# INFLUENCE OF SKID RESISTANCE IN MICROSCOPIC SIMULATED TRAFFIC CONFLICTS

Sued Lacerda Costa
Universidade Federal do Ceará
Campus do PICI, s/n – Bloco 703, Fortaleza, CE, Brazil
Phone: + 55 85 3366-9488 E-mail: sued@det.ufc.br

Co-authors(s); Flávio José Craveiro Cunto, Universidade Federal do Ceará; Verônica Teixeira Franco Castelo Branco, Universidade Federal do Ceará

## ABSTRACT

The assessment of skid resistance impact on traffic safety is a complex task due to the stochastic nature of car crashes. Vehicular conflicts and traffic microscopic simulation are presented as an alternative for estimating this relation. This paper evaluates the effects of different paving techniques skid resistance in both frequency and severity of micro simulated rear-end conflicts. Firstly, frictional coefficients were estimated for conventional hot mixture asphalt (HMA), HMA with grooving (HMAg), and double asphalt surface treatment (DAST). Afterwards, different scenarios were run on micro simulator VISSIM, considering three different levels of both traffic flow and desired speed. Traffic conflicts were then collected by Surrogate Safety Assessment Model (SSAM) software. The results indicate that the more loaded scenario presented both more conflicts and lower average of deceleration rates during the conflicts. In order to verify statistical relationship of each variable evaluated on vehicular interaction severity, a three-way ANOVA was performed. Traffic flow and paving technique have shown statistical influence, also the combination of traffic flow and desired speed. This result highlights the importance of aspects related to surface conditioning, once higher magnitudes of skid resistance contribute to minimize the occurrence of traffic conflicts.

## 1. INTRODUCTION

The high fatalities rates recorded as a result of traffic accidents represent, worldwide, one of the major public health problems of modern society. WHO (2013) estimates that yearly 1.24 million people are killed and others 50 million are injured as a consequence of traffic accidents.

Several factors are mentioned as main contributors to the occurrence of traffic accidents, which can be grouped into three main components: the driver, the roadway environment and the vehicle. However, although identified, many of these factors cannot be reasonably measured and controlled. Furthermore, these factors can also occur individually or in conjunction, contributing to an extra layer of uncertainty to studies focused on assigning cause and effect relationships among these components.

Several studies in the literature highlight the positive effects that adequate friction conditions lead to reductions in accident rates in the order of 60% (Milton *et al.*, 2008; Mayora and Piña, 2009). Although usually considered as a deterministic variable in traffic safety studies, the levels of skid resistance may vary significantly between paving techniques, which can positively contribute both to vehicle control as well as to braking conditions. Nonetheless, it is a hard task to account for this influence; there is a variability of skid resistance magnitude due to several factors, such as traffic effects on pavement polishing, aging process of paving materials, presence of water film on surface, type of vehicle (weight, tires, brake system), and others. Therefore, a precise characterization of frictional conditions of pavements may add reality to assessing safety from skid resistance.

As an alternative approach to assess road safety performance, several studies have applied the concept of traffic conflicts. This technique uses spatio-temporal proximity indicators of vehicles also called surrogate measures of safety (SMoS) such as time to collision (TTC), post-encroachment time (PET), deceleration rate to avoid the crash (DRAC), among others (Hayward, 1972; Cooper and Fergunson, 1976).

Recently, microscopic simulation has been widely used for estimating vehicular conflicts to assess road safety performance. This approach allows evaluating alternatives in a controlled environment that might reduce the inherent subjectivity to the original traffic conflicts technique, in which field observers need to estimate relative speeds and distances between vehicles in conflicts (Huguenin *et al.*, 2005; Cunto, 2008).

Despite of the potential to reduce traffic risks that both surface condition and such proactive approach presents, there are no records of the incorporation of the skid resistance on conflict SMoS obtained by microscopic simulations. In this context, this paper aims to evaluate the influence of surface friction conditions of different types of paving techniques on microscopic simulated rear-end conflicts.

## 2. SKID RESISTANCE AND TRAFFIC SAFETY STUDIES

Pavement surface condition is the main determinant of existing adhesion at the interface between the tire and the pavement. As a vehicle travels on the road, frictional forces allow it to perform all the necessary maneuvers, and also enables braking and acceleration. Regardless the uncontrolled driver behavior, it is still possible that greater skid resistance condition enhances the possibility to perform evasive maneuvers.

Skid resistance can be defined as a combination of two distinct and independent factors: macro and microtexture. The former is related to the surface texture, defined as the pavement surface roughness caused by protrusions of coarse aggregates. The latter is related to the roughness of each aggregate used in paving mixture (Wambold *et al.*, 1995).

The macrotexture pattern is directly influenced by factors involving the adopted type of paving technique. For example, in asphalt mixtures which particle size distribution is open-graded, the resultant high concentration of coarse aggregate leads, consequently, to a greater variation of the composite surface texture and therefore pavement friction levels.

Microtexture is directly linked to the aggregate capacity to resist the effects of surface polishing. Satisfactory maintenance of aggregates roughness contributes to increased friction forces, as the aggregate roughness interacts directly with the tire, creating adhesion force that composes friction. Furthermore, on wet surfaces, microtexture plays an important role as it breaks the thin water film existing in tire-pavement interface (Henry, 2000).

The importance of these parameters for road safety is linked to the ability to perform evasive maneuvers. At low speeds (< 20*km/h*), skid resistance magnitude lies on microtexture quality because of the greater interaction with the tire surface roughness of aggregates. As the travel speed increases, the frictional forces tend to decrease due to the loss of surface contact, being aggravated on pavements with low average macrotexture depth (Noyce *et al.*, 2005).

In the literature, several studies suggest that the frequency of collisions is greater on wet roads. Also, some results indicate the existence of significant negative linear correlation between skid resistance and accident rates (Kamplade, 1990; Milton *et al*., 2008; Mayora and Piña, 2009).

Li *et al.* (2013) found that low-friction conditions do not necessarily reflect in greater crash severity. The authors explain their results based on an interrelation between the surface quality of the pavement and human behavior, because drivers tend to accelerate more over good surface conditions. Lee et al. (2015) obtained similar results; however, only for low-speed single-collisions, which involves only one vehicle. For multiple collisions, between two or more vehicles, bad surface conditions tend to increase the severity of accidents.

Regarding the positive effects of pavements that received a treatment to improve its frictional condition, Mayora and Piña (2009) conducted a before and after analysis, based on superficial restoration of more than 1.750km of highways. The authors reported a mean reduction of 68% in accident rates over wet pavements due to 18% skid resistance improvement. However, the evaluation was limited to segments with uniform geometry, excluding intersections and access roads.

Amini and Beigi (2015) proposed an exponential model based on linear regression to estimate the accident rate at unsignalized intersections. For low speed range (20-40*km/h*), the modelling results estimated a 7.5% reduction in the occurrence of accidents for every 1% improvement in surface friction. Nonetheless, the model calibration was based on 26 observations of intersections with similar characteristics from several others that exist. Moreover, its validation was limited to a 6 observations sample. The validation of the accident prevision model was limited to a 6 observations sample, which presents several statistical limitations.

Lyon and Persaud (2015) have proposed an evaluation of the effects on traffic safety of specific treatments whose only purpose is to improve the surface condition. The safety performance was evaluated based on an analysis of crash data before and after treatments were installed, by using the empirical Bayes method. It was found that some types of treatments applied not only did not present any effect on reducing wet crashes rates, but also it was verified an increase on collision rates on dry pavements.

Because of the randomness and rareness of accidents and also the complexity aroused by the dependency between the various contributing factors of traffic accidents, conclusive and definitive results of the relationship between surface friction conditions and road safety is not a trivial task. The use of indicators representing more frequent events and in an environment that provides greater control over the various factors involved has an unknown potential to enable a promising analysis of this phenomenon.

# 3. TRAFFIC CONFLICTS AND MICROSCOPIC SIMULATION

Conflicts are defined as vehicular interactions between two or more vehicles which present collision risks, if speeds and directions remain unchangeable (Hydén and Amundsen, 1977). According to Hydén (1987), factors that lead to a collision occur in chronological order, decreasing the probability of an event to occur as the severity of the interaction increases.

In order to quantify conflicts, some proxy indicators have been proposed. Based on the indicator of the time required for the occurrence of a collision between two or more vehicles (time to collision, TTC), Hayward (1972) defined interactions with TTC $\leq 1{,}5s$ as the critical instant. Cooper and Ferguson (1976) proposed a proxy measure that considers the effects of kinetic energy in the severity of conflicts. Thus, the deceleration rate to avoid the crash (DRAC) can be interpreted as the necessary braking power so a collision would not occur.

Facing the fact that conflicts are a largely more frequent event and also due to the mechanical process of vehicular interactions, surrogate measures of safety constitute as an alternative approach to estimate safety performance from high risk situations. Moreover, these proxy indicators quantify situations of risk of collisions and can highlight problems that would have gone unnoticed by the traditional analysis of traffic accidents records (Chin and Quek, 1997).

In search to incorporate technological developments, Cooper and Ferguson (1976) proposed to simulate traffic interactions to evaluate road safety. According to Cunto (2008), the simulation allows the analyst to reproduce traffic conditions under a controlled environment, supporting the identification of factors that influenced the increase in traffic risks. Besides, the main benefit of computer simulation is the ability to evaluate alternatives prior to the intervention.

According to Huguenin *et al.* (2005), micro simulator models provide important outputs for the safety assessment, differently than macroscopic simulations. In these models, details such as position, velocity and acceleration of any vehicle at any time are possible to be identified, which allows the calculation of proxy security indicators.

# 4. METHODOLOGY

The method proposed in this paper, aimed at evaluating the influence of different levels of surface condition in micro simulated vehicular conflicts, consists of four methodological steps; namely: i) estimation of different paving techniques skid resistance; ii) preparation and implementation of microscopic simulation plan; iii) estimation of surrogate measures of safety; and iv) analysis of conflicts. Each step of the proposed activities is further detailed.

*Figure 1: Methodological steps*

## 4.1. Estimation of Skid Resistance

From literature, data of micro and macrotexture measures carried out on the field for different paving techniques were obtained. Three different types of paving techniques were evaluated as follows: i) Conventional Hot Mixture Asphalt (HMA), usually applied to urban roads; ii) HMA with grooving (HMAg), applied on landing and takeoff airport lanes due to the required high levels of skid resistance (Figure 2a); and iii) Double Asphalt Surface Treatment (DAST), commonly used in low traffic volume and surface restoration (Figure 2b).

*Figure 2: (a) HMA with Grooving (HMAg) e (b) Double Asphalt Surface Treatment (DAST)*

It was decided to also use HMAg paving technique, applied to airport runways, because it represents the maximum possible friction conditions to be obtained from the pavement; although, not yet applied to conventional surfacing. Moreover, there is a wide availability of information because the friction condition is mandatory for the operation of airport runways. Table 1 summarizes a statistical description of the data set.

The microtexture parameters were obtained by performing the test using the British Pendulum (ASTM E303-93, 2013). The test result is expressed by the British Pendulum Number (BPN), which measures the impedance that the surface exerts on the movement of a rod with a rubber tip. For macrotexture, the volumtric test of Sand Patch (ASTM E965-96, 2006) quantified all observations. By a default volume of $25cm^3$ of a specific material, the Height of Sand (HS) estimates the average depth from the surface through the height of a cylinder by measuring the diameter of the patch.

| *Paving Technique* | *Index* | *n* | *Mean* | *Standard Deviation* | *Variance* | *CV (%)* |
|---|---|---|---|---|---|---|
| *HMA* | *BPN* | *142* | *57,63* | *11,23* | *126,11* | *19* |
| | *HS* | | *0,50* | *0,15* | *0,02* | *30* |
| *DAST* | *BPN* | *62* | *58,32* | *9,87* | *97,2* | *17* |
| | *HS* | | *1,28* | *0,43* | *0,18* | *34* |
| *HMAg* | *BPN* | *80* | *99,57* | *13,19* | *173,98* | *13* |
| | *HS* | | *1,34* | *0,14* | *0,02* | *10* |

*Table 1: Statistical description of each paving technique (Aps, 2006; Rodrigues Filho, 2006; Pereira, 2010)*

For each pair of observations, it was determined the coefficient of friction by the International Friction Index method (IFI) (ASTM E1960-07, 2011). Due to the existence of several tests to quantify both micro- and macro texture, Wambold *et al.* (1995) proposed to standardize each parameter on a single scale, correcting them by a constant regression. Initially, the method determines the slip speed constant ($S_P$, *km/h*) by applying HS (*mm*) on equation 1. Then, it corrects BPN speed test with the British Pendulum (10*km/h*) to the default speed of 60*km/h* (Equation 2). Finally, $F_{60}$ reports skid resistance at a speed of 60*km/h* (Equation 3). Additionally, IFI method enables to determine standardize friction coefficient ($F_S$) at different speed levels (S, *km/h*) (Equation 4).

$$S_P = -11.6 + 113.6 \cdot HS \rightarrow FR_{60} = BPN \cdot e^{[(10-60)/S_P]} \qquad (1) \text{ and } (2)$$

$$F_{60} = 0.056 + 0.008 \cdot FR_{60} \qquad (3)$$

$$F_S = F_{60} \cdot e^{[(S-60)/S_P]} \qquad (4)$$

After the construction of the database, statistical analysis were performed for each paving technique micro- and macro texture data. Shapiro-Wilk test on the R software were used, with null hypothesis that the sample observations derived from populations normally distributed. It was chosen 0.05 as the significance level (α).

Finally, in order to avoid erroneous analysis, data considered as inconsistent were deleted from the database. The criterion for the inconsistancy was defined as IFI values for speeds of 5 and 60*km/h* obtained by equation 4*;* IFI $< 0.1$ for the former, IFI $\geq 1.0$ for the latter.

## 4.2. Microscopic Simulation Experiment

The German microscopic simulation package VISSIM © was applied as the platform to investigate the influence of different paving techniques on simulated traffic conflicts. This microscopic simulator has been extensively used on research efforts to estimate safety performance using SMoS. It considers four types of regimes where drivers adjust their desired spacing and speeds through changes in their acceleration and deceleration rates. Wiedemann's car-following four driving regimes are: un-influenced driving, closing process, following process, and emergency braking (Huguenin *et al.*, 2005; Cunto, 2008).

The sample road network for the case study consists of seven minor streets and two main corridors, differing in their geometrical aspects (width, intersection types, existence and width of shoulders, signaling presence, etc.). For vehicles input, traffic volumes were collected on field at morning peak during a typical week day, varying from 75 to 1137 vehicles at morning peak hour for minor streets and from 700 to 1060 vehicles in morning peak hour for the corridors. Lacerda (2014) calibrated and validated the network, which reflects the scenario of an intense traffic region in Fortaleza, a major Brazilian city (Figure 3). Both calibration and validation process were performed based on traffic flow performance indicators, such as travel time and average speed.

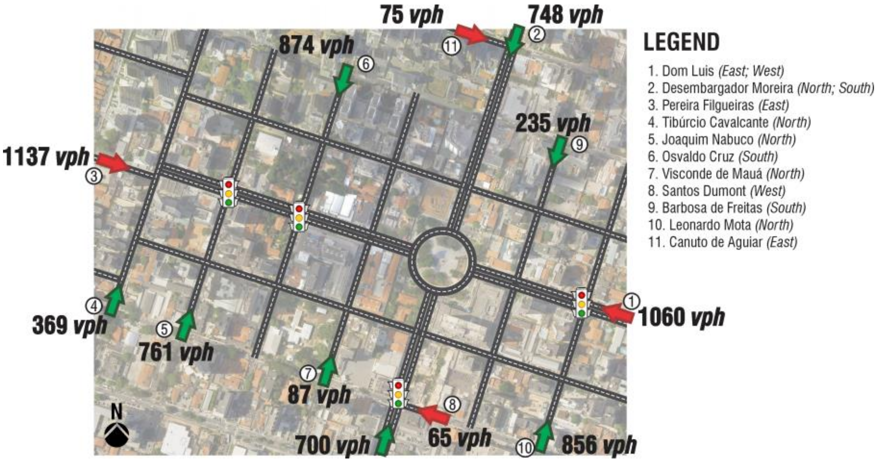

*Figure 3: Network and traffic volume at morning peak hour*

Different scenarios were evaluated in order to detect the effects of traffic volume in both the occurrence and in the severity of conflicts. For each scenario, three different levels of desired speed were simulated, in search to detect the influence of this parameter as well, since it influences the magnitude of skid resistance. Also, the assessment of surface condition was performed considering HMAg, DAST and HMA paving techniques (Figure 4). Road friction level is not considered at microscopic simulation, therefore it is relevant to state that the drivers does not detect low skid resistance regardless of which type of surface is under analysis.

A total of 30 simulations were performed for each traffic volume and desired speed scenario. The duration of each simulation was 3,600 seconds, with an additional warm-up time of 600 seconds. Considering all possible flow, desired speed, pavement material combinations as well as the replicates the complete simulation design  required 810 simulaton runs (3x3x3x30).

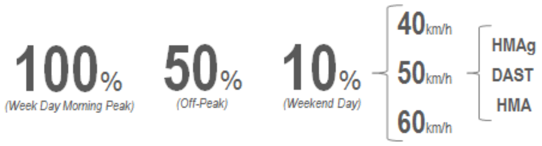

*Figure 4: Traffic flow, desired speed and paving technique*

## 4.3. Estimating the Surrogate Measures of Safety

The conflict analysis was performed using the Surrogate Safety Assessment Model software (SSAM). The SSAM estimates individual traffic conflicts using detailed vehicular information for each recorded interaction.

After each microscopic simulation, VISSIM generates a file extension "*.trj*". These outputs contain information about each simulated vehicle trajectory.  Threshold values for defining a conflict in SSAM were TTC of 1.5 sec (Hayward, 1972) and PET of 5.0 sec (provided default value). For this analysis, only rear-end conflicts occurring at the same lane were considered. Furthermore, TTC values recorded as 0s were disregarded, due to possible unconformities presented throughout the simulation.

Based on the location coordinates of each conflicting vehicle at its critical instant, characterized by conflict minimum TTC, provided by the SSAM, it was determined the stopping available distance (D, *m*). Then, DRAC was calculated (*m/s²*) to the follower vehicle in each conflict. At equation, such information as the differential speed of vehicles (DeltaS, *m/s*), and also the leading vehicle length (FirstLength, *m*) and the follower vehicle (SecondLength, *m*) were considered.

$$DRAC = \frac{(DeltaS)^2}{2D - (FirstLength + SecondLength)} \qquad (5)$$

At the vehicular interactions, situations where the necessary braking rate (DRAC) may be compromised due to surface condition and/or conflicting vehicle speed may arise. Also, one may not imply that DRAC itself is enough to assure the inexistence of a conflict. Beyond the required braking power, each situation displays different levels of possible deceleration rate, characterized by several factors, such as pavement, tires, braking system, speed, vehicular weight, among others. Thus, for each vehicular interaction, there is a maximum available deceleration rate (MADR).

In order to link surface friction for each type of paving technique, there is an initial mapping between micro- and macro texture (BPN and HS indicators) and the IFI (Equations 1 to 4). IFI method accounts for skid resistance based on slip speed, which differs from travel speed. Therefore, it was assumed that braking is performed with fully locked wheels, indicating an emergency maneuver. To consider possible variability on pavement surfaces HS and BPN values have been randomly generated based on their distributions (truncated normal or empirical). Therefore, for each registered conflict on SSAM, a random pair of BPN and HS data was generated to estimate the skid resistance (IFI) of the location where the interaction was placed.

AASHTO (2001) simplified method for determining the availability of braking rate (MADR) was applied, considering the IFI as the friction coefficient. Equation 6 shows the model on which the MADR ($d_{max}$, *m/s²*) is a function of IFI (μ) and the gravity (g, *m/s²*).

$$d_{max} = \mu \cdot g \therefore MADR = IFI \cdot g \qquad (6)$$

## 4.4. Conflict Analysis

Regardless of the required deceleration (DRAC), the existence of a conflict depends on the availability of braking (MADR). For different speeds on different pavements, there is a variation in the maximum available deceleration. Thus, a conflict is defined as a situation where the vehicle needs to brake at rates above the availability (DRAC ≥ MADR). Otherwise, it is considered as a vehicular interaction with variable collision potential (DRAC <MADR).

Severity of simple interactions was computed by the ratio of DRAC and MADR (Equation 7). Index $p_c$ can be interpreted as the proportion of the available braking and necessary to prevent further conflict aggravation. Finally, it was also performed a three-way ANOVA in order to confirm a dependency between traffic flow, desired speed and type of paving technique and severity ($p_c$) of the vehicle interactions.

$$p_c = DRAC/MADR \qquad (7)$$

# 5. RESULTS

Analyzing the empirical curves of friction coefficient versus velocity (Figure 5), it is observed that DAST pavement has low susceptibility to the effects of speed when compared to HMA. This is justified by HMA dense asphalt mix characteristic, resulting in a low-depth macrotexture. Also, DAST pavement constructions apply the inverted penetration technique, which consists in the application and compaction of coarse aggregate after applying the asphalt binder on track hence the coarse aggregates are more prevalent on the surface. Still by Figure 5, HMAg friction constantly remains superior to others techniques. These results might be explained due to the implementation of transverse grooves to track's axis, which contributes significantly to increasing the macrotexture. Finally, it also important to acknowledge that IFI method might not be appropriate to describe skid resistance for higher vehicular speeds, although it was considered that it fairly represents the urban scenario due to its low traffic flow velocity, which is this paper's scope.

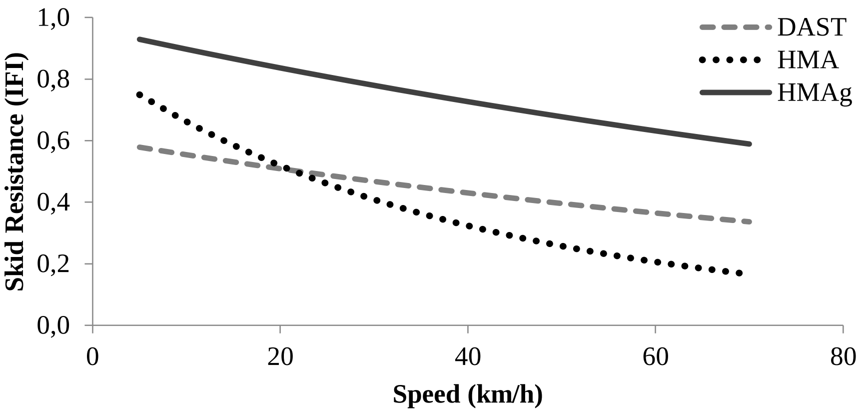

*Figure 5: Skid resistance by IFI method versus Speed*

Shapiro-Wilk test for the normality of BPN and HS rejected the null hypothesis for both HMA and HMAg, which means that the samples are not derived from a normally distributed population. Thus, to overcome this fact, empirical distributions were adopted, so there friction values to be used in the estimation of vehicular conflicts were generated. Nonetheless, the null hypothesis was accepted for both DAST parameters (*p*-value of 0.11 and 0.16 for BPN and HS, respectively).

After simulating different scenarios in VISSIM and, then, evaluating conflicts in SSAM, rear-end conflicts occurring in both same link and lane were filtered; for each registered event, DRAC was determined. Table 2 shows the results of average and standard deviations for all scenarios.

| *Traffic Flow* | | *10%* | | | *50%* | | | *100%* | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Desired Speed (km/h)* | | *40* | *50* | *60* | *40* | *50* | *60* | *40* | *50* | *60* |
| *Rear-end Conflicts* | $\bar{x}$ | *5.27* | *4.73* | *4.03* | *44.70* | *44.83* | *46.13* | *61.13* | *73.00* | *79.47* |
| | *s* | *2.38* | *2.03* | *1.81* | *6.31* | *6.96* | *5.29* | *8.97* | *9.38* | *8.35* |
| *DRAC (m/s²)* | $\bar{x}$ | *1.83* | *1.79* | *1.73* | *1.77* | *1.80* | *1.81* | *1.53* | *1.61* | *1.65* |
| | *s* | *0.25* | *0.29* | *0.41* | *0.07* | *0.07* | *0.08* | *0.10* | *0.08* | *0.10* |

*Table 2: Rear-end conflicts recorded and DRAC magnitude for each scenario*

It can be noticed that the more saturated is the scenario the higher is the amount of recorded rear-end conflicts. One can attribute this result to the reduction on average time headway among vehicles in greater traffic flow scenarios. However, it is not possible to identify any direct trend regarding the increase in the average desired speed and the occurrence of rear-end conflicts. As for the DRAC, it is identified that the most congested scenario has the lowest average in comparison to the others. Possibly due to a more congested network, vehicles cannot develop higher speeds, besides the fact that vehicles are closer to each other, which directly influences the magnitude of the deceleration required to avoid a crash.

In order to assess statistical results of relevance of each factor considered (speed, traffic flow and paving technique), a three-way ANOVA was performed on R software. Table 3 presents the summary results obtained by R analysis, considering severity ($p_c$) as analysis response.

| *Factor* | | *Df* | *Sum Sq* | *Mean Sq* | *F Value* | | *Pr (> F)* |
|---|---|---|---|---|---|---|---|
| *Desired Speed* | *A* | *2* | *0.00440* | *0.00222* | *1.3479* | | *0.260* |
| *Traffic Flow* | *B* | *2* | *0.24258* | *0.12129* | *73.6423* | < | *2.200E-16* |
| *Paving Technique* | *C* | *2* | *2.58762* | *1.29381* | *785.5540* | < | *2.200E-16* |
| | *A:B* | *4* | *0.04810* | *0.01202* | *7.3007* | | *8.961E-06* |
| | *A:C* | *4* | *0.00193* | *0.00048* | *0.2929* | | *0.883* |
| | *B:C* | *4* | *0.01324* | *0.00331* | *2.0099* | | *0.091* |
| | *A:B:C* | *8* | *0.00703* | *0.00088* | *0.5336* | | *0.832* |
| | *Residuals* | *783* | *1.28961* | *0.00165* | | | |

*Table 3: Three-way ANOVA performed on R software*

According to the results, considering the first order effect, only desired speed presents no statistical significance in the severity of vehicle interactions. Speed itself depends not only of desired magnitude, but also if there is the possibility to achieve such ranges.

Traffic flow and paving technique presented strong influence on $p_c$. Vehicular volume defines the intensity of interaction; in urban cases, the vehicles in a network with high traffic volume tend to be in following process with lower speeds, so one may state that it presents a higher amount of low severity conflicts. Pavements with greater skid resistance conditioning also influence because there is an enhacement in performing weaving maneuvers and emergency braking with higher grip. Since both factors influence

For the effects of combined factors, only the interaction desired speed and traffic flow was significant. One may argument that, although the prior establishment of speed ranges, this factor is directly dependent on the vehicle network loading. For saturated networks, hardly the vehicles will reach high speeds, which may explain the significance of the interaction speed and flow in the $p_c$ index severity.

# 6. CONCLUSIONS

The analysis performed on this paper sought to consider the effects of desired speed, traffic volume, and paving technique on vehicular conflicts. Based on field data collected during a morning peak hour of a typical week day, three volumes of traffic composed the evaluated scenarios: 100%, as a peak morning hour; 50%, as an off-peak hour; and 10%, as a weekend day hour. For each volume, 40, 50, and 60km/h desired speeds were assessed. For the paving technique, conventional HMA, HMA with grooving, and DAST were evaluated. Since friction levels are not included into the microscopic simulation, it was assumed that drivers might not take account of whether skid resistance is higher or lower.

After the analysis, it was found that the scenario with higher traffic flow (100%) presented the greater amount of recorded rear-end conflicts (in average, around 1.5 times greater than 50% scenario and 15 times than 10% scenario). Although the greater amount of events, 100% scenario has the lowest mean value for DRAC. The morning peak hour scenario promoted greater interaction between vehicles due to network's congestion, making it difficult for them to reach higher speeds. Therefore, one may expect a higher incidence of rear-end conflicts presenting a lower DRAC magnitude. It is relevant to highlight that both calibration and validation of simulated network were conducted based on traffic flow performance indicators, disregarding some others parameter that somehow could alter the results. Major findings can be obtained by calibrating driving responses for safety purposes, such as identifying the role played by weather conditions (e.g. presence of water or snow) on human behavior.

Three-way ANOVA was performed to assess the statistical significance of analyzed factors. Results shown that one might expect an influence of not only traffic flow and paving technique on the severity of vehicular interactions, but also the combination of both desired speed and traffic flow. These findings indicated that, in average, greater skid resistance conditions contribute to minimize the severity of interactions, which can be associated to higher braking power. Also, traffic flow affects directly speed of vehicles; although allowed, one might fail to develop greater speeds if the network is saturated.

As a suggestion for future work, further research is required in order to assess the conflicts extracted from VISSIM with TTC equals to 0 seconds. Also, the assessment of conflicts not only by its critical moment, but also by time increments could provide better understanding of the interaction between vehicles (total duration of the conflict and its variation of severity over time). Another relevant aspect is regarding the calibration of the models, because drivers' behavior tends to change in different traffic scenarios. Regarding to the surface condition, the braking process is influenced by dynamic aspects, besides its dependence on the efficiency of the vehicular. Thus, applying more sophisticated deceleration models to determine MADR may present in more realistic results.

# REFERENCES

AASHTO (2001). A Policy on Geometric Design of Highways and Streets (4th ed.). American Association of State Highway and Transportation Officials, Washington, D. C., United States of America

Amini, B. and Beigi, H. H. A. (2015). Modeling the Effect of Road Surface Friction on the Accident Rate of Urban Un-Signalized Intersections. Transportation Research Board (TRB) 94th Annual Meeting Compendium of Papers. Washington, D.C., United States of America.

Amundsen, F. and Hydén, C. (1977). Proceedings: First Workshop on Traffic Conflicts. Institute of Transport Economics, Oslo, Norway.

Aps, M. (2006). Classificação da Aderência Pneu-Pavimento pelo Índice Combinado IFI – International Friction Index para Revestimentos Asfálticos. Tese de Doutorado, Escola Politécnica da Universidade de São Paulo, São Paulo, Brasil.

ASTM (2006). E965-96 – Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique. Pennsylvania, United States of America.

ASTM (2011). E1960-07 – Standard Test Method for Calculating International Friction Index of Pavement Surface. Pennsylvania, United States of America.

ASTM (2013). E303-93 – Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester. Pennsylvania, United States of America.

Chin, H. C. and Quek, S. T. (1997). Measurements of Traffic Conflict. Safety Science, vol. 26, No. 3, p 169-185.

Cooper, D. and Fergunson, N. (1976). A Conflict Simulation Model. Traffic Engineering and Control, v. 17, p. 306-309.

Cunto, F. J. C. (2008). Assessing Safety Performance of Transportation Systems Using Microscopic Simulation. Doctoral Thesis, Department of Civil and Environmental Engineering, University of Waterloo, Ontario, Canada.

Hayward, J. C. (1972). Report No. TTSC-7115 – Near-miss Determination through Use of Scale of Danger. Pennsylvania Transportation and Traffic Safety Center, Pennsylvania, United States of America.

Henry, J. J. (2000). Evaluation of Pavement Friction Characteristics – A Synthesis of Highway Practice. NCHRP Synthesis 291, National Cooperative Highway Research Program, Washington D. C., USA.

Huguenin, F.; Torday, A. e Dumont, A. G. (2005). Evaluation of Traffic Safety Using Microsimulation. 5th Swiss Transport Research Conference (STRC), Ascona, Switzerland.

Hydén, C. (1987). The Development of a Method for Traffic Safety Evaluation: The Swedish Traffic Conflicts Technique.Doctoral Thesis, Department of Traffic Planning and Engineering, Lund University, Lund, Sweden.

Lacerda, V. M. (2014). Simulação Microscópica do Tráfego de um Trecho da Avenida Dom Luís com a Nova Configuração do Binário. Departamento de Engenharia de Transportes (DET), Universidade Federal do Ceará (UFC), Ceará, Brasil.

Lee, J.; Nam, B. and Abdel-Aty, M. (2015). Investigation of the Effect of Pavement Conditions on Crash Injury Severity.Transportation Research Board (TRB) 94th Annual Meeting Compendium of Papers. Washington, D.C., United States of America.

Li, Y.; Liu, C. and Ding, L. (2013). Impact of Pavement Conditions on Crash Severity.Accident Analysis and Prevention, v. 59, p. 399-406.

Lyon, C. and Persaud, B. (2015). Large Scale Safety Evaluation of Low Cost Treatments that Improve Pavement Friction. Transportation Research Board (TRB) 94th Annual Meeting Compendium of Papers. Washington, D. C., USA.

Mayora, J. M. P. and Piña, R. J. (2009). As Assessment of the Skid Resistance Effect on Traffic Safety Under Wet-Pavement Conditions. Accident Analysis and Prevention, v. 41, p. 881-886.

Milton, J.; Shankar, V. and Mannering, F. (2008). Highway Accident Severities and the Mixed Logit Model: an Exploratory Empirical Analysis. Accident Analysis and Prevention, v. 40, No. 1, p. 260–266.

Noyce, D. A.; Bahia, H. U.; Yambó, J. M.; Kim, G. (2005). Incorporating Road Safety Into Pavement Management: Maximizing Asphalt Pavement Surface Friction for Road Safety Improvements – Draft Literature Review and State Surveys. Wisconsin, USA.

OMS (2013). Global Status Report on Road Safety: Supporting a Decade of Action. Organização Mundial da Saúde.

Pereira, C. A. (2010). Análise da Aderência Pneu-Pavimento em Rodovias do Estado de Pernambuco e da Paraíba com Elevado Índice de Acidentes. Tese de Doutorado, Universidade Federal de Pernambuco, Recife, Brasil.

Perkins, S. R. and Harris, J. L. (1968). Traffic Conflict Characteristics – Accident Potential at Intersections.Highway Research Record, No. 225, p 35-43.

Rodrigues Filho, O. S. (2006). Característica de Aderência de Revestimentos Asfálticos Aeroportuários – Estudo de Caso do Aeroporto Internacional de São Paulo/Congonhas. Dissertação de Mestrado, Escola Politécnica da Universidade de São Paulo, São Paulo, Brasil.

Wambold, J. C.; Antle, C. E.; Henry, J. J. and Rado, Z. (1995). International PIARC Experiment to Compare and Harmonize Texture and Skid Resistance Measurements. PIARC World Road Association, Paris, France.