Safety and sustainability paradoxes: the case of large trees on roadsides of high speed roads

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Abstract: The risk and severity of injuries can be increased by trees on roadsides of high speeds roads, which may lead to a vehicle colliding into this vegetation and hindering the life of the vehicles occupants. By using qualitative methods, a structured literature review and technical visits, it was observed that the laws in Brazil are bureaucratic and time-consuming to solve problems that involve clearing trees, especially the native ones. Therefore on high-speed roads it is essential to maintain a clear safety zone on roadsides for the safety of drivers. This is an important issue especially in developing countries, where the used of barriers at roadsides are not proper used or maintenance due to budget restrictions. That brings the paradox of sustainability since the environmental legislation is a risk factor for road safety regarding the removal of trees that can cause not only a road accident, but also an environmental impact related to a possible road accident. In other words, the impediments of removal of trees at roadside – due to the environmental legislation – can culminate in death of human beings and also in incommensurable environmental impacts in the case of a road accident.

Keywords: tree; roadside; clear zone; road safety; accidents; run-off.

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1 Introduction

There are several risk factors involved in a road accident. Although the human factor (driver) is the most common one, the road/environment has a significant contribution, especially in developing countries, where the infrastructure standards are inferior to developed countries standards. In addition the road/environment is closely associated to the human factor, because it is related with the individual's action. For example, in accidents where the driver is forced to divert to the roadside, if this roadside is not adequate the driver and car occupants could suffer an injury and/or fatal accident. The risk factor road/environment reaches about 38% of the urban and road accidents (Scaringella, 2011). One of the main risk factors in road/environment is the presence of large trees on roadsides.

In the economic growth of 2010 decade in Latin America significantly increasing the vehicle fleet and in consequence the number of accidents, mainly those called run-off-road (ROR) accidents. According to the definition given in AASHTO (2004) these accidents occur as a consequence of vehicles leaving the hard shoulder and invading the roadside, reaching external areas, leading the vehicle to the potential risk of hitting one or more fixed objects.

According to WHO (2013) traffic accidents are the main cause of violent death among individuals in the range of 10 to 24 years. In developed countries, traffic accidents represent almost 10% among all other causes of premature death among people in the range between five and 44 years old. At least 1.2 million people die every year on roads around the world. Accidents and their respective consequence in the human body are a worldwide major public health concern. During the last few decades, Brazil has gradually reached a place among the world leaders in traffic accidents.

Therefore, the consequence of collision with trees on rights of way can lead to fatalities, resulting in serious damage, such as economic, social and environmental, as well as human (physical and psychological), those which are irreparable. Large trees with a trunk diameter than 20 in are associated with higher driver and occupants fatality rates in ROR accidents (Zeigler, 1986; Fitzpatrick et al., 2016a).

Accordingly to AASHTO (2011a) the clear zone is a design element to provide a recovery area for errant vehicles, it should be a minimum of 7 and 10 ft on roads with and without curb, respectively. Also AASHTO (2011b) advice clear zone widths based on speed, traffic volume, roadway geometry, side slope and curb heights.

The removal of large trees in the technical point view it is the most cost effective measure to enhance safety in high speed roads (FHWA, 2017). However, by the environmental legislation point view the trees are put in first regarding the human life (Kemp, 2017).

In this way the main aim of this work is to study the Brazilian legislation regarding the removal of roadside vegetation that hindered the safety of drivers and discuss the paradox of the environmental legislation that protect the trees to the detriment of human lives, which could lead to more environmental burdens than the tree removal if a vehicle collide with this tree.

2 Research methodology

Research on the subject was developed by initially carrying out a structured literature review and a bibliographic revision of technical materials and legislation. It was also necessary going on technical visits to government bodies in order to understand the bureaucratic procedures involved. These activities are described in the following subsections.

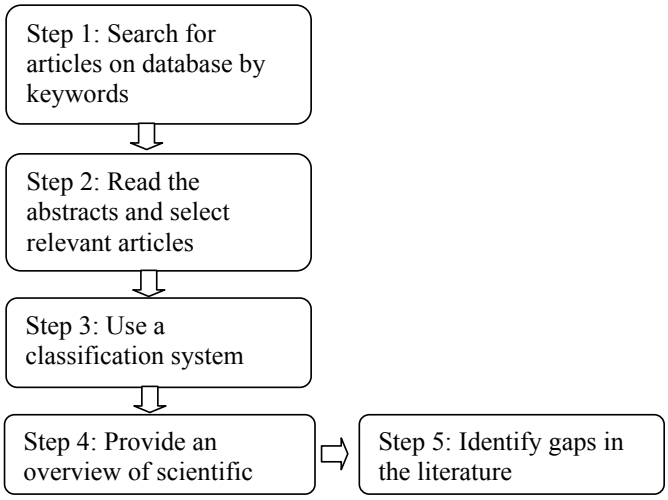
2.1 Structured literature review

A structured literature review was performed following the procedures described in Lage and Filho (2010) and Fiorini and Jabbour (2017). Initially, the keywords ‘roadside safety’ was defined to start the search. Thus 256 articles were found. A second search adding the keyword ‘tree’ reduce the papers to 16. Another search was performed using ‘run-off’ and ‘trees’ which find another 11 papers. A third search was made using the keywords ‘road accident’ AND ‘run-off’. The search was made in December of 2017. The steps for the structured literature are shown in Figure 1. The search was conducted in Scopus database using the following search fields: title, abstract, keywords. At first it was founded 528 papers that were narrow to 19 by selecting only journal papers and excluding repeated papers.

After selecting the papers that addressed the issue of road accidents and trees, a classification system was developed in order to classify the articles selected (Step 3). The classification was based on in five dimensions, according to literature studied, which used an alpha numeric pattern (see Table 3). Classification 1 to 3 was based on Lage and Filho (2010) and Fiorini and Jabbour (2017). Classification 1 refers to the context where the research was developed. Classification 2 refers to the focus of the papers: road safety or

environment. Classification 3 refers to the research method. Classification 4 indicates the beneficiaries of the actions proposed: road users or environment. Classification 5 identifies the hazard tree treatment discussed in the papers. Table 4 presented the 19 paper classified according to Table 3.

Figure 1 Structured literature review steps



Source: Adapted from Fiorini and Jabbour (2017)

Table 1 Database search results

Keywords	*Search results*	*Relevant papers*
	Number of papers	*Number of papers*
'Roadside safety' AND trees	236	16
'Run-off' AND 'trees'	248	11
'Road accident' AND 'run-off'	39	18
Repeated papers		7
Total	523	38

Table 2 Papers selected

Criteria	*Number of papers*
Papers selected in the database search	38
Papers selected after reading the abstract/paper	18
Papers included by unstructured search	1
Total	19

Figure 2 presented the publication trend regarding this subject. As can be seen the subject arises in the 1980 decade and are still an update discussion. Thus, showing the complexity of this issue, that is the paradox between road safety and sustainable environment regarding the large trees at roadside.

Table 3 Framework for classifying the papers analysed

Classification	*Description*	*Categories*
1	Context	A Developed country
		B Developing country
		C Urban roads
		D Rural roads
		E Not applicable
2	Focus	A Road safety
		B Environmental
3	Research method	A Quantitative
		B Qualitative
		C Conceptual
		D Review
		E Survey
		F Case studies
4	Beneficiares	A Road users
		B Environmental
5	Hazard tree treatment	A Removal
		B Barriers
		C Speed reduction
		D Monitoring
		E Rumble strips
		F Widing clearzone
		G Not applicable

Figure 2 Publication trend on this subject (see online version for colours)

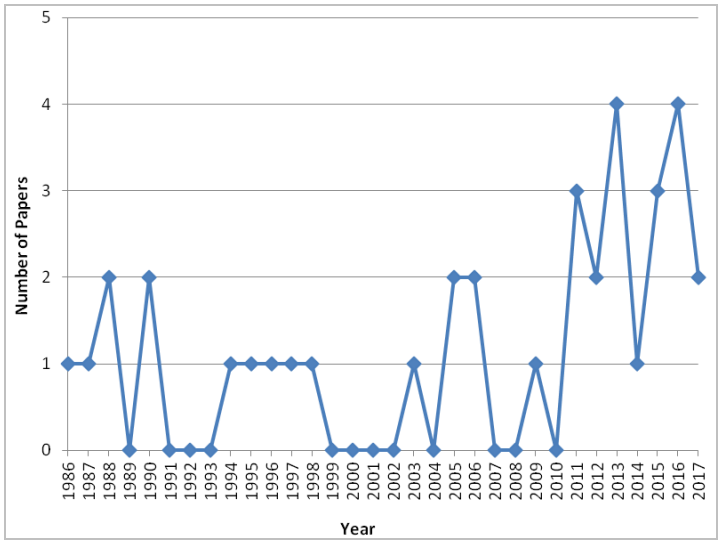


Table 4 Classification and coding of the papers analysed

Paper	*Context*	*Focus*	*Method*	*Beneficiares*	*Hazard tree treatment*
Ray (1998)	1A, 1D	2A	3A, 3F	4A	5A, 5B, 5F
Turner and Mansfield (1990)	1A, 1C, 1D	2A	3A, 3D	4A	5A, 5B, 5F
Taneerananon and Cheewapattananuwong (2003)	1B, 1F	2A	3A, 3F	4A	5G
Mok et al. (2006)	1A, 1C, 1D	2A, 2B	3A, 3F	4A, 4B	5G
Martinez et al. (2009)	1A, 1D	2A	3A, 3F	4A	5A, 5B, 5F
Carrigan and Ray (2011)	1A,1D	2A,2B	3A, 3F	4A	5A, 5B, 5D, 5F
Tomasch et al. (2011)	1A,1D	2A	3A, 3F	4A	5B
Somchainuck et al. (2013a)	1 B, 1D	2A	3A, 3F	4A	5A, 5B, 5D,5F
Somchainuck et al. (2013b)	1 B, 1D	2A	3A, 3F	4A	5A, 5B, 5C, 5D, 5F
Bella (2013)	1A,1D	2A	3A, 3F	4A	5A, 5B
López et al. (2014)	1A,1D	2A	3A, 3F	4A	5A, 5B, 5F
Fitzpatrick et al. (2014)	1A,1C, 1D	2A, 2B	3A, 3F	4A, 4B	5A, 5B, 5F
Zou and Tarko (2016)	1A, 1D	2A	3A, 3F	4A	5A, 5C, 5F
Jalayer and Zhou (2016)	1A, 1D	2A	3A, 3F	4A	5A, 5B, 5F
Abraham et al. (2016)	1A, 1D	2A	3A, 3F	4A	5B
Fitzpatrick et al. (2016)	1A, 1D	2A, 2B	3A, 3F	4A, 4B	5F
Eustace et al. (2016)	1A, 1D	2A	3A, 3F	4A	5G
Budzynski et al. (2016)	1A, 1C, 1D	2A	3A, 3C, 3E, 3F	4A	5A, 5B, 5C, 5D, 5F
Treese et al. (2017)	1A, 1C, 1D	2A, 2B	3B, 3C, 3D	4A, 4B	5G

2.2 Legislation search

A legislation search was carried out covering the following subjects at the Brazilian legislation: legislation, doctrine, jurisprudence, comparative law and other kinds of rules for the provision of the subject being studied, in particular the Brazilian Code for Transit, Civil Code, Forest Code, Manuals of the Department of Roads and Transportation of the State of São Paulo (DER-SP) and National Department of Transport Infrastructure (DNIT), as well as special laws, decrees, ordinances, resolutions, by-laws and so on.

2.3 Technical visits

In order to understand the procedures concerning orientation, guidelines and bureaucratic procedures about tree clearing and compensation, technical visits were made to the

following offices: Secretary of Transportation and Department of Roads and Transportation (DER) of the State of São Paulo, who are responsible for some of the roads in the region of Bauru-SP and other municipalities in the region; road concessionaires in the region of Bauru-SP in order to analyse contracts and terms of use of those roads; secretary of environment's offices, responsible for some of the municipalities in the region of Bauru and also Companhia Ambiental do Estado de São Paulo (CETESB), an Environmental Agency of the State of São Paulo. In the technical visits it was asked what are the legal requirements and legislation to follow for a tree removal and all the procedures that are necessary in this endeavour.

3 Results and discussion

The results of the structured literature review presented in Table 5, shows that the collision with trees are a serious problem worldwide. Some studies point out that collisions with trees account for almost 30% of road fatalities in their countries (Fitzpatrick et al., 2016a; Turner and Mansfield, 1990; Taneerananon and Cheewapattananuwong, 2003; Martinez et al., 2009; Somchainuck et al., 2013a, 2013b; Budzynski et al., 2016).

Also that shield the trees with barriers: are expensive (Carrigan and Ray, 2011), the barriers could lead to vehicles returning to the road causing a secondary collision (Zou, and Tarko, 2016), the position of the barriers and its length could have an oppose effect on safety (Martinez et al., 2009; Tomasch et al., 2011; Zou and Tarko, 2016; Jalayer and Zhou, 2016) and the standard of the barriers must be reviewed since the run-off accidents had angles superior to the 20º angle prescribed in the international norms (Abraham et al., 2016) and also the standard length (Tomasch et al., 2011).

The width of the clear zone is crucial for the safety of the drivers. The trees must be at least 50 feet from the edge of the pavement in high speed roads (Martinez et al., 2009; Tomasch et al., 2011; Jalayer and Zhou, 2016; Abraham et al., 2016).

Despite some papers indicates that trees in the roadsides could have influence in drivers behaviours towards safety (slow speed and stress) (AASHTO, 2011a; Mok et al., 2006; López et al., 2014; Treese et al., 2017). Although, other papers suggested that this effect was not found (López et al., 2014; Fitzpatrick et al., 2016b; Treese et al., 2017). Horizontal curves have influence in run-off accidents and the presence of trees in this kind of geometry design increases the hazard of these locations (Martinez et al., 2009; Carrigan and Ray, 2011; Tomasch et al., 2011).

In addition, trees in rural areas, especially in two lanes roads, are more hazardous than in urban areas (Turner and Mansfield, 1990; Taneerananon and Cheewapattananuwong, 2003). Speed is a risk factor for the severity of the collisions with trees (Martinez et al., 2009; Somchainuck et al., 2013a, 2013b; Jalayer and Zhou, 2016; Budzynski et al., 2016).

The literature reviews as well as the departments responsible for road safety have shown their support regarding clearing vegetation along the roadsides, considering the threat this vegetation represents to road safety, especially at roadside of high speed roads (Fitzpatrick et al., 2016a; Ray, 1998; Turner and Mansfield, 1990; Martinez et al., 2009; Carrigan and Ray, 2011; Somchainuck et al., 2013a, 2013b; Bella, 2013; López et al.,

2014; Zou and Tarko, 2016; Jalayer and Zhou, 2016; Abraham et al., 2016; Eustace et al., 2016).

Table 5 Main contribution of the papers analysed

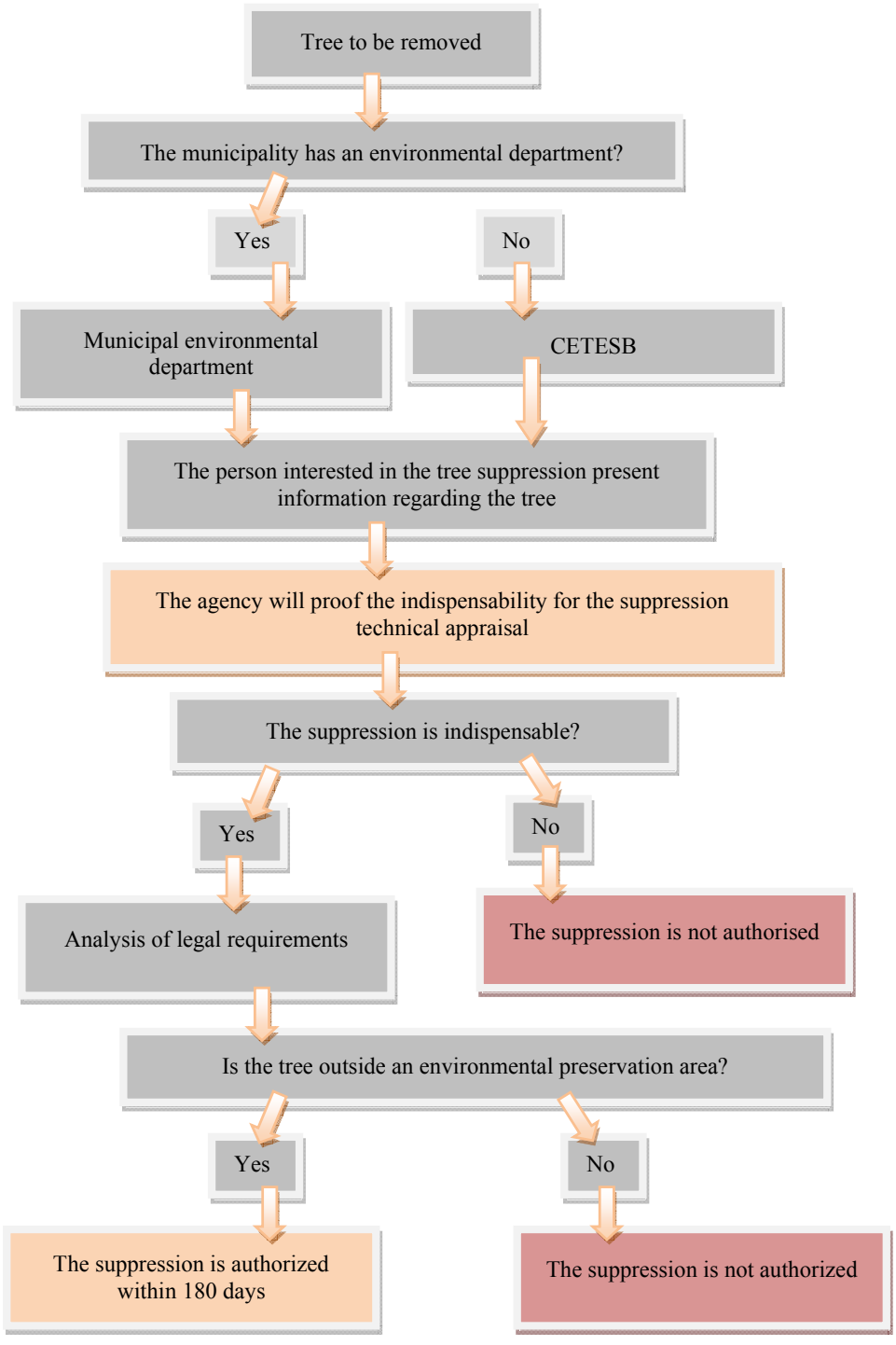
Paper	*Main findings*
Ray (1998)	A method is described for determining the rockcut width that best balances the cost of construction with the improvements in safety that would result from a wider clearzone in the rockcut
Turner and Mansfield (1990)	There were strong similarities between urban and rural tree collision patterns. However the rural accidents were more severe; and 80% of the collisions were within 20 ft of the pavement edge.
Taneerananon and Cheewapattananuwong (2003)	Roadside crash are one of the main causes of severe and fatal injuries and that trees, road signs, signal poles, unprotected bridge and guardrails are the dominant roadside hazards hit by vehicles in Thailand.
Mok et al. (2006)	The authors' findings some effects of the landscape on driver behaviour. However the authors suggested that more research is need to reduce the confounding factors such as the changes of the design and landscape treatments. That is the safety effect found must be due to other facts than the improvement in the landscape.
Martinez et al. (2009)	In tree-related crashes the majority of vehicles run-off more than 30 feet from the edge of the roadway before hitting a tree. For speeds greater than 60 mph, the majority of vehicles run-off distances greater than the current recommended clear zone values. Thus indicated that the clear zone policy and guidelines does not provide enough clear space necessary to prevent fixed object hits in run-off-road crashes.
Carrigan and Ray (2011)	The best option for improving road safety is remove or shield all fixed objects. The best approach is removing trees entirely or/and installing roadside barrier in location prone to crashes and treat the most hazardous locations.
Tomasch et al. (2011)	The authors developed a relationship between guardrail length and the speed at which vehicles depart the roadway. If the guardrails are flared away from the carriageway, the required length will be reduced 30%. Also the findings suggested that extending the current length standard of guardrails would reduce the number of fatalities among occupants of vehicles.
Somchainuck et al. (2013a)	Accidents involving vehicle hitting trees is the common roadside hazard in Thailand, were found to be the most serious and common roadside crashes accounting for 62% of the fatalities. The authors urge road directored to take actions to deal with this serious problem
Somchainuck et al. (2013b)	Roadsides crash accounts 44% of all accidents in Thailand. Speeding vehicles are more likely to be involved in roadside crashes. Also hitting trees are the main problems concern run-off accidents.
Bella (2013)	Although the presence of trees along the road represents a factor that increases the severity of run-off-road accidents, drivers do not change their behaviour when barriers are not present. Concerning the effects of the beginning of the barrier, MANOVA revealed a main effect for roadside configuration on lateral position but not on speed.

Table 5 Main contribution of the papers analysed (continued)

Paper	*Main findings*
López et al. (2014)	The authors presented a method to investigating crash patterns and contributory factors on rural two-lane highways so as to propose specific road safety countermeasures.
Fitzpatrick et al. (2014)	The paper point out that trees are the most harmful roadside object involved in ROR crashes. The study demonstrates the relationship between clear zone design – clear zone width and vegetation density – and driver behaviour, which could improve clear zone design practices and thus roadway safety.
Zou and Tarko (2016)	Barriers near the road edge it is associated with a higher risk of redirecting errant vehicles back to the roadway which could collide with other vehicles. Cable barriers installed on the far-side edge of a median had a lower probability of being hit by errant vehicles and of redirecting vehicles into traffic than the nearside cable barriers. The roadside guardrails can reduce the percentage of hazardous off-road crashes if well placed.
Jalayer and Zhou (2016)	The clear zone width and sideslope are used to determine roadside hazard ratings (RHRs) to quantify the roadside safety of rural two-lane roadways. The paper presented a new approach for defining the reliability index for measuring roadside safety on rural two-lane roads. The paper confirms that this new approach can serve as indicators to gauge safety levels, such that the greater the reliability index value, the lower the ROR crash rate.
Abraham et al. (2016)	The paper concludes that the majority of accidents have an impact angle higher than 20º, which is the test angles recommended for barriers. Thus, a review of EN 1317 should be made.
Fitzpatrick et al. (2016)	The paper indicates that the roadside vegetation density does not reduced driver speeds or their lateral positioning and the roadside clear zone width does provide safe driver behaviour.
Eustace et al. (2016)	The authors finding the factors that increasing the likelihood of ROR incapacitating and fatal injuries: alcohol and drugs use, curves and grades, female victims, overturn/rollover crashes, dry roadway surfaces.
Budzynski et al. (2016)	The authors propose actions regarding tree hazardous for driver safety, in strategic, tactical and operational level.
Treese et al. (2017)	The authors stated that roadside vegetation had a posite psychology effect on drivers (reduce stress and frustration) and reduced drivers speed. However, more studies are necessary to understand the frequency and severety of tree-related crashes, and the perception risk and behaviour of drivers related to the presence of trees at the roadside.

The DER (Brasil, 1975), which assigns to DER the attributions of bodies and managers' competence, establishes the maintenance of rights of way as one of their responsibilities, as well as REMOVING trees and bushes from the roadsides. Moreover, Transportation Regulatory Agency for the State of São Paulo (ARTESP) recommended, as a safety measure, that no trees would be planted on the roadsides and, also in a public announcement, that all road concessionaries should clear trees that represent hazard to traffic on rights of way in 24-hours' time (ARTESP, 1997).

Figure 3 Framework for tree removal (see online version for colours)



The problem is that clearing trees, especially native trees, according to environmental law is a lengthy process and requires environmental compensation. In addition to a wide bureaucratic procedure of inspection of the tree specimen to be cleared by the responsible bodies, with a return period to the interested party of up to 180 days (Brasil, 2007) regardless of the risk that that tree specimen could represent. The framework for the tree removal is presented in Figure 3. Also the bureaucratic procedure costs are estimated to be around US$ 2,500.00 for each native tree, which makes it impracticable.

Taking this into account, it is important to highlight that prevention is always the best attitude to be considered. The environment is an extension to the right to life, to health and so on and as such environmental rights can only be considered valid if it is possible to ensure the right to life, since the former is complementary to the latter (Trindade, 1992). In addition, in article 225, the Brazilian Federal Constitution (Brasil, 1988) says: "All have the right to an environment that is ecologically balanced, an asset that is of common use for people and essential to a healthy quality of life, imposing to the Public Authorities and to the community the duty to defend and protect it for present and future generations." It is clear from this juridical ordinance that is fully sustainable the thesis that the right to the environment is a genuinely human one, being therefore an object to be protected, that is, the value of nature is limited to its relation with the human being and its protection is justified by the need to protect human life, be it present or future.

Regarding the case being presented in this work, trees on roadsides represent a strong influence concerning hindering the workers' safety while they go to and from work. Considering the fact that the right to the environment is an extension to the right to life and that the current procedure of clearing and the consequent environmental compensation is extremely bureaucratic and lengthy, thus, becoming essential to act in such a way as to ensure the safety of workers during their commuting. Therefore, it is highlighted that prevention is the best attitude to reduce the risk of ROR accidents and the sites should be inspected, as well as clearing existing tree species from the roadsides safety zone, whether they are native or not, without environmental compensation, so that the major right be ensured: the right to life.

Employers and government bodies responsible for road safety should act towards the absence of risks on the route workers, that in an emergency situation could lose control of their vehicle due to various factors such as an exhausting day of work or the rush to arrive at work on time, among other factors that lead drivers to divert their vehicles run-off the road.

The search for preserve the environment is valid and necessary. Therefore, this quest must be reasonable and coherent, since the protection of one tree could bring catastrophic consequences to the environment. For example, a truck driver transporting hazardous material could collide with this tree and cause an intangible environmental consequence as contamination of the soil and rivers, fauna and flora, that could will demand years to be environmentally recovery. Also a collision with a tree could quickly spread the fire to areas of environmental preservation.

The environmental legislation presented here are from Brazil, but this discussion of the paradox between road safety and sustainability is worldwide, as was shown in the structured review. The road safety specialists recommend that removal of the trees. The environment specialists defend the preservation of the trees on the roadsides and even state safety benefices. Nevertheless, those safety benefices only can be observed in urban

areas in low speed environments and the results are in some extend lacking more validate results.

4 Final considerations

Large trees near at high speed roads, which are not usually protected, reveals that this segment of the road is a potential hazard to the safety of drivers using this route. The paper demonstrated that the environmental legislation impaired a proactive action, that is, the removal of trees at the roadside safety zone.

To deal with this problem, another alternative would be to place barriers along the road allowing for the existing vegetation to be preserved. However, this alternative would not have the same cost-benefit of removing the vegetation as, in addition to the high cost of implementing and maintaining it. Furthermore, in accidents involving vehicles at high speed there is the possibility of crossing these barriers and consequently collide into trees, or even swerve the uncontrolled vehicle back onto the road, possibly involving other vehicles in the accident.

Therefore, the most efficient alternative for the major asset, that is life, which is always ensured, is to clear the existing vegetation along roadsides. Latin America has one of the higher accident rates, deaths and injured in traffic, with an economic loss estimated in 5% of GDP (WHO, 2013a; Ferraz et al., 2012). Thus, making use of a simple tool could bring a reduction in the high rates of deaths in traffic accidents and ratifying that prevention is still the best option in these cases. Considering this, when a tree sample hinders the safety of drivers, the vegetation should be cleared without environmental compensation, as environmental asset is an extension of life asset, where the former should be a priority only to ensure the latter. In this way, the safety of the drivers should be preserved in first place.

The main gaps about these subjects are: the study of the beneficial of the trees on roadsides in driver behaviour; the angle to be used when design road barriers; a guideline for landscape in roadsides of high speed roads; the life cycle assessment of tree removal against road accidents that could occur with the presence of the tree.

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