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## Evaluating bus accident risks in public transport

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### Abstract

Public transit buses may be considered a safer transportation mode as opposed to others (*e.g.*, private cars). However, safety is a crucial issue regarding transit buses from the perspectives of operators and passengers due to the relevant implications it generates. Therefore, evaluating the accident risk on bus routes provides an opportunity to improve the safety performance of transit operators. Previous research identified patterns of bus accidents and shed light on understanding the effects of many factors regarding frequency and severity of bus accidents. However, no studies have investigated accident risks in bus transit, while considering frequency, severity and exposure factors in a single function.

This paper proposes a new methodology for evaluating the accident risk for each transit bus route. At first, the methodology identifies the risk components in terms of frequency, severity and exposure factors that may affect bus accidents. Next, it integrates these terms, to build a risk bus accident function providing a ranking of safety performance for each route.

The feasibility of this methodology is demonstrated in a real case study using 3,457 bus accidents provided by a mid-sized Italian bus operator. This experiment shows that transit managers could adopt this methodology to perform an accurate safety analysis on each route. Moreover, this methodology may be implemented in a road traffic safety management system for bus transit operators interested in the monitoring of safety performance, in the evaluation of the risk of accidents on routes, and in the certification process according to recent safety norms.

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## 1. Introduction

Bus safety is a relevant issue for some reasons. First, safety in transit buses is crucial for Public Transport Companies (PTCs) and passengers due to the relevant implications it generates. From the PTCs' perspective, relevant and/or severe bus accidents decrease service reliability and safety, may lead to serious injuries or even death, and cause property and image damages. Better said, bus accidents increase costs in an industry, which is already characterized by low revenues and high operational costs (Barabino, 2018; Barabino and Di Francesco, 2016). From the passenger's perspective, relevant and/or severe bus accidents may affect public opinion. Indeed, bus accidents may be perceived much more than what the objective data show, either because individual accidents may result in a lot of injuries (*e.g.*, coach buses) or may generate the feeling the PTC has a greater responsibility than the people using the road at own risk. Second, over the past decade, the issue of bus safety has received wide-spread attention by many stakeholders engaged in improving transit safety, and several international policies have been implemented for this purpose. For instance, ISO 39001 (2012) drives PTC to improve its safety performance by adopting a Road Traffic Safety Management System (RTSMS) that needs to be based on a proper method.

Despite these reasons, the interest in bus accident risk evaluation and bus safety is not studied much in the literature, because public transportation is usually considered safer than other motor-vehicles (*e.g.*, cars) and it is generally accepted that public transportation improves road safety by reducing vehicular traffic (*e.g.*, Albertson and Falkmer, 2005; Cafisio *et al.*, 2013). The literature is quite rich about methods and applications to perform a risk assessment in many fields such as medical, chemical, economic and financing, industrial, engineering, *etc.* (*e.g.*, Fine, 1971; CCPS, 1995; Andrew and Moss, 2002; Mullai, 2006; ISO 31010, 2009). However, to the best of our knowledge, little is known on the application of risk assessment methods in the domain of bus safety, where there are only a handful of studies aimed at defining some accident risk indexes (Tiboni and Rossetti, 2013; Mitsakis *et al.*, 2015; Ye *et al.*, 2016; Law *et al.*, 2017). In addition, the literature on bus safety largely concerned separate studies which: 1) presented descriptive statistics on the occurrences of bus accidents and severities (*e.g.*, Evans and Courtney, 1985; Jovanis *et al.*, 1991; Zegeer *et al.*, 1994; Bjornstig *et al.*, 2005); 2) largely identified multivariate patterns of bus accidents and shed light on understanding the effects of different safety and exposure risk factors (determinants, or attributes, or variables) to the prediction of the frequency (*e.g.*, Cheung *et al.*, 2008; Strathman *et al.*, 2010; Chimba *et al.*, 2010; Quintero *et al.*, 2013, Goth *et al.*, 2014) and to the severity of the bus accidents (*e.g.*, Kaplan and Prato, 2012; Prato and Kaplan, 2014).

The objective of this paper is to develop a methodology for the evaluation of bus safety performance according to a risk accident index for each transit route, also encompassing the requirements of ISO 39001 (2012). Moreover, this methodology builds on the framework of Jovanis *et al.* (1991), but it differs since it enlarges the number of variables involved and integrates a method of evaluating the bus accident risk on each route. More precisely, at first this methodology identifies the safety factors, and the risk exposure factors as well. Next, it specifies the risk components in terms of frequency (or probability), severity (or vulnerability) and exposure variables that may cause or influence bus accidents. Finally, the method integrates these terms, to build a risk bus accident function providing a ranking of safety performance for each route.

This methodology uses a variant of the well-known risk index first introduced by Fine (1971) who considered the following three components: the potential consequences of an accident, the exposure factor and the probability factor. However, unlike Fine (1971) who used predefined numerical ratings for these components, our index is considered as a measurable quantity expressed by a mathematical relationship based on real accident data. Moreover, unlike previous studies on bus accident risk assessment, we include in a unique index the frequency and severity functions linked to the accident occurrences. In addition, even if previous bus safety studies explored the effect of specific variables on the frequency and severity of bus accidents, these studies provided separate analysis for them. Integrating factors that are associated with bus accident frequency and severity as well as with exposure can alert the public transport company (PTC) of the situations associated with bus accident risks. Thus, this knowledge can serve as a fundamental tool to improve bus safety performance.

This paper is expected to contribute to both theory and practice. From a theoretical perspective, this paper covers a research area that has not been explored much and provides useful outcomes for many applications. On the practical side, this methodology helps implement an RTSMS for PTCs interested in evaluating the risk of accidents on bus routes, in monitoring safety transit performance and in the safety certification process according to ISO 39001 (2012).

The remaining paper is organized as follows. Section 2 proposes a methodology to evaluate the bus accident risk for each route. Section 3 illustrates its experimentation on a real case study. Section 4 draws conclusions and future research.

## 2. Methodology

In this section, we present a methodology to evaluate the risk of accidents according to the scheme shown in Fig. 1. This methodology integrates the safety factors and the risk assessment method. This methodology is briefly summarized in what follows.

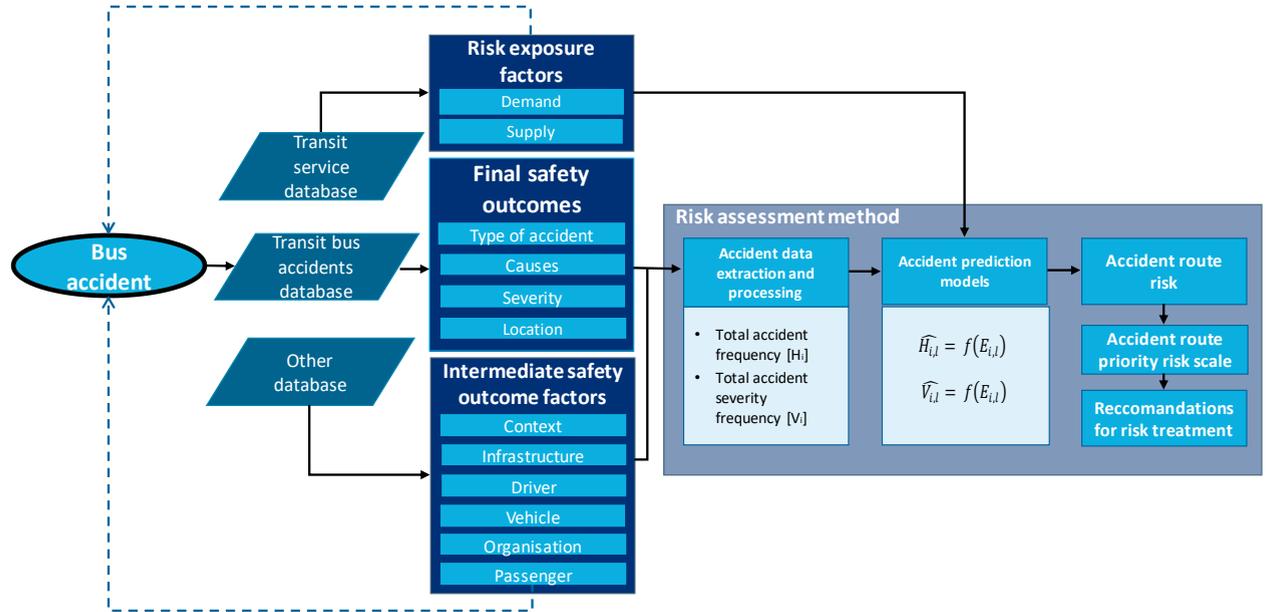


Figure 1: Methodology for transit bus accident risk evaluation

### 2.1. Safety factors

Generally speaking, the event of a road accident is viewed as the result of the interaction among four relevant factors *i.e.*, the context, the infrastructure, the driver, and the vehicle. Transit bus accidents surely fall into this structure, but there are two additional factors, *i.e.*, organisation PTC-related and passenger-related, which do not have a parallel structure in traditional road transportation. All these six factors (and related sub-factors) reflect safe planning and design as well as the use of the public transport network. They are namely *intermediate safety outcome factors*, according to ISO 39001 (2012). In addition, PTCs have a proper database which contains data about the supply of transit service (*e.g.*, route length, frequency, *etc.*) and passenger volumes. Thus, this database helps identify those factors reflecting the amount of people or services interested by the occurrence of accidents. These factors are namely *risk exposure factors*, according to ISO 39001 (2012) and may be divided into supply-oriented and demand-oriented factors. The former includes *e.g.*, the number of passengers travelling along a route during a time interval. The latter may consider the service production (*e.g.*, the kilometres travelled by buses) and/or the temporal characteristics of the work (*e.g.*, the total working hours). Hence, the event of an accident is viewed as the result of the interaction among *risk exposure factors* (see top-dotted arrow in Fig.1) and *intermediate safety outcome factors* (see down-dotted arrow in Fig.1).

Most advanced PTCs record the bus accident in a specific database, with some other factors reflecting the type and the severity of accidents in terms of the number of people killed, serious injuries, and property damage. In addition, owing to the settlement of insurance claims and for the evaluation of the accident’s costs with high granularity, many PTCs collect additional factors (*e.g.*, location, causes, *etc.*). These factors are namely *final safety outcomes*, according to ISO 39001 (2012). It is worth noting that some PTCs managers might include accidents in their safety database

also due to voluntary damage and/or personal injuries owing to criminal and/or vandalism actions. Since these accidents are deliberate acts of damage and do not have the same meaning of accidents in the traditional sense, they are neglected in this methodology. Moreover, we consider accidents reported by the PCT staff, only, due to the level of uncertainty that characterized accidents (claims) reported by third parts.

## 2.2. Risk assessment method

In this section, we present a quantitative method for assessing the accident risk for each bus route and intermediate outcome factor. This method is based on a risk index including the frequency and the severity of an accident, which are linked with the exposure factors.

Let:  $l$  be the route of interest;  $i$  be the index of the intermediate outcome factor (or the associated sub-factor);  $n$  be the total number of intermediate outcome factors;  $H_{i,l}$  be the probability of the accident occurrence on route  $l$ , which can be evaluated as the total number of accidents in a predefined time interval (e.g., a year) in which factor  $i$  manifests itself;  $V_{i,l}$  be the potential consequence of the accident on route  $l$ , which can be evaluated as the total number of the accident severity in a predefined time interval (e.g., a year) in which factor  $i$  manifests itself;  $E_{i,l}$  be the exposure factor on route  $l$  associated with factor  $i$ .

The risk index on route  $l$  ( $R_l$ ) may be defined as:

$$R_l = \prod_{i=1}^n H_{i,l} * V_{i,l} * E_{i,l} \quad \forall i = 1, \dots, n; \forall l = 1, \dots, L \quad (1)$$

Even though the calculation of eqn. (1) is simple, each component needs to be estimated separately.

First, we compute  $H_{i,l}$  and  $V_{i,l}$  by querying the transit accident database and counting the frequencies of the occurrences for each  $i$ . More precisely, let:  $j$  be the index of the accident;  $m$  be the total number of accidents;  $h_{ijl}$  be a binary variable which is 1 if accident  $j$  occurred on route  $l$  due to factor  $i$ , 0 otherwise;  $v_{ijl}$  be an ordered variable related to the accident severity according to the amount of damage reported. In this paper, this variable is 1 if accident  $j$  occurred on route  $l$ , due to factor  $i$ , provoked material damage; 2 if accident  $j$  provoked injuries; 3 if people were killed. Nevertheless, this is not a drawback of the method, which can be applied with different scales.

The total frequency of accidents and the associated severities are computed as follows:

$$H_{i,l} = \sum_{j=1}^m h_{ijl} \quad \forall i = 1, \dots, n; \forall l = 1, \dots, L \quad (2)$$

$$V_{i,l} = \sum_{j=1}^m v_{ijl} \quad \forall i = 1, \dots, n; \forall l = 1, \dots, L \quad (3)$$

Second, for each intermediate factor  $i$ , we provide bivariate models to estimate the frequency and the severity of transit bus accidents in which the response variables are represented by  $H_{i,l}$  and  $V_{i,l}$ , respectively, and the predictors are represented only by exposure factor  $E_{i,l}$ . This choice impedes us to evaluate the relationships among competitive intermediate outcome safety factors in a single model. However, the simple formulation, the immediate understanding of the results among practitioners, and the chance to control each factor one-by-one resulted as crucial elements associated to this choice. Thus, we can model  $H_{i,l}$  and  $V_{i,l}$  according to  $E_{i,l}$  to predict a number of frequency and severity models as many as are intermediate safety factors considered.

Since accidents are random, infrequent and non-negative integer events, it is widely accepted to predict the frequency of accidents using the Generalized Linear Modelling approach that assumes a negative binomial or Poisson error structure (e.g., Mannering and Bath, 2014). However, in our bivariate models, a non-linear relationship exists between the frequency of accidents and exposure factors, and  $E_{i,l}$  refers to a variable that when it assumes zero value, the frequency of accidents and severities must be zero. Hence, according to e.g., Cheung et al. (2008) and Quintero et al. (2013), we adopted a power distribution function, instead of an exponential one to consider this condition. More precisely, let  $\alpha_{1i}, \alpha_{2i}, \beta_{1i}, \beta_{2i}$  be the coefficients of the model, the prediction model of frequency and severity were computed as follows:

$$\widehat{H}_{i,l} = \alpha_{1i} * E_{i,l}^{\alpha_{2i}} \quad \forall i = 1, \dots, n; \forall l = 1, \dots, L \quad (4)$$

$$\widehat{V}_{i,l} = \beta_{1i} * E_{i,l}^{\beta_{2i}} \quad \forall i = 1, \dots, n; \forall l = 1, \dots, L \quad (5)$$

In eqns. (4) and (5) it is assumed that there is a cause-effect relationship between  $\widehat{H}_{i,l}$  (and  $\widehat{V}_{i,l}$ ) and the exposure factor  $E_{i,l}$ , respectively. Moreover, for each  $i$ , the values of  $H_{i,l}$ ,  $V_{i,l}$ , and  $E_{i,l}$  are clearly referred to the same time interval.

Different goodness-of-fit measures assess the validity of each model: the check of the statistical significance according to the F-test, the Pearson correlation coefficient and Pearson  $R^2$ . Moreover, the pseudo- $R^2$  indicates how well the variance of data is explained in a relative sense. In addition, the sign and the significance of coefficients are evaluated for each model.

Third, once functions  $H_{i,l}$  and  $V_{i,l}$  have been estimated, we can evaluate the risk of accidents for each transit route adjusting eqn. (1) as follows:

$$R_l = \prod_{i=1}^n \widehat{H}_{i,l}(E_{i,l}) * \widehat{V}_{i,l}(E_{i,l}) = \prod_{i=1}^n (\alpha_{1,i,l} * E_{i,l}^{\alpha_2}) * (\beta_{1,i,l} * E_{i,l}^{\beta_2}) \quad \forall l = 1, \dots, L \quad (6)$$

Since eqn. (6) returns a very high value of the risk, which may be difficult to interpret, we refer to the logarithm of  $R_l$  thanks to its properties. Thus, we can rewrite eqn. (6) as follows:

$$\text{Log } R_l = \sum_{i=1}^n \log[(\alpha_{1,i,l} * E_{i,l}^{\alpha_2}) * (\beta_{1,i,l} * E_{i,l}^{\beta_2})] \quad \forall l = 1, \dots, L \quad (7)$$

Fourth, to prioritize actions, it may be useful to classify routes according to a predefined risk scale. Many scales can be built. In this paper, we propose a simple scale dividing the range between the maximum and the minimum values of  $R_l$  in some identical-sized intervals. Thus, each route is classified within an interval. For instance, using a four-risk point scale, we may consider the following risk levels:  $R_1$  - Maximum risk;  $R_2$  - High risk;  $R_3$  - Average risk;  $R_4$  - Low risk.

Fifth, once critical routes have been prioritized, treatments can be taken to address safety shortcomings or their impact. For instance, it may be crucial to determine the reasons for poor performance safety on the routes having a  $R_1$  and  $R_2$  risk level by using a detailed analysis of the accidents and its severity for risk mitigation. The latter may be pursued referring to eqn. (7) by working on prevention actions to reduce  $\widehat{H}_{i,l}(E_{i,l})$  values and/or protection treatments to reduce  $\widehat{V}_{i,l}(E_{i,l})$  values, respectively.

### 3. 3. Experimentation in a real bus transit network

The methodology presented in Section 2 was experimented in the metropolitan area of Cagliari, an Italian coastal area located on the island of Sardinia. The main local PTC, namely CTM, manages the public transportation with 271 vehicles (*i.e.*, buses and trolleys) operating in a heterogeneous context and serves approximately 38.9 million bus journeys a year on 32 routes (CTM, 2018).

Data for this experimentation have been collected from three sources. The first source includes data accidents that occurred on the transit network of CTM (final safety factors). These data were obtained by merging accident data both recorded on a paper format and on an electronic repository in Microsoft Excel. An 'accident' recorded by CTM is an event that occurred with or without collision in which a vehicle, object and/or a person were involved, and generated damage-only and/or injuries and/or fatalities. A total of 3,457 bus accidents reported from 1997 to 2001 in the metropolitan area of Cagliari were retrieved (Barabino *et al.*, 2006).

The second source mainly includes data on the infrastructure (*i.e.*, road and roadside characteristics) where accidents occurred (intermediate safety outcome factors).

The third source enlarges data on further intermediate outcome factors related to the organisation, since it includes data on the spatial and temporal characteristics of the bus network (*e.g.*, itineraries). These data were collected considering the bus network of year 2001. Moreover, these data are adopted to generate the exposure factors for each year of interest. In this experiment, 27 bus routes are considered.

Next, querying the accident database and according to eqns. (2) and (3), we calculated the total frequency of accidents ( $H_i$ ) and the associated severities ( $V_i$ ) for each intermediate outcome factor  $i$  and route  $l$ , before prediction. Next, we estimated the exposure factors for each  $i$  and route  $l$  as the bus\*km travelled and number of buses at peak hour for bus type, in the time period considered. For practical reasons, we ran the experiment using only the intermediate outcome factors that are associated with available exposures factors.

Table 1 lists the intermediate safety outcome factors adopted for this experiment. They are divided into factors (1<sup>st</sup> column) and sub-factors (2<sup>nd</sup> column). Each sub-factor can be dichotomous (which can take two values only) or categorical (which can take more than two values) and their notations are bold-edited and reported in square brackets. For instance, sub-factor Lighting is dichotomous; its values are day and night that are denoted by D and N, respectively. Notations D and N will be adopted for distinguishing among models associated with Lighting.

Table 1: Intermediate safety outcomes factors (i)

Factors	Sub-factors
Context	Lighting (Day [D]; Night [N]) - Season (Winter [Win]; Spring [Spr]; Summer [Sum]; Autumn [Aut]) - Type of day (Weekday [WD]; Saturday [S]; Festive [F])
Infrastructure	N <sup>o</sup> of lanes (1 [nl1]; 2 [nl2]; 3 [nl3]; 3+ [nl3+]; n/a [nl_n/a]) - Lane width (2.75m [lw2.75]; 3m [lw3]; 3.25m [lw3.25]; 3.5+m [lw3.5+]; n/a [lw_n/a]) - Side walk width (0 [sw0]; 0.5m [sw0.5]; 1.0m [sw1]; 1.5m [sw1.5]; 2.0m [sw2]; 2.5+m [sw2.5+]; n/a [sw_n/a]) - Road type (Primary Extraurban road [PEr]; Secondary Extraurban road [SEr]; Express urban road [EUr]; Neighborhood road [Nr]; local road [Lr]; Motorway road [Mr]; n/a road [Rn/a])
Organization	Bus route (High frequencies [HF]; Middle frequencies [MF]; Low frequencies [LF]; n/a [Fn/a]) - Dedicated bus lane (Yes [bLY]; No [blN]; n/a [bl_n/a])
Vehicle	Type (Standard [StB]; Medium [MB]; Short [ShB]; Trolley [TB])

Next, we estimated  $\widehat{H}_{i,l}(E_{i,l})$  and  $\widehat{V}_{i,l}(E_{i,l})$  for each intermediate outcome factor  $i$ , by a power regression, using Microsoft Excel. A total of 34 intermediate outcome factors were considered and 68 bivariate models were estimated for the prediction of the frequency and the severity of accidents, respectively. Due to the limited space available in the article, we report an extract of results in Table 2, which includes some of the best models.

Table 2: Power regression models results estimating  $\widehat{H}_{i,l}(E_{i,l})$  and  $\widehat{V}_{i,l}(E_{i,l})$  - Extract

Model	Regression	Obs	F	F-test (model)	R	R <sup>2</sup>	Adjusted R <sup>2</sup>	T-statistics (p value)
<b>Context aspect</b>								
...	...	...	...	...	...	...	...	...
15	$H_D=0.001E_D^{0.753}$	117	113.147	$8.17 \cdot 10^{-19}$	0.704	0.496	0.492	$\alpha_i=10.637 (<0.001)$
16	$V_D=0.001E_D^{0.772}$	117	117.737	$2.57 \cdot 10^{-19}$	0.711	0.506	0.502	$\beta_i=10.851 (<0.001)$
...	...	...	...	...	...	...	...	...
<b>Vehicle aspect</b>								
...	...	...	...	...	...	...	...	...
23	$H_{STB}=1.828E_{STB}^{1.223}$	63	70.025	$1.03 \cdot 10^{-11}$	0.731	0.534	0.527	$\alpha_i=8.368 (<0.001)$
24	$V_{STB}=2.289E_{STB}^{1.213}$	63	67.278	$1.97 \cdot 10^{-11}$	0.724	0.524	0.517	$\beta_i=8.202 (<0.001)$
...	...	...	...	...	...	...	...	...
<b>Infrastructure aspect</b>								
...	...	...	...	...	...	...	...	...
33	$H_{Nr}=0.001E_{Nr}^{0.802}$	113	183.018	$3.16 \cdot 10^{-25}$	0.789	0.622	0.619	$\alpha_i=13.528 (<0.001)$
34	$V_{Nr}=0.001E_{Nr}^{0.823}$	113	167.927	$5.98 \cdot 10^{-24}$	0.776	0.602	0.598	$\beta_i=12.959 (<0.001)$
...	...	...	...	...	...	...	...	...
41	$H_{nl2}=0.011E_{nl2}^{0.544}$	103	98.473	$1.32 \cdot 10^{-16}$	0.703	0.494	0.489	$\alpha_i=9.923 (<0.001)$
42	$V_{nl2}=0.017E_{nl2}^{0.524}$	103	80.219	$1.78 \cdot 10^{-14}$	0.665	0.443	0.437	$\beta_i=8.957 (<0.001)$
43	$H_{nl3}=0.042E_{nl3}^{0.405}$	34	28.577	$7.26 \cdot 10^{-06}$	0.687	0.472	0.455	$\alpha_i=5.346 (<0.001)$
44	$V_{nl3}=0.037E_{nl3}^{0.437}$	34	27.217	$1.06 \cdot 10^{-05}$	0.678	0.460	0.443	$\beta_i=5.217 (<0.001)$
...	...	...	...	...	...	...	...	...
61	$H_{sw2}=0.001E_{sw2}^{0.728}$	76	125.163	$1.43 \cdot 10^{-17}$	0.793	0.628	0.623	$\alpha_i=11.188 (<0.001)$
62	$V_{sw2}=0.002E_{sw2}^{0.731}$	76	106.403	$5.72 \cdot 10^{-16}$	0.768	0.590	0.584	$\beta_i=10.315 (<0.001)$
...	...	...	...	...	...	...	...	...
<b>Organization aspect</b>								
65	$H_{blN}=0.001E_{blN}^{0.764}$	121	121.339	$6.99 \cdot 10^{-20}$	0.505	0.501	0.000	$\alpha_i=11.015 (<0.001)$
66	$V_{blN}=0.001E_{blN}^{0.781}$	121	121.954	$5.99 \cdot 10^{-20}$	0.711	0.506	0.502	$\beta_i=11.043 (<0.001)$
...	...	...	...	...	...	...	...	...

Generally speaking, the large majority of these models provide a good data fit. As expected, more significant models were estimated when a high number of observations (OBS) were available. More precisely, the best models are associated with the following intermediate outcome sub-factors *i.e.*, diurnal lighting conditions (15, 16), standard

buses (23-24), neighborhood roads (33, 34), sidewalk geometry width of 1.5m and 2.0m respectively (59-62), and the absence of priority strategy (65, 66). As expected, all significant models give evidence that by increasing exposure factor  $E_{i,l}$ ,  $\widehat{H}_{i,l}$  and  $\widehat{V}_{i,l}$  increase as well. The results related to the intermediate outcome factors of the context show e.g., that travelling by day will result in a frequency and severity of an accident slightly greater than travelling at night. Although the result of severity differs from e.g., Zegeer et al. (1994), it may be justified since urban buses travel at low speeds also at night, where buses are less exposed to other traffic flows.

Focusing on the vehicle factors, the results show that the highest value of  $\widehat{H}_{i,l}(E_{i,l})$  and  $\widehat{V}_{i,l}(E_{i,l})$  will result for standard buses as opposed to medium ones, per the same number of buses per route at the peak hour.

Focusing on the infrastructure factors, models associated with neighborhood roads have the highest values of  $\widehat{H}_{i,l}(E_{i,l})$  and  $\widehat{V}_{i,l}(E_{i,l})$ , respectively. However, the lack of significance for other road types impedes us to generalize the results. In addition, as expected, travelling on roads with 2 or 3 lanes decreases the associated values of  $\widehat{H}_{i,l}(E_{i,l})$  and  $\widehat{V}_{i,l}(E_{i,l})$ , respectively. Conversely, if buses travel on roads characterized by wide sidewalks, the associated values of  $\widehat{H}_{i,l}(E_{i,l})$  and  $\widehat{V}_{i,l}(E_{i,l})$  appear to increase until the sidewalk's width was less than 2 m. Although this result might be unexpected, it might be justified as follows: The wide sidewalks can be explained by the greater number of pedestrians and this might result in a higher likelihood of accidents between buses and pedestrians.

Finally, focusing on organization factors, unlike Quintero et al. (2013) and according to Goh et al. (2014), the results show that the right of way priority strategy will increase safety performance for buses since it will reduce the frequency and the severity of accidents.

Next, having estimated  $\widehat{H}_{i,l}(E_{i,l})$  and  $\widehat{V}_{i,l}(E_{i,l})$ , we can compute the risk index by using eqns. (6) and (7) for each route and classify it according to the risk scale introduced in Section 2. More precisely, considering weekdays and the season with the highest values of  $\widehat{H}_{i,l}(E_{i,l})$  and  $\widehat{V}_{i,l}(E_{i,l})$  - i.e., winter - the logarithm risk values for each route are reported Figure 2, which is self-explicative.

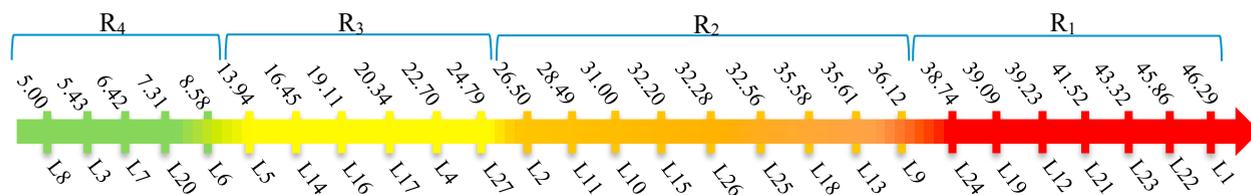


Figure 2: Risk values and ranking (top) for each route (down). High-risk routes are reported to the right. L1 is the highest risk route

Focusing on routes classified as R<sub>1</sub>, we may observe what follows. First, R<sub>1</sub> routes have a nominal length of about 10 km, except for route L22. Therefore, the highest risk is associated with medium-length routes. Second, R<sub>1</sub> routes travel on paths characterized by 1 lane or 2 lanes per travel direction and a lane width of less than 3.25 m. Both these characteristics cannot guarantee safer maneuvers and result in the highest risk values. Third, six of seven R<sub>1</sub> routes use standard buses. As shown in Table 2, models for these types of vehicles have a greater  $\alpha_2$  and  $\beta_2$  value, thus leading to higher risk values. The maneuverability of these vehicles as opposed to short vehicle types might explain these results.

Some recommendations follow. First, the PTC is suggested to revise the paths by addressing routes on roads with more than 2 lanes per travel direction, if any. Moreover, other treatments such as right of way priority strategies are suggested to reduce the risk of accident to separate the different traffic flows on the streets. Second, medium and short buses are the safest type of vehicle to use. Therefore, the PTC should consider using these types of vehicles along R<sub>1</sub> routes, if passenger volumes and fleet's availability make possible this option. Finally, in order to obtain more accurate results, the PCT is suggested to refine its accident database with more data on exposure, final and intermediate safety factors and, therefore, considering as much information as possible from each bus accident occurred.

#### 4. Conclusions and research perspectives

Evaluating the accident risk on bus routes provides an opportunity to improve the safety performance of transit operators and may result in profitable actions to reduce the insurance premium costs. However, as far as the authors' knowledge, no previous study quantified the accident risk in bus transit, while considering frequency, severity and

exposure factors in a single function. This paper introduced a new methodology, illustrated in a real case study, that helps evaluate the risk of accidents for each bus route. This framework identifies factors that largely affect the risk of accidents and may be used to qualify the transport company for ISO 39001 (2012). Moreover, it is possible to assess the risk of accidents for new planned routes using the models calibrated on existing ones.

A further development of this research may evaluate the risk of accidents not only for routes, but also for accident types (e.g., sideswipe, rear-end, etc.) and causes, to better understand which treatments may reduce and/or eliminate specific risks. Moreover, multivariate models may be developed including several intermediate outcome factors and exposure ones as predictors of frequency and severity of accidents to refine the accident risk assessment.

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