ALERTINFRAPL: A SAFETY TOOL FOR INFRASTRUCTURE DIAGNOSIS DEVOTED TO HEAVY VEHICLES

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Abstract

AlertinfraPL is a diagnosis tool devoted to heavy vehicles safety, which detects automatically dangerous areas of infrastructure. This tool considers different types of risks. The method is based on a multicriteria analysis, which aims at detecting dangerous configurations of infrastructure (i.e. combinations of geometric and surface characteristics values that may entail a risk of accident). Software based on these configurations was developed. It allows an automatic analysis of a road database containing parameters of infrastructure (radius of curvature, crossfall, longitudinal slope, unevenness, skid resistance and macrotexture) and indicates warning messages when dangerous configurations are detected. These risky configurations are called "warnings". In a first part, the methodology applied in this study is detailed. In a second part, the warnings implemented in the diagnosis tool are described. In a last part, the validation of some warnings by statistical methods is presented.

1. Introduction

This paper presents the results of a global study funded by IFSTTAR, which aims at developing a diagnosis tool for safety studies. This tool, called "AlertinfraPL" is a software, which detects automatically risky areas for heavy vehicles, especially for articulated vehicles. These risky situations are represented by "warnings". These warnings are a combination of values taken by road characteristics (crossfall, radius, skid resistance, slope), which exceed at the same time thresholds values that we have to define. Thus, AlertinfraPL can be used to warn road managers about dangerous configurations of infrastructure focusing on heavy vehicles behaviour. Indeed, the dimensions of HGV are definitely higher than those of the passenger cars and their dynamics behaviour is rather different (multi-axles, attachment of the trailer…). Moreover, HGV drivers have a higher level of knowledge and practice than other road users. Thus, accidents involving heavy vehicles are rather different from accidents involving other users (jack-knifing, rollover, etc.). That is why a special tool focusing on heavy vehicles' safety was developed.

This paper is divided into three parts. In a first part, the methodology applied in this study is detailed. In a second part, the warnings implemented in the diagnosis tool are described. In a last part, the validation of some warnings by statistical methods is presented.

2. Methodology

First, a bibliographical study aims at mapping the most dangerous situations for heavy vehicles. The objective of this step lies in the fact that it reduces the number of situations of interest that we have to analyze for AlertinfraPL. It provides a mapping of the most dangerous situations for heavy vehicles regarding infrastructure characteristics (UNIFI, 2003) (Cerezo et al., 2007) (Dolcemascolo et al., 2008).

Then, numerical models are developed to evaluate the maximum speed a heavy vehicle can drive without skidding or rolling over, depending on the characteristics of the infrastructure (slope, crossfall, radius). The study focuses on tractor semi-trailer considering they represent a half of the heavy vehicle traffic in France. Both a model with 12-degrees of freedom and a commercial software called PROSPER are used to define the maximum values of speed (Bouteldja et al., 2010).

After, some abacus giving values of V85 in curves are updated. These V85 values are the speed reference values. They correspond to thresholds values under which 85% of the people drive in a given situation. In straight line, the reference value is the legal speed. Thus, the comparison between V85 and maximum speed allows determining the most risky area and choosing the thresholds values for the various parameters included in the warnings.

Lastly, the warnings are validated with real accidents data by statistical methods. The tool is applied on several itineraries. Risky areas are detected and analysed regarding heavy vehicles accidents. The accident rates are calculated and compared between areas with and without warnings detected.

3. Development of AlertinfraPL

AlertinfraPL focused both on dual carriageways roads (high trafficked primary roads and motorways) and on rural bi-directional roads. The study led to the proposal of warnings on these two types of roads. Thus, two warnings in ramps and eleven warnings in curves and/or in exit ways are determined on dual carriageway roads. Moreover, four warnings on roundabouts and five warnings in curves are proposed on single carriageway roads.

However, the warnings are determined by comparing the maximum speed and the reference speed (V85). That's why, both an update of V85 formulae and a method of prediction of maximum speed for heavy vehicles are proposed.

3.1 Determination of the reference speed V85

Formulae where proposed by SETRA in the nineties. These relationships give the value of the V85 speed for all vehicles (thus mainly passenger cars) depending on the radius of curvature of roads. An update is proposed for various categories of heavy vehicles. Measurements are realized on curves, which radius ranges from 150 to around 400 m. Only "free" vehicles are taken into account in this study. "Free vehicle" is a vehicle, whose behaviour is not disturbed by other vehicles. This means that a gap of several hundred of meters exists between the "free vehicle" and the other vehicles. Thus, the "free vehicle" can adopt the wished speed.

The relationship proposed in (SETRA, 1994) for primary roads with two or three lanes (6 or 7 m width) is:

$$V85 = 102 / (1 + 346/R^{1.5}) \tag{1}$$

With   R: radius of curvature (in m)

The update consists in looking for relationships with the same shape than (1) but adapted to three categories of heavy vehicles considered here. Category 2 is composed of 2-axels heavy vehicles and 3-axels tractors. Category 7 is composed of 4-axels articulated vehicles (tractor with 2 axels and trailer with 2 axels or tractor with 3 axels and trailer with 1 axel). Category 10 is composed of 5-axles articulated heavy vehicles. The adjustment of the model on experimental data led to three new relationships:

Table 1 - V85 updated relationships

Type of vehicles	Formulae
Category 2	$V85 = 98 / (1 + 346/R^{1.5})$
Category 7	$V85 = 94 / (1 + 346/R^{1.5})$
Category 10	$V85 = 92 / (1 + 346/R^{1.5})$

3.2 Determination of the warnings on dual carriageways roads

Ramps/ descents
Ramps are long inclined roadways connecting different levels. Safety studies realized in France showed that a great number of heavy vehicles' accidents occurred by front-rear collisions on ramps, considering both corporal and material accidents (Cerezo et al., 2008). These accidents seem to be due to a wide gap of speed between the vehicles involved. In most cases, a truck or a passenger car, which drove faster than the heavy vehicle behind them, crashed it. The average speed of the slow vehicle was around 40 to 50 km/h.

A study was realised in order to characterize more precisely the link between heavy vehicles' speed variations and longitudinal slope value, and the impact of the type of heavy vehicle on the speed variations. This work was based both on experimental measurements of speed on some ramps and numerical simulations. Simulations revealed that the decrease of speed happened in the first 1500 meters of the rise, considering two types of heavy vehicles (5-axels tractor semi-trailer, 2-axels rigid trucks), whatever the load (from empty to fully loaded).

In descent, the mechanism of accident is different. Accidents are mainly due to non-adapted speed with braking problems. In most of cases, the driver is not able to use the various braking systems in the trucks and a malfunctioning of the vehicle leads to accident.

Thus, the two warnings proposed are:
− Ramps with a length exceeding 1500 m and a slope superior to 4% without specific lane for slow vehicles,
− Descent with a slope exceeding 3%.

Curves/ exit-way
The exit-ways are curves designed with radius of curvature ranging between 100 and 500 m, which allow leaving motorways and dual carriageways. Two main mechanisms of accidents depending on the skid resistance of the road can be observed on these sites. When friction is weak, accidents rather occur by skidding. HGV go off the road or are victims of jack-knifing. When the friction level is high, rollover can be observed, especially when the height of the centre of gravity is superior to 1800 mm (in the terrestrial line). Thus, the alerts on curves are determined by considering the gap between V85 and maximum speed determined with numerical models like in (Bouteldja et al., 2010)
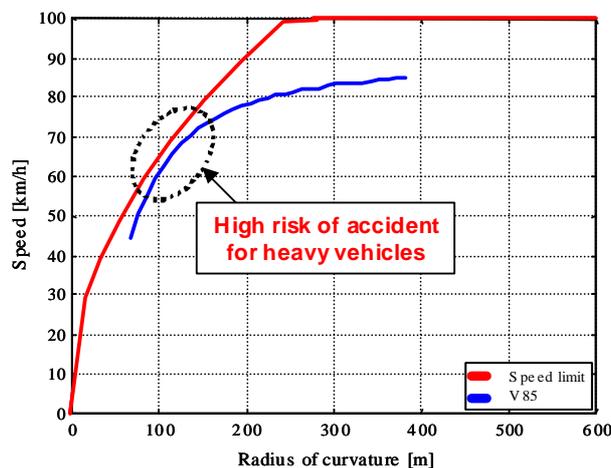

Figure 1 – Determination of the thresholds value for radius of curvature in the warning

Six configurations in curves are proposed for the warnings. The combinations include parameters such as radius of curvature, skid resistance, slope and crossfall.

Table 2 – definition of the warnings in curves on dual carriageway roads

Warning	Radius of curvature (m)	Skid resistance	Slope (%)	Crossfall (%)
1	R < 120 m	SFC < 0.40	-	-
2	R < 120 m	-	-	Gap with theoretical value > 2%
3	R < 120 m	-	< - 3% (descent)	-
4	R < 120 m with geometrical problems	-	-	-
5	Risky successive curves	-	-	-
6	R < 120 m	-	> 4% (ramp)	-

3.3 Determination of the warnings on single carriageways roads

Roundabouts
A roundabout is one of the safest control devices for regulating traffic flow at intersections (Kiattikomol et al., 2005). However, most of the accidents on roundabouts have a particular typology, which is not taken into account in accident statistics. Statistics focus on injuries and fatalities and not on cases with material damages. In spite of their good results in term of accidents, roundabouts are frequently blamed for overturned heavy vehicles.

(Dupré et al., 1998) and (Cerezo et al. 2006) highlighted the fact that certain infrastructure characteristics play a role in personal injury accidents involving a HGV, in particular slopes, radius of curvature of the ring and the pavement surface condition (dry or wet). Moreover, accidents in roundabout mainly occurred by rollover and run off after the middle of the roundabout.

Thus, some warnings based on thresholds values concerning the radius of curvature of the ring, the skid resistance and the longitudinal slope in the ring are proposed. Five combinations are implemented in the software.

Curves
Globally, curves represent a risky area considering vehicle dynamics (Brenac, 1996). Indeed, some efforts are generated in the tire/road contact area to struggle against the natural trend of the vehicle to go outside the curve due to centrifugal forces. This transversal friction is necessary to keep the trajectory of the vehicles.

The various safety studies and the simulation work realised in (Bouteldja et al., 2010) (Bouteldja et al., 2006) leads to the determination of thresholds values in curves concerning geometrical characteristics and skid resistance. Thus, five configurations are implemented in the software.

Table 3 – definition of the warnings in curves on single carriageway roads

Warning	Radius of curvature (m)	Skid resistance	Crossfall (%)
1	R < 120 m	SFC < 0.40	-
2	R < 120 m	SFC < 0.60	
3	R < 120 m	-	-
4	R < 120 m	-	< 5%
5	R < 150 m with geometrical problems	-	-

4. Validation of some warnings

Following the implementation of the warnings in this diagnosis tool, a validation process is applied. The method is based on accidents ratio analyses and the use of statistical tests. Road characteristics and accidents data are collected on primary and secondary roads network. More than 1000 km of motorways and around 500 km of single carriageway roads are included in the database. Then, the network is divided in homogeneous areas based on infrastructure characteristics and classes are defined for the relevant parameters (Conche et al., 2010). Curves and straight lines are separated. A split is done on the longitudinal profile (flat section, ramp, descent). After, bound values are proposed for the various parameters to define the classes used in the analyses. Accidents ratios are calculated by adding all the accidents data obtained on a given class. Statistical tests allow a comparison between the ratios calculated on the various classes to estimate if one class of characteristics represents a significant risk for heavy vehicles. A level of confidence of 90% is used to compare the risk levels.

Ramps/descents
As an example, five classes can be defined for the longitudinal profile: slope < -4%, -4% < slope < -2%, -2% < slope < 2%, 2% < slope < 4%, slope > 4%. The whole accidents data are merged in view of determining accident ratio for each class of characteristics. The analyses of figure 2 shows that the accidents ratio obtained on the sections with a slope > 4% is significant as compared with the accidents ratio obtained on flat sections (-2% < slope < 2%) considering the fact that the confidence intervals are separated. The statistical tests confirm that ramp with a slope superior to 4% is a risky configuration.

A second analysis is realised on more than 1000 km of motorways (figure 3). The bounds of the classes are modified as follows:
− P2 : -4.5 % < x < -3.2 %
− P1 : -3.2 % < x < -1.2 %
− PL : -1.2 % < x < 1.2 %
− R1 : 1.2 % < x < 3.2 %
− R2 : 3.2 % < x < 4.5 %.
The choice of the bound values is linked with the quantity of data available on the different classes. The statistical tests need to have representative classes with a sufficient amount of data.
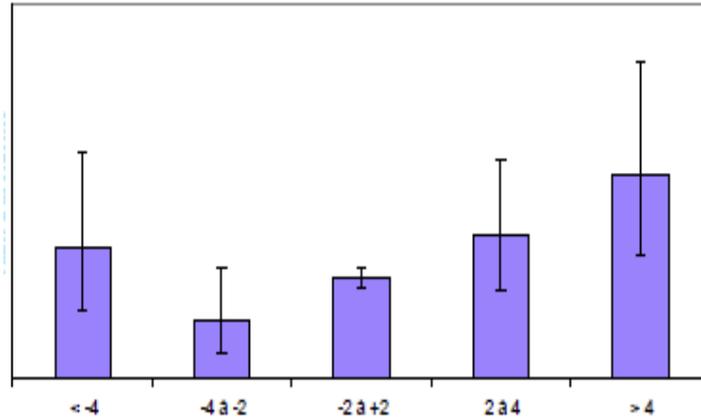
Figure 2 – Comparison of the accidents ratios obtained with the five classes of slope (in %) with a level of confidence of 90% on 420 km of motorways

By considering the category PL as the reference value, we can notice that classes R2 and P2 have separated confidence intervals with the reference class PL. This fact confirm that a ramp with a longitudinal slope superior to 3.2% represent a risk for heavy vehicles. On the same way, a descent with a slope superior to 3.2% represents a significant risk.
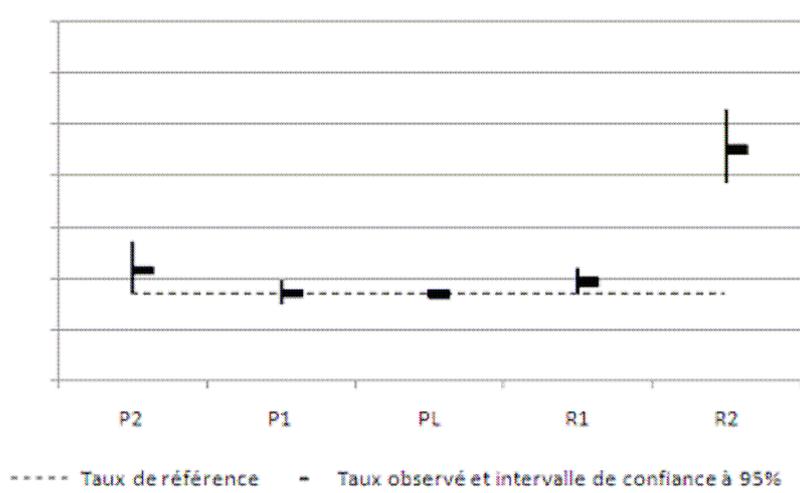

Figure 3 – Comparison of the accidents ratios obtained with the five classes of slope (in %) with a level of confidence of 95% on 1000 km of motorways

Curves

A similar method is applied for curves on single carriageway roads. The example of validation of warning 3, which corresponds to radius of curvature inferior to 120 m, is given on figure 4. Three situations are considered: accidents involving at least one heavy vehicle, accidents where heavy vehicle is supposed to be responsible, accidents involving a heavy vehicle alone. For each case, accidents ratios on section where the warning is detected are compared with accidents ratios on section where the warning is not detected. Figure 4 shows that the accidents ratios calculated on sections with this warning are significantly higher than the accidents ratios calculated on sections without the warning.
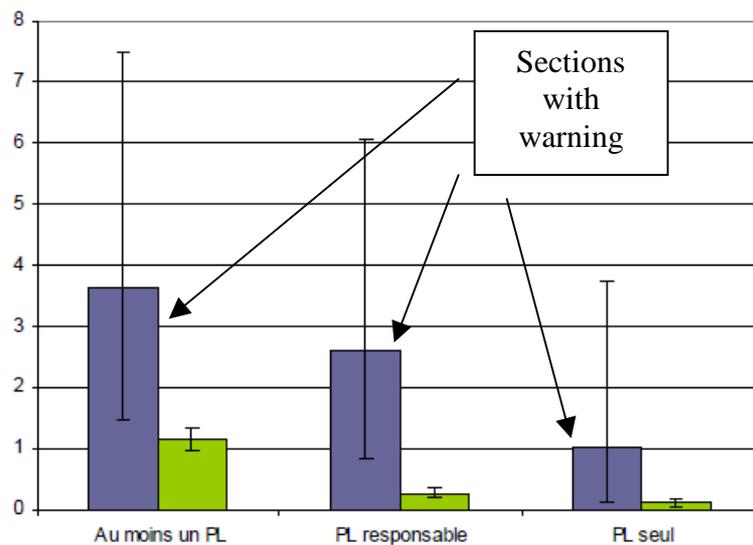
Figure 4 – Comparison of the accidents ratios obtained on curves with radius of curvature > 120 m with a level of confidence of 95%

5. Conclusion

AlertinfraPL is a safety tool, which allows correlating infrastructure characteristics and accidents. It detects automatically areas that could present a risk for a specific category of road users (heavy vehicles and especially articulated vehicles). The input data are road geometry (radius, crossfall, slope) and surface characteristics (skid resistance, macrotexture). The output data are brought together in a table containing the location of dangerous areas and the type of warnings.

AlertinfraPL is a useful tool for safety diagnoses: it helps identifying accident factors and zones with accident-prone characteristics. This tool is developed by using bibliographical results and numerical simulations. The warnings proposed are then validated by statistical tests.

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