Acceleration Impact Investigation for Control Road Geometry Parameters

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Introduction

In existing road design practice vehicle motion during curve negotiation is examined under steady state cornering conditions. This generalization actually fails to assess the impact of the acceleration effect during cornering.

This assumption has been proved false by many researchers since acceleration – deceleration rates are present on curves as well. Moreover, certain studies have concluded that deceleration – acceleration rates increase with curvature on two-lane rural roads and that their determination based on operating speed profiles underestimates the actual rates experienced by the drivers.

Objectives

The objective of the present paper is to assess the acceleration impact in vehicle safety during tractive mode and more specifically quantify the potential safety hazard at impending skid conditions for control road geometry parameters and vehicle speed at and below the suggested relevant design speed value.

Moreover, the overall intention is to highlight the importance of vehicle horse-power utilization in order to incorporate such information in a more sophisticated intelligent speed adaption (ISA) process of vehicle advanced driver assistance systems (ADAS) in the near future.

Methodology

A previous vehicle dynamics model developed by the authors was utilized where all forces and moments applied to the vehicle were analyzed into a moving three dimensional coordinate system, 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.

Through the developed equations, the vehicle (C-class passenger car) is examined at impending skid conditions taking under consideration the friction distribution to the longitudinal and lateral direction of travel. As a result, by accelerating the vehicle at impending skid conditions, the vehicle's horse-power utilization can be defined.

This approach is far more complete compared to the conventional approach according to which on a given curve the driver should solely comply with the posted speed limit. Even if a driver negotiates a curve with speed values below the design speed, depending on the acceleration rate, which is a result of the horse power utilization, critical safety concerns might rise.

An assessment of the vehicle motion is examined for a range of control design parameters and vehicle speed at and below the suggested relevant design speed values for 3 values of peak friction coefficients (supply friction), namely; 0.35, 0.50 and 0.65 in order to assess pavements with poor friction performance under both wet (0.35) and dry (0.65) pavement conditions.

Field Measurements

Instrumented field measurements on speed distance data and pavement friction supply were collected utilizing a FWD C-Class passenger car with 100hp of nominal horse-power rate and correlated against an existing dynamic model in order to examine the interaction between vehicle dynamics and road geometry.

The field measurements were carried out on a steep upgraded (s=7%) 2-lane service road section of the major PATHE motorway located at Agios Stefanos area near Athens. The horizontal alignment was formed by a right curve of R=95m, followed by a left curve of R=190m (Figure 1).

Instrumented speed distance data were recorded solely inside the circular arcs for various initial speed values under free flow conditions through the Vericom VC4000 accelerometer. The device was also utilized to measure the peak pavement friction, based on the braking performance for various runs of the test vehicle on the tangent road section between the two curves.

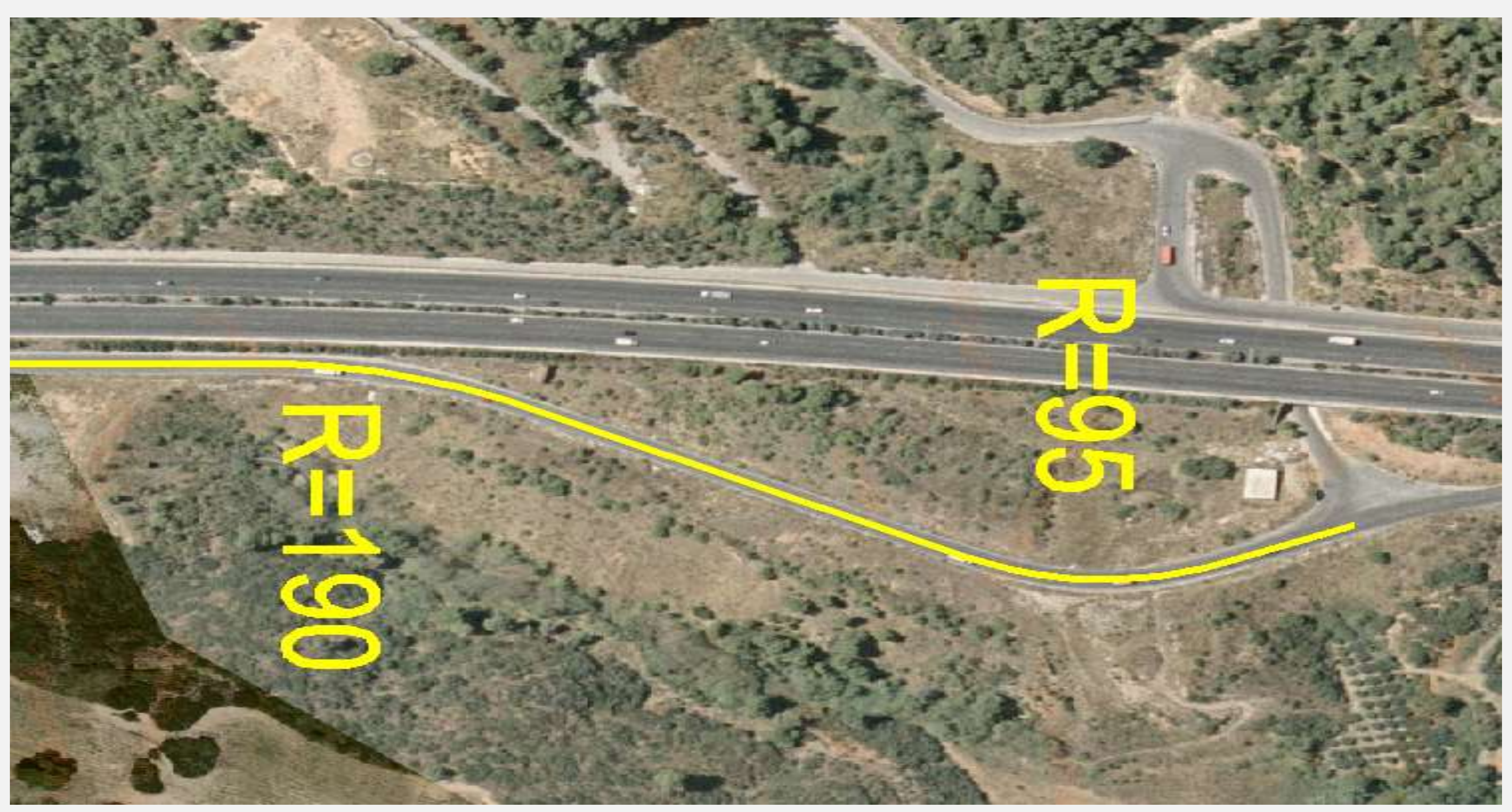

Figure 1. Plan View of the Curved Road Sections

The objective was to drive aggressively, beyond driver's comfort, in terms of utilizing as much as possible the available horse power of the vehicle without braking. There were cases where the driver felt some kind of lateral drifting. Cases with braking were also reported but excluded from the analysis.

In total 8 runs in total were adopted (4 per curve) satisfying the above criteria (no braking, driver feeling uncomfortable), which more or less revealed the same findings.

Vehicle Performance against Model's Outputs

As expected, since the model's data are extracted at continuous impending skid conditions, the relevant vehicle speed values are always greater. However, in certain cases the speed values from these two different approaches seem rather close implying that the vehicle was driven near impending conditions too.

Based on this correlation it is interesting to analyze in more detail the variation of certain vehicle dynamic characteristics extracted from the model, but based on the measured data in terms of road geometry, friction and speed variation.

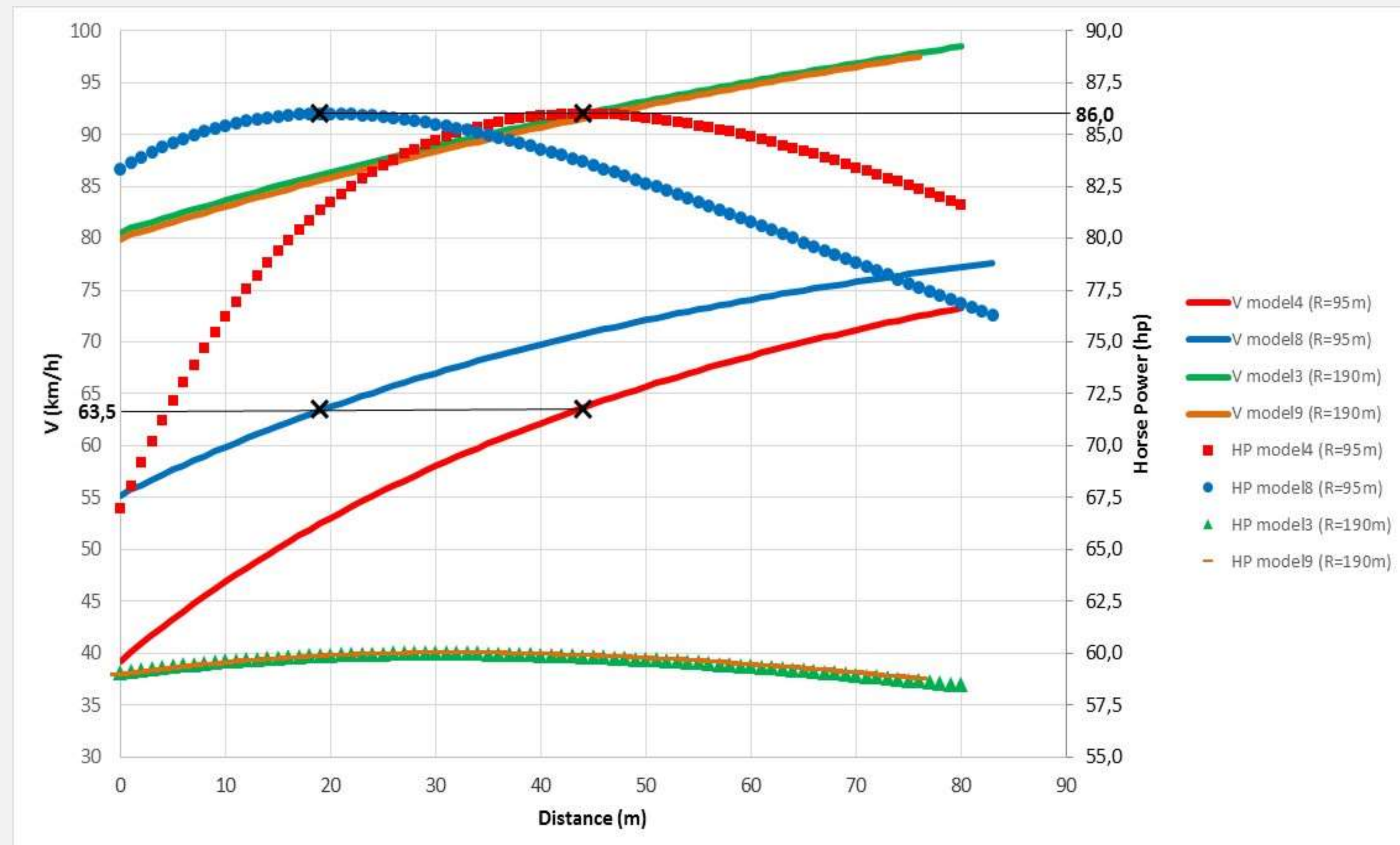

Figure 2a. Speed and Horse Power Utilization Variation vs Distance

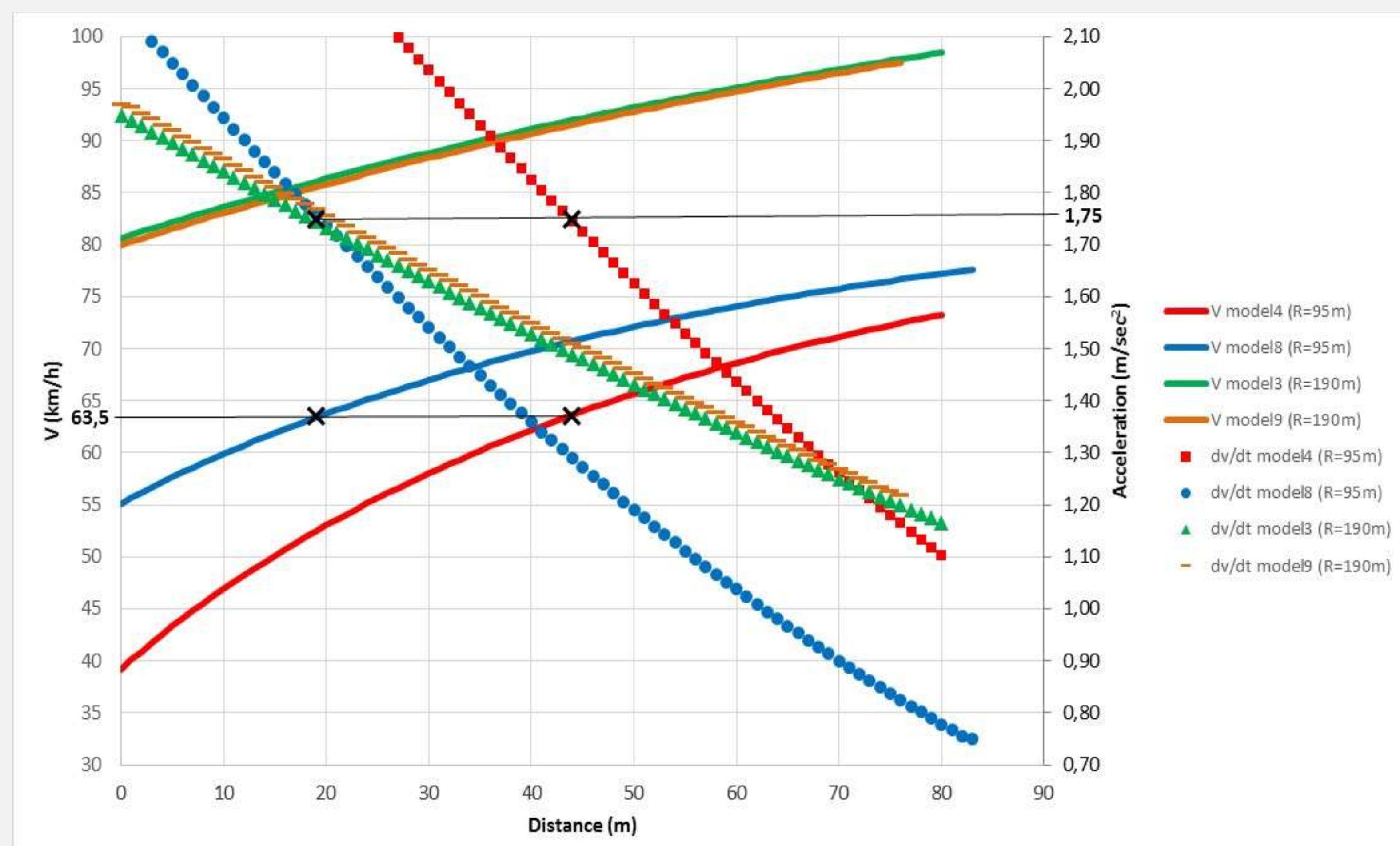

Figure 2b. Speed and Acceleration Variation vs Distance

Figure 2a and Figure 2b illustrate the model's speed distance outputs on the primary (left) vertical axis, where the variation of the vehicles' horse power utilization and acceleration are shown on the secondary vertical axis respectively.

More specifically in Figure 2a it can be seen that the horse power utilization, which has a parabolic variation, reaches its peak value (86.0hp) for the same vehicle's instant speed value of 63.5km/h. At the same time the acceleration seems continuously decreasing, which is not surprising since speed is increasing, and reaches the value of 1.75m/sec^2 at the same peak horse power utilization value of 86.0hp (Figure 2b).

As a result, it can be concluded that during vehicle acceleration on curved road sections and continuous impending skid conditions, every speed value can be paired to a certain horse power utilization rate. This assessment is mostly critical in terms of safety, since beyond this rate vehicle skidding occurs. Moreover, there is a certain point where the vehicle reaches a peak horse power utilization, where even though it decreases after, the vehicle's speed still increases until the acceleration reduction reaches zero (point of vehicle's maximum attainable constant speed).

Therefore, it is essential to investigate the acceleration impact in current practice by quantifying the potential safety hazards for control road geometry parameters and vehicle speed at and below the suggested relevant design speed.

The conventional approach of addressing vehicle safety on curves based on posted speed management seems inadequate, since, even when the speed of the vehicle is less than the relevant posted value, the acceleration effect which depends on the utilized horse power rates may result in vehicle skidding.

Acceleration Impact Investigation In Current Practice

The impact of vehicle acceleration during cornering was examined for design speed values ranging from 50km/h – 90km/h and the corresponding control horizontal radii based on AASHTO 2011 Design Guidelines, where the superelevation rate was set to 6% for all examined cases.

As far as pavement friction values are concerned, besides the values adopted by AASHTO, it is evident that the sliding friction coefficient and consequently the relevant peak value are subject to marginal variations in terms of wet-dry pavement conditions as well. For this reason, in the present analysis the vehicle motion was examined under 3 values of peak friction coefficients (supply friction) for each of the above design speed values.

In order to assess more sufficiently the acceleration impact during vehicle cornering, besides vehicle motion under the design speed, speed values of 10km/h and 20km/h below the design speed were used as well as for every set of control parameters.

In the present analysis, the breakpoint where the vehicle reaches a peak horse power utilization, after which it decreases, was found for speed values beyond the design speed and therefore, it was not further investigated.

The vehicle's horse power rates for the examined cases are shown through Figure 3. For every colored set, the three different shapes (box, partial pyramid and cylinder) represent horse power rates extracted for vehicle motion under the design speed, 10km/h below and 20km/h below (Vdesign, Vdesign-10km/h, Vdesign-20km/h) respectively. This process was performed for every utilized value of peak friction coefficient.

During vehicle cornering on control alignments under the above conditions, if the driver attempts to utilize more horse power rates compared to the values shown in Figure 3, the vehicle will skid.

From Figure 3 it can be seen that vehicle acceleration at impending skid conditions under speed values below the respective design speed are more critical. As a result, during curve negotiation the safety performance of a vehicle may be violated if the driver attempts to accelerate the vehicle more aggressively at such speed values. When the vehicle accelerates at impending skid conditions under the design speed value and on poor wet friction pavement (fmax=0.35) the horse power rates are 1hp-3hp and 6hp-8hp higher compared to speed values 10km/h and 20km/h respectively below the design speed. For fmax=0.65, the respective horse power rates range between 7hp-9hp and 19hp-20hp.

Another interesting finding is that vehicle performance in terms of horse power utilization for pavements with friction supply between fmax=0.35 and fmax=0.65 can be increased by approximately 80%. Therefore, it is very important to monitor friction supply and schedule friction improvement programmes on a regular basis.

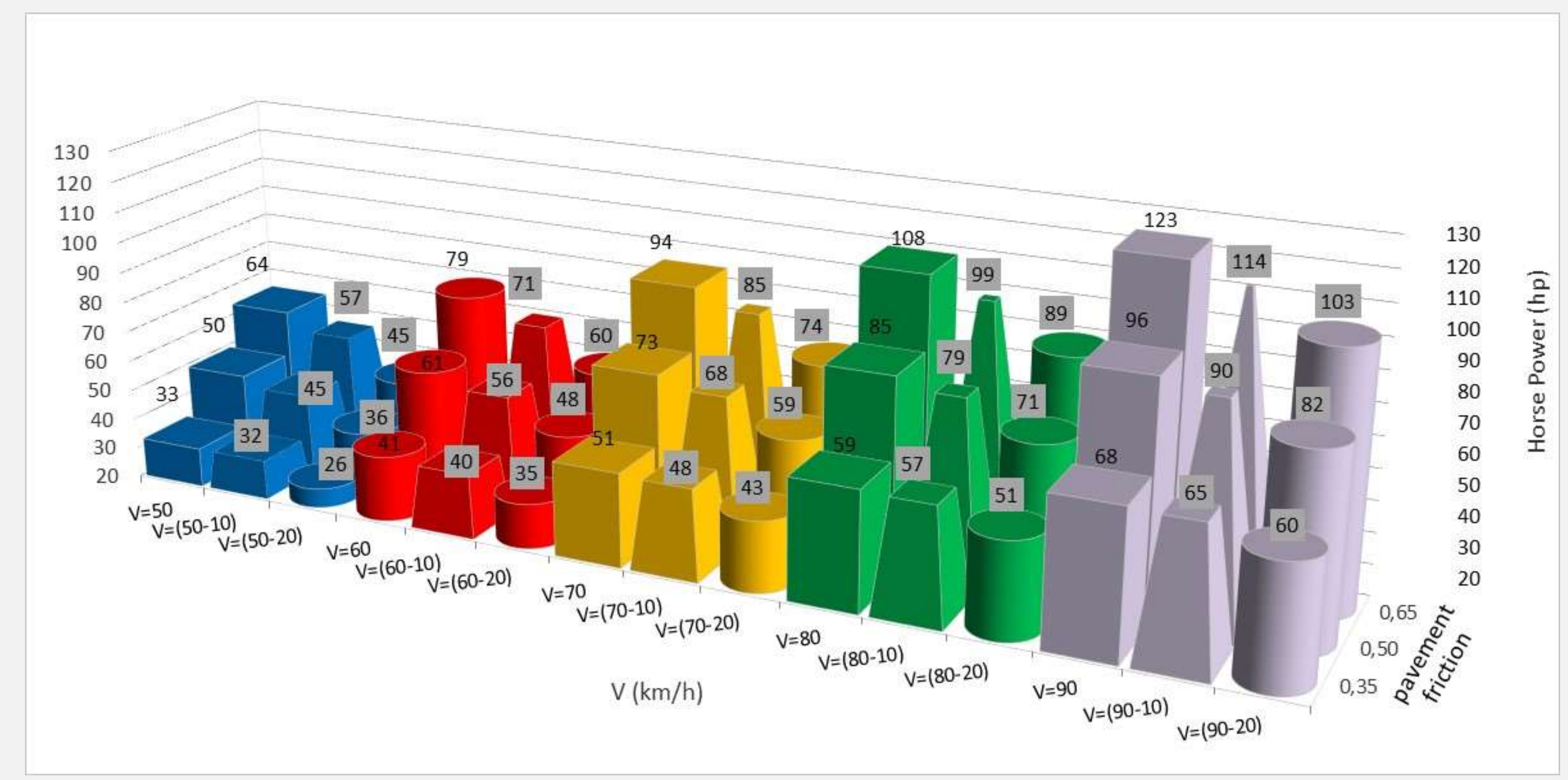

Figure 3. Horse Power Utilization at Impending Skid Conditions for Control Design Values

Conclusions

Speed – distance of a C-class FWD passenger car along with pavement friction supply were collected on two upgraded curved road sections and correlated against an existing dynamic model in order to examine the interaction between vehicle dynamics and road geometry.

Aiming to quantify the potential safety hazard during vehicle acceleration at impending skid conditions, the authors examined alignments with control road geometry parameters based on AASHTO 2011 Design Guidelines and vehicle speeds at and below the suggested relevant design speed values which ranged from 50km/h to 90km/h. This assessment was performed for three values of peak friction coefficients in order to assess pavements with poor friction performance under both wet and dry pavement conditions. The analysis delivered specific horse power rates for every examined case, beyond which the vehicle will skid.

Among other important findings, stands the necessity for monitoring friction supply and scheduling friction improvement programmes on a regular basis as well as the fact that vehicles equipped with excessive amounts of horse power rates must be driven very conservatively, especially on sharp curves with poor friction supply.

The conventional approach of addressing vehicle safety on curves based on posted speed management seems inadequate, since even when the speed of the vehicle is less than the relevant posted value, depending on the utilized acceleration cases of vehicle skidding may occur.

Such information incorporated in more sophisticated intelligent speed adaption (ISA) process of vehicle advanced driver assistance systems (ADAS) in the near future will provide integrated and more comprehensive in terms of safety guidance to drivers.