THE ECOLOGICAL FOOTPRINT OF HIGHWAY INCIDENTS

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ABSTRACT

The purpose of this study is to measure the impact of road incidents that interrupt the normal flow of vehicles using the ecological footprint model. The method proposed in this work enables identifying the impact of incidents, basically road accidents and maintenance works, on the transportation ecological footprint. The case study comprises the operation along a single lane highway and emissions were estimated with the use of traffic simulation. We obtained an ecological footprint of 2,180 ha due to road incidents over a period of one year. This corresponds to 4% of the ecological footprint of normal road operations.

1. INTRODUCTION

At the end of the last century, Wackernagel and Rees (1996) developed a method to measure the impact of human activities on nature, the Ecological Footprint. This method assumes that each person needs an amount of area of land, water and energy to produce what is consumed in over a year. The Ecological Footprint is related to the concept of carrying capacity, which is the regenerative capacity of nature's resources in order to sustain a population in a given region.

The world population increasing and global economic development encourage a growth in the use of materials and energy to meet consumption needs. As a consequence, there was an increase in pollutants and the generation of waste released into the environment. This growing demand for resources to maintain the standard of life of a population has manifested more intensely on the issue of energy use. This energy can be represented by a theoretical area that should be reserved for absorption of CO_2. This area is called the hypothetical area of energy or carbon footprint. The area of energy is a major component of the ecological footprint of the transportation sector.

From the earliest calculations, the transportation sector has significant contribution in the ecological footprint. Important for the economic development of urban areas, the sector is among those who most energy-consuming and more contribute to emissions of greenhouse gases. With the increase of motorized trips there was also an increase in the occurrence of road incidents. There are incidents that can be predicted, such as the works for track maintenance and suitability capacity. Others are random character such as accidents and natural disasters. In both cases incidents are events that interrupt the flow and reduce the capacity of the track, causing delays, long queues, increased fuel consumption and increase in emissions.

The literature is extensive on developing studies that analyze the occurrence of road incidents. Some topics considered are capacity reduction pathways , analysis of the behavior of motorists regarding lane changing and gap acceptance , change of route from information provided by traffic information systems , risk assessment of accidents through safety audits road , identifying critical points in the pathways to prioritize actions to reduce the rate of accidents and their severity , among others (Alvarez and Hadi , 2010) . In case of accidents, quite a point addressed is the question of economic or financial cost . Some authors propose methods for measuring costs considering items such as loss of production associated with death of persons or temporary interruption of its activities and medical costs of repairing damaged vehicles (IPEA , 2003). However, studies on the impact of incidents on the ecological footprint of the transport sector were not identified.

In the case of works of highway building, or even capacity expansion, growing environmental requirements requested by international multilateral agencies for providing funding. Already, the environmental impacts caused by incidents affecting the road when its operation. These impacts are generated by traffic congestion or stopped in the period in which the roads are blocked for both work and for removal of victims and vehicles involved in accidents.

Since it the share of the displacements corresponding to the incident so far not been directly considered in the ecological footprint calculation of the transportation sector, this paper develops a method to estimate the carbon footprint of road incidents. The estimate of the impact that the incidents have on the environment can be used to justify investments, in road safety in resources to meet the occurrences or increase capacity of highways.

This article is organized into five sections. After this introduction, the literature review on the concept of ecological footprint and its relation to transport is made. Section 3 presents the proposed estimate the carbon footprint of road incidents method. Section 4 presents an application of the method and, finally, section 5 presents conclusions.

2. THE ECOLOGICAL FOOTPRINT AND THE TRANSPORTATION SECTOR

The ecological footprint is an indicator resulting of a method proposed in the 90s in order to measure the relationship between nature and human consumption (Rees, 1992). This relationship is based on the fact that each individual requires an area on the earth's surface that provides goods and services essential to life (Chambers et al., 2000). The concept of carrying capacity is associated with the Ecological Footprint. Carrying capacity believes that the earth is a virtually closed system and that the resources on which they depend human activities are finite (Arrow et al., 1995).

The calculation of the ecological footprint proposes to show, in terms of a unit area, how a particular population is using the resources of nature to maintain your standard of life. Visualization is possible when compared with biocapacity, which is the maximum theoretical rate of regenerative supply of resources provided by nature. The end result has been the ecological balance, which according Monfreda et al. (2004), evaluates the environmental sustainability of a region. The ecological balance is the difference between biocapacity and ecological footprint. A positive result indicates that the region can be considered environmentally sustainable, it has a smaller footprint than the biocapacity. Otherwise, a negative result indicates that the footprint of a population exceeds the regenerative capacity of the existing natural capital in this region, considering the environmentally unsustainable.

The focus of the ecological footprint method is the evaluation of the use of bioproductive areas to provide resources, products and assimilate CO_2 emissions. These areas include global ecosystems that supply the human economy with most of its renewable biological resources. The bioproductive areas are classified into six different kind of areas: (a) growing areas (for production of fruits, vegetables , cereals and derivatives) , (b) grazing areas (for meat and derivatives) , (c) forest areas (for production of paper and wood) , (d) fishing areas (for the production of fish for human consumption) , (e) built-up areas (for housing , transport and business and industrial activities) and (f) the energy area (area hypothetical it should be reserved for the absorption of CO_2) (Wackernagel et al. , 2005). To enable comparisons on a global scale in different countries, which have different qualities and characteristics of areas for crops, pasture, forests and fisheries, the equivalency factors that weigh the productivity of each type of area with world average productivity are used. Thus, the ecological footprint , expressed in global hectares, is estimated by Equation (1) , which relates the amount of resources consumed (tonnes) with the resource productivity (tonnes per hectare) for each type of area (Ai) weighing the corresponding equivalence factor (in global hectares per hectare) :

$$PE\ (gha) = \sum_{Ai=1}^{6} \frac{Consumption\ (ton)}{Productivity\ \left(\frac{ton}{ha}\right)} \times Equivalence\ Factor\ \left(\frac{gha}{ha}\right) \quad (1)$$

The equivalency factors are listed in Table 1. An equivalence factor of crop area equal to 2.51 means that every actual hectare equals 2.51 global hectares and indicates that the global average productivity of cultivated land is more than double the world average productivity for all areas . Grazing areas have equivalency factor of 0.46 which means that, on average, less than half the world-average productivity bioproductive hectares (Ewing et al., 2010).

The ecological footprint assumes that the infrastructure and human settlements are located along the most fertile regions of the country. Therefore the equivalence factor for built area is the same of growing areas. Importantly, the reported equivalence factors are the same for all countries.

Area type	*Equivalence factor (gha/ha)*
Growing areas	2,51
Forests areas	1,26
Grazing areas	0,46
Fishing areas	0,37
Building areas	2,51

Table 1: Equivalence Factors
Source: Ewing et al. (2010)

In the case of the energy area, productivity is given by the rate of CO_2 sequestration, which is the ability of the world's forests to absorb the resulting CO_2 emissions. The proportion of carbon absorbed by forests is related to forest type, growth and age. Different types of forests store different amounts of carbon in their biomass. Likewise, remove carbon in larger proportions when young and growing. As they reach maturity and growth stabilizes, carbon uptake is reduced. In conventional ecological footprint , this value is calculated from the model of the Global Fibre Supply Model - FAO (FAO , 2000) and is equal to 1.09 tC / ha / year (Scotti et al , 2009). Considering the relationship between the molecular weight of CO_2 and the carbon has been that this rate is equivalent to the kidnapping of 3.9966 t CO_2/ha/ano. Thus, the ecological footprint of a tonne of CO_2 emitted by offsets conducted over one year is 0.92 hectares of forests or 1.16 global hectares. This means that 0.92 hectares of forests are needed to absorb every tonne of CO_2 emitted.

Specific contributions to the transportation sector were presented in some works such as Barrett (2003) and Muñiz (2005) for urban passenger transport. Emphasizing urban goods are important contributions Holden (2004) that analyzes the influence of the location of commercial activities on the ecological footprint of urban goods deliveries, and Muñuzuri et al. (2010) which provide a specific method to estimate the ecological footprint of urban goods transport. To contribute to the planning of transport, Chi and Stone Jr (2005) present a methodology for assessing the ecological footprint of networks of current and future transport with application to the Houghton County in Michigan.

3. A METHOD FOR CALCULATION ECOLOGICAL FOOTPRINT OF ROAD INCIDENTS

The proposed method to calculating the ecological footprint of the incidents is composed of four steps. (i) study area definition, (ii) incidents identification and classification, (iii) assessing the impacts of incidents, (iv) calculating the ecological footprint. These steps, summarized below, are detailed in Dexheimer (2012).

3.1. Study area definition

To calculate the ecological footprint of road incidents the places that have a high rate of incidents that require the blocking of lane or part thereof shall be identified. This is to ensure that those places where impacts are more significant incidents are analyzed. It is understood by incidents all events that disrupt the normal flow of operation causing a reduction in road capacity, for example, accidents, construction and for maintenance of the road.

3.2. Incidents identification and classification

This step involves the identification of incidents that interrupted the normal flow of highway operations within one year of operation, which are included in the study. Additionally, the incidents are characterized according to their nature in works and accidents. Accidents are classified according to severity (mild, medium and severe), the type of blocking that cause in the lane (partial and total), the design flow required after the occurrence (or deviation with alternating movement speed reduction), the time that the track was obstructed (short, medium and long) and if there was leakage of hazardous material (or not contaminated croplands, pasture and fishing). Likewise works are classified according to the type of repair performed, the type of blocking that cause the lane (partial and total), the design of movement necessary for the occurrence (or alternating movement speed reduced deviation) and the time the lane was obstructed (short, medium and long).

3.3. Assessing the impacts of incidents

In sequence, the assessment of the impacts of incidents concerning the generation of emissions and contamination of land and water due to accidents with dangerous goods in places where the highway crosses land and productive waters is performed . To identify areas of contaminated land and water are necessary collections of information with local environmental agencies.

Emissions are calculated by their level of variation compared with the normal flow operation. For the identification of variations in the levels of emissions from road incidents, a simulation of traffic so check emissions without the occurrence of incidents and later with its occurrence is performed. The emission analysis is made based on scenarios from the types of incidents identified and classified as 3.2 item. For the creation of scenarios is necessary to determine the operating conditions of the lane, including traffic volume, traffic composition and the physical dimension of the incident.

3.4. Calculating the ecological footprint

The next step is to calculate the ecological footprint of road incidents. This calculation is normally done for a period of one year and is expressed in global hectares per year drive (gha/year), which means the area of natural resources have been impacted by the occurrence of incidents. The share of the ecological footprint of road incidents can be represented by two equation and is composed of the sum of ecological footprints corresponding to the equivalent amount of CO_2 emitted during the incidents, croplands and grazing and fishing areas, whose productivity was lost in result of the incident.

$$\boldsymbol{PE_{IR}} = \boldsymbol{PE_{EM}} + \boldsymbol{PE_{C}} + \boldsymbol{PE_{PA}} + \boldsymbol{PE_{PE}} \quad (2)$$

PE_{IR} = ecological footprint of road incidents (gha/year);
PE_{EM} = plots of the ecological footprint that corresponds to emissions (gha/year);
PE_{C} = plots of the ecological footprint that corresponds to the loss of productive area used for growing (gha/year);
PE_{PA} = plots of the ecological footprint that corresponds to the loss of productive area used for grazing (gha/year);
PE_{PE} = plots of the ecological footprint that corresponds to the loss of productive fishing area (gha/year)

The plots are expressed by the equations presented in Table 2:

PLOTS	COMPONENTS OF PLOT
Concerning to **Energy area**: $\boldsymbol{PE_{EM}} = \sum_{i=1}^{N}\left[\frac{(\Delta EM_i \times T_{Bi} \times O_i)}{FSC}\right]$	Δ **EM** = CO_2 equivalent emissions generated in the incident *i* (kg CO_2/h) $\mathbf{T_B}$ = Time that the lane was blocked in the incident type *i* (h) **O** = Occurrences number of the event type *i* by year **FSC** = Carbon Sequestration Factor (kg CO_2/year) ***i*** = Considered incident type;
Concerning to **Growing area:** $\boldsymbol{PE_C} = \mathbf{AC} \times \boldsymbol{FE_C}$	**AC** = Growing contaminated area (ha / year) $\mathbf{FE_C}$ = Crop Equivalency Factor (gha / ha)
Concerning to **Grazing area:** $\boldsymbol{PE_{PA}} = \mathbf{APA} \times \boldsymbol{FE_{PA}}$	**APA** = Grazing contaminated area (ha / year) $\mathbf{FE_{PA}}$ = Grazing Equivalency Factor (gha/ha)
Concerning to **Fishing area**: $\boldsymbol{PE_{PE}} = \mathbf{APE} \times \boldsymbol{FE_{PE}}$	**APE** = Fishing contaminated area (ha/ano) $\mathbf{FE_{PE}}$ = Fishing Equivalence Factor (gha/ha)

Table 2: Summary table of the Ecological Footprint plots of road incidents

4. CASE STUDY

To illustrate the application of the method we developed a case study in a section of the BR-386, a federal highway that connects the metropolitan region of Porto Alegre with the city of Iraí on the border with the State of Santa Catarina.

4.1. Study area definition

The section under analysis is composed by 40 km of a single lane in BR-386 highway between city of Lajeado and intersection with the RS-287 highway. This section was selected because of a high incidence of accidents and works. The incidents were analyzed within one year. For accidents, the average value of the last three years and was used. For the works were considered two types of interventions that are carried out in all the kilometers for one year and in some cases even more than once a year. In the period of analysis were considered 200 accidents, 400 located repairs and 40 applications of micro - asphalt coating on this section, totaling 640 incidents.

4.2. Incidents identification and classification (accidents and works)

Those 200 accidents under analysis were classified according to Table 3.

CRITERIA FOR CLASSIFICATION	LEVELS	VALUES	METHOD FOR OBTAINING
Severity	High (with fatal victim)	3%	The Severity Standard Unit - UPS according to the methodology DENATRAN (1987) was adopted to calculate the average number of accidents that occurred the years 2008-2010. Source: History of accidents BR 386 (UNIVIAS, 2011).
	Medium (with injuries)	40%	
	Low (property damage only)	57%	
Type blocking that provoke the lane	Total	33,3%	Were applied to the total number of accidents, the percentages relating to the severity type blocking as follows: lane is completely blocked in 90% of cases of fatal crashes (UPS 13) in 50% of cases of accidents involving injured people (UPS 5) and in 20% of cases of property damage only accidents (UPS 1) occur in the remaining cases the lane is partially blocked with alternating movement.
	Partial (with alternating movement)	66,7%	
Design movement required after the occurrence	Alternating movement	100%	In Manual Signaling Works and Emergency by DNIT (2010) projects-type for signaling emergencies and traffic diversion in the event of accidents are predicted. In highway traffic study deviations are not used.
	Deviation with speed reduction	-	
Time that the lane was obstructed	Total blocking	10 min	For calculating the footprint were adopted 4 stroke blocking: (i) Total blocking 10 min because it was identified that would be the maximum time that a

	Partial blocking 1	15 min	driver leave the vehicle started waiting for the release of the lane, (ii) Partial blocking 1: 15 min, the minimum time required for the solution of small conflicts, (iii) Partial blocking 2: 40 min, intermediate value which fits within a larger amount of the cases (iv) Partial blocking 3: 1h and 50 min, intermediate value between hour and fifteen minutes and two hours and thirty minutes when there is little variation in the frequency of occurrence as the histogram of Figure 1. It was considered that after total blockade the lane is partially released before returning to normal operation.
	Partial blocking 2	40 min	
	Partial blocking 3	1 h 50 min	
Occurrence of hazardous material leakage	YES ou NO	NO	Records of accidents did not indicate the occurrence of an accident involving hazardous materials.

Table 3: Accidents classification for calculating the ecological footprint

To do a time analysis of the lane obstructions due to the accidents care it was drawn the histogram in Figure 1 from the data of the concessionary responsible for operating the route. It is observed that 80% of cases blocked the lane, or portion thereof up to three hours, and largely cases, 47% of cases, up to one hour. Accidents with up to five and a half hours blocking account for 90% of cases.

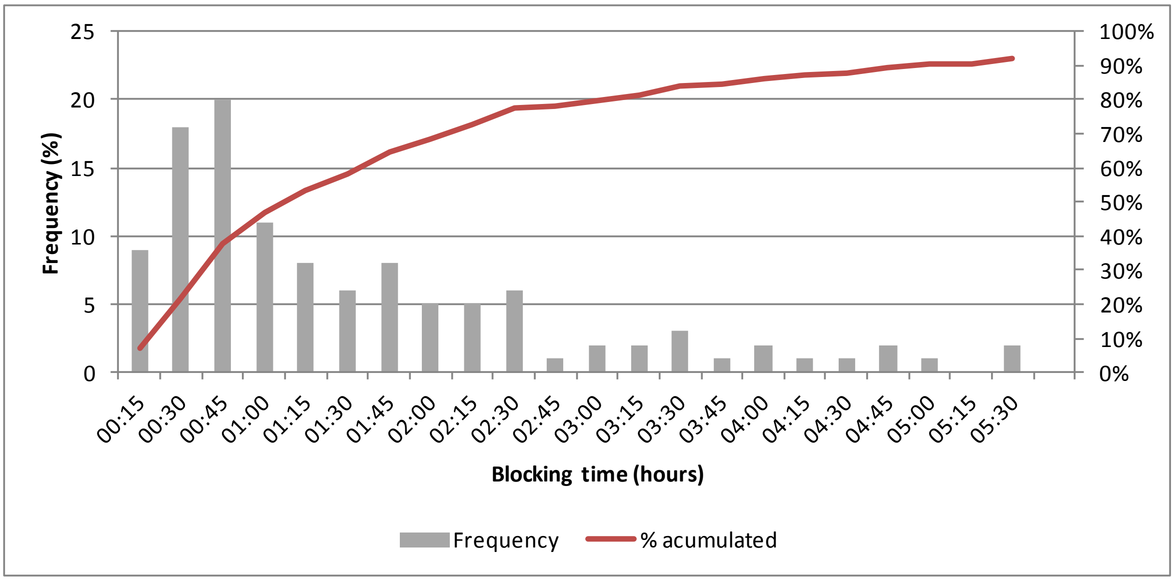

Figure 1: Occurrence frequency of time obstruction lane

4.2.2. Works

There are many necessary for the maintenance of the highway throughout its life works. For this work are considered only two incidents type works: (i) localized repairs and (ii) application of micro - asphalt coating. These incidents were chosen because they represent the highest incidence throughout the year and also necessarily occur along the roadway, causing the need to interrupt the flow. Repairs are located "patches" made on the floor surface and can be performed in a timely manner or in large areas. The localized repair is fast, lasts about an hour and extent of work varies from 100 to 500m. The micro- lining is a mixture of aggregate, asphalt emulsion, additives and water is applied to the road surface for sealing fissures and cracks. For application it is necessary to interrupt 1-3 km route and healing time between the implementation and the range is interrupted about half the day shift. Both are meant to improve the comfort of the bearing. Table 4 shows the classification.

CRITERIA FOR CLASSIFICATION	WORKS TYPE	VALUES	METHOD FOR OBTAINING
Movements project	Localized repair	Alternating movement	Average values obtained from the concessionary that operates the studied.
	Micro - asphalt coating	Alternating movement	
Type of blocking that they provoke	Localized repair	Partial of 100 m	
	Micro - asphalt coating	Partial of 1 km	
Time of obstruction lane	Localized repair	1 hour	
	Micro - asphalt coating	6 hours	

Table 4: Works classification for calculating the ecological footprint

4.3. Assessing the impacts of incidents

The assessment of changes in the levels of emissions from road incidents was performed using the traffic simulation model CORSIM - CORridor SIMulation. The CORSIM is a micro-simulation model developed by the Federal Highway Administration - FHWA for analysis of highways, urban roads and lanes or traffic networks (Moreira, 2005). To analyze the occurrence of incidents in real operating conditions scenarios that represented the best combination between the flows of vehicles and the occurrence of the incidents were created.

Five scenarios were defined for study:

→ Scenario 1: Normal Operation - ON

Normal system operation, with all vehicles classes circulating without obstruction on the lanes.

→ Scenario 2: Accident with total blocking lanes – AC1

Incident occurrence of crash type with total blocking of lane. When an incident of this type occurs, the release of the lane is done gradually, first passing an alternating movement in middle lane and then full release. It was used a time to total blocking and three more times with blocking middle lane and alternating movement.

→ Scenario 3: Accident with partially blocking lane and alternating movement – AC2

Incident occurrence incident of crash type with partial blocking of lane, which in this case study is a tread. The movement of vehicles is alternating in middle lane and three times blocking are used.

→ Scenario 4: Work 1 with partially blocking lane and alternating movement – OB1

Incident occurrence type work, to perform located repair with blocking a tread. The time used was fixed in one hour and during this period the circulation of vehicles is alternating in middle lane.

→ Scenario 5: Work 2 with partially blocking lane and alternating movement – OB2

Incident occurrence type work, to perform micro - asphalt coating, with blocking a tread. The time used was fixed in six hours and during this period the circulation of vehicles is alternating in middle lane.

To the scenarios 2 to 5 was simulated an incident occurrence which starts one hour after a normal operation. After the incident, the road back to normal operation for another hour for the system to stabilize again. Five rounds were performed for each combination of time and flow in all scenarios, totaling 115 rounds. Each round uses a different model value (seed) for generating the vehicle and the driver's behavior in order to check the consistency of the results. In all scenarios simulated results showed a standard deviation of about 2%, so the average emission value of the five rounds were used. CO emissions were converted into CO_2 equivalent to a GWP - Global Warming Potential of 3.0 (IPCC, 2007). Amounts relating to the contamination of land and water were not included because there was no accident contamination.

4.4. Calculating the ecological footprint

The calculation of the ecological footprint was performed using equation 2. Emission changes were used in each stage as compared to the normal operation, the time that the lane was cut off and the number of occurrences for each scenario. The carbon sequestration factor used was 1.09 tC / ha year (Scotti et al. 2009). To calculate the ecological footprint of normal operation, the equation relating the share of emissions from Table 2 was used, but was not considered at the time the lane was interrupted, since in this case there is no blocking. The values of the ecological footprint for all scenarios over a year of operation as well as the values used for each variable are presented in Table 5.

Scenario	*Name*	*Time of total blocking*	*Time of partial blocking*	*Flow (Vehicles/h)*	*Ecological Footprint (ha)*	*Total ecological footprint by scenario (ha)*
1	ON	-	-	900 700 300	20.312,32 15.830,56 13,749,17	49.892,04
2	AC1	10 min	15 min 40 min 01 h 50 min	900 700 300	366, 86 154,39 90,30	611,54
3	AC2	-	15 min 40 min 01 h 50 min	900 700 300	143,12 63,44 45,30	251,85
4	OB1	-	1 h	700	600,25	600,25
5	OB2	-	6 h	700	717,07	717,07

Table 5: Ecological footprint for all scenarios

5. RESULT ANALYSIS

The annual ecological footprint of all road incidents (accidents and works) for the 40 km route under study (scenarios 2-5) amounts to 2,180.72 ha or 2,747.71 gha. This amount represents the fictional area that would be necessary for the absorption of CO_2 emissions resulting from road incidents during one year of operation. This corresponds to 4% of the ecological footprint of the highway under normal operating conditions (49,892.04 ha or 62,863. 97 gha).

In Figure 2 it can be observed that both types of works together contribute 60% of the ecological footprint of the incidents, and the activity of micro-coating application (OB2) has a slightly larger impact that the localized repair (OB1). While the application of micro-coating causes a change in the level 12 times greater than the repair located latter emission occurs over more than a year, reducing that difference. It is important to remember that This paper considers only two types of maintenance works. It is very likely that the ecological footprint of the incidents is even greater due to the large percentage share of the work. The maintenance of roads can not be prevented, but may be designed to minimize its impact on the environment. Investment in materials with greater durability, or that promotes lower fuel consumption, and the use of alternative diversion of traffic could contribute to reducing the ecological footprint of maintaining the highway.

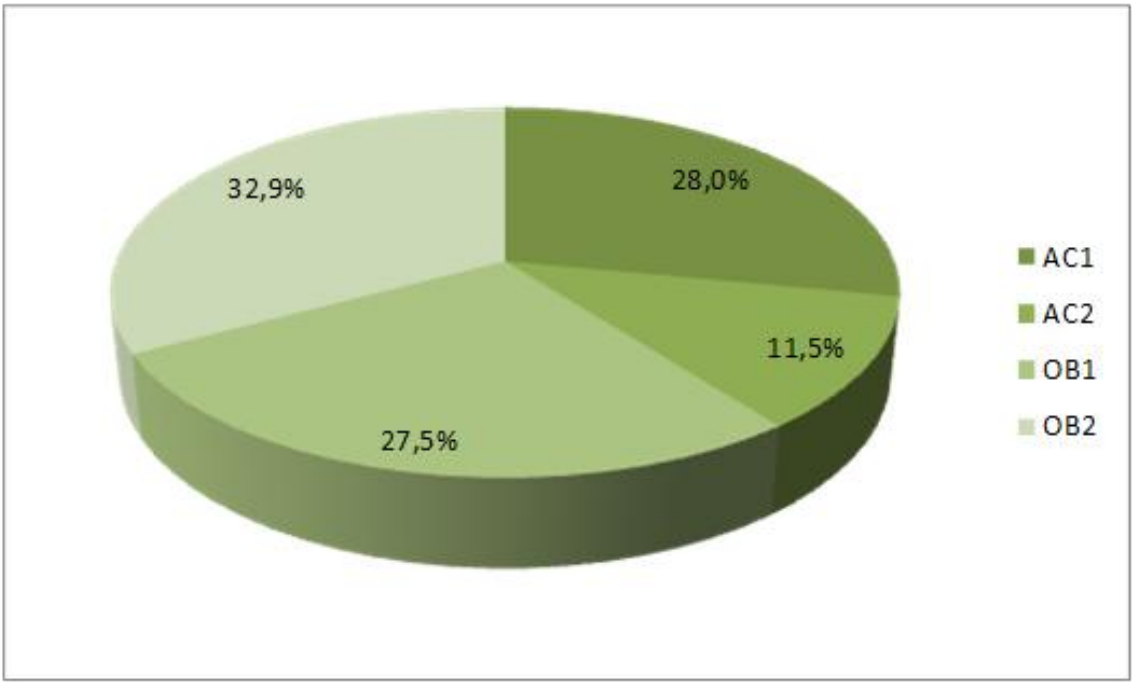

Fig. 2: Percentage participation of Ecological Footprint by type of incident in one year operation

Regarding to accidents, it is observed that serious occurrences, which is more likely to cause total interruption in the flow of vehicles, despite a percentage of occurrence twice lower throughout the year, as they contribute to 33.3 % of the total, have a much greater impact on the ecological footprint than accidents in which the track is partially blocked, the difference reaches 140 %. Analyzing the unit values of the ecological footprint , shown in Figure 3, it is observed that in scenario 2 the difference in values between the largest and smallest block time in the same flow rate, reaches a maximum of 26% to 700 Veic/h while in the third scenario the variation can reach 290% for 300 Veic/h. Notin the simulations it appears that the difference lies in the fact that when the track is totally interrupted even for a short time, the network is heavily loaded. To partially release the passage, the number of vehicles in the system is much higher in scenario 2 than in scenario 3. This information may help to justify investments in road safety in order to reduce this type of incident. Or justify the deployment of berms with adequate width to allow the diversion of traffic as recommended by the manual DNIT (DNIT, 2010).

It is possible to observe in Figure 3 a big difference when analyzed values of incidents in different levels of flow. As was hoping for ecological footprint of an incident in peak hours has a greater impact than the ecological footprint of incidents that occur outside the time of peak can get to a difference of 175% as in the case of longer block scenario 2. In scenario 3 the variation was around 150%.

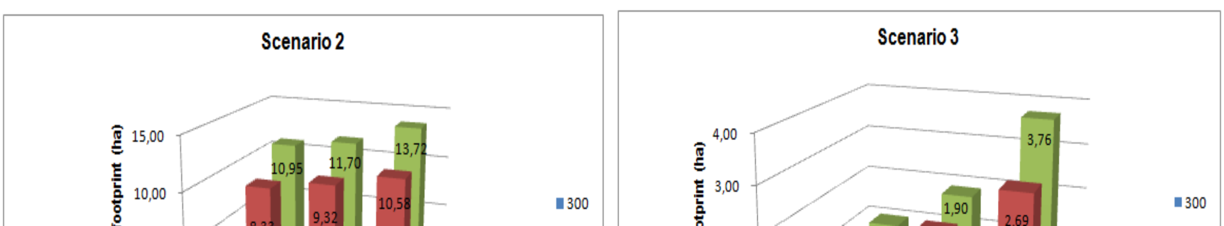

Fig. 3: Ecological Footprint of an incident in different flows for scenarios 2 and 3

6. CONCLUSIONS

This study aims to model the ecological footprint of road incidents. A study was conducted in a 40 km section of the BR-386 highway, which calculate the ecological footprint of two types of events: incident type works, located repair and application of micro - coating, both causing partial interruption of lane, and incidents type accidents that block all or part of the lane. Through traffic simulation has been possible to obtain the values of CO_2 emissions equivalent of highway in normal operation and during incidents for use in the calculation. The results showed the annual carbon footprint of road incidents as 2,180.72 ha, representing the amount of forest area required to absorb emissions from these incidents . This corresponds to 4 % of the total ecological footprint of the highway in normal operation without the occurrence of incidents .

The proposed method enables the assessment of the impacts of the incident on the environment, allowing you to view this information in terms of area required to offset the extra emissions generated by the incident. In the case reported, the energy sector is the fictional area required to absorb the CO_2 emissions of all incidents that occur in a year operating the route. The results support the process of decision making for investments in highways in that the environmental impacts along with those impacts caused by road incidents cause numerous social damage, thus preventing the promotion of sustainability.

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