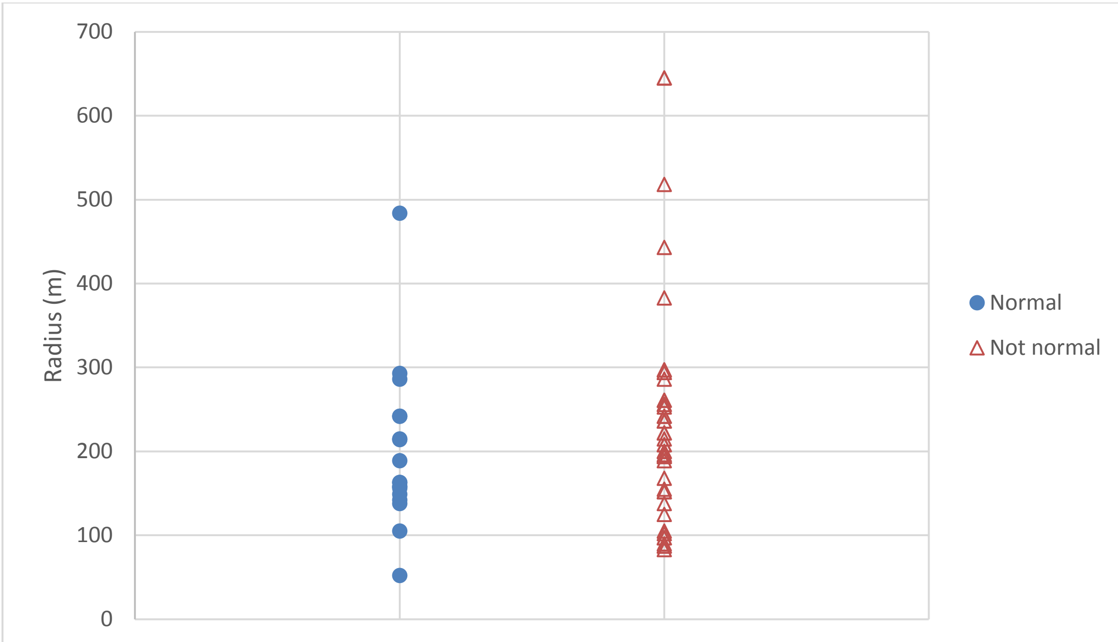

FIGURE 5 Distribution per radius

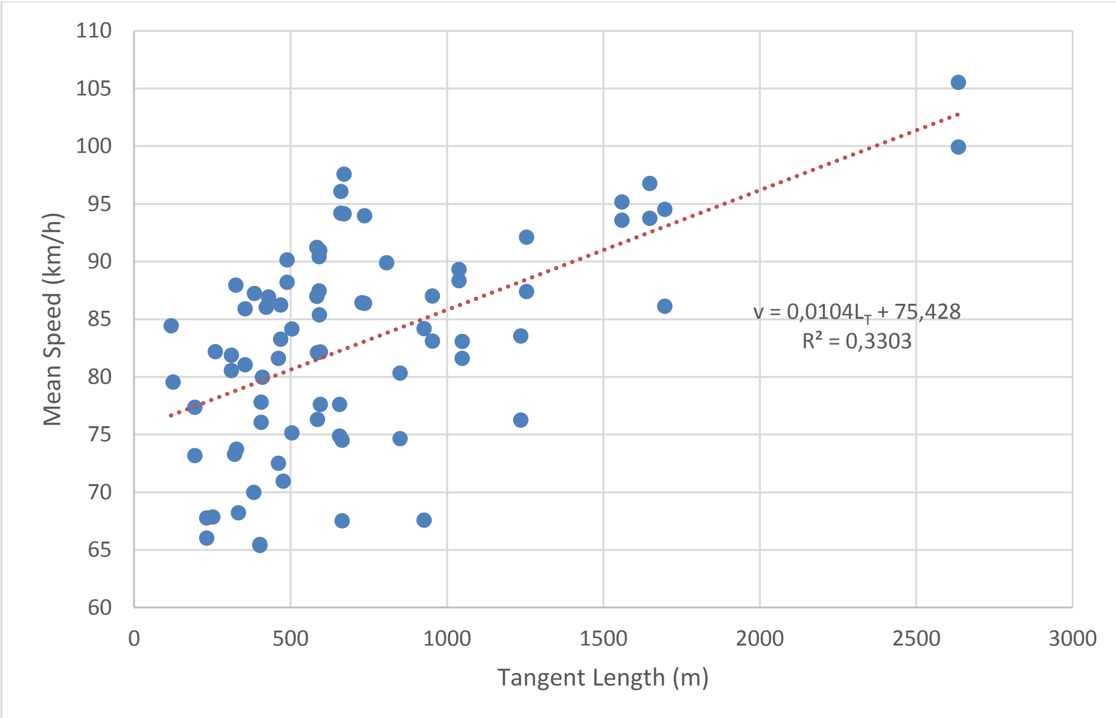

FIGURE 6 Mean speed vs tangent length

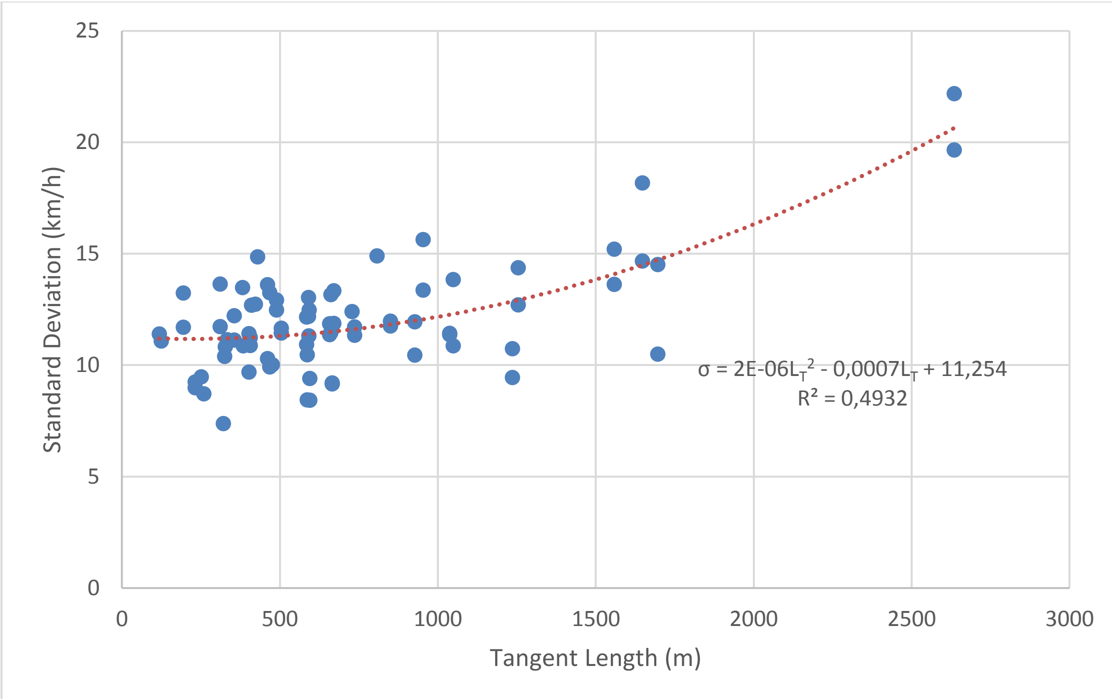

FIGURE 7 Standard deviation vs tangent length

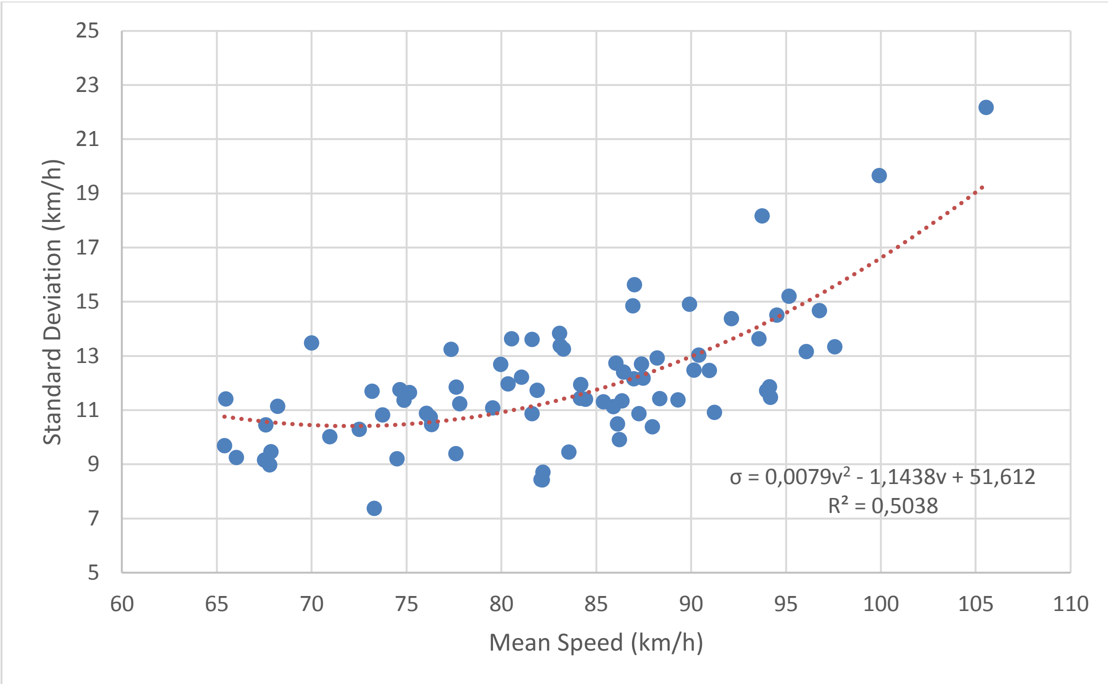

FIGURE 8 Mean speed vs standard deviation in tangents

FIGURE 9 Distribution per tangent length

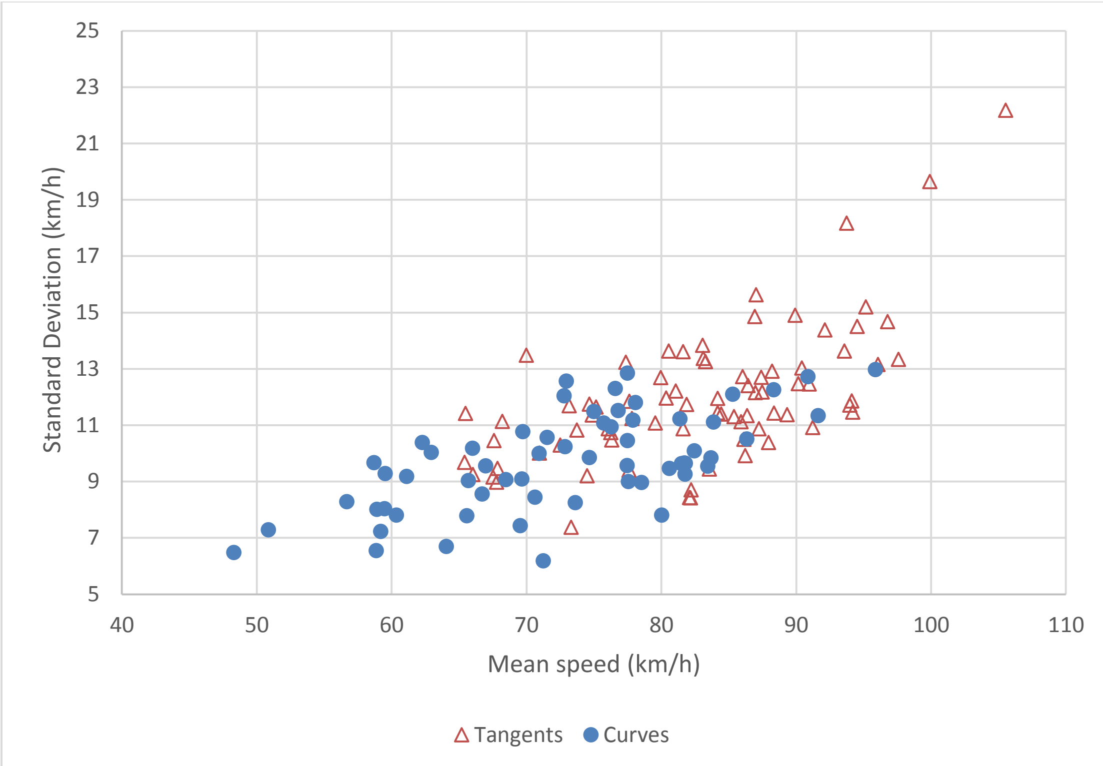

FIGURE 10 Mean speed vs standard deviation