

Application of the Composition of Probabilistic Preferences in Modal Choice for Freight Transportation of Hazardous Materials

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RESUMO

Considerando-se os impactos ambientais ocasionados pelo transporte de carga, especificamente para o caso de produtos perigosos, o presente artigo propõe uma aplicação da composição probabilística de preferências como método de escolha modal considerando medidas associadas a riscos de acidentes e de eco-eficiência. O propósito do método de escolha modal é estabelecer uma ordem de prioridade entre os modos de transporte, permitindo que o tomador de decisões escolha o que melhor lhe convier. Tradicionalmente, no Brasil, a avaliação dos modos de transporte não considera os riscos e os impactos ambientais, sendo o custo o principal critério de decisão. Diante disso, no presente trabalho escolheu-se um conjunto de indicadores de eco-eficiência e um indicador de risco, custo de acidente, e lançou-se mão da composição probabilística de preferência para estabelecer uma ordem de prioridade entre as alternativas disponíveis. O caso de aplicação refere-se ao transporte para exportação de bioetanol, produzido na região Centro-Sul do país. Os resultados obtidos indicam que, independente do perfil do decisor, o modo puramente rodoviário não deveria ser o preferível. Esse resultado prevalece mesmo para um perfil médio de decisor.

PALAVRAS CHAVE. Transporte de carga, Eco-eficiência, Composição probabilística de preferências

Área principal (ADM - Multicriteria Decision Support // ADM - Apoyo a la Decisión

Multicriterio // ADM - Apoio à Decisão Multicritério

L & T - Logistics and Transport // L & T - Logística y Transporte // L&T - Logística e Transportes)

ABSTRACT

Considering the environmental impacts caused by freight transportation activities, especially in the case of hazardous materials, this paper proposes the application of the Composition of Probabilistic Preferences (CPP) to the Modal Choice Method (MCM), considering the risk of accident and eco-efficiency measures. The purpose of the MCM is to establish a ranking among the transportation modes, allowing the decision makers to choose that one with best performance. Traditionally, in Brazil, transportation modal choice doesn't consider risks or environmental impacts, being the cost the main considered factor. Then, we selected a set of eco-efficiency measures and applied the CPP, a multi-criteria tool, to establish the priority ranking among the

transportation modes. We applied this method specifically to analyze the transport for exportation of Brazilian bio-ethanol produced from the country's South-Central region. The obtained results show that, independently of the decision maker profiling, the simplest roadway transportation mode is not the preferable one. This result stills the same if one considers a mean profile for decision making.

KEYWORDS. Freight transportation, ecoefficiency, Composition of probabilistic preferences.

Main area (ADM - Multicriteria Decision Support // ADM - Apoyo a la Decisión Multicriterio // ADM - Apoio à Decisão Multicritério
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1. Introduction

Due to its importance and potential impacts, the performance of transport activities must be evaluated (Guimarães, Leal Jr and Garcia, 2014). It become even more important when we are dealing with dangerous freight due to its intrinsic characteristics and the severe impacts related to accidents. Although, performance assessment of freight transport is not simple, since it is a process involving complex decision due to the number of variables and subjects' judgments involved (Leal Jr and D'Agosto, 2009).

Besides, in order to be competitive, without compromising the environment, organizations need to consider the eco-efficiency concept to evaluate the performance of their activities (WBCSD, 2000 and 2006). In the transport, this consideration is essential due to the amount of resources they moved and to the environmental influences related to their activities (Pereira, 2005; Mickwitz et al, 2006; Leal Jr., 2010; Leal Jr. and D'Agosto, 2011; Leal Jr. et al, 2012; Leal Jr. and Guimarães, 2013).

Regarding about hazardous goods, adopting eco-efficiency concept become even more relevant because their transportation may cause negative environmental impact (due to goods' characteristics). Besides, accident risks must be considered since some accidents can be really severe and increase negative impacts in environment. So, the use of a method to guide the decision-making process, such as Modal Choice Method - MCM is critical.

MCM, proposed by Leal Jr. and D'Agosto (2011), assist in decision making regarding the choice of transportation mode, based on its performance evaluation. The MCM, for being flexible, allows the use of a structure that uses eco-efficiency measures that have a differential for companies that value the environmental issues (Leal Jr and D'Agosto, 2011). In this context, this work is based on the following question: Can the consideration of accident risk influence the decision by the transportation mode?

To answer this question, this paper aims to apply the MCM in a real situation, considering the eco-efficiency measures combined with accident risks of each transportation mode under evaluation. For this study, we conducted a case of transport of ethanol produced in the Brazil's South-Central region to a port for export. The main hypothesis states that the use of accident risks in the analysis of eco-efficiency improve the performance of the transportation alternatives and interferes in the decision making process.

For the data analysis we used Composition of Probabilistic Preferences to support the identification of the most appropriate alternatives. The results show that the current practice for bio-ethanol transportation used in Brazil is never the best one, if considering the measures and method here discussed. From this introduction, this paper has four other sections: (i) considerations about modal choice method and eco-efficiency, (ii) method application, (iii) discussion of results, and (iv) final considerations.

2. Modal Choice Method and Eco-Efficiency Measures

In order to better meet the demand, companies evaluate new forms of transport, which may involve the choice of different transport modes, or combinations of them in the form of intermodal transport. This choice may strongly interfere in the way that company will serve customers and concur with its competitors and should be aligned with business strategy. The development of tools that assist in this choice is of fundamental importance to the business strategy (Manheim, 1980; Morlok, 1980; D'Agosto, 1999).

The Modal Choice Method - MCM (Leal Jr and D'Agosto, 2011) details the process of decision making in transportation design and apply the modal choice of transport in general. This method is essentially dynamic and the results can be reviewed over time, because the final result can be used to power a new cycle of assessment. All details of the method can be accessed at Leal Jr and D'Agosto (2011).

In this work the MCM uses the concept as a basis for establishing eco-efficiency measures. This approach focuses on the proper use of material and energy resources, in order to reduce costs and / or to improve profits (WBCSD, 2000 and 2006; Pereira, 2005; Mickwitz et al,

2006; Leal Jr., 2010; EPA, 2011; Leal Jr. and D'Agosto, 2011; Leal Jr. et al, 2012; Leal Jr. and Guimarães, 2013). Then, eco-efficiency can be understood as the ability to simultaneously meet production goals and cost with quality and performance, reduce environmental impacts and conserve natural resources. The eco-efficiency allows companies to become more responsible environmentally and more profitable in the economic, encouraging them to innovation and competitiveness (WBCSD, 2000 and 2006)

The eco-efficiency indicators can be used for all general and business activities, or specific to a particular sector (WBCSD, 2000 and 2006). Regarding transportation sector, ecoefficiency concept has been applied in: Kuosmanen and Kortelainen, 2005; Lee et al, 2011; Usón et al, 2011; Leal Jr. Garcia and D'Agosto, 2012; Leal Jr and Guimarães, 2013; Guabiroba et al, 2014; Guimarães, Leal Jr and Garcia, 2014; Song, 2014. WBCSD (2000 and 2006) presents a methodology for assessing eco-efficiency that can be used by some businesses to measure the economic and environmental aspects. To determine the eco-efficiency in transport, this paper proposes a structure based on WBCSD (2000 and 2006).

The use of eco-efficiency indicators generates specific measures based on the ratio value of the product or service with the environmental influence and which are represented by equation 1, according to WBCSD (2000 and 2006).

$$Eco\text{-}Efficiency = \frac{\text{Value of Service}}{\text{Environmental Influence}} \quad (1)$$

As suggested by Leal Jr. and D'Agosto (2011) and WBCSD (2000 and 2006), it is possible to use only one indicator for the value of service (as numerator), combining it with the most representative indicators of environmental influences considered.

3. Method Application

To apply the methodology proposed, we present a case study of bio-ethanol produced in the Brazil's South-Central region and intended for export. From TRANSPETRO (2008), we identified the network for transportation of ethanol (Figure 1) which has the terminals, the Tietê-Paraná waterway project, the ethanol pipeline connecting Senador Canedo (in Goiás state) and the Port of San Sebastian in São Paulo. We considered the current rail and road networks, based on ANTT (2008). For export we consider the port of São Sebastião, because it has a TRANSPETRO terminal and should be the main exporter terminal of ethanol (Rodrigues, 2007).

For the application of the MCM, we considered the municipality of Turvelândia – GO as the point of origin, which is among the 10 largest producers of ethanol from Brazil (Rodrigues, 2007). Its choice is due to the geographical position that allows the use of different modal alternatives to apply the MCM. It was established that all the bio-ethanol produced is collected via road until arriving at a terminal in the network shown, as the practice adopted by most producers. The road is more used to transport ethanol accounts for 96% of the movement (Rodrigues, 2007). The transportation alternatives considered are presented in Figure 1.

The indicators were selected to the establishment of the measures according to Leal Jr and D'Agosto (2011) and they were calculated according to equation 1. As indicator of value of service we selected the revenue freight received and as indicators of environmental influence we choose: (i) accident costs, (ii) total energy consumption, (iii) emission of CO₂ and (iv) lubricating oil discarded.

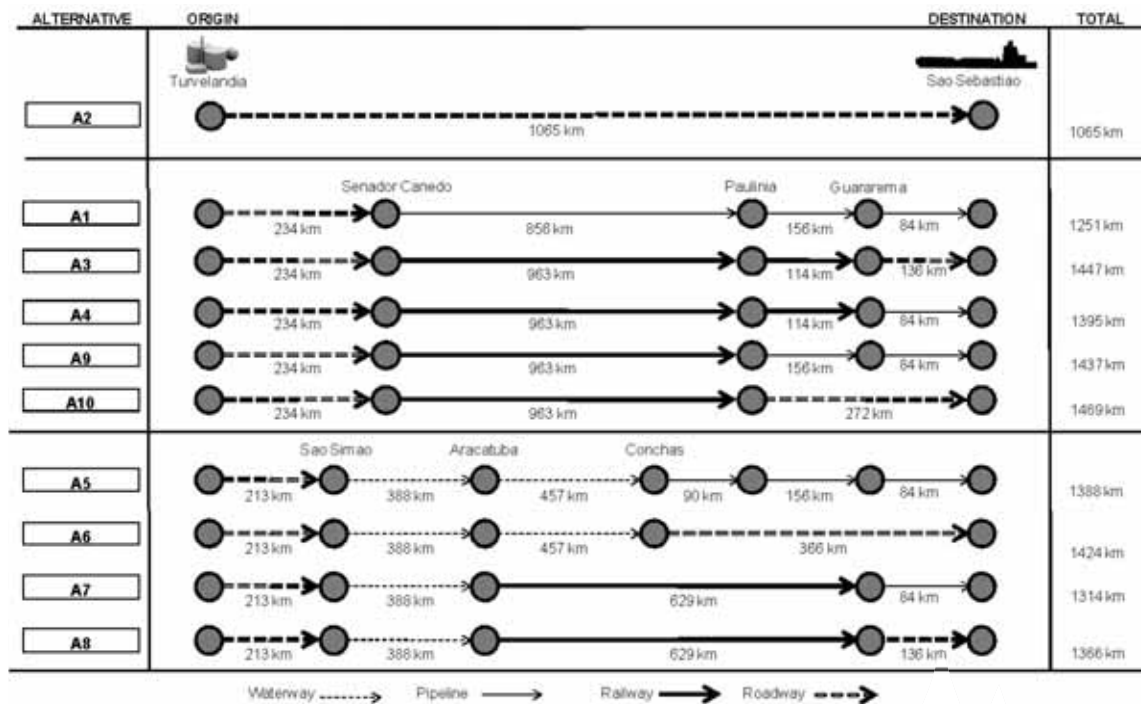


Figure 1: Network for the flow of ethanol in the south-central Brazil to export

Based on Rodrigues (2007), Odebrecht (2007), CETESB (2008), Gama (2008), Lopes and Ferreira (2004) and TRANSPETRO (2008) data were obtained for the indicators and measures were calculated for each alternative eco-efficiency, according table 1. The analysis that consider the risk of accidents was based on DNIT (2004), MRS Logística (2009), ANTAQ (2009), Pezzi Filho (2003), ANTT (2005), CETESB (2008), STSP (2007), according Table 2. The accidents frequencies were obtained through historical analyses and the costs of accidents based on company reports.

Table 1: Measures of eco-efficiency and risk

Alternatives	Revenue [US\$/1000.t.km]	Accident cost [US\$/1000.t.km]	Energy consumption [MJ/1000.t.km]	CO ₂ Emission [kg/1000.t.km]	Oil discard [l/1000.t.km]
A1	77,84	0,40	402,10	22,29	0,014
A2	97,96	1,06	1663,09	119,17	0,077
A3	95,54	0,32	784,63	56,22	0,040
A4	92,28	0,25	658,48	46,70	0,034
A5	70,52	0,23	454,47	30,66	0,032
A6	83,04	0,44	844,48	60,51	0,051
A7	92,39	0,23	591,60	41,88	0,035
A8	95,64	0,31	727,78	52,15	0,041
A9	90,11	0,26	613,08	42,59	0,031
A10	99,57	0,41	889,37	63,73	0,044

The data gathered have been treated using the technique to support multi-criteria decision analysis known as Composition of Probabilistic Preference – CPP (Sant’Anna, 2002). CPP is an approach developed to take into account the uncertainties in preference evaluations. According to Roy (1985), multi-criteria support to decisions is an attempt to provide answers,

through a clearly specified model, to questions raised by the entities involved in the decision-making process. By considering the uncertainties in the model specification, the CPP model more nearly reflects the reality.

CPP, according to Sant'Anna (2005), permits objectively combining classifications according to different criteria. In CPP, the classification of options is the result of the composing preferences according to each of the multiple criteria involved in the analysis measured as probabilities. After assessing the preferences based on each criterion by means of probabilities, the overall preference can be evaluated by comparing joint probabilities (Sant'Anna, Nogueira & Rabelo, 2011). So, this technique is developed in two stages: (1) Defining the probability of being the best or worst option and (2) Composition of the probabilistic preferences.

In the first one, it is possible to establish an order of priority by means of determining the preferences, depending on the type of criterion – the higher the better, the smaller the better or the closer to some chosen value the better. After determining the ranking of the options based on each criterion, the next step is to calculate the probability that the option is the best according to each criterion individually.

According to Sant'Anna (2010), this probabilistic transformation is the key point for the composition of the preferences considering the uncertainties. For this purpose, one must consider that the relative position obtained in the preceding step is, for each option, a measure of the location of the probability distribution of the preference for the same according to the criterion under analysis. Simple distributions are considered preferentially, such as the uniform, triangular or normal. In the present case we considered a triangular distribution.

The probability of an option being the best according to each criterion is computed by the integral of the joint density function of the option under analysis, considering an interval for which this option is the best among all options. To compute this probability, we recommend considering the amplitude of the data for the criterion, taking into account the interest in enabling the switching of position among all the options. Equation (2) presents this computation.

$$P_{ik} = \int_{L_{ik}}^{U_{ik}} \left[\prod_{j=1}^n \int_{L_{jk}}^{U_{jk}} f_{jk}(x) dx \right] f_{ik}(x) dx = \int_{L_{ik}}^{U_{ik}} \left[\prod_{j=1}^n \int_{L_{jk}}^{U_{jk}} f_{jk}(x) dx \right] f_{ik}(x) dx \quad (2)$$

In Equation (2), L_{ik} and U_{ik} are, respectively, the lower and upper bounds of the domain of a random variable X_{ik} that represents the preference for option k according to criterion i , while n is the number of options being analyzed and f_{jk} is the probability density function. The product sequence inside the brackets is the product of the probabilities that the variables are lower than X_{ik} , $(X_{jk} < X_{ik})$, for all the other options involved in the analysis.

Another probability measure is the minimum one, which represents the probability of being the last preferable alternative in the criterion.

$$P_{ik} = \int_{L_{ik}}^{U_{ik}} \left[\prod_{j=1}^n \int_{L_{jk}}^{U_{jk}} f_{jk}(x) dx \right] f_{ik}(x) dx = \int_{L_{ik}}^{U_{ik}} \left[\prod_{j=1}^n \int_{L_{jk}}^{U_{jk}} f_{jk}(x) dx \right] f_{ik}(x) dx \quad (3)$$

Notice that, in both equations, the product carries the implicit hypothesis of independence of the disturbances of the evaluations of different options. Note that X_{ik} is compared to the distributions of the other positions, X_{jk} . After making this comparison for each possible value of X_i , since it is a random variable, the next step is to calculate the expected value of this product sequence according to the distribution of X_i . This calculation must be performed for each option in each criterion. Therefore, M_{ik} is the probability that option k is the best one according to criterion i , and m_{ik} is the probability that option k is the worst one, according to the same criterion i .

Having calculated the values of the options' probabilities according to each criterion, the next step is to combine the probabilistic preferences to generate an overall probabilistic preference (Stage 2).

A way to calculate a general average preference from the probabilities of the option being chosen according to each criterion is by considering these probabilities as being conditional on the choice of the respective criterion and calculating the total probability of preference. The difficulty of this approach is to determine the marginal selection probabilities of each criterion, and this difficulty increases if the criteria are correlated. The problem can be overcome if it is possible to establish a ranking of the criteria and to model the joint distribution of these ranks. In this case, the probabilities of choosing each criterion can be computed in the same way as the probabilities of the option being chosen according to each criterion individually.

The dependence between the criteria can be considered directly to determine the overall preferences in terms of joint probabilities of preference. Modeling the dependence is also subject to distortions, while the probabilistic assessment to the preferences allows for developing and comparing evaluations based on simple assumptions on dependence. Different joint probabilities can be employed, depending on the point of view considered. The viewpoints can be characterized in terms of the choices between extreme positions in two basic orientations, or axes: optimistic versus pessimistic and progressive versus conservative.

With respect to the progressive versus conservative axis, the analyst pays more attention to the probabilities of maximizing the preference. The progressive evaluator looks at the options that are first in excellence, while the conservative evaluator examines them by their ability of not minimizing the preference. The term conservative can be defined as being risk averse, while the term progressive applies to the aim of attaining higher standards.

In the optimistic versus pessimistic axis, the optimistic evaluator is considered satisfied if at least one of the criteria is the best. All the criteria are considered, but the composition employs the conjunction "or". The joint probability is computed so as to maximize the preference according to at least one of the criteria. On the other hand, the pessimistic evaluator prefers options that satisfy all the criteria simultaneously. In this case, the conjunction "and" is used and the joint probability is that which maximizes (or does not minimize) simultaneously the preference according to all the criteria. The expressions optimistic and pessimistic are related to the idea of believing that the most favorable, or least favorable, criterion will prevail, respectively.

By combining the positions at the extremes of the two axes, four measures are generated: (i) optimistic-conservative (OC) – $\prod_{k=1}^n p_{ik}$, (ii) optimistic-progressive (OP) – $\prod_{k=1}^n (1 - p_{ik})$, (iii) pessimistic-conservative (PC) – $\prod_{k=1}^n (1 - p_{ik})$, and (iv) pessimistic-progressive (PP) – $\prod_{k=1}^n p_{ik}$. For all the cases, the product sequence varies in i , i.e., along the criteria considered. As described before, p_{ik} is the probability that option i is the best for criterion k and $1 - p_{ik}$ is the probability that option i is the worst criterion k . All the general probabilities described are based on the premise of independence of the criteria. For the case of dependent criteria, see Sant'Anna (2010).

4. Discussion of results

Following the procedures proposed by Sant'Anna (2013), observing the data from Table 1, we obtain the following Tables.

The first step consists on establishing a priority rank for each criteria. These criteria are those presented in Table 1. Table 2 present these ranking.

Table 2: Ranking for the criteria from Table 1

Alternatives	C1	C2	C3	C4	C5
A1	2,000	4,000	10,000	10,000	10,000
A2	9,000	1,000	1,000	1,000	1,000
A3	7,000	5,000	4,000	4,000	5,000
A4	5,000	8,000	6,000	6,000	7,000
A5	1,000	9,000	9,000	9,000	8,000
A6	3,000	2,000	3,000	3,000	2,000
A7	6,000	10,000	8,000	6,000	6,000
A8	8,000	6,000	5,000	5,000	4,000
A9	4,000	7,000	7,000	7,000	9,000
A10	10,000	3,000	2,000	2,000	3,000

Established the ranking of the alternatives for each criteria, we must apply the equations 2 and 3 for calculating the maximum and minimum probability, i.e, probability of be the best choice and the worst one. Table 3 presents the maximum probability of each alternative be the best one in each criterion, Mik and Table 4 present the minimum probability of each alternative. This is the probability of not been preferable considering the other alternatives.

Table 3: Probability of maximum preferences

Alternatives	C1	C2	C3	C4	C5
A1	0,0403	0,0527	0,268	0,28	0,268
A2	0,1884	0,0361	0,0361	0,0384	0,0361
A3	0,0977	0,0623	0,0527	0,0563	0,0623
A4	0,0623	0,1327	0,0762	0,0815	0,0977
A5	0,0361	0,1884	0,1884	0,1993	0,1327
A6	0,0457	0,0403	0,0457	0,0487	0,0403
A7	0,0762	0,268	0,1327	0,0815	0,0762
A8	0,1327	0,0762	0,0623	0,0666	0,0527
A9	0,0527	0,0977	0,0977	0,1047	0,1884
A10	0,268	0,0457	0,0403	0,043	0,0457

Table 4: Probability of minimum preference

Alternatives	C1	C2	C3	C4	C5
A1	0,1884	0,0977	0,0361	0,0354	0,0361
A2	0,0403	0,268	0,268	0,2648	0,268
A3	0,0527	0,0762	0,0977	0,0959	0,0762
A4	0,0762	0,0457	0,0623	0,0611	0,0527
A5	0,268	0,0403	0,0403	0,0396	0,0457
A6	0,1327	0,1884	0,1327	0,1302	0,1884
A7	0,0623	0,0361	0,0457	0,0611	0,0623
A8	0,0457	0,0623	0,0762	0,0748	0,0977
A9	0,0977	0,0527	0,0527	0,0517	0,0403
A10	0,0361	0,1327	0,1884	0,1854	0,1327

Combining these two probability figures to each alternative, considering all criteria under analysis, we obtain four decision maker profiles: optimistic-conservative (OC); optimistic-progressive (OP); pessimistic-conservative (PC); and pessimistic-progressive (PP).

Table 5: Composition of Probabilistic Preferences

Alternatives	OC	OP	PC	PP
A1	0,999999151	0,64927	0,65630	4,2711E-05
A2	0,999794587	0,30107	0,27674	3,4036E-07
A3	0,999997133	0,29075	0,65949	1,1251E-06
A4	0,999999301	0,37735	0,73525	5,0161E-06
A5	0,999999212	0,55908	0,61790	3,3888E-05
A6	0,999918621	0,20208	0,43097	1,6519E-07
A7	0,999999609	0,50236	0,75939	1,6830E-05
A8	0,999998415	0,33570	0,69010	2,2111E-06
A9	0,999999435	0,43960	0,73690	9,9226E-06
A10	0,999977796	0,38775	0,47935	9,6993E-07

Observing the OC profile, all the alternatives are equally good, i.e, the differences are practically imperceptible. Mathematically speaking, alternative A2 is the worst one. Considering the other profiles, the alternative A2, which represent the common mode considered in Brazil, is not observed among the best. In spite that, we can consider a mean profile for decision making. This mean profile is calculated through the mean probability of preference.

Table 6: Mean Probability of Preference

Alternatives	Mean Profile
A1	0,7685
A2	0,525869
A3	0,65008
A4	0,7042
A5	0,725662
A6	0,544322
A7	0,753916
A8	0,675266
A9	0,725498
A10	0,622361

Observing this mean profile, again the alternative A2 is not among the preferable. Reflecting that, considering the composition of probabilistic preference and measures of risk and eco-efficiency, the transportation of bio-ethanol by roadway lonely is not recommended.

5. Final Considerations and Suggestions

This paper proposed the use of the composition of probabilistic preference for ranking the transportation mode for bio-ethanol. This approach can be considered interesting because it considers the uncertainty in the preference ranking. These uncertainties are important because the data are not easily available, so it is important to carries them to the results and represent the preference through a probability figure.

The work presented shows how a structured approach can bring benefits to decision-makers in the selection of modes of transport of dangerous goods. The transport of ethanol has particularities that make it different from others in terms of evaluation, mainly by the volume transported and the environmental influences.

The pipeline transport is a better classification than the others by having low costs and lower environmental influences. Despite the initial investment for implementation of the pipeline to be high, with the high volume transported the recovery of that capital may be feasible with the operation.

Note that for the pipeline a good risk management can bring advantages due to its low probability of accidents. It is important to observe that roadway is not the preferable alternative, but still been the choice in Brazil. May be this can be explained by others measures not considered in the present work.

The eco-efficiency measures for a modal choice are a strategic alternative for organizations that want to improve their playing and contributing positively to the surrounding environment. By its flexibility, the method allows the eco-efficiency measures, including considerations of risk of accidents, are used, making it feasible for decision making.

A limitation is that the results presented here reflect only the case investigated. A more comprehensive and detailed work can better reflect reality and serve to other situations involving other dangerous goods.

For additional work is proposed to using of a wider network for the case of ethanol, other alternatives to disposal for export and domestic distribution. Nowadays the transportation of nuclear wastes is a very sensitive topic from an environmental angle. The proposed method could be appropriate in that case, for example. A sensitivity analysis of results in relation to weights and values used is recommended in a future work.

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