Evaluation of the impact of pavement degradation on driving comfort and safety using a dynamic simulation model

D'Amico, Fabrizio, Calvi, Alessandro, Bianchini Ciampoli, Luca, Brancadoro, Maria Giulia and Tosti, Fabio ORCID logoORCID: https://orcid.org/0000-0003-0291-9937 (2017) Evaluation of the impact of pavement degradation on driving comfort and safety using a dynamic simulation model. In: RSS2017 - Road Safety & Simulation International Conference, 17-19 Oct 2017, The Hague, The Netherlands.

Evaluation of the impact of pavement degradation on driving comfort and safety using a dynamic simulation model

Fabrizio D'Amico, Alessandro Calvi, Luca Bianchini Ciampoli, Maria Giulia Brancadoro, Fabio Tosti

Department of Engineering, Roma Tre University, via Vito Volterra 60, 00146 Rome, Italy,
fabrizio.damico@uniroma3.it, alessandro.calvi@uniroma3.it,
luca.bianchiniciampoli@uniroma3.it, mariagiulia.brancadoro@uniroma3.it
School of Computing and Engineering, University of West London (UWL),
St Mary's Road, Ealing, London W55RF, United Kingdom,
fabio.tosti@uwl.ac.uk

Abstract

The dynamic effects induced by vehicles on road pavement have been thoroughly analysed over years [1]. The main reason of such focus is the major influence exerted on the propagation and worsening of pavement damages by the dynamic loads rather than the static ones [2]. To date, the modelling theories of systems have evolved, along with the computational capability of modern calculators. To this effect, three-dimensional simulations of the tire-surface interaction [3, 4] are commonly used. The simulations take into account both the dynamics of the load and the consequent deformation of the pavement.

However, previous studies aimed at analyzing the above interaction for the optimisation strategies of the maintenance activities within the context of effective road asset management. On the contrary, this work focuses on the safety-related issues by the dynamic effects suffered by the vehicle, when passing on different road defects. The goal of this study is to numerically analyse the kinematic and dynamic impacts of the pavement degradations (and in particular rutting) on the driving safety.

The simulation of the main characteristics and evolution of the pavement damages over the time, such as the simulation of the tire-pavement contacts and the dynamic response on the vehicles, is a useful tool for developing safe and comprehensive rehabilitation programs. These are of paramount importance to limit the accident rates. The impact on driving safety was analysed using a simulation model for the simulation of the vehicles behaviour in the case of damaged pavements. Specifically, different road geometries and vehicle's typologies were considered to evaluate the rutting effects on safety, as a function of the evolution stage of this pavement damage. In more detail, the performance characteristics of the vehicles, the dynamic and cinematic parameters (e.g. the vehicle trajectory and the vertical acceleration), were collected for increasingly rutted pavement conditions.

The study proposes qualitative relationships between differing stages and location of rutting, and the consequent impacts on driving safety for different types of vehicles (passenger cars and powered two wheelers). It is important to emphasize how this analysis could be helpful to the road agencies in prioritizing maintenance actions on large-scale road assets. Prioritization will be mainly focused on the level of risk associated with pavement degradations.

Keywords

Vehicle behaviour, kinematic and dynamic impacts, pavement damages, maintenance system.

1. Introduction

According to field-related literature, the main causes of road accidents are related to human factors, vehicles' performance, roads and environmental conditions.

To raise the prevention of accidents, several measures could be undertaken in terms of drivers' education, development of safer vehicles and improvement of infrastructure maintenance policies [5]. With regard to the latter, it has to be pointed out that the rate of road accidents caused by pavement defects is relevant in many countries worldwide. Clearly, the severity of such an issue varies geographically, according to several factors. In this regard, we can mention the presence of maintenance programs, the financial resources invested in pavement maintenance, or the significant presence of Powered Two Wheelers (PTW), that are some of the most vulnerable users due to their dynamical behaviour [6-8].

In 2014, about 26.000 people were killed in road accidents throughout the EU. Motorcycle and moped fatalities, together referred to as Powered Two Wheelers (PTW), accounted for 17% of those fatalities (16% in 2005) [8].

In the last decades, researchers' efforts have been addressed to the development of support solutions for road safety managers, aiming at reducing the risk of accidental events by hitting the probability and the gravity of crashes [5, 9].In terms of accidental probability, the development of effective methods for identifying the different pavement damages and the evaluation of their relevant effects on vehicles' dynamics and cinematics, are mandatory for the identification of the most effective maintenance measure.

In view of the above, highway designers and road engineers are increasingly using simulation codes to analyse how roadway design choices or pavement conditions may affect the vehicles' dynamics, hence, the driving safety. As a result, simulation software companies have recently invested significant resources to raise the reliability of the models. The evaluation of the vehicles' dynamic behaviour could be analysed by vehicle dynamics models. These have an enhanced capability of reproducing the vehicle dynamics including pitch, yaw, and roll, and generating realistic vehicle trajectories. In general terms, it is known that the forces and the moments generated between the tire and the ground rule the vehicle motion; hence, the validity of such virtual tests depends on the quality of both the tire model and the characterization of the ground surface.

The topic was tackled in 2002 by Sayers et al. [10], who deepened how mathematical models of vehicles could be used to infer about their dynamic behaviour. Traditionally, computer simulation analyses have been limited to commercial-addressed experts' specific questions about the vehicles' performance. However, less experienced engineers can also run mathematical models when simulation technology is combined with a modern graphical interface and a database of vehicle properties. Sayers described features in the user interface that supported quick learning on the part of the user.

Later on, Gillespie [11] provided an overview of the simulation software applications, also showing how these softwares were used in automotive engineering courses, to analyse acceleration, braking, aerodynamics and cornering performances. In particular, he reports that the CarSim® vehicle dynamics simulation software has been introduced, at the University of Michigan, as a tool for raising the learning experience in laboratory courses.

Yu and Johnson [12] reported successful validations of the model with regard to the steering input and the lateral acceleration conditions. Furthermore, Carsim was used by Xu et al [13] for brake system testing in a virtual environment, due to the relatively high cost and limited coverage of test conditions related to the real-scale experimental verification. The software allowed to record the performance of a reference vehicle in many different test conditions. As a result, simulations proved time- and cost-effective performances. Indeed, several applications with the support of mathematical models are already witnessed in literature [14-16].

With regard to the motorcycles case, more scientific contributions [17, 18] focused on the effects exerted by the pavement conditions on the dynamics of PTWs. Purposely, a further high-reliability simulation software, namely Bikesim® was used with promising outcomes. This study reports on the preliminary activities performed within a wider research path [19], and deals with the evaluation of the impacts exerted by the presence of pavement rutting, on the vehicles' dynamics. The pavement rutting is generally described as a longitudinal deformation along the wheel paths, characterized by two main attributes, depth and width, and generally caused by several possible causes such as the inadequate compaction in surfacing or base, the plastic deformation of bituminous materials (accelerated by the combination of traffic and high temperature) and the structural failure of the subgrade. In particular, a driving scenario characterized by increasing rutting conditions was virtually tested by means of Carsim® and Bikesim® softwares [20], to evaluate the dynamic impact suffered by cars and PTW, respectively. As a result, useful suggestions for planning maintenance interventions, based on the evaluation of the risk connected to different configurations, are retrieved.

The paper is outlined as follows. In section 2, the different variables characterizing the simulation scenarios are given, and the analysis criteria are described. In section 3, the outcomes from the simulations are reported with respect to the different geometries and vehicles taken into account. An interpretation of the results by deeper analysis and cross comparison between different configurations is proposed in section 4. Finally, conclusions and future perspectives of the research are given in section 5.

2. Methodology

The simulation codes used provide accurate reproduction of the dynamic performance of cars and motorcycles in different pavement conditions. According to a specific research program, simulation layouts including several pavement degradations, such as polishing, potholes, etc., were previously tested [17-19]. In this work, the authors tackled the topic of dynamic impacts on vehicles' motion of one of the most frequent damages, i.e. the rutting in bituminous pavements.

The experimental design aims at defining the variables majorly affecting the dynamic behaviour of both cars and PTW, travelling along different road elements affected by rutting. The investigated variables were both geometrical and functional. In particular, i) the geometrical features of the road elements where damages are located, ii) the rutting geometrical characteristics and iii) the speed of the vehicles were investigated.

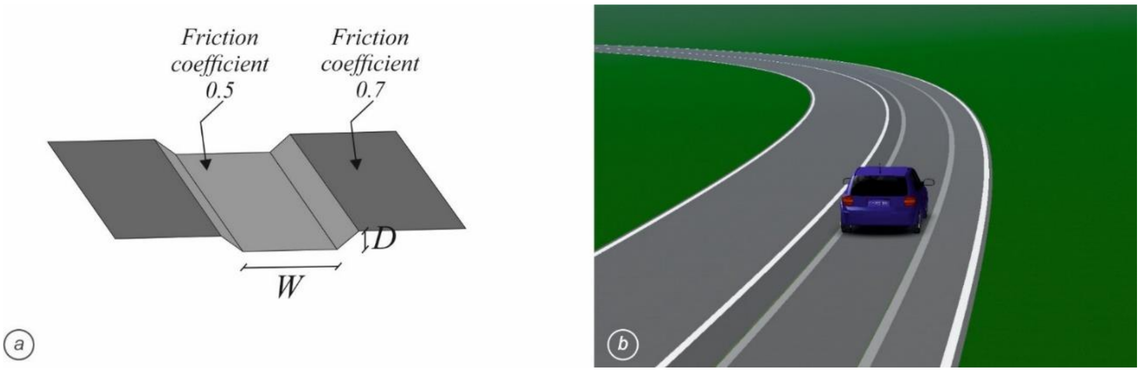


Figure 1: Rutting characteristics and localization.

With regard to the geometrical conditions, two different cases were accounted for. Firstly, the presence of a longitudinal rutting in a straight road element was evaluated, then, the curve case was considered. To ensure an intersection between the vehicle trajectories and the rutting paths, vehicles were committed to "virtual overpassing manoeuvres" when traveling in straight road sections. In the curve element cases, instead, the trajectory of the vehicles always met the longitudinal ruts. This was due to the lateral offset induced by the later forces and the adherence conditions (Figures 2a and 2b).

To contain the number of the variables, a single value of radius (R=400 m) was considered, for reproducing rural road curve elements. The vehicle speed (S), regardless the geometrical conditions, was ranged between 70 and 150 km/h, in order to investigate the dynamic effects induced in rural road conditions.

According to the international distress classification standards [21-25], the severity of the rutting was defined with regard to two main attributes: depth and width. More specifically, rut depth (D) and width (W) were set to range between 2 and 6 cm and between 20 and 40 cm, respectively (see Figure 1a).

In order to reproduce rutting effectively, a different tire/ground friction coefficient was used inside the ruts, to simulate an internal polishing or the presence of water. In more detail, a general value of tire/ground friction was set as 0.7 for a "regular" pavement friction level, whereas a lower value of 0.5 was used inside the ruts (see Figure 1a), in accordance to the suggestions of the software manuals [20].

The vehicles for the simulations were chosen to reproduce a C-class passenger car (Figure 1b) and a standard model of a PTW, respectively (Figure 2). However, several models of passenger cars and motorvehicles are implemented in the software databases, and will be employed to evaluate different dynamic responses in future papers. All of the aforementioned parameters held as input data for the simulation softwares. After running the mathematical models, the results were returned as both video and numerical outputs. The former allow the users to macroscopically understand the dynamic responses of both cars and motorcycles, in order to have an immediate visualization of the incurred issues. On the other hand, the latter allow the users to a further data processing aimed at highlighting correlations between the variables.

With regard to the video output, the following four macroscopic behaviours were recorded:

- No particular dynamic effects induced by rutting
- Skid effect
- Severe skid effect, followed up by a roadway departure or fall down
- Rails effect: vehicle trajectory is fully constrained by rutting

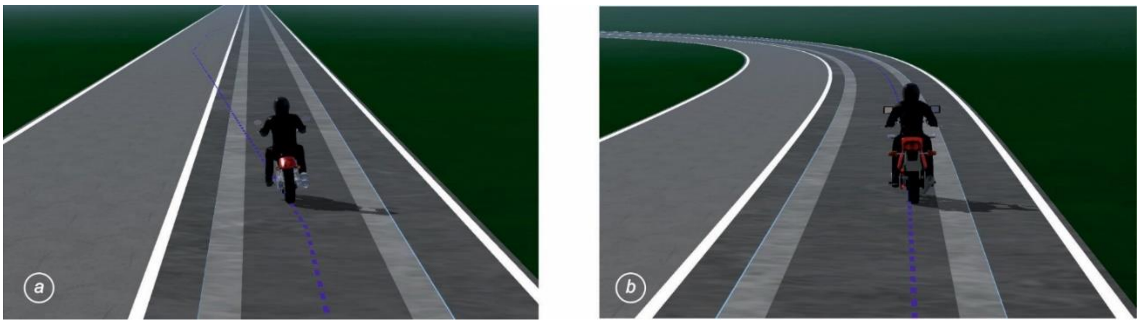


Figure 2: Localization of rutting damage and simulated manoeuvre in both Straight and Curve elements.

Concerning the numerical output, several driving parameters were recorded. Among these, we can mention the three components of the acceleration applied to the mass-centre of the motorcycle (longitudinal, transverse and vertical), the three components of the rear tire force, the three components of the front tire force, the destabilizing moment on the front tire and the lateral position (trajectory) of the vehicles against the damages.

In this paper, an evaluation of the large number of the only video results was performed in order to preliminarily define the dynamic responses of the vehicles in different simulation scenarios, through a qualitative approach. More than one thousand simulations (3 widths * 5 depths * 17 speeds * 2 geometrical elements * 2 vehicles types) were realized and analysed. The processed numerical database is expected to be used for the development of predictive models, in forthcoming studies.

3. Analysis and Results

According to the methodology, the vehicle's dynamic response was recorded, with varying travel speed and rutting conditions. Table 1 summarizes the considered simulation scenarios.

The results from the tests are hereafter presented by means of graphical tables illustrating vehicles' behaviour with respect to speed and rutting conditions. Three or four main effects on the vehicles are recorded and identified by a chromatic scale, for each considered vehicle-geometry configuration. In more detail, Tables 2 and 3 illustrate the results recorded in straight road condition tests, whereas Tables 4 and 5 refer to the curve element simulations.

3.1 Straight road element

The dynamic response of the vehicles in the case of a straight road element affected by rutting was evaluated by forcing the vehicle to a double deviation from its straight trajectory. In view of this, an overpassing manoeuvre was simulated. Accordingly, the intersection between the vehicle trajectory and the longitudinal rut was always granted (Fig. 2a).

In order to evaluate the same test conditions, the deviation angle between the vehicle trajectory and the rut was set to be the same, regardless the travel speed. As far as the trajectory of the vehicle during the overpassing manoeuvre is concerned, it was defined according to the Italian standards for the construction of roads [26].

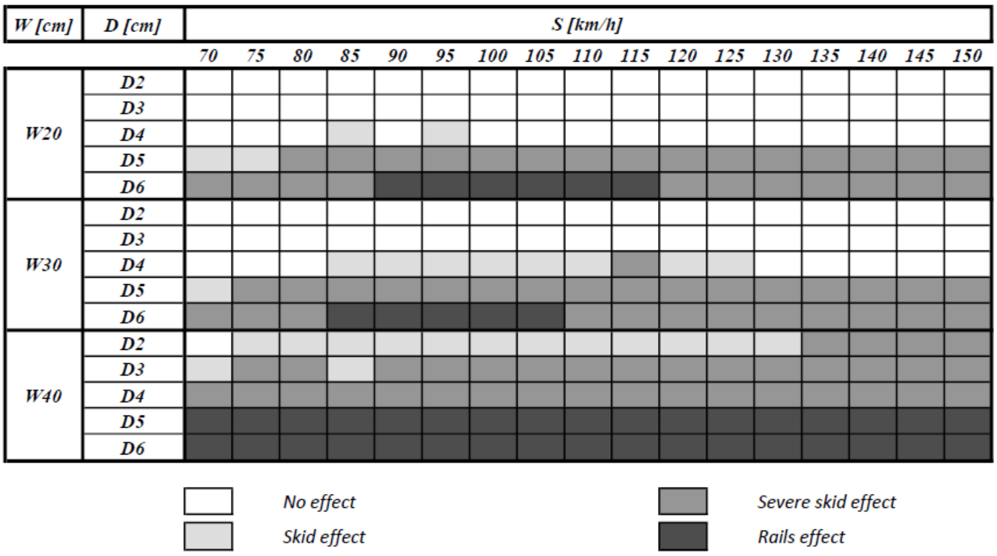
3.1.1 Carsim simulation code

Table 2 illustrates the dynamic response of the cars travelling along a straight road element, by simulations run in CarSim software. The whole set of macroscopic dynamic behaviours presented in Section 2 was encountered once the outputs had been analysed. They were marked with different shades of gray, ranging from white to dark gray, and standing for "no effect" and "rails effect", respectively.

Table 1: Simulation scenarios

		Straight road element	Curve element		
Rutting characteristics	*Width [cm]*	20/30/40	20/30/40	*Carsim simulation code*	*Bikesim simulation code*
	Depth [cm]	from 2 to 6	from 2 to 6		
	Friction Coefficient	0,5	0,5		
Geometrical characteristics	*Vehicle Manouvre*	Overpassing manouvre	Target path -1,75 m		
	Curvature [1/R]	0	0,0025		
	Transversal gradient [%]	2.5	from 2.5 to 7		
	Friction Coefficient	0,7	0,7		
	Speed [Km/h]	from 70 to 150	from 70 to 150		

Table 2: Passenger Car Behaviour in Straight Road Element



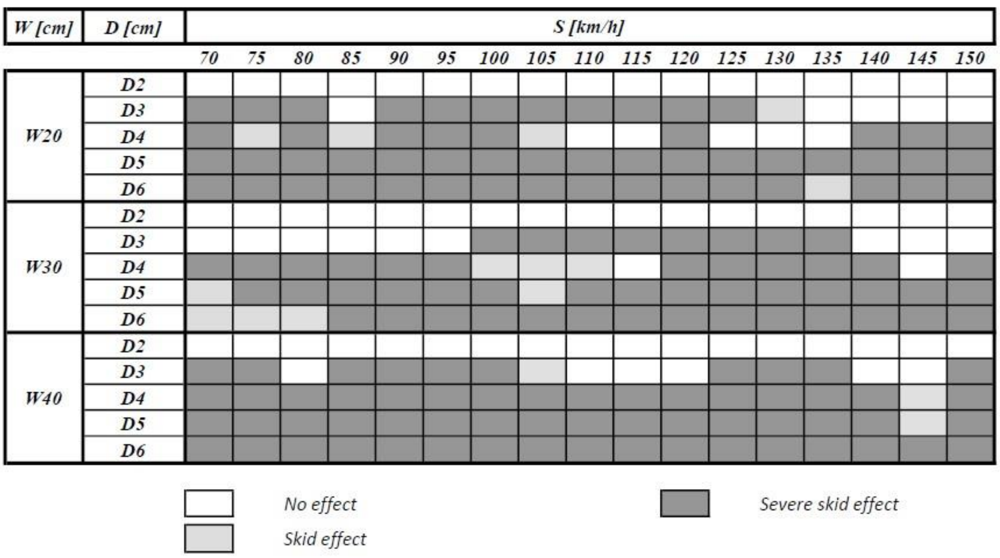
As it is represented in Table 2, the dynamic behaviour of the vehicle shows no dependence on the speed of the vehicle itself. Conversely, the rutting geometrical features (i.e., width and depth) significantly influence the dynamics of the vehicle. In particular, as the value of rutting width is kept constant, the vehicle tends to lose stability as the depth of the rut increases. On the contrary, unstable dynamic behaviours were recorded for shallower rutting depth if we consider wider ruts. This was verified up to the case of 40 cm wide ruts, where unstable behaviours were observed even in the lower considered depth range (2-3 cm).

If both the depth and the width increase, the vehicle route (trajectory) is increasingly affected by rutting, up to occurrence of rails effect. In the case of width of 40 cm, for instance, this occurrence is verified from 5 cm of depth.

3.1.2 Bikesim simulation code

The motorcycles behaviour in straight elements were analysed by running the same simulations in Bikesim software. In this case, only three categories of dynamic effects were observed, ranging between "no effect" to "sever skid effect". Despite few exceptions, Table 3 shows that travel speed seems not to particularly affect the interaction between the rutting and the vehicle dynamics. On the contrary, rutting conditions strongly affect the motorcycle stability, even for low depth and width values. An exception to this behaviour was observed at the depth of 2 cm.

Table 3: Motorcycle Behaviour in Straight Road Element



3.2 Curve element

In this case, the intersection between the vehicles trajectory and the longitudinal rutting was granted by the lateral offset from the set trajectory. This is exterted on the vehicle by the lateral forces and the adherence conditions (Fig. 2b).

3.2.1 Carsim simulation code

As Table 4 demonstrates, in this case the vehicle behaviour is more affected by the travel speed rather than the rutting features. Indeed, the vehicles motion gets the more unstable as the speed increases. The analysed simulations pointed out that, in the whole set of considered speeds, the skid conditions are always witnessed. More specifically, at a speed of 85-110 Km/h, simple skid effects are observed to turn into rails phenomena (regardless of the rutting conditions). If the velocity keeps increasing, the vehicles behaviour skips to severe skid conditions, generally leading to a roadway way out of the vehicle.

3.2.2 Bikesim simulation code

Table 5 witnesses the severe effects exerted by the presence of rutting on the motorcycle dynamics while traveling in a curve road section. In most cases, this type of pavement defect produces dangerous instabilities, generally leading to a fall down. Within a rutting depth lower than 5 cm, it is always recognizable a range of speed related to stability conditions. This means that in some particular cases the speed can help to increase the stability of a motorcycle interfering with the longitudinal rutting.

Table 4: Passenger Car Behaviour in Curve Element

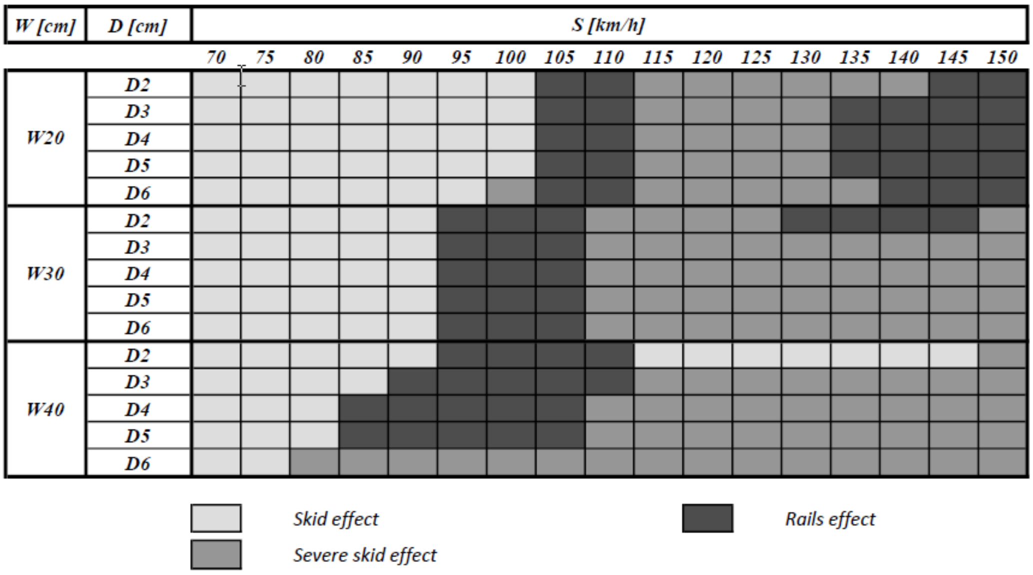
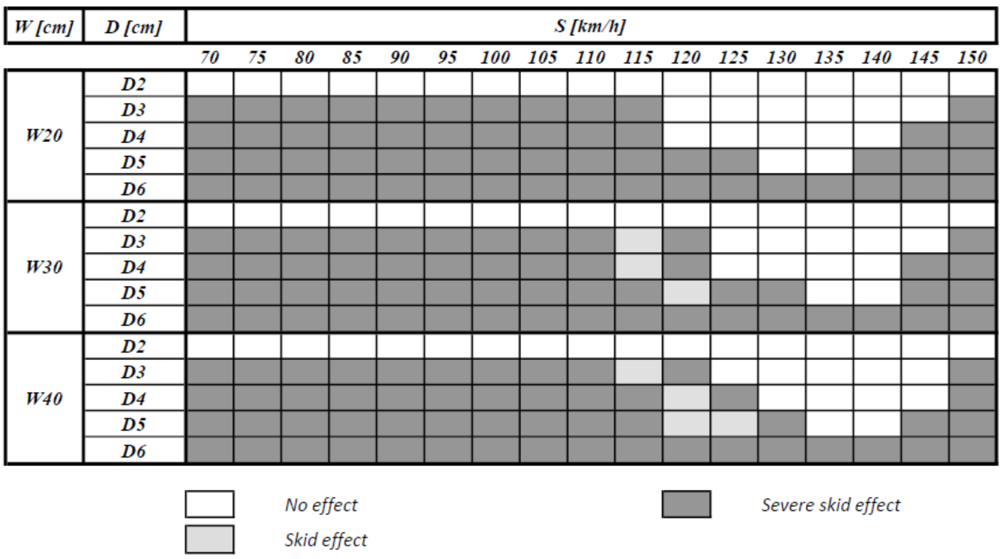


Table 5: Motorcycle Behaviour in Curve Element



4. Discussion

In this section, the aforementioned simulation outcomes are commented more thoroughly. In Section 3, the dependence of the dynamic behaviour of both cars and motorcycles in different geometric configurations (Curve or Straight road elements) has been pointed out. Such a results is hereafter discussed with regards to: (i) vehicles typology and (ii) geometric element analysis.

4.1 Vehicles behaviour

As far as the passenger car is concerned, Carsim simulations have highlighted a strong dependence of the vehicles dynamics on the severity of the rutting conditions rather than travelling speed, for straight and curve geometrical conditions, respectively (Tables 2-3). In more detail, for straight conditions, the rutting depth seems to be the variable most impacting onto the vehicle stability.

Moreover, cars have showed to be highly subjected by rails effect. Such an effect is detected for different stages of dynamic and rutting conditions. Indeed, for straight elements, the rails effect were detected for the most critical scenarios, represented by the deepest ruts. On the contrary, for curve elements, rails effect is recorded as an intermediate condition, recognized for a range of speeds approximatively located in the center of the considered set of speeds. This fact can be explained by referring to the higher values of later force recorded in curve elements, allowing the vehicles to get out from the rut path.

Concerning the motorcycle case, simulations showed generally more severe effects of rutting on the stability of the PTW (Tables 4-5). This is particularly true for the curve case, where, in addition, the applied later force and the balance condition amplify the effect of the defects on the PTW’s stability.

4.2 Geometric elements

At different rate of impact, the presence of rutting in a straight road element generates non-negligible effects on both cars and motorcycles. In particular, the severity of these effects was found to depend on the rutting depth, in the only former case (Table 2). In the latter, severe effects were recorded all along the depth range, for values higher than 3 cm (Table 3). In such a framework, it is worthwhile noting that this behaviour could be strictly related to the geometry of the vehicle trajectory. In particular, simulations should be run for more trajectory-rutting deviation angle, in order to assess their relationship.

With regard to the curve elements, Table 3 shows that for the cars simulations, the speed is the most impacting variable. It is also showed that, for the considered curve radius, critical dynamic conditions are reached for speeds higher than 85 Km/h. In these conditions, rails effects were recorded.

This can be related to the higher values of the lateral force applied, forcing the vehicles trajectory towards the rutting direction. For speed levels higher than 110 Km/h, the later force reaches values sufficient for the vehicle to overcome the rut, but also involving a roadway departure.

Concerning the motorcycle case, a diffused instability condition was observed for the whole set of tested configurations, with the exception of a speed range, spanning between 120 and 145 Km/h, and between 2 and 5 cm of depth (Table 5). Due to its particularity, this case was furtherly deepened, as described in Section 4.3.

4.3 Further remarks

From a further analysis of the simulations, it was possible to divide the motorcycles falls down in two different phenomena, namely:

- Rutting fall
- Dynamic fall

The former refers to a fall occurring during the exit of the motorcycle from the rut path. This is strictly related to the deviation angle between the trajectory and the rutting, and to the lower speeds, within the analysed range. On the other hand, the latter refers to the dynamic instability caused by the too high speed at that particular geometrical condition. Indeed, the weak equilibrium of the motorcycle induced by its leaning during the curve, generates the fall down as the PTW come to interfere with the rutting. In this case, the fall down occurs at the first intersection of the motorcycle with the rutting.

By detecting these two major behaviours within the simulation scenarios, Table 2 could be updated to a new version, presented in Table 6, including four conditions, namely, stability, skid effect, rutting fall and dynamic fall.

It is worthwhile noting how, regardless the rutting width conditions, it is always possible to detect between the areas related to the two types of fall down, a stability area which tends to extinguish as the rutting depth reaches a critical level (6 cm).

This particular feature can be interpreted by considering the dynamic condition undergone by the motorcycles between the two fall-down areas. In this context, on the one hand the rutting fall is compromised by the inertial force generated by the high speed (that allows the motorcycle to overcome the rutting borders).On the other hand, the applied lateral forces are not sufficient to make the cycle falling down.

In Figure 3 the aforementioned behavioural analysis was summarized into three plots describing the stability conditions of the motorcycles, within the considered range of speed and rutting depth. Each plot refers to an increasing rutting width level.

5. Conclusions and future perspectives

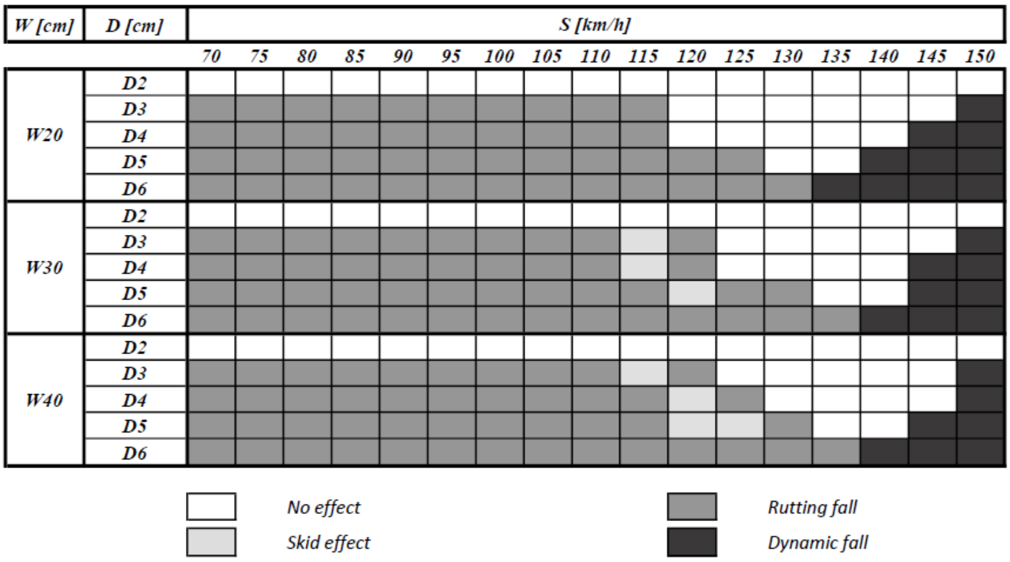
This paper reports a preliminary analysis of the dynamic effects induced by longitudinal rutting to the motion of cars and motorcycles in different road elements.

The analysis was performed by running the same virtual scenarios by means of two vehicle dynamic simulation softwares, namely, CarSim and BikeSim. These allowed to easily reproduce different rutting conditions and travelling speeds.

At the present stage of the research, a qualitative analysis of the macroscopic effects induced by the particular rutting/speed configurations was carried out and reported by means of grey-scaled tables. As a result, promising considerations could be made with regard to the different dynamic behaviours recorded at various tested conditions. It is important to emphasize how this analysis can be helpful for agencies to prioritize maintenance actions on large-scale road assets, with a special focus on the level of risk associated with the pavement degradation.

As a major upgrade of the research, a thorough numerical analysis of the dataset is planned to provide quantitative relationships between the test parameters and the induced dynamic effects. Furthermore, the gathered database should be extended to different damages conditions, more curve geometries, vehicle types and simulation conditions.

Table 6: Motorcycle Falling Conditions in Curve Element



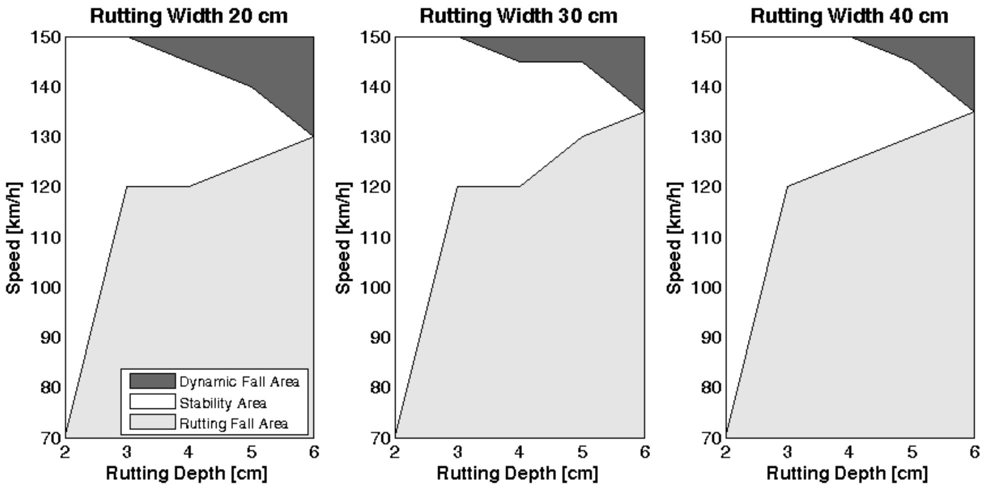


Figure 3: Safety diagrams in case of Motorcycle Falling Conditions in Curve Element.

References

1. Beskou, N.D., and D.D Theodorakopuolos, *Dynamic effects of moving loads on road pavements: A review*. Soil Dynamics and Earthquake Engineering, 2011. **31**(4): p. 547-567.
2. Markow, M. J., J. K. Hedrick, B. D. Brademeyer, and E. Abbo, *Analyzing the interactions between dynamic vehicle loads and highway pavements*. Transportation Research Records, 1988. **1196**: p. 161–169.
3. Xu, Y. L., and W. H. Guo, *Effects of bridge motion and cross- wind on ride comfort of road vehicles*. Journal of Wind Engineering & Industrial Aerodynamics, 2004. **92**(7–8): p. 641–662.
4. Shi, M.X., and C.S. Cai, *Simulation of Dynamic Effects of Vehicles on Pavement Using a 3D Interaction Model*. Journal of Transportation Engineering, 2009. **135**(10): p. 736-744.
5. DaCoTA (2012) Roads, Deliverable 4.8q of the EC FP7 project DaCoTA.
6. Road safety in the European Union - trends, statistics and main challenges. 2015. European Commission, Brussels.
7. European Commission, Annual Accident Report, European Commission, Directorate General for Transport, 2016.
8. European Commission, Traffic Safety Basic Facts on Motorcycles & Mopeds, European Commission, Directorate General for Transport, June 2016.
9. European Road Safety Observatory, *Roads*, 2006. SafetyNet, retrieved March 5, 2007 from www.erso.eu
10. Sayers, M.W., C.W. Mousseau, and T.D. Gillespie, *Using simulation to learn about vehicle dynamics*. International Journal of Vehicle Design, 2002. **29** (1-2): p. 112-117.
11. Gillespie, T.D., *Using Vehicle Dynamics Simulation as a Teaching Tool in Automotive Engineering Courses*. SAE Technical Paper, 2005. doi:10.4271/2005-01-1795.
12. Yu, J., and M. Johnson, *Vehicle dynamics simulation for predicting steering power-off limit performance*. SAE International Journal of Passenger Cars - Electronic and Electrical Systems, 2009. **1** (1): p. 498-503.
13. Xu, L., R. Guo and X. Liu, *Virtual validation and verification method of brake system model*. Advanced Materials Research, 2014. **1056**: p. 177-181.
14. Cuomo, V., *The influence of roughness, evenness and road geometry on wheel-road interaction by means of a numerical simulation procedure*. Proceedings of III SIIV International Conference, 2005, Bari, Italy.
15. Brown, A., and S. Brennan, *Comparison of field measurements of vehicle dynamics to simulations using both design plans and LIDAR-scanned road geometry*. Proceedings of 4th International Conference on Road Safety and Simulation, 2013, Rome, Italy.
16. Dhahir, B. and Y. Hassan, *Reliability-based design of horizontal curves on two-lane rural highways.* Transportation Research Record, 2016. **2588**: p. 22-31.
17. Bella, F., F. D'Amico, and L. Ferranti, *Analysis of the effects of pavement defects on safety of powered two wheelers*. 5th International Conference bituminous mixtures and pavements. 2011, Thessaloniki, Greece.
18. Bella, F., A. Calvi, and F. D'Amico, *Impact of Pavement Defects on Motorcycles' Road Safety*. Procedia - Social and Behavioral Sciences, 2012. **53**: p. 942-951.
19. D'Amico, F., *Simulation of road defects to incorporate safety measures in programming maintenance interventions*. Proceedings of Road Safety and Simulation 2007 International Conference. 2007, Rome, Italy.
20. CarSim® & BikeSim® Mechanical Simulation Corporation, *Reference Manuals*, USA 2010, http://www.carsim.com
21. CNR, *Istruzioni sulla pianificazione della manutenzione stradale*, 1986. Italy.
22. CORD, *Catalogue of road defects*, Research and Development Division, Highways Dpt., Pub. N. RD/GN/015. 2013.
23. SETRA, LCPC, *Entretien preventif du reseau routier national*. 1979, France.
24. SHRP National Research Council, *Distress identification manual for the long-term pavement performance project*. 1993, USA.
25. VSS Norme Suisse, *Catalogue des degradations*. 1991, Switzerland.
26. Ministero delle Infrastrutture e dei Trasporti, *Norme funzionali e geometriche per la costruzione delle strade*. Gazzetta Ufficiale, No. 3, January 4, 2002.