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Analysis of greenhouse gas emissions in the road freight transportation using simulation

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ABSTRACT

The objective of this paper was to analyze the behavior of environmental and performance variables in the Lean Manufacturing versus Green Manufacturing context in a road freight transportation system. Thus, a survey analysis was carried out by applying a satisfaction questionnaire to evaluate the customers, workers and managers perception concerning some environmental issues. It was verified the possibility for managers to develop different sustainable strategies considering the type of commercial vehicle available in the company, the vehicle age and the eco-driving behavior among drivers. Discrete Event Simulation was also applied to investigate the behavior of typical scenarios of transport operations in the Supply Chain encompassing greenhouse gas emissions and transport time of operation routes. In order to verify which factors most influenced the emissions, an experimental project using simulation models was employed. Investigating the results, it could be seen that the behavior of the transport structures cannot be generalized, as different scenarios had different results on the performance of the Supply Chain when analyzing factors such as Types of delivery fleet, Age of the fleet and Driving style. It was also identified that some simulations that present low emission have greater transport time. Thus, the green consumer behavior will carry greater weight on manager's decisions; this way, actions that meet the lean and green can be established in a way that both practices can add value to eco-efficiency or greater sustainability to the Supply Chain.

1. Introduction

Data provided by the World Energy Outlook (2015) have demonstrated a possible decoupling between economic expansion and greenhouse gas (GHG) emissions at a global level for the second year in a row (2014 and 2015). This seems to demonstrate that mitigation measures internationally adopted have been working to reduce the growth of those emissions. Therefore, that information may represent a progress in terms of sustainability, as the carbon dioxide (CO_2) is the gas with the highest rate of emission compared to others such as methane (CH_4), nitrous oxide (N_2O) and sulphur dioxide (SO_2) (Dekker et al., 2012).

Within this context, it is important to highlight that the transport sector is primarily responsible for global emissions of CO_2, according to the report provided by the International Energy Agency (2015). The report noticed that the transport sector was responsible for the second largest amount of GHG emission in 2013, with a participation equal to 23% of total global emissions, just below the electric and heat sector, which represent together 42% of the emissions. However, in the transport sector, at the same period, 75% of the emissions were relative to the participation of the road transport.

Focusing on the road transportation sector, there is an intense contribution to energy efficiency especially of the Supply Chain (SC) as it is used for the feedstock movement and flow of the manufacturing production (Saif and Elhedhli, 2016). In this respect, there is a relationship between the SC and the transport sector particularly in the Lean Manufacturing (LM) due to the need to provide the appropriate amount of material at the right time. Nevertheless, the LM contributes significantly to the GHG emissions in the SC (Bergenwall et al., 2012).

In view of this, researches have shown that LM versus Green Manufacturing (GM) have been investigated to verify what are the advantages and/or difficulties when using those techniques, and to evaluate the correlation between them in the GHG emission scenario (Dües et al., 2013). LM models may cause an increase in emissions in specific situations as they increase the frequency of transports. In contrast, the inventory practices managed by the supplier may minimize those emissions in the SC (Ugarte et al., 2016). This way, modifications in the structure of logistics systems and SC can help reduce the GHG emissions with no investments in new technology, but only with changes in the existing operational structures.

Thus, the objective of this work was to analyze the behavior of environmental and performance variables in the LM and GM context in a road freight transportation system. The Discrete Event Simula-

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tion (DES) was applied to investigate the behavior of typical scenarios of SC, which covered the transport operations involving GHG emissions. The information was related to a field research conducted by means of a satisfaction questionnaire to evaluate the customers' perception with respect to environmental issues, and to verify the viability of managers to create sustainable strategies with the help of information obtained from the customers.

The work is structured as follows: Section 2 presents an overview of some issues that are the basis and justifies the research purpose. section 3 describes the system under consideration. section 4 presents the materials and methods used in the work, such as the formulation and application of the questionnaires, the experimental model proposed and statistical design applied. Section 5 illustrates the main results and the discussions pertinent to the theme. Finally, section 6 highlights the conclusions and recommendations for future researches.

2. Review of lean versus green on supply chain management and logistics

Lean Manufacturing can be characterized as a series of systematized operations focused on the disposal of waste in manufacturing process. Some practices have been listed in the set that constitutes the LM, such as Just in Time, Total Productive Maintenance and Total Quality Management (Yang et al., 2011). Another definition employed for the LM describes it as a set of practices, which main objective is to reduce unnecessary activities and waste in the whole value chain (Govindan et al., 2014).

Green Manufacturing can be defined as a practice of ecological dimensions in different planning levels in SC (Fahimnia et al., 2015). A more specific definition (Domingo and Aguado, 2015) reports GM as a manufacture of products with potential to aggregate long-term benefits for the environment, while maintaining the quality of the product.

The SC operations that include the lean and green principles have been the subject of many studies interested in the impacts of those logistics practices on the environment. Ugarte et al. (2016) have raised two research hypotheses about what are the impacts on the GHG emissions in an approach based on lean and green. The first case suggested that it might have an increase of GHG emissions related to the increase of transport frequency. The second one proposed that the inventory management practices by the supplier could decrease the emissions because of the increase of flexibility of the SC due to the supply and demand uncertainties.

Fahimnia et al. (2015) present an exploratory analysis, which investigated some critical issues involving the discussion about lean versus green at a tactical level of planning. Results showed that although some lean practices cause green results, especially with waste and lead time reduction, not all lean practices at a tactical level are in line with green results. Authors also highlighted that a strictly lean situation is presented as a disadvantageous alternative in terms of sustainability if it is employed in a non-flexible Supply Chains. Under environmental aspects, it would be preferable a less lean situation in a more flexible SC system.

Bergenwall et al. (2012) reported that sustainable development involves the relation between LM and environmental performance, suggesting that the exchanges between them may involve the construction of cumulative capabilities by means of sequential and simultaneous development. The research also discussed the need to evaluate the LM topic considering a Triple Bottom Line (TBL) analysis, that is, think about that issue from an economic, social and environmental dimension. That suggests investigating which lean aspects meet the green from a TBL analysis.

Miller et al. (2010) carried out a case study applying DES, demonstrating a more significant positive impact when the lean and green measures were applied concomitantly. Studies demonstrated that the lean transcends the green. As an example, lean practices on stock reduction and on production rates reduce the energy consumption, or the reduction in the number of suppliers make the Supply Chain more sustainable, as it reduces the amount of transport. In those cases, the lean measures adopted consequently brought green benefits.

While the LM practices focus on how to improve operations and reduce waste under the customer's point of view, GM practices have a perspective that may benefit the environment, the manufacturers and the customers. Lean and green may provide competitive advantages and profits in the SC when associated (Verrier et al., 2014). In both practices, the logistics and transport operations are substantially affected. They can be seen as object of study, capable of being structurally modified to possible reductions of GHG emissions.

3. System description

This research considered the analysis of a typical system of SC emphasizing the respective logistics operations. According to Byrne et al. (2010), SC structures have undergone changes and interventions of techniques such as LM, among others, that have represented a redesign of the traditional SC structures. In this regard, the authors highlight the increase of the complexity level of that system and the focus noticed in their transport operations. Rangel and Cordeiro (2015) also used that system applying computational simulation to aid the decision making referred to environmental and economic aspects. To this work, that system was composed of three raw material suppliers, a manufacturer, two customers, which can be intermediate or final, and trucks for the load transport.

According to Ballou (2004), this system can have different configurations typically used in road logistics, each with different emphasis, which can be verified by the variation among the respective configurations. In configuration 1, the emphasis consists of the speed on the transport operations as one truck is used for each supplier to transport products directly to the manufacturer. The same way, the speed of delivery of finished products is prioritized, using trucks for each customer to reduce Transport Time (TT), which corresponds to the period between the loading of the vehicle in the suppliers' plant and its unloading at the customers. Configuration 2 focuses on the minimization of transport cost from both the supplier and the customer. That is why it is only used one truck, which drives around each of the suppliers to collect goods and transport them to the manufacturer; another one is utilized to deliver the finished product in each of the customers in sequence (Fig. 1).

4. Materials and methods

The costumers' behavior on the environmental issues reflects their way of thinking, directly influencing all society. Each person contributes to GHG emissions in several ways, which has been leading to climate changes. Knowing the perception of the customers about the emissions reveals their level of awareness and contributes to provide a macro view to the managers and researchers on how society sees environmental problems, thus, contributing to the implementation of mitigation policies (Alessandrini et al., 2012). In this context, the customers' behavior and needs may influence the logistics operations of Supply Chain, and, consequently, affect the GHG emissions. Thus, it

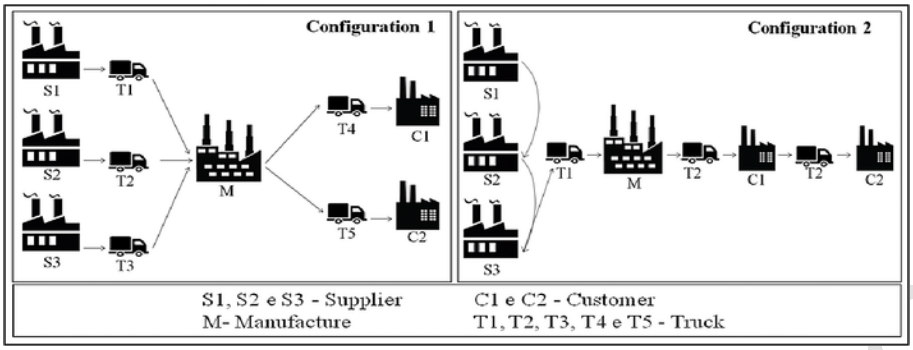

Fig. 1. Layouts typically used in transportation and logistics industries, according to Ballou (2004): configuration 1 - emphasis on lower TT, and configuration 2 - emphasis on lower cost to the supplier or consumer.

was proposed to examine the behavior of the customers as a possible analysis tool for decision making of managers, who try to make their businesses competitive yet remaining sustainable.

4.1. Design and implementation of questionnaires

The application of questionnaires intended to investigate the environmental perception of customers about GHG emissions in automobile vehicles. A data collection was carried out to provide information about that issue by applying a quantitative questionnaire containing 11 questions about environmental perception of the interviewees concerning the emissions from road freight vehicles.

The theoretical survey included themes that contributed to comprehend the matter researched. The questionnaire was elaborated from issues addressed in several articles related to environmental and sustainable questions. Among them, Richardson (2005), Rangel and Cordeiro (2015) and Qian and Eglese (2016) can be cited.

The content of the questions corresponded to aspects that characterize the level of awareness of customers by means of their actions, intentions and perceptions. Closed-ended questions, closed-ended/open-ended questions, dependent questions and multiple-choice questions were considered. The closed-ended questions on intentions and perceptions were elaborated with alternatives in gradation, that is, with the use of the scale of five points (Likert, 1932), according to Table 1.

During the field research, 136 people were interviewed in Campos dos Goytacazes, a medium-sized municipality (approximately 500,000 inhabitants) located in the countryside of Rio de Janeiro State. The data collection was made between February and March 2016 in five groups of people: Group I corresponds to ordinary people interviewed downtown, characterizing a diversity of customers' profile in general population (N = 30); Group II is composed of university students interviewed in one of the universities of the municipality, identifying the profile of academic awareness (N = 30); Group III consists of bus drivers interviewed in their work places and in bus stops presenting the profile of public transport (N = 30); and, classifying the profile of the freight transport sector, Groups IV (N = 30) and V (N = 16); Group IV is composed of truck drivers that were interviewed in fuel stations at several places in town, and Group V, logistics professionals interviewed in freight transport companies. In all cases, the interviewer was responsible to fill in the questionnaires. Table 2 presents some information about gender, marital status, age and education of the interviewees belonging to the five groups.

Table 1
Likert scale adopted in the questionnaires.

Scale	Content Issues	
	Questions regarding intention	Questions regarding perception
−2	Certainly not	Very low
−1	Probably not	Low
0	Maybe yes, maybe no	Regular
+1	Probably yes	High
+2	Certainly yes	Very high
N	I do not know/I would prefer not to give my opinion	I do not know/I would prefer not to give my opinion

4.2. Experimental modeling

The computational models designed in this research followed the methodology proposed by Banks et al. (2010), where the following steps were applied: formulation and analysis of the problem; elaboration of the conceptual model; elaboration of the simulation model; verification and validation; experimentation and interpretation; and

Table 2
Characterizing the public interviewed.

Feature	Options	Groups - response rate (%)					Total (=N)
		I	II	III	IV	V	
Gender	Male	14.0	14.0	32.3	32.3	7.5	93
	Female	39.5	39.5	–	–	20.9	43
Marital status	Not married	25.8	45.2	14.5	4.8	9.7	62
	Married	19.7	2.8	25.4	38.0	14.1	71
	Separated	–	–	100.0	–	–	3
Age group	under fifteen years old	–	–	–	–	–	–
	15 ⊢⊣ 19	45.5	54.5	–	–	–	11
	20 ⊢⊣ 24	23.7	52.6	7.9	5.3	10.5	38
	25 ⊢⊣ 29	22.7	18.2	9.1	13.6	36.4	22
	30 ⊢⊣ 39	16.7	–	50.0	25.0	8.3	24
	40 ⊢⊣ 49	13.0	–	8.7	69.6	8.7	23
	50 ⊢⊣ 59	8.3	–	66.7	25.0	–	12
	60 ⊢⊣ 69	40.0	–	60.0	–	–	5
	70 ⊢⊣ 79	100.0	–	–	–	–	1
	≥80 years old	–	–	–	–	–	–
Education level	IPE	–	–	75.0	25.0	–	8
	CPE	7.1	–	71.4	21.4	–	14
	PHS	13.3	–	6.7	80.0	–	15
	CHS	29.7	–	35.1	24.3	10.8	37
	HS	25.8	48.4	–	6.5	19.4	62

Notes: I-General public, II-University students. III-Bus drivers, IV-Truck drivers, V-Logistics professionals, IPE-Incomplete Primary Education, CPE-Complete Primary Education, PHS-Incomplete High School, CHS-Complete High School and HS-Higher Education.

statistical analysis of data. The verification and validation of the models followed the steps suggested by Sargent (2013).

The first step to construct the computational models consisted of analyzing the structure of the system and the data needed to develop models able to present reliable results and maintain the system behavior. Thus, both the diversification of the vehicle capabilities and their respective characteristics, distance variation between suppliers, manufacture and customers, and the variation in loading times, were kept. In this work, it was not considered neither the kind of load transported nor the variations in speed during the vehicle routes. The models were run the Ururau 1.0 software, a Free and Open Source Software (FOSS) that uses the Java Simulation Library (JSL), an open-source object-oriented library, proposed by Rossetti (2008). More information about the software can be found at http://ururau.ucam-campos.br/ or in Peixoto et al. (2016).

The simulation models run in a Dell machine with ADM Athlon ™ 64 X2 Dual Core Processor 4200 + 2.20 GHz, Operational Windows 7 Professional 64 bits System. The execution time of simulation processed by the machine was of 12 s.

Figs. 2 and 3 illustrate the computational models used to represent the configurations proposed by Ballou (2004), seen in Fig. 1. The parameter descriptions applied can be found in Appendix A. Module E1, to the left, is responsible for the creation of the entities, in this case, the freight vehicles. The modules beginning with letter F correspond to the loading of material in the suppliers' plant in order to deliver it to the manufacturer, and the loading of the finished products in the manufacturer to be delivered to the customers; also correspond to the unloading of materials in the manufacture and to the unloading of the finished products in the customers. The modules beginning with letter R represent the resources or work teams with workers or machines used to loading and unloading of material or finished products. The modules that begin with letter C have the function of calculating the emissions originated from the transport operations. T1 and T2 are responsible for counting the entities that run the system. The X module operates as a decisor to direct the flow of vehicles in function of a specific condition satisfied. Finally, the J module works to dislocate the vehicles from one place to the other; in this case, its employment comes from a better adjustment to the layout of the screen of the software.

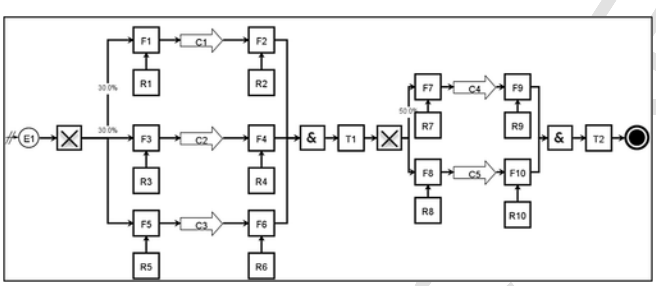

Fig. 2. Computational model developed in the Ururau 1.0 software for configuration 1 (Ballou, 2004).

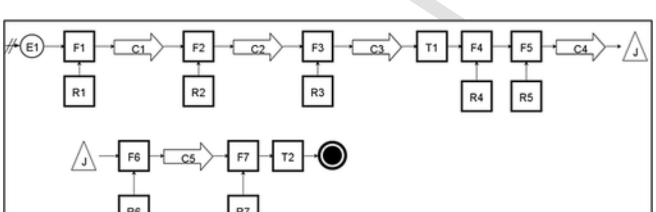

Fig. 3. Computational model developed in the Ururau 1.0 software for configuration 2 (Ballou, 2004).

4.3. Statistical design and analysis

The experiments were conducted in a complete randomized design with factorial structure 2^k, where the proceedings were the combinations of the two levels and k factors (Montgomery, 2009). Their combinations were evaluated according to the configurations 1 and 2, proposed by Ballou (2004). The chosen factors were Types of delivery-fleet (A) to suppliers or customers, Ages of fleet (B), and Driving style (C) because they are frequently associated with GHG emissions. The levels for each of the factors were chosen as follows: In factor A, levels represent size and weight limits for two types of fleet-vehicles (small or large); factor B refers to two ages of fleet-vehicles (new or old); and factor C are driving styles of drivers (standard or eco-driving). The experimental project was divided into two phases: 1) 16 simulations of scenarios with only one type of fleet (small or large); and 2) 16 simulations with mixed fleet (small and large). Four replications were applied in those experiments, each one with 35 sample elements, totalling 40 elements for each simulated scenario in simple fleet and 140 elements in mixed fleet (Table 3).

The power and emission coefficients of the vehicles used in the modeling of the scenarios were: 1) power of the small vehicle motor of 136 kW and to the large vehicle of 265 kW, according to the instruction manual for the vehicles; 2) emission coefficients to new fleet of 1.5 g/kW·h and to old fleet of 2.1 g/kW·h, according to the Brazilian Program of Air Pollution Control from Automotive Vehicles (PROCONVE, Brazil); 3) Eco driving style represented by the standard power of the vehicle motor and standard driving style (more aggressive) with addition of 10% in the standard power of the vehicle motor.

The data obtained from the response variables EM (kgCO) and TT (h) were submitted to analysis of variance at the level of 99% of reli-

Table 3
Simulated scenarios to the configurations 1 and 2 (Ballou, 2004) with simple and mixed fleet.

Phases	Features of the fleet			Scenarios	
	Delivery-fleet (A)	Ages (B)	Driving style (C)	Configuration 1	Configuration 2
Single Fleet	Supplier: Small Customer: Small	New	Eco	1	9
			Standard	2	10
		Old	Eco	3	11
			Standard	4	12
	Supplier: Large Customer: Large	New	Eco	5	13
			Standard	6	14
		Old	Eco	7	15
			Standard	8	16
Mixed Fleet	Supplier: Small Customer: Large	New	Eco	1	9
			Standard	2	10
		Old	Eco	3	11
			Standard	4	12
	Supplier: Large Customer: Small	New	Eco	5	13
			Standard	6	14
		Old	Eco	7	15
			Standard	8	16

Notes: (A) power of the vehicles (Small: 136 kW and Large: 265 kW) used for delivery to suppliers or customers; (B) emission coefficients (CO-g/kW.h) of fleet vehicles (new: 1.5 or old: 2.1); and (C) standard driving style referring to the power of motor (+ 10%) and eco driving (without increases).

ability, with prior verification of the presumptions of homoscedasticity and normality of the errors by means of Cochran & Bartlet e Lillifors tests (Montgomery, 2009), respectively. After the analyses, it was verified that the EM variable presented data with homogeneity and normality, while the TT variable obtained heterogeneous errors, distinguishing two groups that will be presented subsequently. The descriptive analysis of the EM variable was carried out by means and standard deviation, being the comparisons of means executed by the Tukey Test (P ≤ 0,05). The statistical model adopted can be observed in Equation (1).

$$y_{ijk} = \mu + \alpha_i + \beta_j + \delta_k + (\alpha\beta\delta)_{ijk} + e_{ijkn.,} \quad (1)$$

where.

μ = constant;
αi = effect of the i-th level of factor A; i = 1, …, a;
βj = effect of the j-th level of factor B; j = 1, …, b;
δk = effect of the k-th level of factor C; k = 1, …, c;
(αβδ) = effect of the interaction between the i-th level of factor A, j-th level of factor B, and k-th level of factor C;
*e*ijkn = error associated to the i-th level of factor A, j-th level of factor B, k-th level of factor C, and the n-th repetition n = 1 …, r;
For the errors, it is assumed that *e*ijkn has adherence to the normal distribution $(0, \sigma^2)$.

5. Results and discussion

5.1. Questionnaire

According to the alternatives proposed, the mean results in relation to the interviewees' awareness about what are the responsible sources for the GHG emissions are: vehicles, 85.29%; industries, 92.65%; animals, 19.12%; agricultural activities, 19.85%; others, 1.47%; and incorrect or do not know any response, 0.74%. The most cited items by all groups were industries and vehicles, which demonstrates that, regardless of the group studied, both are seen as the major sources of pollution that cause the greenhouse gas emission (Table 4).

The interviewees' choice to shop online, which transport operations to deliver emits lower GHG emissions, was related to the acquisition cost. The objective was to see whether the interviewees were environmentally sensitive and able to take decisions considering sustainability. The purpose was to understand how the price variation of the product would affect those interviewees' decisions. Results showed that, in case they knew they could choose for a transport that generated lower emission, most of the interviewees would pick out the one that emitted less pollution as long as it might not alter the original price of the product (56.62%) (Table 5).

Table 4
Interviewees' perception about the responsibles of the GHG emissions.

Group	Response rate (%)					
	Vehicles	Industries	Animals	Agriculture	Others	Undecided
I	93.33	96.67	20.00	16.67	0.00	0.00
II	90.00	90.00	16.67	30.00	3.33	0.00
III	73.33	90.00	16.67	13.33	0.00	3.33
IV	76.67	90.00	20.00	6.67	3.33	0.00
V	100.00	100.00	25.00	43.75	0.00	0.00
Mean	**85.29**	**92.65**	**19.12**	**19.85**	**1.47**	**0.74**

Note: Undecided refers to incorrect responses or do not know any of them.

Table 5
Preference for logistics operations with lower GHG emissions in relation to the cost.

Group	Opinions - Response rate (%)					
	A	B	C	D	E	Total
I	3.33	0.00	30.00	43.33	23.33	100.00
II	3.33	20.00	20.00	50.00	6.67	100.00
III	13.33	3.33	13.33	53.33	16.67	100.00
IV	3.33	6.67	16.67	63.33	10.00	100.00
V	0.00	12.50	0.00	87.50	0.00	100.00
Mean	**5.15**	**8.09**	**17.65**	**56.62**	**12.50**	**100.00**

Notes: Opinions of interviewees: A-No, even without price change, B-No, because of the price change, C-Maybe yes, maybe no, D-Yes, provided they do not alter the price, E-Yes, even with price increase.

The interviewees' preferences for buying online, in which transport of products emits lower GHG, was also related to delivery time. Answers revealed that most of the interviewees of Groups II, III, IV and V would choose the transport more environmentally appropriate since it did not alter the initial delivery time of the product. In Group I, the percentage of people that would wait longer for the product delivery exceeded the ones that would not, with percentages of 30% and 23.33%, respectively. In general, that analysis compared to the previous one (which main issue was the cost) proved greater flexibility of the groups in waiting longer for delivery (Table 6).

The questionnaires presented people's awareness of the issue and investigated their behavior on sustainable questions perceiving preferences and priorities. That survey provided a view on the potential influence of people's decisions in the functioning of the logistics systems, showing how each person contributes to GHG emissions in the road freight transport. There are indications that people have knowledge about GHG and its sources but they are not sensitive enough to sustainable questions due to their personal preferences mainly related to economic aspects. However, a deeper view could show that there is a small number of people that would be able to choose a less aggressive alternative to the environment, considering buying products which emissions would be lower during transport even if it takes more time or costs more. From this perspective, there is an opportunity to make consumers consider their contribution for the emission reduction at the time of buying. From lean versus green point of view, it is important to investigate the influence of those practices in the logistics systems of road freight transport focusing on GHG emissions.

5.2. Simulated scenarios

The results relating to the EM and TT simulated for each of the scenarios according to configurations 1 and 2 of Ballou (2004) are in

Table 6
Preference for logistics operations with lower GHG emissions in relation to the delivery time.

Group	Opinions - Response rate (%)					
	A	B	C	D	E	Total
I	6.67	0.00	40.00	23.33	30.00	100.00
II	3.33	16.67	20.00	56.67	3.33	100.00
III	3.33	3.33	6.67	56.67	30.00	100.00
IV	6.67	0.00	23.33	63.33	6.67	100.00
V	0.00	6.25	18.75	43.75	31.25	100.00
Mean	**4.41**	**5.15**	**22.06**	**49.26**	**19.12**	**100.00**

Notes: Opinions of interviewees: A-No, even if the delivery time was kept; B-No, because the delivery time would be longer; C- Maybe yes, maybe no; D-Yes, as long as it did not alter the delivery time; E-Yes, even with the rise of the delivery time.

Table 7. It can be seen that the EM means are expressed in kgCO because of the ease in calculating them; however, it is possible to understand by analogy the emission behavior of the other gases. The TT response variable refers to the mean time spent by the vehicle to drive the route during the simulations and meet the deliveries.

Considering the single fleet in configuration 1, the scenarios from 1 to 4 represent the small vehicles; this is why they presented lowest TT (59.80 h) that represented 34.80% of reduction in relation to the scenarios from 5 to 8, which represented large vehicles. The EM (kgCO) observed in the scenarios 1 (298.56 ± 0.08), 2 (328.42 ± 0.09), 3 (417.99 ± 0.12), and 4 (459.79 ± 0.13) were significantly different according to the statistical analyses carried out (Tukey, $P \leq 0,01$), as shown in Fig. 4 (configuration 1). It is also checked in this figure that the eco-driving style reduced the EM between scenarios 1 and 2 as well as between scenarios 3 and 4. Therefore, it is concluded by those four first simulations that the customer's decision is relevant, that is, if the customer has urgency of delivery, scenario 1 is the one that causes lower EM, a reduction of 35.07%, when using simple fleet with small, new, eco-driving vehicles.

Table 7
Mean EM (Mean, kgCO) from fleet-vehicles and TT (Mean, h) obtained in scenarios simulation to the configurations 1 and 2 (Ballou, 2004).

Phases	Configuration 1					Configuration 2				
	SS	EM (kgCO)	↓ EM (%)	TT (h)	↓ TT (%)	SS	EM (kgCO)	↓ EM (%)	TT (h)	↓ ((
Single Fleet	1	298.56	35.07	59.80	34.80	9	402.83	35.06	92.26	1
	2	328.42	28.57	59.80	34.80	10	443.11	28.57	92.26	1
	3	417.99	9.09	59.80	34.80	11	563.96	9.09	92.26	1
	4	459.79	0.00	59.80	34.80	12	620.35	0.00	92.26	1
	5	234.62	48.97	91.72	0.00	13	319.29	48.53	109.99	0
	6	258.08	43.87	91.72	0.00	14	351.22	43.38	109.99	0
	7	328.46	28.56	91.72	0.00	15	447.01	27.94	109.99	0
	8	361.31	21.42	91.72	0.00	16	491.71	20.74	109.99	0
Mixed Fleet	1	284.37	35.06	85.43	0.00	9	394.15	35.06	103.88	0
	2	312.81	28.57	85.43	0.00	10	433.56	28.57	103.88	0
	3	398.12	9.09	85.43	0.00	11	551.81	9.09	103.88	0
	4	437.93	0.00	85.43	0.00	12	606.99	0.00	103.88	0
	5	223.97	48.86	79.07	7.44	13	323.65	46.68	103.86	0
	6	246.37	43.74	79.07	7.44	14	343.76	43.37	103.86	0
	7	313.56	28.40	79.07	7.44	15	404.10	33.43	103.86	0
	8	344.91	21.24	79.07	7.44	16	432.25	28.79	103.86	0

Notes: SS - simulated scenarios; EM - CO emissions (kgCO); ↓ EM - percentage reduction of CO emissions; TT - transport time (h); ↓ TT (%) - percentage reduction of TT.

On the other hand, in case the customer does not have urgency, regarding the delivery, or agrees in receiving the product with greater TT and lower EM, the scenarios from 5 to 8, with large vehicles, assume relevance in decisions taken by the manager. The EM observed in the scenarios 5 (234.62 ± 0.01), 6 (258.08 ± 0.01), 7 (328.46 ± 0.02), and 8 (361.31 ± 0.02) presented in Fig. 4 (configuration 1) differ from new vehicles used in the scenarios 5 and 6, to old vehicles used in scenarios 7 and 8. Among them, the eco-driving style provided, again, significant mean differences (Tukey, $P \leq 0.01$), and the scenario 5 was able to reduce in almost 50% the EM.

The overall conclusion for the single fleet in configuration 1 is that the logistics companies should adopt the eco-driving style as an indicator of business sustainability, and that the customer should be educated in order that, whenever possible, he/she opts by deliveries with low EM even if the TT is higher. The manager shall promote gradual processes of depreciation of the costs of freight, planning its fractional substitution over time in a way that most of the freight is always new. It is important that the small vehicles are only used in emergency cases; therefore, they should constitute the smallest parcel of the freight.

In the analysis of the single fleet in configuration 2, observed in Table 7, the values of the scenarios 9, 10, 11, and 12 (small vehicles) presented TT of 92.26 h, and the scenarios 13, 14, 15, and 16 (large vehicles) presented TT of 109.99 h, that is, an increase of 16.12%. In relation to the EM, the small vehicles presented higher values than the larger ones, according to the data obtained from the scenarios 9 (402.83 ± 0.01), 10 (443.11 ± 0.01), 11 (563.96 ± 0.01), and 12 (620.35 ± 0.02) corresponding to small vehicles, and to the scenarios 13 (319.29 ± 0.06), 14 (351.22 ± 0.06), 15 (447.01 ± 0.08), and 16 (491.71 ± 0.09) for larger vehicles. The scenario with lower EM of configuration 2 in single fleet also used new, large, eco-driving vehicles; however, they presented higher TT (scenario 13).

In general, for single fleet in both configurations, when using larger vehicles, the EM decreases due to the higher total load capacity of each vehicle; however, the TT increases mostly because of the necessity of a higher time spent on loading in each step of the process. On the other hand, when configurations are simulated applying small

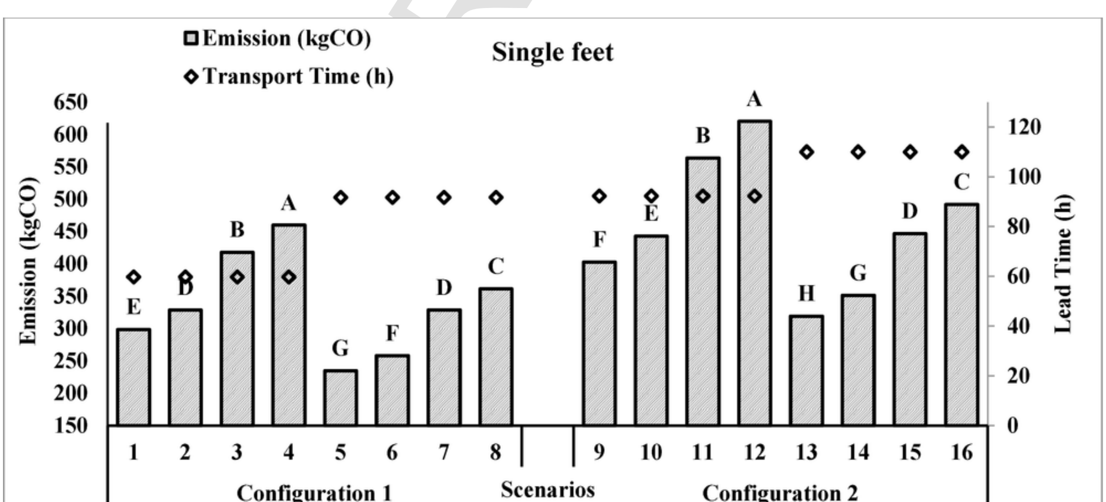

Fig. 4. Simulation results and Tukey's test for configurations 1 and 2 (Ballou, 2004) using single fleet.

vehicles, the TT decreases as many truck movements and loadings may occur at the same time. Under those circumstances, the individual load capacity is smaller, making the truck loading processes faster. What we need to know is why those emissions were higher. One probable answer could be the following: if the total of load driven in the logistics process was fixed for all scenarios, the small vehicles, when compared to the largest ones, would certainly have to repeat the process more often in order to execute the task.

In the mixed fleet in configuration 1 (Table 7), the scenarios from 1 to 4 are delivery-fleet arrangements that use small vehicles for the supply of raw material, and large vehicles for the delivery of products for customers; scenarios from 5 to 8 have inverse arrangement. The scenarios from 1 to 4 presented TT (85.43 h) with reduction of 7.44% in relation to the scenarios from 5 to 8 (79.07 h), to which the delivery-fleet arrangements were inverted. The EM (kgCO) observed in the scenarios 1 (284.37 ± 0.07), 2 (312.81 ± 0.08), 3 (398.12 ± 0.10), and 4 (437.93 ± 0.11) were significantly different according to the statistical analyses carried out (Tukey, $P \leq 0.01$), according to Fig. 5 (configuration 1). It is noticed that both for old and new fleets, the eco-driving style reduced the EM between scenarios 1 and 2, as well as between scenarios 3 and 4. The EM observed in scenarios 5 (223.97 ± 0.01), 6 (246.37 ± 0.01), 7 (313.56 ± 0.01), and 8 (344.91 ± 0.01), demonstrated in Fig. 5 (configuration 1), differ between new vehicles used in scenarios 5 and 6 and old vehicles applied in scenarios 7 and 8, which, in turn, differ between them (Tukey, $P \leq 0.01$) regarding the eco-driving style. The scenario 5 was able to reduce in almost 50% the EM.

When the mixed fleet for configuration 1 was proposed, it was expected that the advantages observed in single fleet could be intensified in at least one of the eight scenarios with mixed fleet. In fact, it happened with the TT for scenarios from 5 to 8, which used large vehicles, and all the EM obtained (Table 8). Following this reasoning, the TT of the scenarios from 5 to 8 reduced from 91.72 h to 79.07 h, that is, 13 h less. Besides, the EM reduced up to 16.40 kgCO (scenario 8) when the larger vehicle is substituted by the small one in the delivery of the products to the customer. In brief, it was a synergetic interaction between freights. The mixed fleet was surpassed by the single fleet only concerning the TT for scenarios from 1 to 4, which increased from 59.80 h to 85.43 h, an undesirable increase of 25.63 h; thus, an antagonistic interaction between the type of fleet.

In the mixed fleet and configuration 2 (Table 7), the scenarios from 9 to 12 are delivery-fleet arrangements that use small vehicles for the supply of raw material, and large vehicles for delivery of products to customers; the scenarios from 13 to 16 have inverse arrangements. There was not significant differences in the TT of scenarios from 9 to 12 (103.88 h) and in the inversion of the arrangements proposed in the scenarios from 13 to 16 (103.86 h). However, the EM were higher when the scenarios from 9 to 12 were used comparing to the EM of scenarios from 13 to 16. The EM observed were 9 (394.15 ± 0.01), 10 (433.56 ± 0.01), 11 (551.81 ± 0.01), 12 (606.99 ± 0.01), 13 (323.65 ± 0.05), 14 (343.76 ± 0.05), 15 (404.10 ± 0.06), and 16 (432.25 ± 0.07). The scenario 13 presented the lowest EM of the configuration 2 and mixed fleet (new vehicles with eco-driving).

When comparing the single and the mix fleets in the configuration 2, the advantages were the reduction of approximately 7.5–60 kgCO for scenarios from 9 to 16 except the 13, with a non-significant increase of 4.36 kgCO (Table 8). The TT of scenarios from 9 to 12 increased 11.62 h and the ones from 13 to 16 reduced 6.13 h; therefore, the mix fleet was surpassed by the single fleet only in scenarios from 9 to 12, which used small vehicles to get the raw material and large vehicles for deliveries of products to customers. It is highlighted that the scenarios 4 (for configuration 1) and 12 (for configuration 2) were used as references to calculate the percentage of reductions of the EM in the other scenarios. And the percentage reductions of the TT were based on the higher TT in relation to the smaller TT for both configurations.

It was verified that, in results corresponding to the application of single fleet in the configurations 1 and 2 (Ballou, 2004), the levels of EM were first influenced by the type of fleet used, noting that the utilization of larger vehicles reduce the emissions. The use of new vehicles and the style of driving (eco-driving) also contributed to the lowest EM in each fleet. TT presented two different groups of values, which indicated, among the factors analyzed, that the change of the type of fleet was a factor that affected the increase of TT when larger vehicles were used. From those scenarios, it is possible the managers to choose the most adequate option for transportation of products, being able to opt for more sustainable decisions (green), which present the lowest EM and/or the fastest (lean), whose TT are lower (Fig. 4).

In the results regarding the use of mixed fleet in configurations 1 and 2 (Ballou, 2004), it was seen that the type of fleet applied did not

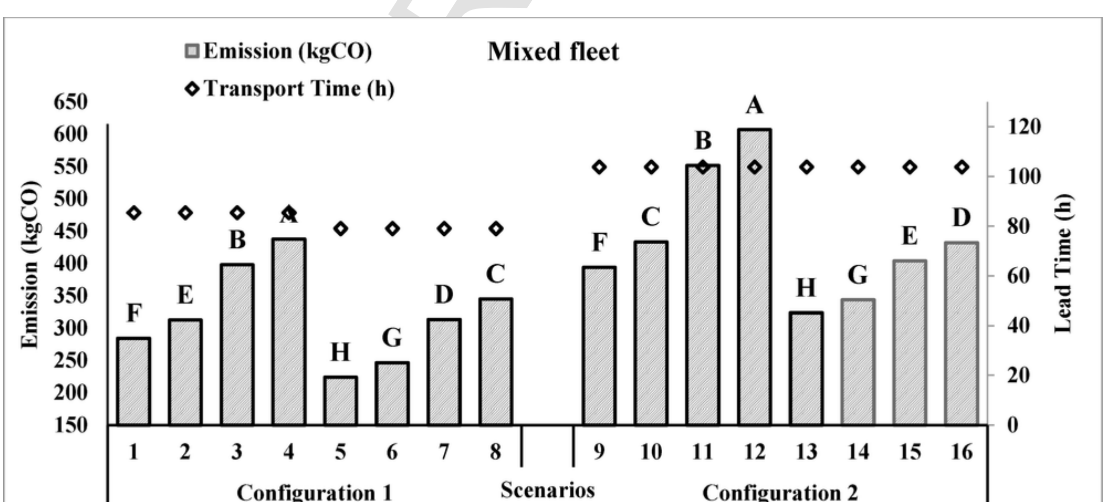

Fig. 5. Simulation results and Tukey's test for configurations 1 and 2 (Ballou, 2004) using mixed fleet.

Table 8
Advantages of using mixed fleet in relation to single fleet for EM (Mean, kgCO) and TT (Mean, h) obtained in scenarios simulation to the configurations 1 and 2 (Ballou, 2004).

Observed variables	Configuration 1				Configuration 2			
	SS	Single Fleet	Mixed Fleet	Variation	SS	Single Fleet	Mixed Fleet	Variation
EM (kgCO)	1	298.56	284.37	−14.19	9	402.83	394.15	−8.68
	2	328.42	312.81	−15.61	10	443.11	433.56	−9.55
	3	417.99	398.12	−19.87	11	563.96	551.81	−12.15
	4	459.79	437.93	−21.86	12	620.35	606.99	−13.36
	5	234.62	223.97	−10.65	13	319.29	323.65	4.36
	6	258.08	246.37	−11.71	14	351.22	343.76	−7.46
	7	328.46	313.56	−14.9	15	447.01	404.10	−42.91
	8	361.31	344.91	−16.4	16	491.71	432.25	−59.46
TT (h)	1	59.80	85.43	25.63*	9	92.26	103.88	11.62*
	2	59.80	85.43	25.63*	10	92.26	103.88	11.62*
	3	59.80	85.43	25.63*	11	92.26	103.88	11.62*
	4	59.80	85.43	25.63*	12	92.26	103.88	11.62*
	5	91.72	79.07	−12.65	13	109.99	103.86	−6.13
	6	91.72	79.07	−12.65	14	109.99	103.86	−6.13
	7	91.72	79.07	−12.65	15	109.99	103.86	−6.13
	8	91.72	79.07	−12.65	16	109.99	103.86	−6.13

Notes: * Scenarios with mixed fleet and inefficient TT.

influence directly in the TT of the scenarios. The lowest levels of EM corresponded to the use of larger vehicles for the transportation of raw material to the manufacturer and small vehicles for the delivery of products to the customers. The inverse then caused the increase of those EM, making more interesting, from both the lean and the green approach, to prioritize logistics structures, which employ vehicles of larger size for the supply of materials. Besides, it was clear that the new vehicles are linked to the reduction of the emissions and the adoption of an ecological driving style (Fig. 5).

The application of the Tukey's test demonstrated that, in each configuration, the means that do not share the same letter are significantly different by the referred test at the level of 99% of reliability. It was checked that only scenarios 2 and 7 (Fig. 4) remained statistically the same, demonstrating that, from the factors studied, different scenarios may, at some point, generate the same levels of EM.

The decision about the Types of delivery-fleet to be used may be influenced by customers due to the variation in relation to the number of orders and the urgency to deliver the products. The decisions concerning the Ages of fleet and Driving style are usually responsibility of the managers and the companies. Therefore, there is the possibility of analyzing transport structures that approach the sustainable issue involving both customers and mangers.

The absolute values found for the EM and the TT were not focused in this work. The main issue here consisted of the analysis of the relative values by comparing each scenario and configuration. This way, it is possible to conclude that the behavior of the configurations cannot be generalized, and that they may or may not be advantageous according to the criteria previously established to the variables involved. The simulation results showed that different scenarios had different results on the SC performance when factors such as Types of delivery-fleet, Ages of fleet, and Driving style were analyzed.

Simão et al. (2016) consider logistics as one of the most adequate sectors of the SC to apply sustainable strategies because it is possible to reduce GHG emissions in that sphere. Based on this statement, the emphasis given to the analyses on the transport operations is justified in this work as they can provide large impacts in all the SC. It is highlighted the importance of thinking SC with a dynamic design able to meet the numerous demands from the market, from competitors, from customers, besides environmental requirements increasingly rigid. In light of this context, it is important to pay attention to each of the parts involved in the process, and search for ways of meeting their different needs. One of the ways to reach that objective may be by means of a closer relationship between managers and customers making them partners of possible logistics strategies.

From the information gathered from customers by the questionnaire applied in this research, it was possible to understand that they have different opinions about environmental issues and GHG emissions. However, there are people who concern about taking decisions considering sustainability. They consider the possibility of adapting the way of buying products on the internet in order to contribute to green logistics strategies. The impact on the reduction of GHG emissions generated by those customers' decisions can be intensified if customers are informed about this issue at the time of purchasing. Moreover, government education campaigns may contribute to aware people and broaden sustainability culture. From a better understanding of customers' behavior, choices may be set to meet the LM and GM in a way that both practices add value to the SC. Even most of the people related in the questionnaire are sensitive to the price and delivery time, it is noted that the behavioral pattern observed has cultural, social and economic aspects of the region where the interviews took place. Therefore, according to the region, different results can be obtained.

Johansson and Sundin (2014) report that despite the increasing attention that has been paid to the LM and GM concepts as essential tools for the business success, there are a few studies, which analyze both concepts in an integrated way. The main question of this research was to analyze the environmental and performance variables in the LM and GM context with the objective of demonstrating that both concepts may and should be seen from a larger perspective. Thus, it was possible to demonstrate that an environmental strategy may correspond to a profitable strategy that aggregates value to the product and, under the competitive aspect, may bring benefits to the companies. In this respect, Dües et al. (2013) point that the LM serves as an important agent for the GM, which, in turn, demands lower time and/or money investments when additionally implemented to the LM existent. Nevertheless, the authors highlight that both practices require further attention concerning investments when they are not interconnected.

6. Concluding remarks

This research investigated environmental and performance variables in Lean Manufacturing and Green Manufacturing context in a road freight transportation system. A questionnaire that showed the customers' behavior in relation to sustainable issues was applied. In the investigation, it was seen the possibility to expand the relationship between managers and customers to develop environmental strategies, as there are customers willing to decide on the product acquisitions even if it costs a little more time or money. It was verified using an experimental project the most influent factors in the greenhouse gas emissions, demonstrating that the Types of delivery-fleet, Ages of fleet and Driving style may influence the emission levels and make transport more or less sustainable. By means of the simulations run, it was seen that, according to the criteria established, the relationship between Lean Manufacturing versus Green Manufacturing may or may not be conflicting. As a result, it was realized that different logistics environments can generate different results, and that, based on the configurations analyzed, one cannot point a scenario or a configuration as the best.

By the simulations and customers' opinions, it was possible to provide information, which may help managers take decisions in logistics environments that take into consideration not only economic aspects but also sustainable ones, which can aggregate value to the product. It was shown that if the customer does not participate in the decisions, there will be a tendency to increase the emissions as a consequence of receiving the product in a lower time.

Therefore, a recommendation suggested in this work is the possibility given to the companies to inform the customers about the emissions that may be generated when choosing a specific transportation for the product purchased. The companies can adopt a process to be employed when finishing the sale in order to let customers know that he/she can be contributing to the reduction of greenhouse gas emissions when choosing a particular service of delivering the product.

Furthermore, a free and open source software was applied to run the simulations. Despite being new, it has proven to be an efficient and versatile software, presenting low cost, favouring small companies. Nevertheless, other simulation softwares are able to carry out those studies.

This work can also help further researches. We suggest that other researchers carry out the same studies from real systems and in different places, as the environmental consciousness may not be the same as of the group studied in this paper. According to information of specific groups, managers can choose different sustainable practices for each situation.

Another proposition from the comments on this paper is the possibility of creating an indicator relating the emissions of gases to the load weight, reporting to the customer the amount of gas emissions produced according to the delivery option of the product. This indicator may then present a more accurate value of the emissions generated from the mass of load transported.

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Appendix A. Ururau modules with description and configuration data.

Table A1 Experiment parameters of configuration 1.

Module	Name	Description	Configuration data
Create	E1	Responsible for creation of the entities	T. arrivals: Constant (1 h) T. prim. arrivals: 0.0 h Max. arrivals: Infinity
Decision maker	X	Deviation of pattern execution	Type: N-way-chance Type: 2-way-by-chance
Loading	F1	Executes a process	Type: Expression Value: 23000/6000
Loading	F3	Executes a process	Type: Expression Value: 23000/6000
Loading	F5	Executes a process	Type: Expression Value: 23000/6000
Loading	F7	Executes a process	Type: Expression Value: 23000/6000
Loading	F8	Executes a process	Type: Expression Value: 23000/6000
Unloading	F2	Executes a process	Type: Expression Value: 23000/8000
Unloading	F4	Executes a process	Type: Expression Value: 23000/8000
Unloading	F6	Executes a process	Type: Expression Value: 23000/8000
Unloading	F9	Executes a process	Type: Expression Value: 23000/8000
Unloading	F10	Executes a process	Type: Expression Value: 23000/8000
Resource team for loading	R1	Adds a resource	Capacity: 1
Resource team for loading	R3	Adds a resource	Capacity: 1
Resource team for loading	R5	Adds a resource	Capacity: 1
Resource team for loading	R7	Adds a resource	Capacity: 1
Resource team for loading	R8	Adds a resource	Capacity: 1
Resource team for unloading	R2	Adds a resource	Capacity: 1
Resource team for unloading	R4	Adds a resource	Capacity: 1
Resource team for unloading	R6	Adds a resource	Capacity: 1
Resource team for unloading	R9	Adds a resource	Capacity: 1
Resource team for unloading	R10	Adds a resource	Capacity: 1
Emissions	C1	Calculates the emissions	Variable name: var1 Time (h): NORM(8,0.8) Emission coefficient (g/kW*h): 1.5 Power (kW): 136 Load (kg): 23000 Legal Combined Total Whole Weight (kg): 23000
Emissions	C2	Calculates the emissions	Variable name: var1 Time (h): NORM(12,1.2) Emission coefficient (g/kW*h): 1.5 Power (kW): 136 Load (kg): 23000 Legal Combined Total Whole Weight (kg): 23000
Emissions	C3	Calculates the emissions	Variable name: var1 Time (h): NORM(7,0.7) Emission coefficient (g/kW*h): 1.5 Power (kW): 136 Load (kg): 23000 Legal Combined Total Whole Weight (kg): 23000
Emissions	C4	Calculates the emissions	Variable name: var1 Time (h): NORM(4,0.4) Emission coefficient (g/kW*h): 1.5 Power (kW): 136 Load (kg): 23000 Legal Combined Total Whole Weight (kg): 23000
Emissions	C5	Calculates the emissions	Variable name: var1 Time (h): NORM(5,0.5) Emission coefficient (g/kW*h): 1.5 Power (kW): 136 Load (kg): 23000 Legal Combined Total Whole Weight (kg): 23000
Accumulator	T1	Counts the entities	Type: Variable Value: cont+1
Accumulator	T2	Counts the entities	Type: Variable Value: cont1+1

Table A2 Experiment parameters of configuration 2.

Module	Name	Description	Configuration data
Create	E1	Responsible for the creation of the entities	T. arrivals: Constant (1 h) T. prim. arrivals: 0.0 h Max. arrivals: Infinity
Loading	F1	Executes a process	Type: Expression Value: 20000/6000
Loading	F2	Executes a process	Type: Expression Value: 25000/6000
Loading	F3	Executes a process	Type: Expression Value: 11000/6000
Unloading	F4	Executes a process	Type: Expression Value: 56000/8000
Loading	F5	Executes a process	Type: Expression Value: 56000/6000
Unloading	F6	Executes a process	Type: Expression Value: 30000/8000
Unloading	F7	Executes a process	Type: Expression Value: 26000/8000
Resource team for loading	R1	Adds a resource	Capacity: 1
Resource team for loading	R2	Adds a resource	Capacity: 1
Resource team for loading	R3	Adds a resource	Capacity: 1
Resource team for unloading	R4	Adds a resource	Capacity: 1
Resource team for loading	R5	Adds a resource	Capacity: 1
Resource team for unloading	R6	Adds a resource	Capacity: 1
Resource team for unloading	R7	Adds a resource	Capacity: 1
Emissions	C1	Calculates the emissions	Variable name: var1 Time (h): NORM(9,0.9) Emissions coefficient (g/kW*h): 1.5 Power (kW): 265 Load (kg): 20000 Legal Combined Total Whole Weight (kg): 56000
Emissions	C2	Calculates the emissions	Variable name: var1 Time (h): NORM(11,1.1) Emissions coefficient (g/kW*h): 1.5 Power (kW): 265 Load (kg): 45000 Legal Combined Total Whole Weight (kg): 56000
Emissions	C3	Calculates the emissions	Variable name: var1 Time (h): NORM(7,0.7) Emissions coefficient (g/kW*h): 1.5 Power (kW): 265 Load (kg): 56000 Legal Combined Total Whole Weight (kg): 56000
Emissions	C4	Calculates the emissions	Variable name: var1 Time (h): NORM(4,0.4) Emissions coefficient (g/kW*h): 1.5 Power (kW): 136 Load (kg): 56000 Legal Combined Total Whole Weight (kg): 56000
Emissions	C5	Calculates the emissions	Variable name: var1 Time (h): NORM(5,0.5) Emissions coefficient (g/kW*h): 1.5 Power (kW): 265 Load (kg): 26000 Legal Combined Total Whole Weight (kg): 56000
Accumulator	T1	Counts the entities	Type: Variable Value: cont1+1
Accumulator	T2	Counts the entities	Type: Variable Value: cont1+1

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