DISCRETE EVENT SIMULATION TO ASSIST IN THE DECISION MAKING PROCESS OF ROAD FREIGHT TRANSPORT

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ABSTRACT

The objective of this work was to verify how discrete event simulation can help decision making process in a logistics environment to make it environmentally sustainable. By reviewing the literature review, it could be possible to evaluate the progress of publications regarding transport and greenhouse gas emissions and the growing concern in developing ways to promote the green logistics system. Sixteen scenarios involving fleet type, fleet age, and driving style were simulated. Results displayed the emissions and transport time of those scenarios, in which each factor could be observed as it influenced the levels of emissions and time required for transport operations. Therefore, transport structures should not have their behavior generalized by one or another variable under analysis but from all the factors that compose it.

KEYWORDS: Transport, CO_2 Emission, Discrete Event Simulation.

Paper topic: L&T - Logistic and Transport

1. Introduction

Song et al. [2015] reported that there is increasing concern about Greenhouse Gas (GHG) emissions due to climate change and the need to develop policies to reconsider energy consumption. Bordonal et al. [2015] reinforced that the adjustment for energy consumption and the development of renewable energy mitigate environmental impacts, thus, promoting sustainable development.

Several sectors of logistics systems contribute to greenhouse gas emissions. Among them, the transport sector has a strong influence. Byrne et al. [2010] exposed that the efficiency in the transport sector requires a high frequency in material delivery flow, which causes variations in GHG emission rates. Regarding this issue, Richardson [2005] reinforced that there is a conflict between the benefits of the road transport, mainly by the truck fleet, and the burden associated with the environment, focusing on the emissions caused by the vehicle exhaust in different logistics systems.

Carbon dioxide is the greenhouse gas released in large quantities to the atmosphere. Then, studies have described that the emissions are becoming increasingly relevant [Jaegler and Burlat 2012]. In this regard, the works of Fioroni et al. [2013], and Rangel and Cordeiro [2015] can be highlighted. Both works applied Discrete Event Simulation (DES) to analyze the gas emissions from freight transport activities.

Concerning the importance of the transport sector and its high contribution to the GHG emissions worldwide, the DES is a tool able to promote the efficiency of the road freight transport. By using a DES model, it is possible to obtain a coherent analysis of a transport system, making it possible to understand the phenomena involved from the simulated scenarios [Arjona et al. 2001].

In light of this context, the problem is to find sustainable alternatives from an environmental perspective based on adjustments made in the road transport sector aiming at reducing GHG emissions. Therefore, this work demonstrates how the use of DES can serve as a supporting tool in decision making process in a logistics system in order to make it more environmentally sustainable and, at the same time, meet the needs of the market.

The article is organized as follows: Section 2 provides a literature review regarding the implementation of DES to promote environmental sustainability in the road transport sector. Section 3 describes the methodology used in the research, such as the system description, the simulation model and the experiment design applied. Section 4 presents the results, and section 5 exposes the concluding remarks.

2. Literature review

The literature review proposed to map the articles that previously addressed the environmental sustainability in the transport sector and the GHG emissions, identifying relevant issues within this approach. Moreover, it intended to identify and discuss directions of this field of study and understand potential contributions of the DES in the context of gas emissions.

The methodology was based on the work of Méxas et al. [2012], and the bibliographic database adopted was SCOPUS, which comprises, among other types of documents, articles from academic journals. Firstly, all articles published from 1960 to February 2018 were analyzed, including all areas of expertise available at the base: Life Sciences, Physical Sciences, Health Sciences, and Social Sciences & Humanities.

The bibliographic survey performed in February 2018, using Scopus database, employed the research terms *"discrete event simulation", "transport*",* and *"emission*"* investigated in titles, abstracts, and keywords. When entering the terms separately, they presented a significant number of articles published in journals, as illustrated in Figure 1. The term *"discrete event simulation"* was in 6,003 articles, *"transport*"* appeared in 1,474,810 articles, and *"emission*"* returned 882,814 articles. However, this research focused on articles that presented the three terms simultaneously. Thus, a new research conducted with the introduction of these terms together (*"discrete event simulation" AND* *"transport*" AND "emission*"*), also examined in titles, abstracts and keywords, returned 15 articles of which 11 were adequate after an analysis to verify similarities to the theme discussed. Table 1 provides the 11 articles, according to Scopus, which contents approach the subject of interest of this article.

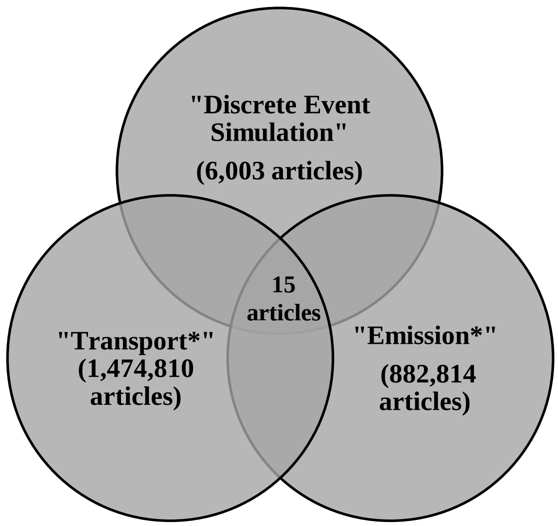

Figure 1: Number of articles returned by Scopus database from the research terms "discrete event simulation", "transport*", and "emission*".

Table 1: Articles returned by Scopus database from the research terms "discrete event simulation " and "transport*" and "emission*".

Title	**Journal**	**Author(s) / Year of publication**	**Number of citations**
Sustainable supply chain design: Capturing dynamic input factors	Journal of Simulation	Byrne et al. [2010]	9
Simulation-based analysis of personal rapid transit systems: Service and energy performance assessment of the Masdar City PRT case	Journal of Advanced Transportation	Mueller and Sgouridis [2011]	32
Carbon friendly supply chains: a simulation study of different scenarios	Production Planning & Control	Jaegler and Burlat [2012]	17
Hinterland operations of sea ports do matter: Dry port usage effects on transportation costs and CO_2 emissions	Transportation Research Part E: Logistics and Transportation Review	Lättilä et al. [2013]	33
Assessing the integration of torrefaction into wood pellet production	Journal of Cleaner Production	Mobini et al. [2014]	22
Free and Open-Source Software for sustainable analysis in logistics systems design	Journal of Simulation	Rangel and Cordeiro [2015]	3

Safety Enhancement and Carbon Dioxide (CO_2) reduction in VANETs	Mobile Networks and Applications	Santamaria et al. [2015]	5
Evaluating electric bus operation for a real-world BRT public transportation using simulation optimization	IEEE Transactions on Intelligent Transportation Systems	Sebastiani et al. [2016]	7
Proposal for a flexible discrete event simulation model for assessing the daily operation decisions in a Ro–Ro terminal	Simulation Modelling Practice and Theory	Iannone et al. [2016]	2
Simulation optimization for analysis of sustainable logistics systems	Pesquisa Operacional	Silva et al. [2017]	0
Analysis of greenhouse gas emissions in the road freight transportation using simulation	Journal of Cleaner Production	Marcilio et al. [2018]	1

The work of Byrne et al. [2010] was the first register in Scopus database that investigated environmental aspcts associated with simulation. The authors suggested the use of DES as a method to capture the dynamic nature of the Supply Chain (SC) operations and to assist decision makers to evaluate and design more environmentally-friendly SC. The goal was to quantify the trade-offs among cost, performance, and environmental impact, analyzing the effects of the operationa decisions regarding transport and their impact on the environment, service levels, and costs.

Mueller and Sgouridis [2011] designed a city model for zero-emission using a fully automated system for the demand of inter-municipal fast traffic by using an underground road network to transport passengers and goods. For that, a DES model was built in order to assist the design and implementation of a city using this innovative system. By simulation, it was estimated the impact of different algorithms of vehicle allocation, charge strategies of electric vehicle battery and their occupancy rates as well as anticipate the behavior of this system under adverse conditions. These models helped optimize the use of the fleet, the energy consumption and reduce the overall system costs.

Jaegler and Burlat [2012] concentrated their analyses on the emissions of CO_2 along the SC from the transport emissions to the inventory storage. A DES model was developed to simulate a three-way SC , with four tunable variables supplied: production capacity, locations, means of transport, and product types. Data were collected from a major manufacturer and distributor of ventilation and air conditioning systems. The purpose of the study was to compare the CO_2 emission levels under different configurations and scenarios, helping managers choose the most sustainable SCs.

Lättilä et al. [2013] emphasized that the reduction in CO_2 emissions is one of the most important tasks of the 21st century society. The authors believe that an alternative would be to use an inland intermodal terminal (dry ports). The study compared two configurations: in the first one, the loaders moved directly to a seaport; in the second configuration, they used dry ports. By assessing both systems using DES models, the authors considered two issues: the CO_2 emission levels and the costs to transport goods in different configurations. The results were compared to a scenario in which, instead of costs, emissions were minimized. Implications on a larger scale in regions where there are restrictions on sulphur emissions were also discussed.

Mobini et al. [2014] developed a hybrid model, DES with continuous simulation, in order to evaluate the integration of torrefaction in the production and distribution of wood pellet. The approach of dynamic simulation was applied to allow considering uncertainty, interdependence, and resource limitations throughout the SC, from the raw material sources to the distribution of final products. This model evaluated the cost of torrefied pellets delivered to various markets, the energy demand, and the CO_2 emissions, comparing them to regular pellets. In that case study, in a Canadian city, results showed that the integration of the torrefaction process led to a lower delivery cost to the current and potential markets and the reduction of the CO_2 emissions due to more efficient transport of the torrified pellets.

Rangel and Cordeiro [2015] pointed out how to calculate GHG emissions from the transports in logistics systems by DES. The modeling built in a free and open source software considered the discrete aspects associated with the transport systems, and the continuous elements referring to the CO emissions by the fleet. Simulations aimed at comparing the trade-offs between environmental and economic variables. Results showed there was no direct proportionality between the transport time and the total of emissions produced by trucks.

Santamaria et al. [2015] presented a cooperative architecture that enables vehicles to communicate among themselves and with an infrastructure connection. The authors suggested a protocol to get relevant data regarding the environment, such as collisions, traffic blocks, levels of emissions, and so forth. Besides, a smart traffic management system was approached in the proposed framework by authors to reduce the CO_2 emissions from vehicles. For validation, the authors applied a DES model with a dynamic mobility generator that permitted to alter control reference areas, area size, and freight rates.

Sebastiani et al. [2016] elaborated a DES model to evaluate the energy consumption of battery-powered electric buses. A mathematical model that considered different load and frictional forces was applied in a simulation optimization approach to minimize the number of load stations and the extra mean time of vehicle stopped to load. The data used in the simulation models were from public transport in Curitiba City including passenger demands, bus speed, and distance. Results showed different arrangements for the number of stations, location of stations and delay in bus timetables.

Iannone et al. [2016] elaborated a study, which aimed at evaluating the impact of manager decisions on the operational planning focusing on the moving vehicle. Because of the high complexity of the problem, mainly caused by the stochastic nature of variables involved, a DES model designed in Arena Rockwell was used. The terminal operations, operational decisions and costs involved in the terminal processes that are not formalized were described. The work assessed the economic impact of the different operational alternatives concerning logistics costs and GHG emissions.

Silva et al. [2017] performed an analysis of different logistics structure from a sustainable environmental perspective. A DES model associated with an optimization algorithm was proposed to provide the best answer to the problem. The tests were compared with a multicriteria model, in which similar results were found. Results presented a relation of direct proportionality between time transport, GHG emissions and lead time response variables.

Marcilio et al. [2018] studied the behavior of CO_2 emissions and transport time variables in lean manufacturing and green manufacturing in a road freight transportation system. They surveyed the influence of customers, drivers, and type of vehicles managed to help develop sustainable environmental strategies. DES models were applied to design the logistics scenarios to be examined. The main results indicated the importance of the customer behavior within the logistics process and the possibility of adjusting lean and green.

By reading the articles cited in this section, it was possible to identify the main issues approached by the actors on the issue of environmentally sustainable transport. Their analyses included the promotion of sustainable SC, use of electric vehicles, restructuration of logistics focusing on the reduction of GHG emissions among others. From 2010 to current times, there have been researchers interested and involved in issues concerning emissions. That has been not only in the theoretical field but also in the application of tools that can give a more realistic view of the issue, such as the use of DES, which can help understand the real behavior of transport and logistics system related to the GHG emissions. The first article found in Scopus database applying simultaneously the terms “discrete event simulation”, “transport*” and “emission*” was published in 2010. It was not registered by the base articles from previous years, suggesting that the issue has recent worldwide repercussions. On the other hand, the transport sector is the second largest GHG emitter, representing 23% of the world emissions, according to data from the International Energy Agency [2015]. In this context, the literature review presented had as objective to improve the understanding about the way researchers have approached environmental sustainability in the transport sector. Thus, it can be noticed their interest in elaborating strategies to control GHG emissions. This study was not focused on presenting a quantitative and conclusive result of this theme, but on using a bibliographical research to understand the trends of this field of study and be the basis of this article. Thus, it was concluded that the environmental sustainability in the transport sector offers a vast field of research, and that there is room for new studies to improve how to deal with this issue. Considering the approaches in the literature and the need for new analyses, this study suggested an experiment of aspects related to the fleet, such as the size and age of vehicles, and to the driver to see how the way he/she drives impacts on the environment; besides, the work linked the research to the use of DES. In other words, the purpose of this article was to introduce simulated scenarios of a road transport system by examining two important decision variables based on a literature review: the CO emissions and the transport time. Hence, it is believed that a restructuring of transport from aspects referred to the fleet and the driver can contribute to environmental sustainability.

3. Methodology

3.1. System description

In this work, the logistics system applied is on work of Ballou [2004]. According to Figure 2, that system can be presented in several formats to fit the needs of the operators involved. It was designed based on two criteria, speed and logistics costs, composing two different configurations.

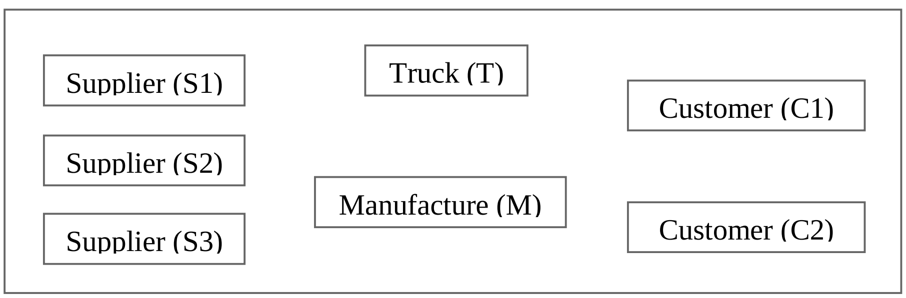

Figure 2: Illustration of the logistics system proposed to design the computational model [Ballou 2004].

3.2. Simulation model

Respecting Figure 2, two configurations usually used in the logistics and transport industries were elaborated. Configuration 1 stresses the lower time in the transport operations. In that configuration, a truck collects the products in every supplier and other one delivers the goods to each client. Thus, this configuration emphasizes the reach of the lowest time in the transports. Configuration 2 focuses on the reduction in transport costs for the suppliers and the clients, since only one truck is used to collect the goods in the suppliers and one truck is utilized to deliver the goods to the clients. Therefore, the aim is to achieve the lowest cost of transports.

Simulation models were developed in the Ururau 1.1 software, a Free and Open-Source Software (FOSS) that applies the Java Simulation Library (JSL) proposed by Rossetti [2008]. This software is based on the IDEF-SIM language used in the conceptual description of a simulation model. It is known as its flexibility in allowing the users to develop customized models by means of the direct change in the source code. Another difference is the template called Emissions, which is responsible for the calculation of carbon monoxide (CO) emissions in grams. This software is at http://ururau.ucam-campos.br/ [Peixoto et al. 2017]. Dagkakis and Heavey [2015] cited the Ururau for sustainable analysis in SC and emission calculation within a ranking of ten free DES softwares. Figures 3 and 4 demonstrate the computational models referring to configurations 1 and 2, respectively, and Table 2 shows their element description [Marcilio et al. 2018].

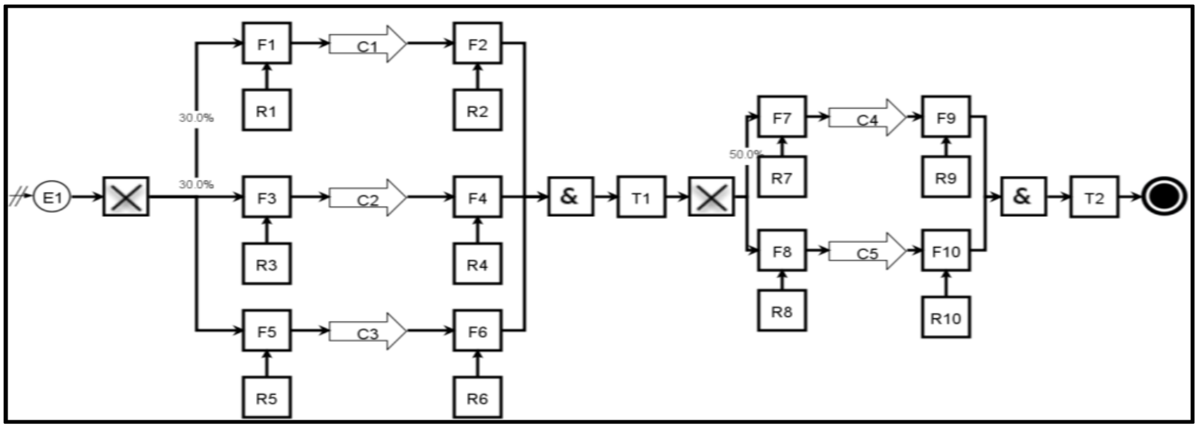

Figure 3: Computational model developed in the Ururau 1.1 software for configuration 1 [Ballou 2004].

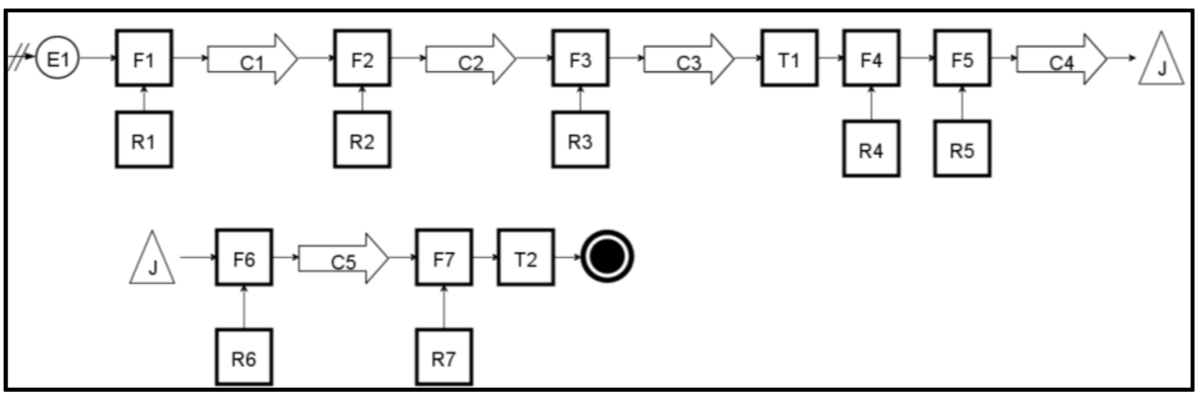

Figure 4: Computational model developed in the Ururau 1.1 software for configuration 2 [Ballou 2004].

Table 2: Element description of the computational models for configurations 1 and 2.

<table>
<tr><th>Module</th><th>Name</th><th>Description</th><th>Details of the models</th></tr>
<tr><td>Create</td><td>E1</td><td>Responsible for the creation of the entities</td><td>The entities come hourly and there is no limit for arrivals</td></tr>
<tr><td>Decision maker</td><td>X</td><td>Deviation of execution of pattern</td><td>The entity flows are divided by percentage between the possible routes</td></tr>
<tr><td>Loading</td><td>F1, F3, F5, F7 e F8 (conf. 1)
F1, F2, F3 e F5 (conf. 2)</td><td rowspan="2">Execute a process</td><td rowspan="2">The small vehicles have maximum capacity of 23,000 kg, and the large vehicles have maximum capacity of 56,000 kg</td></tr>
<tr><td>Unloading</td><td>F2, F4, F6, F9 e F10 (conf. 1)
F4, F6 e F7 (conf. 2)</td></tr>
</table>

Resource team for loading	R1, R3, R5, R7 e R8 (conf. 1) R1, R2, R3 e R5 (conf. 2)	Add a resource	The capacity is equivalent to 1
Resource team for unloading	R2, R4, R6, R9 e R10 (conf. 1) R4, R6 e R7 (conf. 2)		
Emissions	C1, C2, C3, C4 e C5	Calculates the emissions	The calculation of the emissions considers transport time, emission coefficient, power, freight and legal combined total whole weight
Accumulator	T1 e T2	Counts the entities	Variable that presents the quantity of entities that runs through the system

3.3. Analysis of experiment

The experiments were run in a randomized design with 2^k factorial structure, in which, according to Table 3, the treatments were the combinations of the two levels and k factors [Montgomery 2009]. Those treatments were evaluated considering configurations 1 and 2 proposed by Ballou [2004]. The factors chosen were Type of fleet (A) for suppliers or customers, Age of fleet (B), and Driving style (C), as they are frequently associated with GHG emissions. The levels for each of the factors were determined as follows: in factor A, they represent limit size and weight of the two types of fleet (small or large vehicles); in factor B, they refer to two fleet ages (new or old vehicles); in factor C, there is the driving style (standard or eco-driving).

Engine power and coefficients of emissions of the vehicles used in the modeling of scenarios are as follows: 1) engine power of the small vehicle of 136 kW and, for the large vehicle, of 265kW according to the owner's vehicle manual; 2) coefficient of emissions for new fleet of 1.5 g/kW·h and for old fleet of 2.1 g/kW·h, in agreement with the Air Pollution Control Program by Motor Vehicles (PROCONVE, in Portuguese); and 3) eco-driving style represented by standard power of the engine vehicle and standard driving style (aggressive style) with addition of 10% in the standard power of the engine vehicle.

Table 3: Simulated scenarios for configurations 1 and 2 [Ballou 2004].

Characteristics of the fleet			**Scenarios**	
Type of Fleet (A)	**Age of Fleet (B)**	**Driving Style (C)**	**Config. 1**	**Config. 2**
Supplier/Customer: Small	New	Eco	1	9
		Standard	2	10
	Old	Eco	3	11
		Standard	4	12
Supplier/Customer: Large	New	Eco	5	13
		Standard	6	14
	Old	Eco	7	15
		Standard	8	16

Notes: (A) power of vehicles (Small: 136 kW and Large: 265 kW) used for deliveries to suppliers or customers; (B) coefficients of emissions (CO - g/kW·h) of the vehicle fleets (New: 1.5 or Old: 2.1); and (C) style of standard driving refers to the power engine (+10%) and eco-driving (without increasing).

4. Results

The results presented in Figure 5 refer to simulations of CO emissions, in kgCO, of the eight scenarios of configuration 1 (scenarios from 1 to 8) and the eight scenarios of configuration 2 (scenarios from 9 to 16). It can be seen that the mean emissions correspond to the CO emissions; however, by analogy, it is possible to understand the behavior of the other gases.

Analyzing the results, it can be observed that the mean levels of emissions of the scenarios from 1 to 4 (configuration 1) and from 9 to 12 (configuration 2) are higher in relation to the scenarios from 5 to 8 (configuration 1) and from 13 to 16 (configuration 2) due to the factor A (type of fleet). In the two first cases, as the vehicles are smaller, it is necessary a larger amount of vehicles to run the system in order to transport an amount of load. The influence of this factor may affect all supply chain in both load flow and GHG emissions. Smaller vehicles tend to deliver inputs and products faster; however, they can increase transport costs and emit more GHG per kg transported when compared to vehicles with higher capacity of load.

Factor B (Age of fleet) also influenced the levels of emissions, since the newer vehicles emitted less GHG in both configurations. According to Figure 5, scenario 1 emitted less gas compared to scenario 3 as well as to scenario pairs 5-7, 9-11, and 13-15. Only the new vehicle fleet allows the GHG emissions be reduced during the transport. As most of the GHG emissions in the logistics process come from transport activities, the fleet renewal may help promote green logistics. Although replacing the vehicles generates costs, it has compensation for reducing maintenance costs and presenting better vehicle performance and safer transport. Thus, that is a long-term investment, which can bring both economic and environmental return.

Factor C (Driving style) also influenced emissions pointing out that a more ecological driving style can reduce them in both configurations as in scenario 1 compared to scenario 2, in which the first emits less GHG; the same happens to the scenario pairs 3-4, 5-6, 7-8, 9-10, 11-12, 13-14, and 15-16. It highlights the need the drivers be aware of how driving can reduce GHG emissions. From a business point of view, a more ecological driving style can make the company more sustainable with no additional logistics costs, except costs for awareness campaigns.

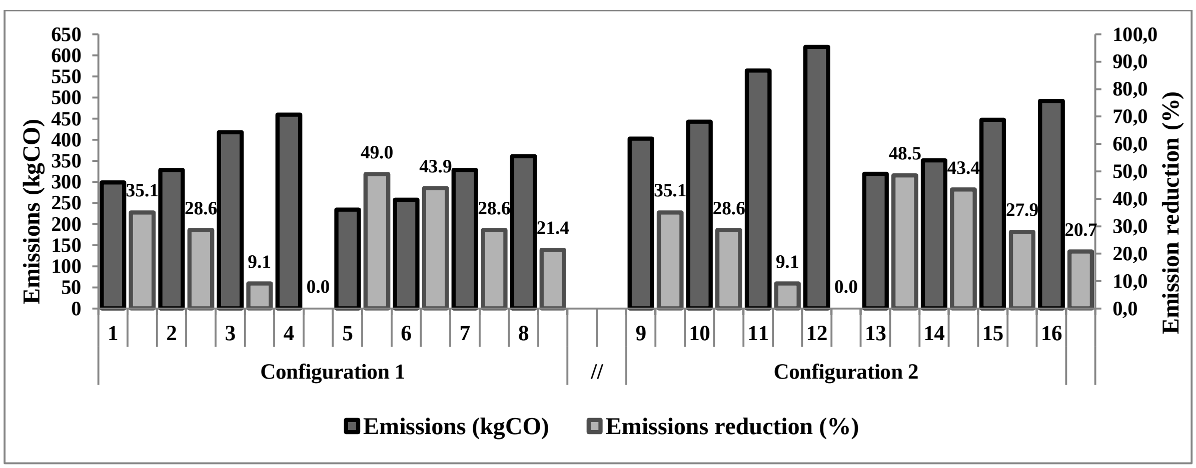

Figure 5: Means of the CO emissions and reduction percentage of the CO emissions of configurations 1 and 2.

In configurations 1 and 2, the scenarios 4 and 12 were the most pollutant. In both cases, they were small, old vehicles and with a non-ecological driving style. Thus, in configuration 1, the best scenario (5) was able to reduce almost 50% of emissions as well as, in configuration 2, the best scenario (13) reduced approximately 49% of its emissions. Such scenarios were created by large, new vehicles and driven under an ecological style.

The results referring to the simulations of transport time, in hours, the eight scenarios of configuration 1 (scenarios 1 to 8), and the eight scenarios of configuration 2 (scenarios 9 to 16) are in Figure 6. That transport time refers to the mean time spent by the vehicle to cover the track during simulations and meet all deliveries.

In configuration 1, the scenarios from 1 to 4, which vehicles are small, presented lower transport time (59.8 hours); that represented 34.8% of reduction compared to the scenarios from 5 to 8, which vehicles are larger. Configuration 2 shows scenarios from 9 to 12 (small vehicles) that presented a transport time equivalent to 92.3 h, while scenarios 13 to 16 (large vehicles) indicated a transport time of 110 h, that is, there was an increase of approximately 16% in time of transport operations.

In general, when large vehicles are driven, the emissions reduce due to the higher total capacity of load of each vehicle; however, the transport time increases mainly because of the need of longer time spent to loading/unloading at each stage of the process. On the other hand, when configurations are simulated using small vehicles, transport time reduces, as much displacement and loading/unloading can occur at the same time.

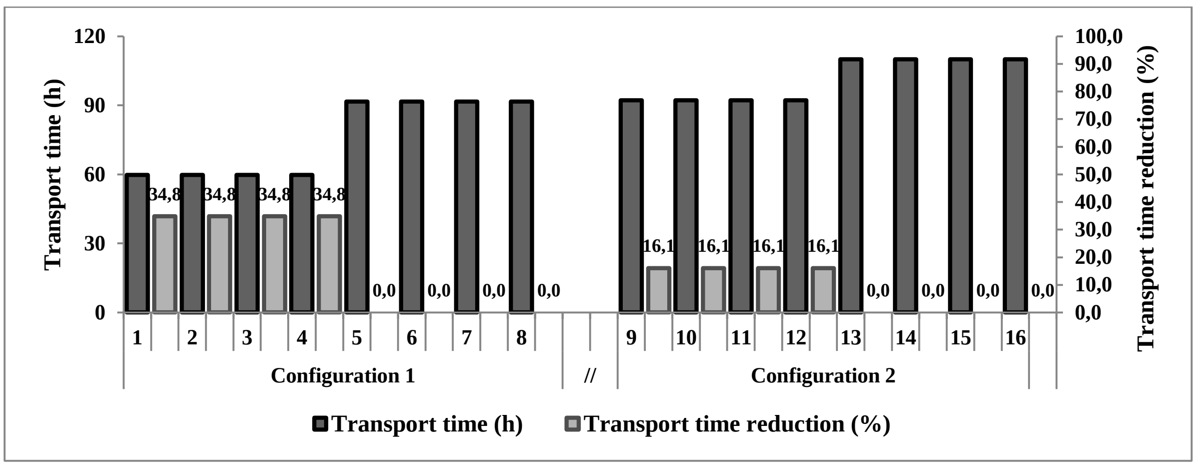

Figure 6: Mean of the transport time and percentage of reduction of transport time of configurations 1 and 2.

5. Concluding remarks

This work initially presented a bibliographic review of papers published in international journals indexed on Scopus database. After reading the articles returned from the database, it was possible to point out discussion topics and understand the current use of discrete event simulation to investigate possible improvements in supply chain sectors, such as transport.

The transport operations environmentally sustainable have been the focus of discussion and scientific research. It is a wide issue that covers the entire world, influences many business sectors, and makes a company more or less competitive regarding the importance given to sustainability.

In this context, the use of discrete event simulation can help the process of decision making in business, raising the issue to the most practical and realistic levels, with less investment when compared to the costs caused by the employment of other techniques as tests using real vehicles. Therefore, simulation can also contribute as a testing environment to obtain the nature and behavior of other variables of logistics systems underexplored, like the relation among mass transported, fuel consumption, type of vehicle, type of product, delivery time, and so on.

In thinking about the greenhouse gas emission issue, this work aims at showing that there is room for energy efficiency associated with the fleet management depending on the form of the distribution of goods. That is to say, it is essential to find the right balance between satisfying the needs of intermediate and/or final consumers to the shorter time that he/she expect to get a product and the necessity of sustainability issues, which is becoming more and more evident in the demanding market. There has been an environmental contribution from the relation between business managers and customers that can be improved. The behavior of customers may play a greater role in manager decisions and then establish actions that meet their needs and lead to their necessities in the distribution of goods. If customers do not contribute in any decision, the trend will be the increase in gas emissions as a result of receiving goods at a lower time, which generates greater gas emissions.

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