

Simulation Based Safety Margin Assessment on Speed Variation between Tangent to Curved Road Alignment

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Abstract

This paper investigates the safety margins of drivers along tangent to curved road sections. A vehicle dynamics model is presented, allowing to assess the vehicle speed variation at impending skid conditions from tangent to curve on the basis of several parameters. This model returns the theoretical curve corresponding to the driver's maximum efficiency, i.e. the maximum safe speed and acceleration along the tangent to curve section when utilizing the outmost of the available vehicle horse power. On the basis of actual vehicle speed profiles, the model also returns the respective curve for the actual efficiency i.e. the utilized share of vehicle horse power, which reflects the driver's safety margin. Data from a driving simulator experiment are used to test the proposed methodology and identify the parameters affecting drivers' efficiency / safety margins. The results suggest that drivers' safety margins towards the examined curve are considerable, with the majority of the drivers using less than 55% of the available vehicle horse power. Higher initial speed was positively correlated with driving efficiency i.e. lower safety margins. On the contrary, a higher safety margin was associated with earlier deceleration before the curve. Driver characteristics were not found to significantly affect the safety margins, except from age <35 years old who were associated with higher share of vehicle motion used. The proposed method has advantages over existing methods; it allows for a better understanding of driver speeding behaviour and a more objective and insightful calculation of the safety margin through the vehicle dynamics, along the entire road section from tangent to curve, which may assist in improving design and interventions at curves.

Keywords – speed variation; safety margin; horizontal curve; driving simulator.

1. Introduction and Problem Statement

The design consistency of a road project is directly associated to safety [1]. Many researches [e.g. 2-7] have pointed out that if design consistency is present, the successive elements of a highway system act in a coordinated way and therefore road safety may be improved significantly. In general, consistency on the alignment is achieved by avoiding abrupt changes of critical alignment elements.

The most common means utilized to assess the design consistency of a road is the operational speed [8-9], which consists a crucial parameter in road geometric design since it is quantifiable (it can be measured). Substantial differences between operational speeds or between design and operational speeds in successive design elements, especially between approaching tangents to horizontal curves [10], may increase erratic manoeuvres and crashes [8, 11]. In a relevant research where the speed differential between approach tangent and curve was examined [12], a direct correlation between safety and variability in speed was reported.

However, in terms of the safety margins utilized, solely the examination of the vehicles' speed variations to assess the drivers' behaviour between the curve and the preceding tangent seem inadequate. The reason is that for most models, through field measurements, spot speed values are collected at specific and/or random points during the vehicle motion on the approach tangent to the curve. Therefore, the accuracy of these models may be biased since vehicles' acceleration – deceleration is extracted assuming either a linear relationship between the measured spot speed data or a linear regression analysis based on the curvature [e.g. 10, 14]. However, the acceleration/deceleration process mainly depends on tangent length, but also on curve features. In addition, the phenomenon cannot be studied from an only tangent-to-curve transition, as the curve conditions significantly influence the deceleration process.

Moreover, in a given alignment, all drivers tend to have a different "breakpoint", i.e. the distance from the curve entrance along the approach tangent where the vehicle speed is beginning to decrease. This "breakpoint", besides the physical and/or psychological condition of the driver depends on the vehicle's speed as well, as

vehicles traveling at higher speeds will generally begin the deceleration process earlier than vehicles traveling at lower speeds. However, this assumption is not generic and significant variation is involved in the way different drivers will behave, also depending on the type of vehicle used.

The present paper aims to examine the speed variation of a tangent to curved road design by assessing the influence of several parameters and their potential correlation to the actual safety margin during the vehicle motion on the approach tangent. This safety margin is assessed on the basis of the driver's efficiency, which is defined here as a percentage of the maximum available horse-power (hp) utilization at impending skid conditions, and is further explained in the following paragraphs.

Driver characteristics examined include the initial speed on the tangent section, the breakpoint on which the driver begins to decelerate, as well as individual driver characteristics i.e. gender and age. A driving simulator experiment was carried out in order to test the proposed methodology and linear models were developed to test the statistical associations between the examined variables.

2. Proposed Methodology

A novel and promising metric to assess the margin of safety experienced by a driver during the vehicle's cornering process, in accelerated or decelerated motion, is the drivers' "efficiency", defined as the drivers' ability to utilize the available horse power, i.e. the percentage of the maximum horse power safely attainable at impending skid conditions. In this sense, the safety margin can be expressed as the difference between the actual vehicle horse power used and the maximum attainable horse power during vehicle's performance at impending skid conditions. This metric is advantageous for two reasons: first, it estimates the safety margin on the basis of an objective reference point (the maximum attainable horse power at impending skid conditions), compared to i.e. the operational speed, and second, it allows for a continuous and non-linear representation of the speed profile along the examined alignment

In general during vehicle motion on tangents, especially long ones, the drivers do not maintain a constant speed; they usually tend to accelerate their vehicles [8, 11]. However, at some point before entering a curve, the drivers adjust (decrease) their speed accordingly. In the present analysis, the safety margin was assessed during the acceleration process, just before vehicle deceleration for entering the curve.

More specifically, a driving simulator experiment was carried out, under free flow conditions, on a 2km., 2-lane rural road alignment of 3.50m/lane without shoulders. In all curves passing was prohibited during curve negotiation (double continuous line marking on the centreline) and no signage was present. The vehicle entrance on a single curve was examined for a number of drivers where in terms of road geometry, the vertical alignment was assumed flat, consisting of a tangent approximately 100m long, followed by a circular curve of R=133m with no entrance spiral and cross slope values. Moreover, the selected alignment was visible throughout the driving process without any sight restrictions (see Figure 1).

The speed data collected from the simulator experiment were used to calculate the proposed metrics on the basis of the vehicle dynamics model, and use them to assess driver speeding behaviour and the related safety margins.

The objective of the experiment was twofold: (i) to define the parameters associated to drivers' efficiency i.e. ability to utilize the available horse power rates as a percentage of the maximum attainable (at impending skid conditions), through the vehicle's speed – distance profile, and (ii) to investigate at which distance (breakpoint) from the curve the vehicle speed decreases, for different drivers and initial speed values

For each run, the collected speed – distance data during the acceleration process at the examined curved area were correlated against an existing vehicle dynamics model where two different speed – distance outputs were extracted; the vehicle's performance at impending skid conditions and the best fitting curve to the collected speed – distance data quantifying in terms of percentage of the maximum attainable (driver efficiency).

As a result the safety margins during the above tangent to curve design were addressed as a percentage of the vehicle motion at impending skid conditions, and correlated to parameters such as the initial speed at the beginning of the alignment, the approach distance to the curve where the drivers reduce speed, as well as individual characteristics of the participants such as their gender and age.

It is noted that this analysis focuses on safety margin variations from the driver's viewpoint. Efficiency and the related safety margins naturally depend on numerous parameters e.g. vehicle parameters (speed, weight distribution, centre of gravity), road design values (road functional class, curve radius, tangent length prior to

curve, sight distance etc.) and driver characteristics (experience, aggressiveness and risk taking, etc.). Most roadway studies are based on drivers' perception of alignment or signage based on questionnaires, as collecting objective performance data for all the potential determinants is difficult. This paper uses the controlled environment of a driving simulator in order to focus on human factors (directly observable or indirectly measured) associated with safety margins at curves. For that purpose, a single curve is examined and the same (simulator) vehicle is used by all drivers, eliminating thus non driver-related confounding factors. This approach has some limitations (see section 5 for a detailed discussion), but allows for an exploratory analysis of driver-related aspects of safety margins on the approach from tangent to curve.

2.1. Vehicle Dynamics Model

A previous vehicle dynamics model developed by the authors [15-17] was utilized according to which the motion of any vehicle can be analysed in three linear movements: longitudinal, lateral, and vertical, as well as three rotational movements: yaw, roll, and pitch.

The basic assumption of the present study is that vehicle motion is considered on a road surface, following the curve centreline, in which all three geometric parameters remain constant; namely, grade s , cross slope e , and horizontal radius R . All forces and moments applied to the vehicle are analysed into a moving three dimensional coordinate system, coinciding at the vehicle gravity centre and formed by the vehicle's longitudinal (X), lateral (Y) and vertical (Z) axis respectively. Through these axes, the influence of certain vehicle technical characteristics, road geometry and tire friction were expressed, such as vehicle speed/ wheel drive/ sprung and unsprung mass and it's position of gravity centre/ aerodynamic drag/ vertical lift/ track width/ wheel-base/ roll centre/ suspension roll stiffness/ cornering stiffness/ grade/ superelevation rate/ rolling resistance tire-road adhesion values and horse-power supply.

Thus with respect to the laws of mechanics, and after slight simplifications the following formulas express the equilibrium around each axis accordingly:

$$\begin{aligned} \sum X &= 0 \\ m \frac{dv}{dt} &= \sum U_i - \sum S_i \theta_i + \frac{mv^2}{R} \beta - mgs - A_d \end{aligned} \quad (1)$$

$$\begin{aligned} \sum Y &= 0 \\ m \frac{dv}{dt} \beta &= \sum U_i \theta_i + \sum S_i - \frac{mv^2}{R} + mge \end{aligned} \quad (2)$$

$$\begin{aligned} \sum Z &= 0 \\ \sum P_i &= mg + \frac{mv^2}{R} e - A_n \end{aligned} \quad (3)$$

where (f=front, r=rear):

dv/dt : vehicle's acceleration rate (positive value) (m/sec^2)

U_f, U_r : driving forces acting to front and rear axle respectively (Nt)

S_f, S_r : lateral forces acting to front and rear axle respectively (Nt)

P_f, P_r : vertical forces acting to front and rear axle respectively (Nt)

m : vehicle mass (kgr)

v : speed (m/sec)

A_n, A_d : air resistance forces acting vertically and on the frontal vehicle area respectively (Nt)

s : grade (%/100)

e : superelevation rate (%/100)

R : curve radius (m)

β : sideslip angle (rad)

θ : steer angle (rad)

The variables for the sideslip angle and the steer angle were taken from the literature [18]. Furthermore the model takes into account the actual wheel load due to the lateral load transfer and the corresponding alteration of the lateral force on each wheel thus creating a four-wheel vehicle dynamics modelling [18-20].

The available tractive effort of the vehicle (driving force minus rolling resistance) acting on the front or rear axle (depending on the driving configuration) should be associated to the vehicle's speed as well the net power available at the driving wheels. Since a vehicle cannot always be driven at 100% of its available horse-power rate, the horse-power utilization factor (n), was utilized through Equation [4] as follows:

$$F_x = 745.6 \frac{P}{v} n \quad (4)$$

where :

F_x : tractive force (Nt)

P : net engine horse-power available at the driven axle (hp)

v : vehicle speed (m/sec)

n : horse-power utilization factor (%/100)

In the current vehicle dynamics model the vehicle's longitudinal acceleration or deceleration of Equation 1 is expressed as a function of vehicle, road, and tire friction parameters creating a four degree polynomial equation [11-13].

At the same time, by applying laws of mechanics, the vehicle's instant acceleration or deceleration can be expressed as a function of vehicle's instant speed as well as driven distance, thus forming the following differential equation which is resolved by applying numerical Runge-Kutta method [21].

$$a(v) = \frac{dv}{dd} v \quad (5)$$

where:

$a(v)$: acceleration-deceleration (m/sec²)

v : speed (m/sec)

d : distance (m)

The solution of Equation 5 delivers the vehicle speed variation as a function of the required distance in order to eliminate the vehicle's acceleration – deceleration [$a(v)=0$]. This procedure takes place at impending skid conditions utilizing the Krempel equation [22] both in longitudinal and lateral direction of travel by adapting each time the horse-power utilization factor 'n' from Equation 4. In other words since the vehicle's speed variation is performed at impending skid conditions, the model delivers for every integration the vehicle's "best" possible performance.

However, it must be stressed that under the term "impeding skid conditions", the model delivers data for the critical wheel. This means that not necessarily vehicle skidding will occur; instead a transition to an unstable vehicle motion is evidenced, which is in every case undesirable. The accuracy of the suggested procedure is subject to the selected integration step (distance step), which in the present analysis was set equal to 0.10 m. The resulting vehicle speed is a function of the driven distance at any predefined alignment. The model's outputs were correlated against the known data derived by two other distinct cases: the final climbing speed of a truck travelling on a grade [23] and the output data from the well-known CARSIM Simulation Software [16]. Both cases revealed a satisfying match.

The parameters inserted to the vehicles dynamics model refer to a Front Wheel Drive (FWD) C-class passenger car, were borrowed from the literature [15] and are shown in Table 1.

2.2. Friction Data

The actual friction in every direction of travel and for every wheel were addressed by the model. However, the peak friction coefficients, assumed equal for the longitudinal and lateral direction of travel (friction circle), were extracted from Equation 6, widely applied in current practice [e.g. 24-27].

$$SSD = v \times t + \frac{v^2}{2g\left(\frac{a}{g} + s\right)} \quad (6)$$

where :

SSD (m) : stopping sight distance

v (m/sec) : vehicle speed

t (sec) : driver's perception – reaction time [2.5sec]

g (m/sec²) : gravitational constant

a (m/sec²) : vehicle deceleration rate [3.4m/sec², AASHTO (20)]

s (%/100) : road grade [(+) upgrades, (-) downgrades]

Table 1 to be inserted here

More specifically, through the driving simulator, various vehicle braking runs were performed on tangent sections for different initial speed values. Since the simulator data could deliver the “pure” braking distance for every run, the first term of Equation 6 was eliminated. Moreover, as already mentioned the road alignment was flat which means that the grade value was set to zero. As a result the peak friction value (a/g) was delivered by solely the initial speed value and the corresponding SSD. Finally for every run the value of $f_{max}=0.95$ was calculated which refers to a high performance dry pavement.

3. Driving Simulator Experiment

3.1. Experiment Design

In order to test the proposed methodology for the assessment of driver's safety margin, a driving simulator experiment was implemented at the driving simulator of the Department of Transportation Planning and Engineering of NTUA. The NTUA driving simulator is a motion base quarter-cab manufactured by the FOERST Company. The simulator consists of 3 LCD wide screens 40'' (full HD: 1920x1080pixels), driving position and support motion base. The dimensions at a full development are 230x180cm, while the base width is 78cm and the total field of view is 170 degrees. The simulator is validated against a real world environment, with satisfactory relative validity as regards gender, age groups and area type i.e. urban or rural - the rural route included both tangents and mild curves [28].

The experiment started with a practice drive for familiarization with the simulator without any time restriction; it took place on a similar road environment as the one of the main experiment, i.e. a rural road with mild horizontal curves, its duration was typically between 10-15 minutes, and the evaluation criteria included handling the simulator (starting, gears, wheel handling etc.), keeping the lateral position of the vehicle, keeping constant speed and appropriate for the road environment, braking and immobilization of the vehicle. The simulated driving task consisted of driving a rural route of 2 km length, single carriageway, lane width 3m, zero gradient, mild horizontal curves, speed limit equal to 70 km/h and low traffic (see Figure 1). More specifically,

ambient vehicles arrivals were drawn from a Gamma distribution with mean $m=12\text{sec}$, and variance $\sigma^2=6\text{ sec}$, corresponding to an average traffic volume $Q=300\text{ vehicles/hour}$ on both traffic streams. This resulted in moderate oncoming traffic on the opposite traffic stream and a lead vehicle at long headway ahead the simulator vehicle, aiming to enhance the fidelity of the virtual road environment with respect to actual conditions, but without affecting the driving behaviour of participants.

Participants were recruited among subjects of a large driving simulator study implemented at the same time at NTUA with more than 300 subjects in total, aiming to assess driving performance of all age groups with focus on elderly. Forty three participants aged from 22 to 87 years of age carried out the simulated drive of the present research. The participants had no known health or vision problems, held a valid driving license and were frequent drivers (i.e. reported driving more than 3 times per week and more than 5,000 annual kilometres travelled). Twenty two of the participant were males and 21 females, and their age distribution was as follows: 18 participants were less than 35 years old, 16 participant were between 35 and 55 years old, and 9 participants were older than 55 years (out of which 4 were older than 65 years). No specific instructions were given to participants as per the purposes of the specific drive; they were asked to drive at their preferred speed as they would normally do and observe the road signs and markings as usual.

For the analysis purposes, a specific road section of the examined route was selected (see Figure 1); this section was selected as being a typical mild curve after a tangent with no traffic signs, roadside obstacles or other features that might affect speeding behaviour. The examined section starts on the entrance from a 100m approximately tangent (at the beginning of which the curve became visible) to a circular arc of $R=133\text{m}$. The distance of 100m before the curve was selected on the basis of exploratory analysis of speed profiles, which indicated that all drivers began decelerating after that point (it is noted that this distance is case specific and in different settings the deceleration process may start earlier e.g. 12, 29-31). The examined alignment was visible throughout the driving process and there were no sight restrictions. There was quite some variation on the initial speed values at the entrance of the examined section. When approaching the curve, all drivers decelerated in tractive mode, by releasing the pressure on the accelerator and without using the vehicle's brakes.

Figure 1 to be inserted here

3.2. Data and Analysis Methods

From the driving simulator metrics, point speed data were extracted for each participant. The speed – distance data during the utilization of the maximum attainable vehicle's horse power rates were also calculated for all drivers, allowing to identify the efficiency curve which best fits each driver's relevant data extracted for the same initial speed - an illustration is presented in the Results section below.

The following parameters are examined in the present analysis:

- Drivers' efficiency (Eff): percentage of vehicles' maximum attainable horse power range during vehicle's performance at impending skid conditions
- Initial speed (V_0): the point speed at the entrance of the examined section e.g. 100 meters before the start of the curve
- Breakpoint (x_{break}): the distance from the beginning of the curve at which the driver first starts to decelerate
- Driver gender
- Driver age group: <35 years, 35-55 years, >55 years

4. Results

4.1. Estimation of Driver Safety Margin

Figure 2 illustrates through the dashed line the actual speed – distance on the selected alignment, indicatively for driver #6. In the same Figure two additional speed – distance curves were extracted from the dynamic model, up to the “breakpoint” where the driver reduces speed. The bold continuous line represents the vehicle motion at impending skid conditions given by the vehicle dynamics model, and as expected the relevant vehicle speed values are as expected greater than the actual speed values. The non-bold continuous line shows the “best fit” of the actual speed data (in dashed line) to the vehicle dynamics model, and was calculated after various tests by setting each time the available horse power rate to a certain percentage of the horse power at impending skid conditions. Therefore, it can be seen that for the specific example, the vehicle, is driven with efficiency equal to 55% compared to impending skid conditions, and therefore a safety margin of 45% is involved on the specific approach from tangent to curve.

In the secondary axis, the relevant acceleration rates for both the runs performed by the dynamic model (maximum attainable horse power at impending skid conditions, and the percentage of this actually used) are shown. When the vehicle is driven at impending skid, the acceleration is far more increased (triangle line) compared to the case where the vehicle is driven with a 55% efficiency (square line).

Figure 2 to be inserted here

4.2. Statistical Analysis of Parameters Affecting the Safety Margin

In this sample drivers’ efficiency calculated ranged from 8% to 55%, with a mean of 27.4 and a standard deviation of 13.4 (i.e. safety margins ranged from 45% to 92%, with a mean of 72.6), suggesting that drivers use a minor share of the available horse power on the examined curve. This may be due to the rural two-way road environment and the presence of oncoming traffic leading drivers to a more conservative driving behaviour. It is also noted that not all drivers exhibited a ‘striking’ peak in their speed profiles; especially in drivers of relatively low speed and efficiency, a ‘plateau’ shaped speed profile was observed, in which the desired speed was attained earlier and maintained up to the curve entrance. In this case, the “breakpoint” was defined on the basis of the distance at which the desired speed was first attained.

Driver efficiency estimates were found to best fit to a log-normal distribution i.e. the natural logarithm of efficiency was found to conform to a normal distribution. Table 2 presents the descriptive statistics and one-way ANOVA tests of the examined variables with respect to driver efficiency. It is noted that initial speeds at the entrance of the examined road section ranged from 38 to 94 km/h, i.e. in several cases well above the displayed speed limit, and this could have resulted in more efficiency / lower safety margins (e.g. more use of the vehicle horse power) when approaching the curve, but drivers approached the curve in a more conservative way by using higher safety margins. It is also noted that the breakpoints were situated along the entire tangent section, from 2 to 94 meters before the curve, revealing large variations in the way drivers negotiated the curve, from very early deceleration to very close to the curve.

Safety margin appears to significantly vary with initial speed and with the breakpoint distance, but less so with driver gender and age group. This was further investigated as follows: it was tested whether initial speed and breakpoint distance are correlated with age and gender, but no strong correlation was found. Next, the safety margins of different age groups were investigated, and it was found that drivers <35 years old differ significantly in terms of efficiency from drivers >35 years old, but no further significant distinction between the second and third age group (i.e. 35-55 and >55) was observed.

It is possible that other (than initial speed and distance of the breakpoint), unobservable driver factors might better differentiate the safety margins between different drivers, e.g. aggressiveness, risk proneness etc. Although driver age and gender may be proxies of these factors (e.g. young males are known to drive more aggressively), they are not perfect correlates. The assumption here was that initial speed and distance of breakpoint are closer correlated of such unobserved driver human factors than age and gender.

Table 2 to be inserted here

A log-normal linear model was developed on the data, associating driver efficiency with the statistically significant parameters. Results in terms of parameter estimates and model fit are presented in Table 3. An R-squared equal to 0.47 was estimated, suggesting that the model explains only about half of the variation in the observed efficiency / safety margins on the basis of the available parameters. On the other hand, most of the variables tested were statistically significant.

More specifically, initial speed is positively associated with driver efficiency, suggesting that those entering the examined tangent at higher speed also tend to have a lower safety margin curve throughout the examined section, i.e. they are more efficient in utilizing greater percentages of maximum attainable horse power rates. Moreover, the breakpoint distance is negatively associated with efficiency, i.e. drivers who decelerate earlier before the curve have lower efficiency and thus higher safety margin, which is intuitive.

As regards the effects of driver characteristics, the safety margin does not appear to be affected by gender, but it appears to be affected by age group (the effect is significant at 93% confidence level). In particular, drivers aged less than 35% have higher efficiency curves, indicating that they use more of the available vehicle horse power when approaching the curve, which is consistent with the commonly known more 'aggressive' driving of younger age groups.

Table 3 to be inserted here

5. Conclusions

The present paper investigated the speed variation and related efficiency / safety margins of drivers on a road section from tangent to curve. A vehicle dynamics model is proposed for the estimation of the safety margin, defined as the difference between the share of vehicle motion used by the driver (efficiency), compared to the maximum available horse power utilization to the impending skid conditions. This approach is advantageous in two ways: first, it allows for a more objective calculation of the safety margin through the vehicle dynamics, compared to other commonly used criteria such as design speed, speed limit etc.; and second, the safety margin is explicitly considered as a profile varying along the entire road section from tangent to curve, taking into account the common acceleration / deceleration speed profile when approaching the curve, allowing for more complete insight on the actual speeding variations. This approach allows for a better understanding and a more detailed and accurate representation of speeding behaviour from tangent to curve road alignments, which may be useful in improving design but also in implementing appropriate interventions (signage, road markings etc.) to assist drivers in negotiating curves.

In order to test the proposed methodology, data from a driving simulator task were used on the basis of a sample of 43 drivers of both genders and all age groups. The data showed large variations in the speed along the examined section and consequently on the calculated safety margins. On average, a low share of vehicle motion was used by most drivers, less than 55%, revealing a conservative speeding behaviour (i.e. minimum safety margin was 45%). It is possible that drivers are reluctant in using the available horse power due to their perception of the rural road environment as a demanding one, their intentions to comply with the speed limit etc. Higher efficiency was associated with younger drivers, who also had higher initial speed at the entrance of the section and decelerated at a smaller distance from the curve. Moreover, the observed speed profiles had different shapes, with others showing a clear acceleration / deceleration peak, and others being rather 'plateau-shaped'. It appears that there are numerous unobserved human factors that affect the examined speeding behaviour, even for a single given curve and a given type of vehicle, and thus it is not possible to generalise these findings.

The present research has some other limitations as well. Due to the relatively small sample and the known lower fidelity of a simulated environment compared to actual roads and the vehicle used by the participants in actual driving, the present results should be considered as exploratory. Moreover, only a single curve was examined, as a first step for understanding the various factors that affect drivers' safety margin, with focus on driver characteristics (observed or unobserved i.e. random variation). Further analysis is needed to determine the impact of more parameters such as curves with various radii values, left and right curves (as it is known that drivers may behave differently), alignments with grades, but also their combined effect. Finally, data enriched

by the actual curve path as well as alignments with different peak friction coefficients seem to be prerequisites before more definite conclusions can be reached.

Finally, it should not be ignored the fact that the human factor, in addition to perception – reaction procedure, might impose additional restrictions and consequently influence the braking process to some extent. The results of the statistical analysis suggest that a large part of speed variations remains unexplained by the variables considered, indicating that other and possibly unobserved factors may influence the speeding behaviour of drivers.

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Table 1. Vehicle Parameters Inserted to the Model

L (m)	2.650	Wheelbase
t_f (m)	1.538	Front track width
t_r (m)	1.536	Rear track width
m (kgr)	1300	Vehicle mass
l_f (m)	1,161	Position of GC from front axle
h (m)	0,620	Position of GC from surface

$K_{\phi f}$ (Nm/rad)	27502	Suspension roll stiffness (front)
$K_{\phi r}$ (Nm/rad)	14324	Suspension roll stiffness (rear)
$C_{\alpha f}$ (kp/rad)	2295.7	Cornering coef. (front)
$C_{\alpha r}$ (kp/rad)	2120.7	Cornering coef. (rear)
m_{uf} (kgr)	92	Unsprung mass (front)
m_{ur} (kgr)	120	Unsprung mass (rear)
h_{Rf} (m)	0,020	Roll centre height (front)
h_{Rr} (m)	0,410	Roll centre height (rear)
r_{dyn} (m)	0,290	Dynamic radius
A_f (m ²)	1,850	Frontal area
C_N	0,280	Lift drag
c_d	0,360	Aerodynamic drag
P (hp)	100	Horse power

Table 2. Descriptive statistics of explanatory variables and ANOVA results (F-tests) on safety margin

Variable	Mean	Std.Dev	Min	Max	F	p-value
Vo	58.481	12.148	38.650	86	14.573	.000
Xbreak	60.884	22.277	2.000	94	3.931	.055
Gender*	0.512	0.506	0	1	2.154	.151
AgeGroup**	1.791	0.773	1	3	2.149	.131

* mean represents the share of males and females in the sample i.e. 0 (males): 22 (51.2%), 1 (females):21

** mean represents the share of age groups in the sample i.e. 1 (<35 years): 18, 2 (35-55 years):16, 3 (>55 years):9

Table 3. Parameter estimates of the log-normal model of driver efficiency

Parameter	B	Std. Error	T-test	p-value
Intercept	1.759	.578	2.999	.005*
Vo	.027	.007	3.718	.001*
Xbreak	-.007	.003	-2.026	.050*
[Gender=male]	.225	.160	1.409	.167
[Gender=female]	.000	-		
[AgeGroup <35 years]	.272	.146	1.865	.070**
[AgeGroup >35 years]	.000	-		

* significant at 95%, ** significant at 90%

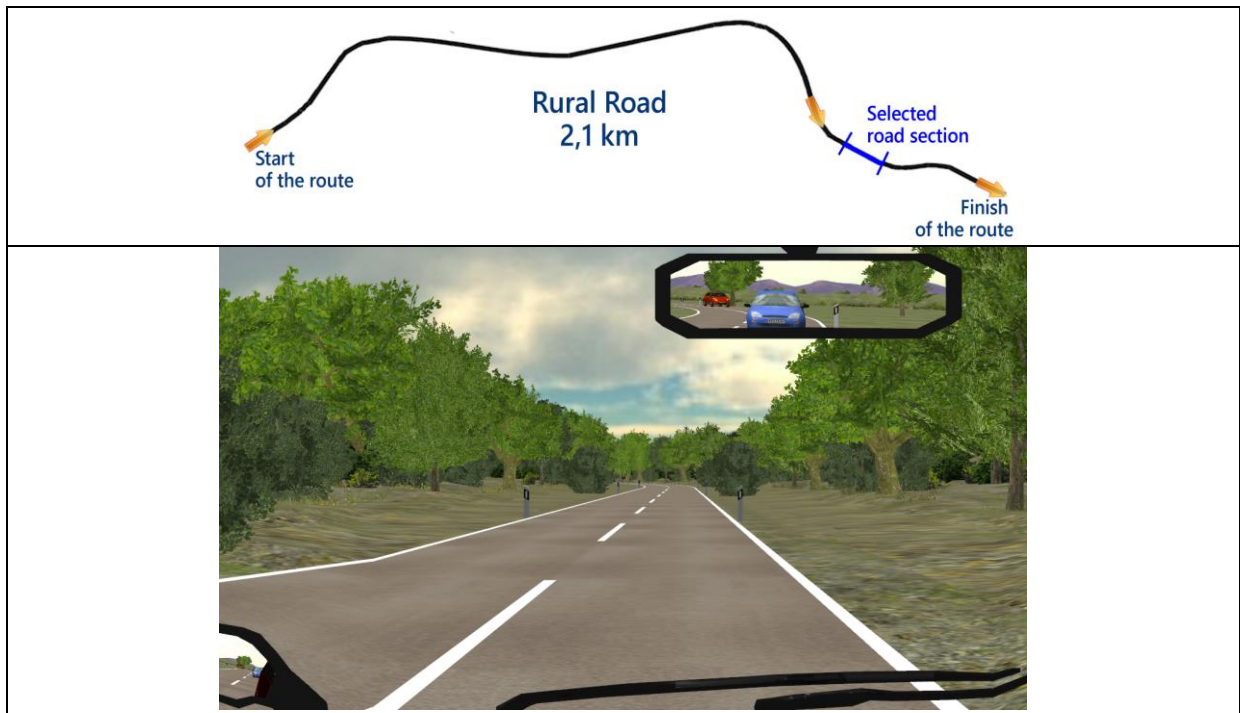
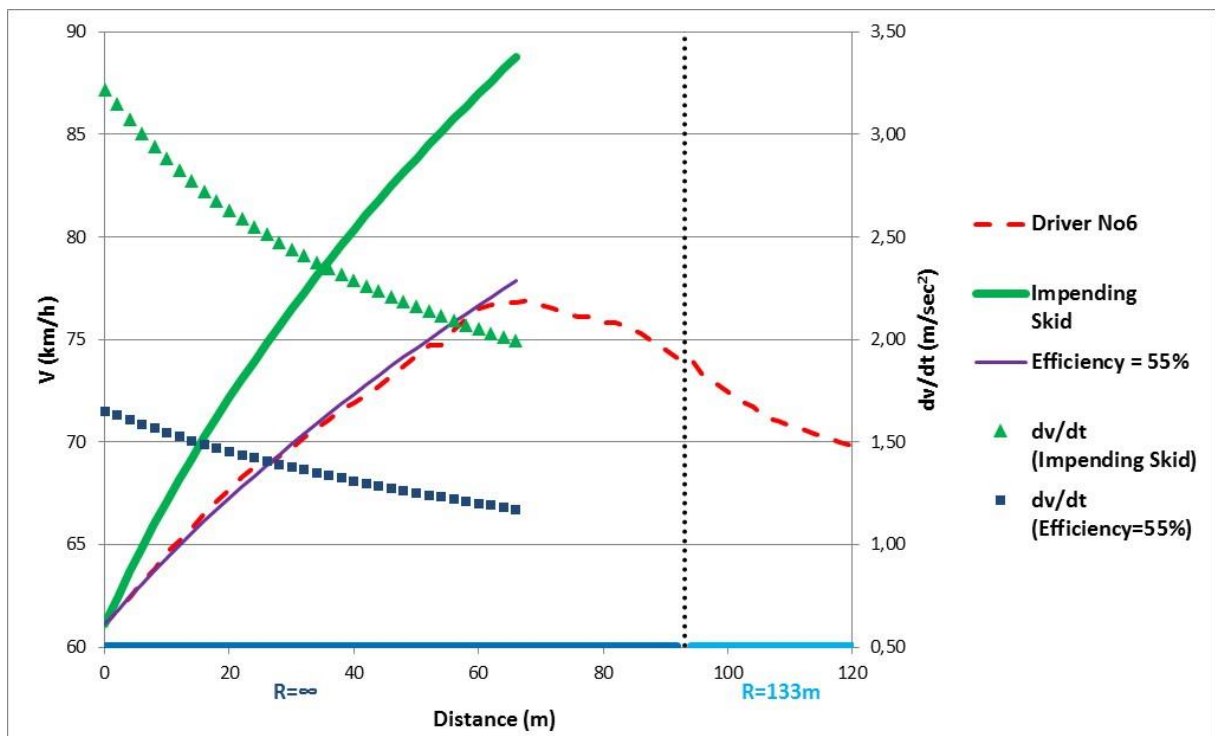


Figure 1. Plan view of the selected road section (top panel) and simulated driving environment - tangent to curve (bottom panel)



NOTE: The continuous lines at the bottom refer to the length of the utilized horizontal geometry.
Figure 2. Example of Speed – Distance Data Run vs Dynamic Model's Outputs.