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ANALYSIS OF CARBON MONOXIDE EMISSIONS IN A OPEN SOURCE DISCRETE-EVENT SIMULATOR

João José de Assis Rangel

Instituto Federal Fluminense
273 Dr. Siqueira st, Pq. Dom Bosco
Campos dos Goytacazes, RJ, 28030-130, BRAZIL

Gabriel Lima de Oliveira

Petrobras - Petróleo Brasilero SA
665 Elias Agostinho st, Centro
Macaé - RJ, 27913-350, BRAZIL

Túlio Almeida Peixoto
Leonardo das Dores Cardoso
Ítalo de Oliveira Matias
Eduardo Shimoda
Universidade Candido Mendes
100 Anita Pessanha st, Pq. São Caetano
Campos dos Goytacazes, RJ, 28030-335, BRAZIL

ABSTRACT

This paper describes an analysis of emissions of carbon monoxide (CO) using a discrete event simulator of open source. It was built a simulation model to evaluate gas emissions emitted by a fleet of trucks during transportation of raw materials in a typical supply system of sugarcane in producer mills of ethanol. The simulation model was implemented in the open source simulator and in a traditional simulator. The model results presented high correlation, with no significant difference between them. It was also possible to contribute with the proposed simulator through a designed specific component able to account the CO emissions.

1 INTRODUCTION

In recent work, Zhou and Kuhl (2011) presented the structure of a toolkit of simulation tools to analyze the emission of greenhouse gases. This toolkit allows the use of discrete event simulation (DES) in systems where factors related to the emission of greenhouse gases can be analyzed. In these systems, the vehicle (truck) is represented as an entity that flows through the logic of the simulation model. Therefore, when an entity is created, the attributes of a truck with the variables that want to visualize are defined for it. The module created by the system is called "Emissions", where the values of the emission of gases generated along the route are calculated and stored. Byrne et al. (2010) also demonstrated that the use of DES can capture the dynamic and stochastic effects aggregated to the emission of gases in logistics systems, thus, being able to show, more precisely, the environmental costs involved in supply chain operations, for example.

Similar to Zhou and Kuhl, the work of Cardoso, Moreira, and Rangel (2011) also presented a model of DES capable of analyzing the emissions of carbon monoxide (CO) produced by a fleet of trucks. This model simulated the CO emissions, using only the modules inherent to the Arena software. The analysis was applied in a system of sugarcane transport, in sugarcane mills producers of ethanol, and proved to be efficient.

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In the context of the ethanol production, one of the main problems is related to the transport of sugarcane between the harvest and the mill. The quality of the raw material is directly linked to the shipping time (Rangel et al. 2010). Also in the context of ethanol production, environmental issues such as the control of the emission of pollutant gases and the reduction of waste that affect the environment have become increasingly present in the center of the main organizational decisions. The current sustainable vision of the companies, either because of punishment or by the concern to achieve proper environmentally goals, has led to reconsider the importance of the reduction of the emissions of pollutant gases in the production context, as well as raise the importance of this factor in the making of business decisions (Widok and Wohlgemuth 2011).

On the other hand, the use of computational simulation in Brazilian companies is still unusual due to the high monetary value spent on importation of commercial software for the development of simulation models. An alternative presented is the possibility of using an open source simulator, such as the recent Ururau (Peixoto et al. 2011). The Ururau is a discrete event simulator which, being open source, provides more freedom to the modelist. In the development environment of Ururau, one can manipulate from the graphical user interface up to the more internal code.

In this sense, this paper describes a model of DES used to evaluate CO emissions produced by a logistics system consisting of a fleet of trucks for transportation of sugarcane. The simulation model was developed using the software Ururau, and the results were compared with other model of the same system developed in the software Arena.

2 DESCRIPTION OF THE SYSTEM

A hypothetical transport logistics system of sugarcane in mills producers of ethanol was idealized. Data from this model were obtained from the work of (Rangel et al. 2010) and (Iannoni and Morabito 2002). Figure 1 shows schematically the supply system, which is typically found in Brazilian sugarcane mills.

There are five harvest fronts (HF), each providing the same amount of sugarcane for the same mill. Five trucks are allocated to each HF, where the time of departure of trucks from the HF follows the same probability distribution. The distances of each HF to the mill are shown in the legend.

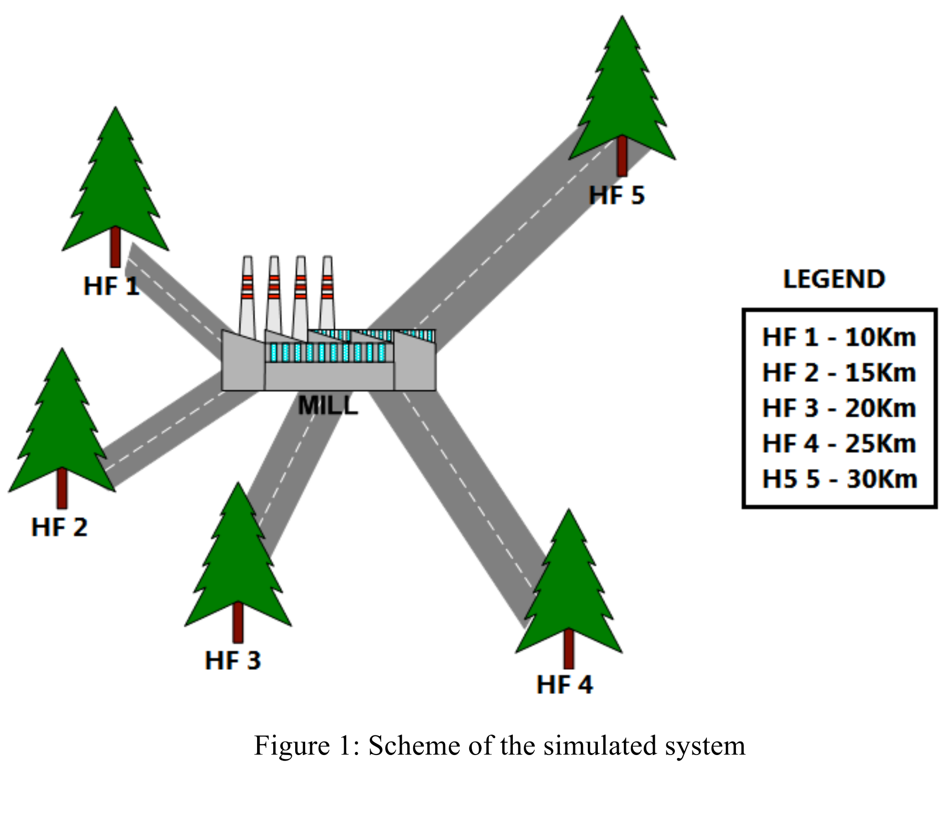

Figure 1: Scheme of the simulated system

The system is composed solely for the transportation and subsequent unloading of trucks. The loading process of sugarcane in a truck in a HF and unloading of the respective trucks at the mill is done mechanically. Therefore, one can consider that the truck engine is turned off in these moments, because the time for these cases is relatively short, not being emitted polluting gases.

The process is simulated as follows: The trucks already loaded with sugarcane are addressed to the mill in the shortest possible time so as not to compromise the quality of raw material transported. The trucks wait their turns to unload when arriving at the mill. This wait is done with the trucks turned off, therefore, their time in the calculation of the inventory of the CO emissions is not taken into consideration. Once unloaded, the trucks return to the HF source in order to restart the transport cycle.

3 SIMULATION MODEL

The methodology by Banks (2009) was followed to prepare this simulation project, according to the next steps: Formulation and analysis of the hypothetical problem; construction of the conceptual model; construction of the simulation model; verification and validation; experimentation; and interpretation and statistical analysis of the results.

From the IDEF-SIM technique (Montevechi et al. 2010), it was possible to construct the conceptual model of the process with a visual aspect of easy understanding and logic similar to that used in programming of the computational model. The conceptual model to carry out computer simulations was translated into software Ururau and Arena (Kelton, Sadowski, and Sturrock 2009). Figure 2 shows the conceptual model of the system.

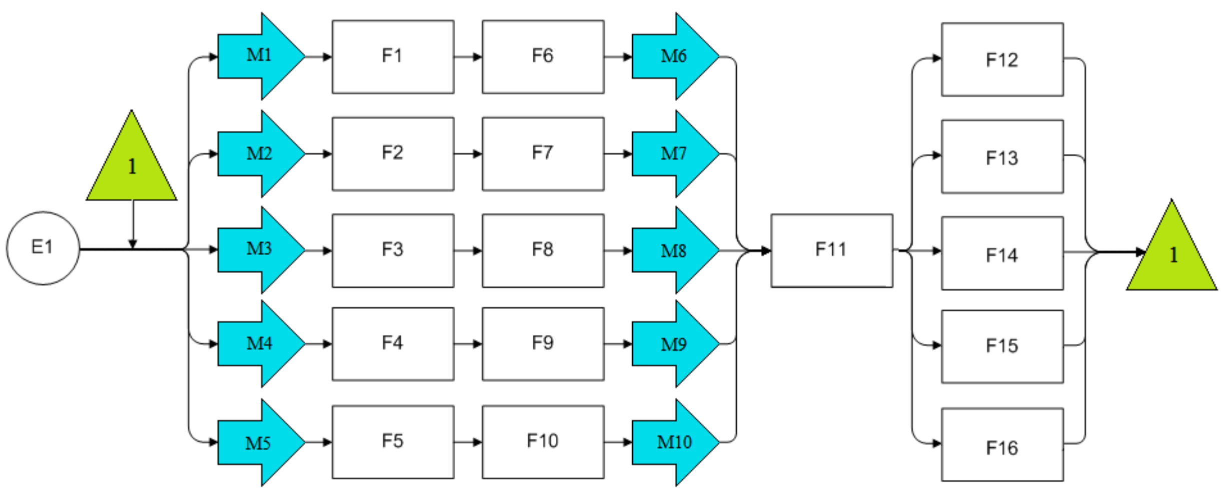

Figure 2. Conceptual Model of the system

It was used, in addition, the methodology proposed by Sargent (2011) for the verification and validation of the model. It is worth mentioning that the computational model was constructed after the conceptual model is ready, fully verified and validated.

The simulated system begins with the acquisition, by the simulation model, of the time needed for the departure of each of the trucks (E1) to the corresponding HF. This path has variable time, since they are at different distances from the mill and may suffer changes generated by factors as traffic.

Then, the trucks follow to their respective HF (M1, M2, M3, M4 and M5). In this way, the pollutants are emitted, with emissions recorded in CO emissions inventory through the functions F1, F2, F3, F4 and F5. Arriving at HF, the trucks are loaded (F6, F7, F8, F9 and F10). The loading and unloading times are not counted in the emissions inventory, since they are performed with the engine off.

Once loaded, the truck returns to the mill, represented by functions M6, M7, M8, M9 and M10, where it waits until the unloading of sugarcane is done (F11). The functions F12, F13, F14, F15 and F16 register the emissions generated by the return of it to the mill. After this process is conducted, a new loading cycle is started.

4 URURAU SIMULATION ENVIRONMENT

The Ururau is an open source simulator designed to allow the user to have the freedom to build simulation models working with anyone of the three levels of available programming, according to the structure illustrated in Figure 3.

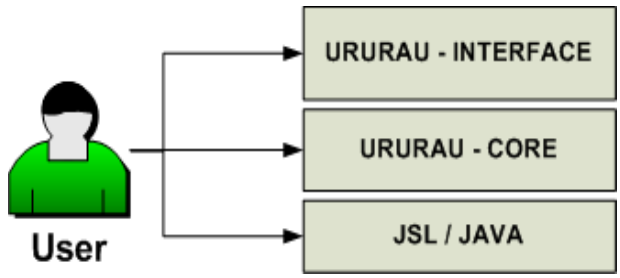

Figure 3: Possible interactions between user and different levels of Ururau

One can interact through its interface, as shown in Figure 4, encoding in the Java programming language and making use of the internal components of Ururau (similar to those found in the Arena, as Process or Decide), or even just using Java and JSL (Java Simulation Library) (Rossetti 2008), which are also used by the core of Ururau.

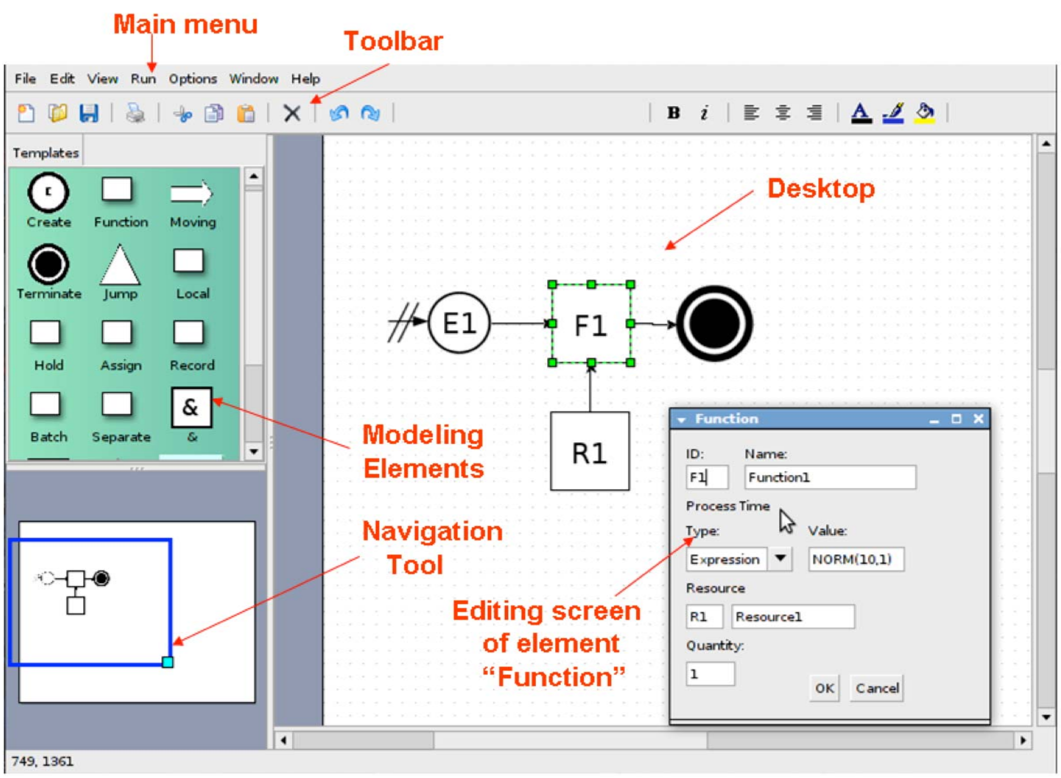

Figure 4: Ururau's interface

The software is freely available from: https://bitbucket.org/tulioap/Ururau/downloads.

5 SIMULATED EXPERIMENTS

For execution of experiments, it was followed the Resolution 315/02 of CONAMA (National Council of Environment, governing body of pollutants in Brazil), whose main purpose according to its Art 1º: "Reduce the emission levels of pollutants in automotive vehicles and promote national technological development, both in design engineering and manufacturing, as in methods and equipment to control the emission of pollutants" (Brasil 2002).

The CONAMA created the PROCONVE (Program of Control of Air Pollution by Motor Vehicles), which follows the Euro standards concerning the rules of emissions of pollutants from automobiles sold in the countries of the European Union (adopted by the European Union since 1991). Table 1 illustrates the situation in Brazil since the beginning of the implementation of such standards (P1) with the PROCONVE in 1989. Currently, the P6 is used with much lower emission levels compared to those allowed from the start. It is observed that, while Brazil adopts the P6 that follows the Euro 4 standard, the European Union already adopt the Euro 5 standard. Although the level of CO is the same in Euro 4 and 5 standards, it is noteworthy that the levels of emission of other pollutants have been reduced from one standard to another.

Table 1: Emission limit for heavy diesel vehicles

PROCONVE	EURO	CO (g/kWh)	TERM	STANDARD (CONAMA)
Phase I (P1)	Without Specification	14,00	1989 a 1993	Res. 18/86
Phase II (P2)	Euro 0	11,20	1994 a 1995	Res. 08/93
Phase III (P3)	Euro 1	4,90	1995 a 1999	Res. 08/93
Phase IV (P4)	Euro 2	4,00	2000 a 2005	Res. 08/93
Phase V (P5)	Euro 3	2,10	2006 a 2008	Res. 315/02
Phase VI (P6)	Euro 4	1,50	2009 a 2012	Res. 315/02
Phase VII (P7)	Euro 5	1,50	Starts in 2012	Res. 403/08

Source: Adapted PROCONVE - Program of Control of Air Pollution by Motor Vehicles

This study examined only the CO emission, which occurred during the transport of the fleet, whose randomness is considered by the model in the time factor. The analysis with only one gas (CO) helped achieve the verification and validation of the model with greater precision. Similarly, it was also possible to better evaluate the performance of the new open source Simulator.

It was considered that 90% of the available total power (130 hp) of the truck is used in the transport of sugarcane from the harvest front to the mill and that only 40% of the available power of the truck is used in the return of this from the mill to the HF, for being empty. Therefore, it is deduced that the emission of pollutants in the return is lower due to the lower load transported.

The amount of emissions generated by the burning of the fuel is a function of several parameters, including the fuel type, power of the truck engine and the time that the engine is running (Manicom et al. 1993). The results of this study provided a list of emission coefficients in units of grams per kilowatt hour (g / kW · h) for various types of fuels including diesel, allowing the relation shown in Equation 1:

$$E_X(t) = Cco*Pot*t \tag{1}$$

Where the emissions produced "E" of the vehicle "x" over the time interval "t" are equal to the emission coefficient Cco (of the vehicle x) times the power of the truck in kilowatts "Pot" times the time "t" (Zhou and Kuhl, 2010).

In Table 2, one can visualize the factors of CO that were used in the experiments described in the scenarios, with the results being shown in Table 3. The difference between the scenarios is in the emission levels. Six scenarios were simulated. Scenario 1 follows the standard P1, which limits an emission of 14g/kW.h until scenario 6, which uses the data of the standards P6 and P7 (1.50 g / kWh).

Table 2: Description of scenarios

COEFFICIENTS	
SCENARIO	EMISSION
1	Level 1
2	Level 2
3	Level 3
4	Level 4
5	Level 5
6	Level 6

Table 3 presents the scenarios, comparing the results of the experiments simulated in Arena and Ururau. One can observe the trend of reduction of CO emissions while the scenarios range from 1 to 6.

Figure 5 also shows the results of total emissions in each scenario, in both simulators. The scenarios were replicated 10 times in each simulation.

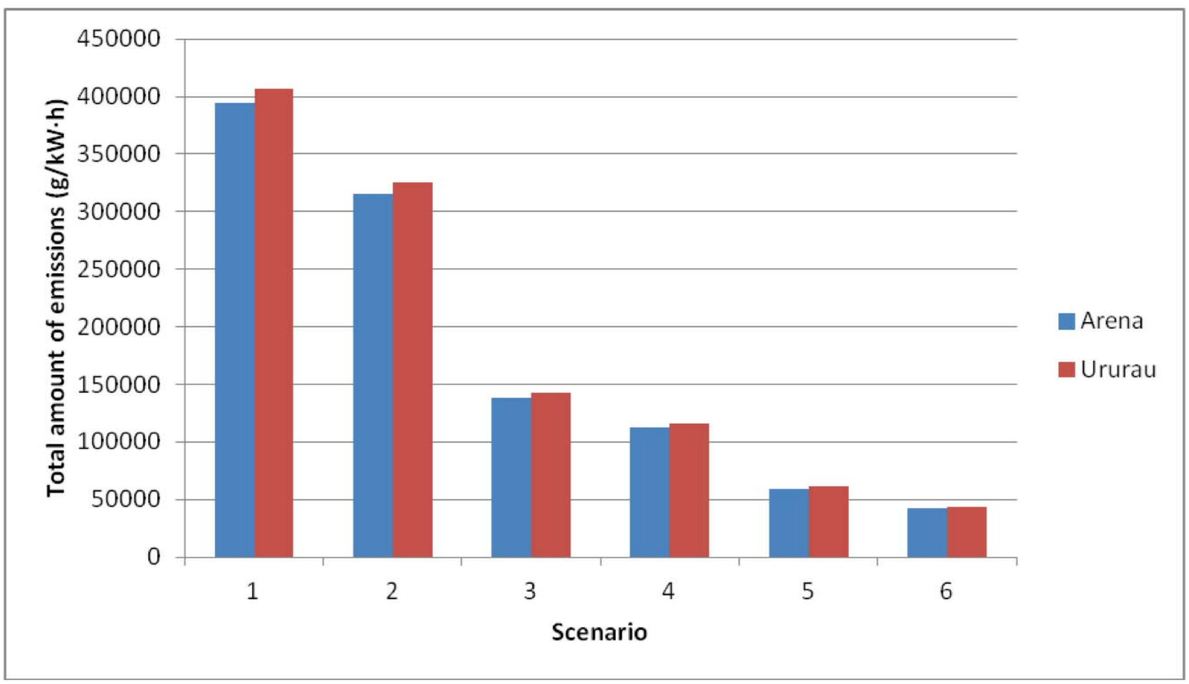

Figure 5: Comparison between the results of the scenarios of Ururau and Arena. Data in g/kWh

One can see that, in each scenario, the emission reductions generated from HF1 to HF5 remains similar in both the model Arena and in Ururau. This relation is because the HFs are at different distances in relation to the mill. Therefore, the HF more distant will emit more CO than the closer one to the mill in all scenarios.

Table 3: Results of the scenarios - Data in g/kWh

Scenario	HF	Emissions on Going		Total on Going		Emissions on Return		Total on Return		Grand Total	
		Arena	Ururau	Arena	Ururau	Arena	Ururau	Arena	Ururau	Arena	Ururau
1	1	47013	50773	284602	296313	18365	19491	109556	110777	394158	407090
	2	53987	56927			21915	21555				
	3	58189	58773			22350	22276				
	4	59368	63480			23032	23380				
	5	66045	66360			23894	24075				
2	1	37611	40619	227706	237050	14708	15593	87660	88621	315366	325671
	2	43190	45541			17532	17244				
	3	46551	47018			17880	17820				
	4	47518	50784			18425	18704				
	5	52836	53088			19115	19260				
3	1	16455	17770	99622	103708	6435	6822	38352	38771	137974	142479
	2	18896	19924			7670	7544				
	3	20366	20570			7823	7796				
	4	20789	22218			8061	8183				
	5	23116	23226			8363	8426				
4	1	13432	14506	81323	84659	5253	5569	31308	31649	112631	116308
	2	15425	16264			6262	6158				
	3	16625	16792			6386	6364				
	4	16971	18137			6580	6680				
	5	18870	18960			6827	6878				
5	1	7052	7616	42695	44447	2758	2923	16437	16615	59132	61062
	2	8098	8539			3287	3233				
	3	8728	8816			3353	3341				
	4	8910	9522			3455	3507				
	5	9907	9954			3584	3611				
6	1	5037	5440	30496	31747	1970	2088	11741	11867	42237	43614
	2	5784	6099			2348	2309				
	3	6235	6297			2395	2386				
	4	6364	6801			2468	2505				
	5	7076	7110			2560	2579				

It was also observed that, at the time of implementation of the norms of PROCONVE in 1090 (P1), the emission levels were very high (400,833 g / kWh) compared to current emissions levels, which has 42,946 g / kWh. Thus, in a period of 22 years, there was a reduction of almost 90% of the levels of CO emissions, reduction also observed in the results of the two simulations.

6 STATISTICAL ANALYSIS OF RESULTS

Statistical analyzes were performed in software "Systems for Analysis Statistics and Genetic" (SAEG, 9.1), adopting the 5% level of significance. We obtained the averages and standard errors of each software (Arena and Ururau) in the two trajectories (round trip) and in the 6 scenarios, as illustrated in Figure 6, being these averages compared by t-test to verify differences between the software.

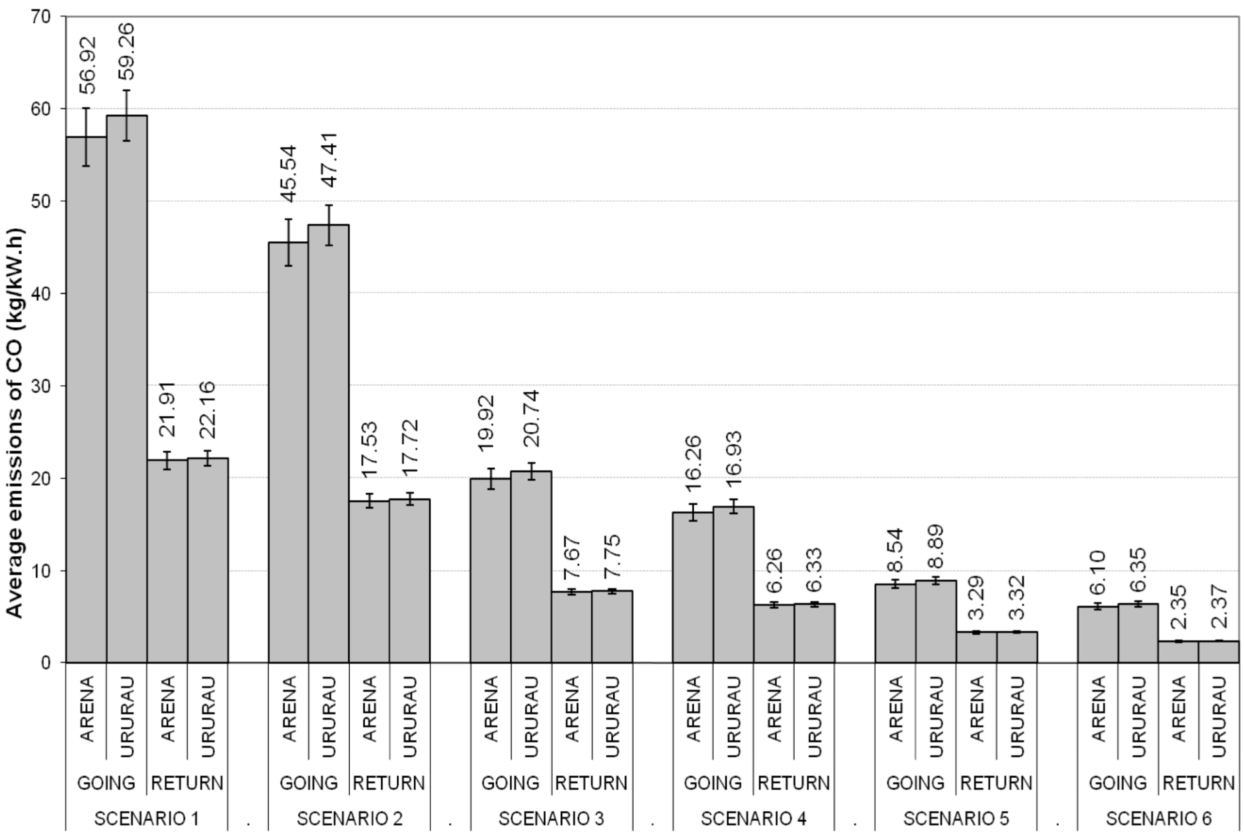

Figure 6: Average emissions of CO. Data in kg/kWh.

It was also obtained an equation of linear regression of the result observed in the software Arena according to the observed in the Ururau, shown in Figure 7, where there were no significant differences between the software in any of the scenarios or trajectories.

Also in Figure 7, one can observe that the results obtained by the two software are related by linear regression, being the equation obtained significant ($P<0.0001$) and with a high coefficient of determination ($R2 = 99.8\%$). The angular coefficient of the regression (0.962) is close to the value 1, which shows that the results of the simulation displayed by Ururau are close to the results obtained by the Arena.

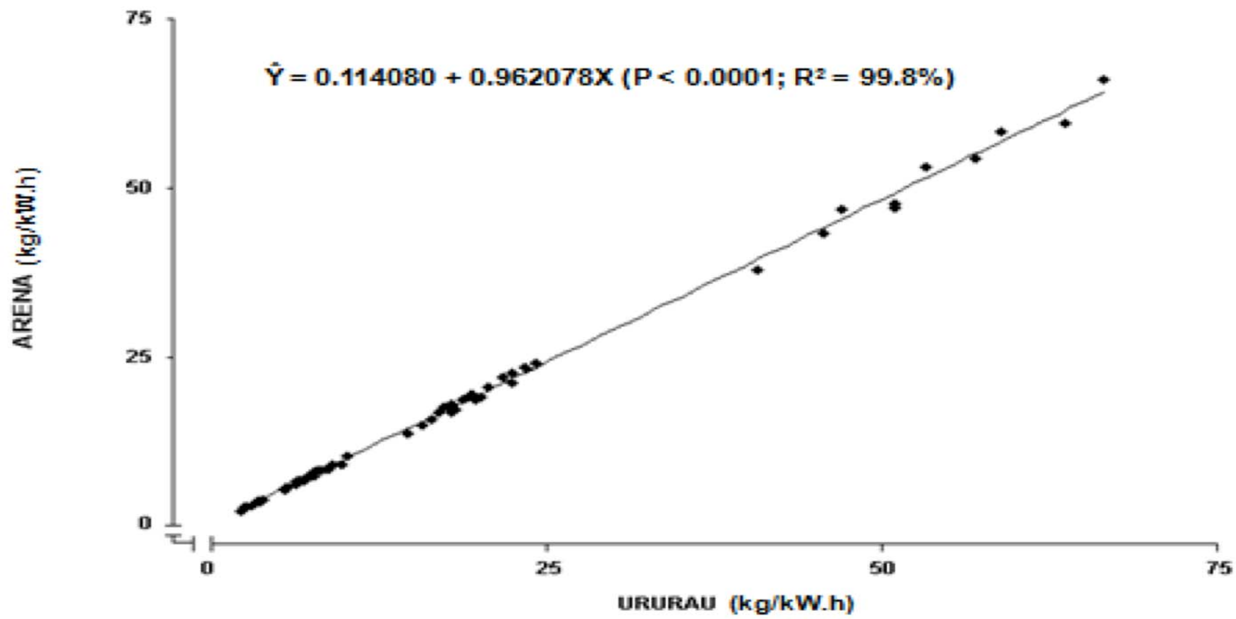

Figure 7: Linear Regression of results of Arena in function of Ururau

7 CONCLUDING REMARKS

The simulation model developed in this study corroborated with the raised possibility of being able to analyze the emission of greenhouse gases as a typical discrete event system.

Likewise, the high correlation between the results of the models developed in Ururau and Arena demonstrated the feasibility of being able to build simulation models with the open source simulator Ururau. Furthermore, for being used in different programming levels, open source simulator allowed the development of a specific component for the proposed model. This fact made the Ururau similarly able to count emissions generated by a fleet of vehicles, such as toolkit developed for the software Arena by Zhou and Kuhl.

The functionality for accounting of emissions was added to the official code of the Ururau, found in its latest version. This was only possible due to the Ururau be an open source simulator, which allows different users to collaborate including other components to the software.

This study compared the analysis only of the CO emissions. However, the model can be expanded to count the other greenhouse gases such as hydrocarbons, nitrogen oxides, particulate materials, among others. Also, other models could be performed using mixed fleets (vehicles of different years of manufacture, which meet different emissions standards). Thus, in general, the intention is also, in subsequent steps of this project, extend the analysis to the other gases and, thus, be able to calculate the emissions inventory of a supply chain, for example.

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A APPENDIX

Parameters of the conceptual model.

CODE	DESCRIPTION	PARAMETER
E1 to E5	Truck	Qnt: 5 entities; Time of Creation: EXPO (1) min
F1	Transport sugarcane from the HF1	NORM(0.5, 0.1) hours
F2	Count CO – Going HF1	V_Cont_going_1 + (V_Comb_1*0.9*V_Pot_1*V_Temp_going_1)
F3	Unload	NORM (5.0, 0.5) min
F4	Back to the HF1	NORM (0.45, 0.045) hours
F5	Count CO - Back HF1	V_Cont_Back_1 + (V_Comb_1*0.4* V_Pot_1*V_Temp_Back_1)
F6	Transport sugarcane from the HF2	NORM(0.7, 0.14) hours
F7	Count CO - Going HF2	V_Cont_Going_2 + (V_Comb_2*0.9*V_Pot_2*V_Temp_Going_2)
F8	Back to the HF2	NORM(0.63, 0.063) hours
F9	Count CO - Back HF2	V_Cont_Back_2 + (V_Comb_2*0.4* V_Pot_2*V_Temp_Back_2)
F10	Transport sugarcane from the HF3	NORM (0.9, 0.18) hours
F11	Count CO - Going HF3	V_Cont_Going_3 + (V_Comb_3*0.9*V_Pot_3*V_Temp_Going_3)
F12	Back to the HF3	NORM (0.81, 0.081) hours
F13	Count CO - Back HF3	V_Cont_Back_3 + (V_Comb_3*0.4* V_Pot_3*V_Temp_Back_3)
F14	Transport sugarcane from theHF4	NORM (1.1, 0.22) hours
F15	Count CO - Going HF4	V_Cont_Going_4 + (V_Comb_4*0.9*V_Pot_4*V_Temp_Going_4)
F16	Back to the HF4	NORM (0.99, 0.099) hours
F17	Count CO - Back HF4	V_Cont_Back_4 + (V_Comb_4*0.4* V_Pot_4*V_Temp_Back_4)
F18	Transportar cana-de-açúcar da FC5	NORM (1.3, 0.26) horas
F19	Count CO - Going HF5	V_Cont_Going_5 + (V_Comb_5*0.9*V_Pot_5*V_Temp_Going_5)
F20	Back to the HF5	NORM (1.17, 0.117) hours
F21	Count CO - Back HF6	V_Cont_Back_5 + (V_Comb_5*0.4* V_Pot_5*V_Temp_Back_5)

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AUTHOR BIOGRAPHIES

JOÃO JOSÉ DE ASSIS RANGEL is a professor at Federal Fluminense Institute (IFF) and Candido Mendes University (UCAM-Campos) in Campos dos Goytacazes, RJ - Brazil. He received a doctoral degree in Materials Engineering at UENF in 1998. His research interests include simulation on logistics and manufacturing, simulation on super hard materials process and simulation education. His e-mail address is joao@ucam-campos.br.

GABRIEL LIMA DE OLIVEIRA is an Industrial Engineering degree from Candido Mendes University (UCAM-Campos) in Campos dos Goytacazes, RJ - Brazil. He is currently an engineer at Petrobras. His e-mail is gabriellima@petrobras.com.br.

TÚLIO ALMEIDA PEIXOTO is a Computer Engineering degree from PUC-Rio in Rio de Janeiro - Brazil and MSc in Operations Research and Computational Intelligence at Candido Mendes University (UCAM-Campos). His e-mail address is tulioap@gmail.com.

LEONARDO DAS DORES CARDOSO is an Industrial Engineering degree from Candido Mendes University (UCAM-Campos) in Campos dos Goytacazes, RJ - Brazil. He is currently an teacher in Institute Federal Fluminense (IFF-Campos) and MSc student in Industrial Engineering at Candido Mendes University (UCAM-Campos). His e-mail is leocardoso@iff.edu.br.

ÍTALO DE OLIVEIRA MATIAS is a professor at Candido Mendes University (UCAM-Campos) and researcher in the TEC-GRPH (PUC-Rio), RJ - Brazil. He received a doctoral degree in Computer Science at UFRJ in 2007. His research interests include operational research and computational Intelligence. His e-mail address is italo@ucam-campos.br.

EDUARDO SHIMODA is a professor at Candido Mendes University (UCAM-Campos). He received a doctoral degree in Animal Science at UENF in 2004. His research interests include operational research and statistic. His e-mail address is shimoda@ucam-campos.br.