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Analysis of waste collection using different modes of transport: Planning scenarios through system dynamics

Glauco Oliveira Rodrigues[1], Federal University of Santa Maria, Rio Grande do Sul, Brazil
Wellington Furtado Santos[2], Farroupilha Federal Institute, São Vicente do Sul, Rio Grande do Sul, Brazil
Eugênio de Oliveira Simonetto[3], Federal University of Santa Maria, Rio Grande do Sul, Brazil
Marco Aurélio Denis Zazyki[4], Federal University of Santa Maria, Rio Grande do Sul, Brazil
Ricardo Cesar Silva[5], Federal University of Santa Maria, Rio Grande do Sul, Brazil
Luiz Cláudio Dalmolin,[6] State University of Santa Catarina, Santa Catarina, Brazil
Nilson Ribeiro Modro[7], State University of Santa Catarina, Santa Catarina, Brazil

RESUMO

Objetivo - O objetivo deste artigo é comparar os modais ferroviário e rodoviário no transporte de resíduos sólidos urbanos por meio de simulação baseada na Dinâmica de Sistemas das diferenças financeiras e ambientais entre ambos.
Desenho / metodologia / abordagem - Para a modelagem adotou-se à metodologia proposta por Law (2015) baseado na Dinâmica de Sistemas. Deste modo, a metodologia de Dinâmica de Sistemas auxiliou a mapear as estruturas do sistema desenvolvido, procurando examinar sua inter-relação em contexto amplo. Através desta simulação a dinâmica aplicada buscou compreender como o sistema em foco evoluiu ao longo do tempo e como as mudanças em suas partes afetam o seu comportamento. A partir dessa compreensão, foi possível diagnosticar e prognosticar o sistema, além de possibilitar simular mais cenários no tempo. O horizonte de tempo utilizado foi de onze anos
Resultados - Os resultados revelam que, visto de uma perspectiva financeira, há uma grande diferença existente entre os modais rodoviário e ferroviário no transporte dos RSU. Portanto, demonstra a importância da valorização das ferrovias, além de apresentar-se como outra opção aos gestores em termos de coleta e transporte do lixo gerado nos municípios estudados.
Originalidade / valor - O modelo desenvolvido poderá ser utilizado por gestores da área de Resíduos Sólidos Urbanos como o foco de auxílio do processo decisório na escolha logística do transporte do resíduo.
Palavras-chave - Urban Solid Waste; Transport Modes; Systems Dynamics; Railroad Modal, Road Modal

ABSTRACT

Purpose – *This paper aims to compare rail and road modes of transport to carry Municipal Solid Waste using a simulation based on the Systems Dynamics of the financial and environmental differences between both.*
Design/methodology/approach – *For modeling, the methodology proposed by Law (2015) based on Systems Dynamics was adopted. As such, the Systems Dynamics methodology helped to map structures for the system developed, seeking to examine its interrelation in a broad context. Through this simulation, the applied dynamics sought to understand how the system in question evolved over time and how changes in its parts affect its behavior. From this understanding, the system could be diagnosed and predicted, in addition to allowing more scenarios to be simulated over time. The time horizon used was eleven years.*
Findings – *The findings show that, as seen from a financial perspective, there is a large difference between road and rail modes of transport to carry MSW. Therefore, it demonstrates the importance of valuing the railroads, in addition to being another option for managers to collect and transport waste generated in the municipalities studied.*
Originality/value – *The model developed can be used by managers in the area of Municipal Solid Waste as a focus to help in the decision-making process to choose logistical options to transport waste.*
Keywords – *Municipal Solid Waste; Modes of Transport; Systems Dynamics; Rail, Road.*

1. Av. Roraima nº 1000, Cidade Universitária, Bairro Camobi, Santa Maria, Rio Grande do Sul, Brasil, CEP: 97105-900, glaucop10@redes.ufsm.br, https://orcid.org/0000-0002-3249-1057; 2. wellington.furtado@gmail.com, https://orcid.org/0000-0001-9612-4339; 3. eosimonetto@gmail.com, https://orcid.org/0000-0001-7572-5338; 4 zazyki@hotmail.com, https://orcid.org/0000-0002-7326-5881; 5. ricardocesar.uabitapevi.si2@gmail.com, https://orcid.org/0000-0003-1303-101X; 6. lcdalmolin@gmail.com, https://orcid.org/0000-0001-6774-6294; 7. nilsonmodro@gmail.com, https://orcid.org/0000-0001-9612-4339.
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1. INTRODUCTION

Brazil has a wide territorial area. Ross (2005) mentions that 8.5 million km² are subject to different climatic conditions, as well as reliefs and soils that enable the development of a wide variety of environments. Therefore, such characteristics cause numerous economic activities to be carried out and each one with its peculiarities and specific demands. In the case of Solid Urban Waste (MSW), it presents itself today as a major problem in society - with greater intensity in urban areas - aggravating the existing environmental problems and resulting in the emergence of others where, most of the time, related to inadequate forms of disposition and inefficiency in their management (TROMBETA; LEAL, 2014).

Gouveia (2012) points out that, although Brazil is a territory that presents great regional differences, the production of waste has increased in all regions and states of the country and a large part of this waste does not have an appropriate sanitary and environmental destination. Normally, MSW are deposited in open dumps - in dumps - a less harmful way would be in controlled landfills, since the waste is covered by land, or, in landfills which, by the method of treatment adopted, reduces the impacts damage to human health from its disposal (FROTA *et al*., 2015).

In Brazil, in the view of God, Battistelle e Silva (2015, p. 686), "investment in solid waste management is essential for its development and growth, especially for the solidification of its infrastructure". In the same way, for Padula (2008), considering the dimensions of the country, a transport infrastructure is essential for its development. However, on the one hand, in most companies, according to Ballou (2006) and Castiglioni and Pigozzo (2014), transport is the most important element when it comes to logistics costs.

On the other hand, Nunes and Silva (2015) explain that collecting solid waste means collecting the waste packaged by the one who produced it and then forwarding it, through proper transport, to a possible transfer station for proper treatment and its treatment. final destination. In view of this, Colavite and Konish (2015) believe that understanding and knowing the relationships between the different characteristics of transport modes becomes an imperative with regard to cargo transport management. Given the above, this article aims to compare the rail and road modes in the transportation of urban solid waste via simulation based on System Dynamics the financial and environmental differences between both.

The motivation for this study is due to factors such as: (a) in Brazil - a country that has a per capita income considered to be intermediate - it is produced daily 1.23 kg / inhab. / Day (Rodrigues; Magalhães Filho and Pereira, 2016) ; in addition, (b) cargo transportation in the country is highly dependent on highways (Bartholomeu and Caixeta Filho, 2008); (c) where such dependence becomes a problem when considering the country's continental dimensions and its precarious and insufficient road infrastructure (Pontes; Carmo and Porto, 2009); and (d) therefore, it is necessary to investigate means that make structures feasible in such a way as to generate less impact (MORAIS; COLESANTI, 2014). As for the structure, after this introductory chapter, the theoretical framework is presented. Then, there is the research method adopted. Then, the description of the development of the model and experiment follows and, later, it ends with the final considerations accompanied by recommendations for future research.

2. THEORETICAL FOUNDATION

The railway modal concerns the type of transport that runs on tracks between cities and the subways that circulate within cities (MARQUES; ODA, 2012). The road, Souza and Markoski (2012) explain that it makes use of highways using vehicles such as trucks and trailers for transportation. In Brazil, the road mode is the most used, reaching almost all points of the Brazilian territory (GOMES, 2004; MAGALHÃES *et al.*, 2013; FARIA; COSTA, 2015).

Seleme *et al.* (2012) and Santos and Silva (2015) consider that such representativeness is due to the fact of the characteristics of the investments made over the last decades that privileged this modality. Furthermore, because it is very flexible, it also helps to explain this issue of being the most expressive in cargo transportation (DIAS; RIBEIRO, 2013; COSTA *et al.*, 2016). However, Gudolle (2016) warns that the road modal has higher costs when compared to the railway. Next, in Frame 1, there is a comparison between the rail and road modes published by the National Waterway Transport Agency (ANTAQ, 2011).

Frame 1 – Comparison between rail and road modes *

Variables	Rail	Road
battery capacity	2,9 Trains Hopper (86 vagões)	172 Bulk Carrier Bi-Train Trailers
Total length (track occupation)	1,7 km	3,5 km (26 km in motion)
Fuel consumption (1 ton / 1,000 km)	10 liters	96 liters
Carbon monoxide emission (1 ton / 1,000 km)	104 grams	219 grams
Energy efficiency (tons./hp)	0,75 (4 x Road)	0,17
Logistical cost (US $ 1,000 km / ton.)	24	36

* For equivalent units of load capacity
Source: Adapted Agência Nacional de Transportes Aquaviários (Antaq, 2011).

It can be seen in Frame 2 - about the load capacity - that while 2.9 Hopper type trains (86 wagons) are needed by rail, 172 bulk bi-train trailers are needed to transport the same equivalent units by road. With regard to fuel consumption, using rail as a means of transport, the difference corresponds to 860% when compared to the road modal. Under this approach, according to data from the National Transport Confederation (CNT, 2018), Frame 3 shows the consumption of diesel oil for both modes.

Frame 2 – Diesel oil consumption (in millions of m3)*

Year	Rail	Road
2012	1,21	38,60
2013	1,20	40,68
2014	1,18	41,40
2015	1,14	40,20
2016	1,12	38,77
2017	1,21	39,17

* Currently, the diesel oil sold in Brazil is B10; that is, it contains 10% of biodiesel in its mixture, as determined by Federal Law nº 13.263 / 2018 and Resolution CNPE nº 23, of 11/09/2019.
Source: Adapted from the National Transport Confederation (CNT, 2019).

It can be seen in Table 3 that in the last six years the consumption of diesel oil has remained practically stable in each mode - with the exception of 2012 (1.21) to 1.12 in 2016 in rail - representing a reduction of 7, 44%. However, the average consumption of diesel oil in the period was 39.80 for road and only 1.18 for rail. It is worth noting that such data have important impacts. On the one hand, Arruda Júnior (2014) points out that in the road modal with diesel oil as the main fuel used, the cost of freight already represents almost 40% in Brazil. Therefore, diesel oil expenditure is one of the heaviest for the sector (CNT, 2012).

On the other hand, climate changes in recent years have been frequently discussed by the most varied channels of civil society (Maciel; Barros Junior; Andreazzi (2015), where such changes have affected everyone and are due to the increase in the concentration of greenhouse gases greenhouse gas (GHG) (NUNNENKAMP; CORTE, 2017). In this sense, Arioli and Lindau (2014) mention that the transport sector is among the main sources of GHG emissions. In addition, Drumm *et al.* (2014) state that in the country 32% of carbon emissions are due to transport activities - this is a high number when compared to the world average - and this is due to the road modal that is predominant over the others. in the country it has an exaggerated dependence on the road mode, being notorious that other means could be used, as in the case of trains and ferries.

3. METHODOLOGICAL PROCEDURES

The methodology used in this article is based on Systems Dynamics, allowing the study to create computational models to analyze the behavior of systems over time, thus allowing the evaluation of the consequences of our decisions. To apply the System Dynamics, computational modeling and scenario planning will be used.

Chwif and Medina (2015) describe computational modeling as a presentation of real systems, having great importance to understand the complexity of the real world. A simulation model is able to more accurately capture the characteristics of time, state and nature and from software these captured characteristics are repeated on a computer with the same behavior that the real system exhibits, thus helping in the decision process (CHWIF; MEDINA, 2015). According to Andrade *et al.* (2006), computational modeling is one of the tools of systemic thinking that adds learning to the process and through it, micro-worlds of the real system are built.

Scenario Planning promotes learning and challenges mental models by visualizing possible futures. With both methodologies acting together to feed the strategic process, there is a methodological contribution capable of offering the benefits described above in a synergistic way. In addition, it prevents the strategic process from suffering difficulties, such as the tendency to focus on events, the ineffective habit of seeking to predict the future, reactive behavior of adapting to the future and focusing only on problem solving (ANDRADE *et al*, 2006).

3.1 Steps of creating the model

Five steps were used to develop the research model. Step (I) represents the exploratory study in scientific articles, technical reports, dialogues with stakeholders and observations of the environment where the data were collected. It is noteworthy that the data were collected directly from a private waste collection company. Through this data, the research objective was specified and structured. Step (II) presents the development of the solution through the construction of formal models capable of representing the problem (definition of variables and their relationships).

The computational implementation of the solution (step III) was carried out with the aid of the Vensim® simulator (VENTANA SYSTEMS, 2019) from the Systems Dynamics area. Stage (IV) is responsible for the verification and evaluation of the solution through laboratory tests and analysis of historical behavior (with the data that were possible) to verify whether the results obtained represent part of the observed reality, as well as through the simulation of an experiment adopting nine scenarios for this. In addition, managers from the areas involved were also interviewed to ensure greater reliability for the study. Finally, the research was analyzed in step (V) where the differences between the existing possibilities were exposed.

4. MODEL DEVELOPMENT AND EXPERIMENT

Melquiades (2015) points out that both the collection and transport of MSW is a critical problem in most cities in Brazil. According to Souza and Guadagnin (2009), the stages of collection and transport spend between 60% and 80% in terms of global costs when it comes to waste management. In this research, the transport logistics of the MSW was simulated, whose model will allow managers to compare transport by train and truck. Therefore, the model must react to different factors, such as: population growth, the average generation of solid urban waste per capita and the cost of transportation.

To build the model, it was necessary to deepen the knowledge about the area of rail and road modals. To assess the collected data, the report of the National Land Transport Agency (ANTT, 2013) was used. It should be noted that in the road transport there are several types of trucks with different sizes and capacities. Thus, in this research, the trucks responsible for collecting MSW are classified as light trucks, because according to the report of the Ministry of the Environment (MMA, 2014), trucks with the capacity to load between 6 and 10 tons fall into this nomenclature.

The consumption of the trucks took into account the daily loaded tonne in addition to the distance traveled and the data were collected directly in the database of the partner company to the study, by calculations composed in the reports of ANTT (2013), National Association of Automotive Vehicle Manufacturers (ANFAVEA, 2014), (MMA, 2014) and PETROBRAS (2018). Generally, collections are carried out from Monday to Saturday for municipalities with 10,000 (ten thousand) inhabitants or more. The cities of Agudo / RS, Cacequi / RS, Restinga Seca / RS and São Francisco / RS fit into this collection model. In the municipalities from 5,000 (five thousand) to 10,000 (ten thousand) inhabitants, collections are made 3 (three) times a week (such as Faxinal do Soturno / RS and Mata / RS). São Martinho da Serra / RS has the collection of MSW 2 (two) times a week, as it has a population of less than 5,000 (five thousand) inhabitants.

The collection carried out in these municipalities is brought to Santa Maria / RS, where the only licensed landfill in the region is located. It should be noted that the cities studied in this research do not have transshipment or screening. In addition, there are few that have selective collection, and in these, the collection is carried out in an unorganized and efficient manner. The values referring to the monthly internal collections of MSW in these regions and the values composed by the shipment to the landfill in the city of Santa Maria / RS are shown in Frame 3.

Frame 3 – Monthly Collection Data

Cities	Nº. Collections	Landfill Shipping	Shabby Diesel	Internal Collection	Shabby Diesel
Agudo	6 per week	3403.2 km	1361.28 liters	500 km	200 liters
Cacequi	6 per week	5952 km	2380.80 liters	480 km	192 liters
Restinga Seca	6 per week	2827.2 km	1130.88 liters	493.4 km	197.36 liters
São Francisco	6 per week	6672 km	2668.80 liters	515.6 km	206.24 liters
Faxinal	3 per week	1406.4 km	562.56 liters	133.6 km	53.44 liters
Mata	3 per week	1992 km	796.80 liters	109.8 km	43.92 liters
São Martinho	2 per week	472 km	188.80 liters	42.8 km	17.12 liters
Total	N/C	19321.6	9089.92	2275.2	910.08

Source: Authors (2020).

For the railway, ANTT uses data provided by each railway concessionaire to inform the average distance traveled by a wagon each month of operation (ANTT, 2013; América

Latina Logística, ALL, 2013). According to Novo (2016), the projection of the cargo volume for the railroad modal occurs in a similar way to the road projection, that is, “both consider the average distance, wagon fleet and average wagon capacity, the value being adjusted by a factor loading to reach the final amount of cargo carried (p. 40). Currently, the lines for the transport of MSW are deactivated, but follow the route of the road modal.

There are two ways to measure transport consumption by rail mode: (1) Gross Kilometer Ton (TKB) which stipulates the “quantity of gross tons (sum of the product's tonnes with the wagon's tare) transported multiplied by the mileage traveled by the same ”(Santos, 2012, p. 56); and (2) by the Useful Kilometer Ton (TKU) which refers to “the quantity of useful tons transported multiplied by the mileage traveled by them” (ANTT, 2016, p. 13). In this article, only the TKU was used, taking into account that the train will only leave loaded, that is, the transport of the train with empty wagons will not be analyzed. To find out the average value of transport consumption in RTK and also its annual behavior, the following Equation (i) was used:

Average Consumption Value = Fleet (wagons) x average path per wagon (km) x wagon capacity (t) x loading factor (i)

The data for the variables described in Equation (i) are exposed in ANTT's annual report (2013). From the aforementioned equation, it is understood that the average journey per wagon uses data provided by each railway concessionaire to inform the average distance traveled by a wagon each month of operation. The wagon's useful capacity is determined by each concessionaire - since the stretches are different - and for the wagon fleet it is informed in ANTT reports on the number of wagons in operation per concessionaire and, finally, the loading factor is represented in the ANTT report for monthly data per concessionaire (measured in liters per TKU). After understanding the variables presented, Frame 4 was generated, showing the annual variation that was used in the simulation.

Frame 4 –Fees I

Year	Fees	
	Births	**Mortality**
2019	11.20	7.08
2020	11.3	7.17
2021	10.83	7.27
2022	10.72	7.37
2023	10.56	7.48
2024	10.4	7.6
2025	10.24	7.72
2026	10.15	7.85
2027	9.99	7.99
2028	9.81	8.13
2029	9.97	8.29

Source: Authors (2020).

Scenario planning was adopted for the simulation and three scenarios were generated for this study. Their differences, rates and the variables that make up each scenario are described in the next section.

4.1 Scenarios

The future is inherently uncertain and unknown, however, based on knowledge, plausible futures can be considered. Through scenario planning it becomes possible to analyze different future projections to make the best decision. Its purpose is to build several plausible scenarios and based on them to define robust strategies for application in the present and, consequently, test the model and the hypotheses generated (ANDRADE *et al.*, 2006).

For the construction of the scenarios it was necessary to understand the logistics of MSW collection in the studied region, in addition to understanding the population growth and, in turn, the generation of waste per capita. The dynamics of the interrelationships between the variables generate patterns of future behavior that are, in fact, scenarios that will be configured if those forces continue to act as mapped. To perform the mapping, data from different platforms were used, as in the case of the reports of the Brazilian Institute of Geography and Statistics (IBGE, 2008), National Agency of Petroleum, Natural Gas and Biofuels (ANP, 2016), among other studies and reports. To analyze the proposal of the article, three scenarios were generated, namely:

- **Current scenario:** responsible for measuring the current behavior of the system. The data used in this scenario will try to represent the collection of solid waste closest to reality;
- **Modal Scenery:** it will simulate the 40% transport of MSW by rail, using the lines still active; and
- **Optimistic Modal Scenario:** it will simulate the transport of MSW by rail using the active and inactive lines, transporting 50% of the total waste generated by the region's population.

The fuel used in the collection is diesel derived from petroleum. According to Petrobras (2018), oil-derived fuels are commodities and their prices are linked to international markets, whose prices vary daily both upwards and downwards. In addition, he adds that the price of the liter sold by the distributors is based on the import parity price, composed of international quotations for these products plus the costs that importers would have (such as transportation and port taxes).

Parity is necessary, since the Brazilian fuel market is open to free competition, offering distributors the option of importing products. In addition, the price takes into account a margin that covers risks (such as exchange and price volatility) (PETROBRAS, 2018). The average prices informed meet the national arithmetic average of the spot prices, free of charges and free of taxes, practiced in the standard sales modality in the innumerable points of supply, with variations throughout the Brazilian territory, for more or less in relation to the average (PETROBRAS, 2018). Table 6 shows the variation in the average price per liter of diesel used.

The data obtained regarding the collection of MSW by road was collected directly at the responsible company and the trucks' performance was validated in interviews with stakeholders in the area. For the railway modal, technical articles and government reports were used. The data referring to the population and their rates were taken from spreadsheets, graphs and projections provided by IBGE (2016), for the generation of urban solid waste, the report of the Brazilian Association of Public Cleaning and Special Waste Companies was used (ABRELPE, 2016). In addition to the data from IBGE (2016) mentioned earlier, other studies were adopted to support the other variables of the model, such as: Pidd (1998), Ford (2009), Strauss (2010), Simonetto *et al.* (2014), Simonetto *et al.* (2016) among other studies.

To contemplate the environmental analysis of the model, the emission of carbon dioxide (CO2) will be studied, which varies according to the fuel consumed. In this research, both modes use diesel oil for locomotion and to differentiate the emissions of each mode per kilometer, data adopted by the National Land Transport Agency (ANTT 2013) were adopted. The data used in the scenarios were tabulated and are shown in Frame 5.

Frame 5 - Fees II

Variable	Scenario		
	Current	Modal	Optimistic Modal
Tx. RSU Truck	100	60	50
Truck Capacity (Kg)	10000	10000	10000
Average Trais RSU	376.8	376.8	376.8
Tx. RSU Train	0	40	50
Average Engine Yield (Km/l)	5.6	5.6	5.6
Distance(Km)	25000	15000	12500
Diesel Price Change (l)	0.08%a.a	0.08%a.a	0.08%a.a
Initial fuel price	R$2.99	R$2.99	R$2.99
Initial Inhabitants	80729	80729	80729
CO_2 modal Road (Kg/TKU)	0,0079	0,0079	0,0079
CO_2 modal Rail (Kg/TKU)	0,0012	0,0012	0,0012

Source: Authors (2020).

For the definition of the model's component variables, the aforementioned data were used, in addition to the logic obtained by the researchers through the knowledge acquired from: observations, bibliographic deepening and study in public documents in the area of MSW. In the next section, the model and its relations will be presented.

4.2 Developed Models

To meet the objective proposed in this article, two models were generated: (1) with a focus on financial analysis; and (2) contemplating the environmental part. Thus, the computational model developed to investigate the financial bias is composed of a stock variable, two flow variables, sixteen auxiliary variables and a “shadow” type variable called time, enabling the indication of the time unit during execution in the Vensim® software. With a view to better understanding, a feedback structure was developed which, for Strauss (2010), feedback relationships are the causal relationships between variables and are represented by links between these variables.

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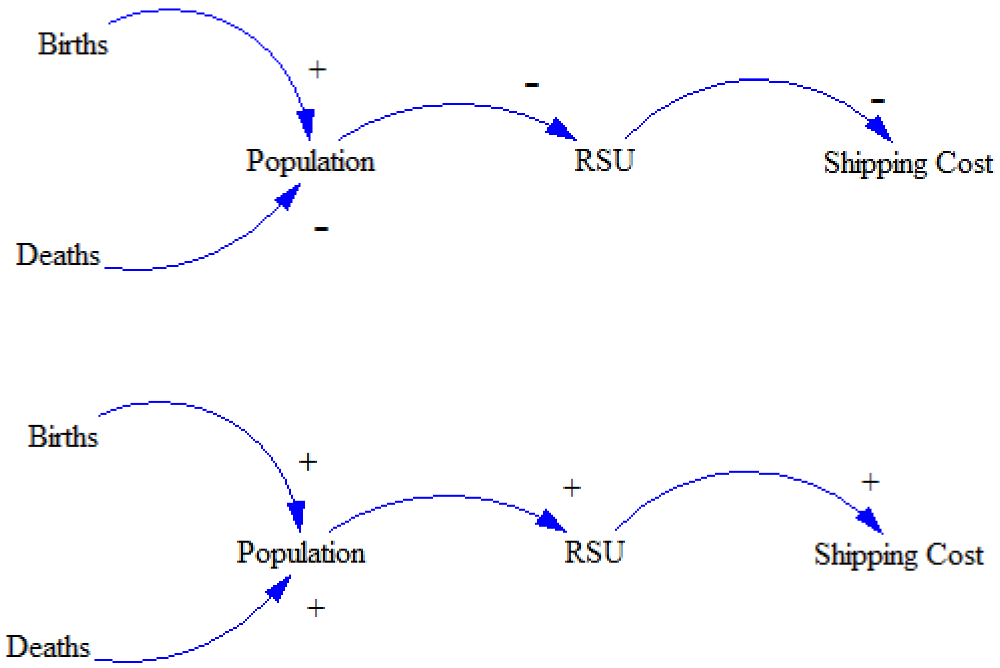
Figure 1 - Feedback structure



Source: Authors (2020).

The "Birth Rate" and "Mortality Rate" directly influence the inflows and outflows ("Births" and "Deaths") of the "Inhabitants" stock variable, this interaction determines the total population in the simulated years of the studied cities . For this, the study by Simonetto et al. (2014) as a reference for building the population logic, using the natural or vegetative growth rate model (total births - total deaths), which corresponds to the only possible way of growth or reduction of the world population. The total MSW in the region generated is the result of multiplying the auxiliary variable "Average MSW" by the total population, a value stored in the stock variable "Inhabitants".

In order to analyze the behavior of solid urban waste collection, it is important to verify the population growth of the studied site. For this, the stock model that will store the total population in the simulated years was configured, the stock variable responsible for this function is called Population. The incoming flows are called Quantity Births and Number of deaths, these flows insert the data of annual births and deaths. To represent the variation in births and deaths, two auxiliary variables were created: Birth rate and Mortality rate. The annual birth rate (Birth rate), the annual mortality rate (Mortality rate), all of which directly influence the inflows and outflows of the population (Quantity Births and Number of deaths), which determine the total population (Population) of the studied region. The rate of natural or vegetative growth (total births - total deaths) was used in the model, which corresponds to the only possible way of growth or reduction of the world population and, when analyzing the growth of specific areas, must also be considered. migrations.

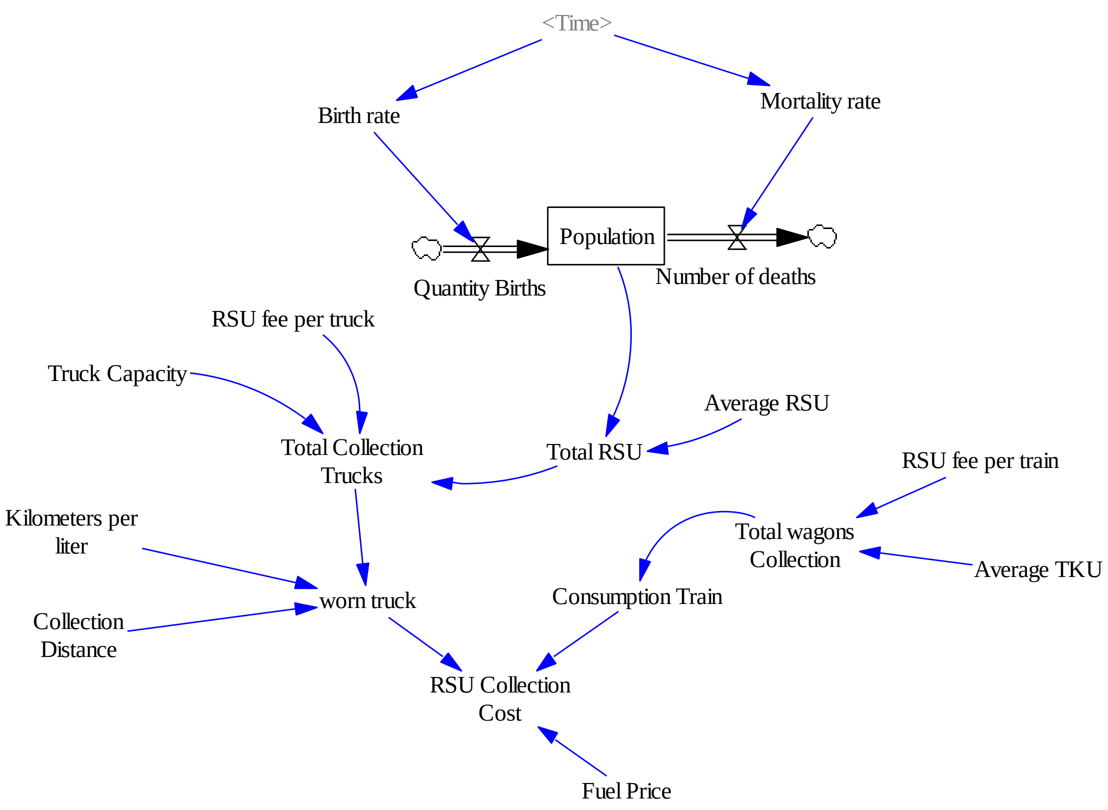
The average amount of waste (Average MSW) generated by each inhabitant multiplied by the total population of the municipality results in the total amount of waste (Total MSW) in the region. The study proposal will simulate the transportation of the waste in different portions divided between train and truck. In order to measure the number of vehicles, it was necessary to know the capacity (in tons) of MSW that a truck transports (Truck Capacity) and how much a train car will withstand waste (Average TKU). In order to divide the quantity of tons of MSW in each modal, two auxiliary variables were necessary: Total Collection Trucks and Total wagons Collection.

To measure the expense of transporting waste by truck, it was necessary to check the average diesel consumption per liter and also the average kilometers traveled by the trucks. For this purpose, auxiliary variables Kilometers per liter and Collection Distance were created. The total consumption of the trucks is stored in the variable worn truck. For the train it was necessary to understand how many wagons the machine would pull for this and the consumption per ton, the consumption values of this modal is stored in the Consumption Train variable.

Finally, to analyze the total cost of the different transport divisions of solid urban waste, the variable RSU Collection Cost was created, which will receive the input values of the consumption mentioned above multiplied by the value of the liter of diesel, a value stored in the variable Fuel Price.

. The model responsible for the cost of collection is shown in Figure 2.

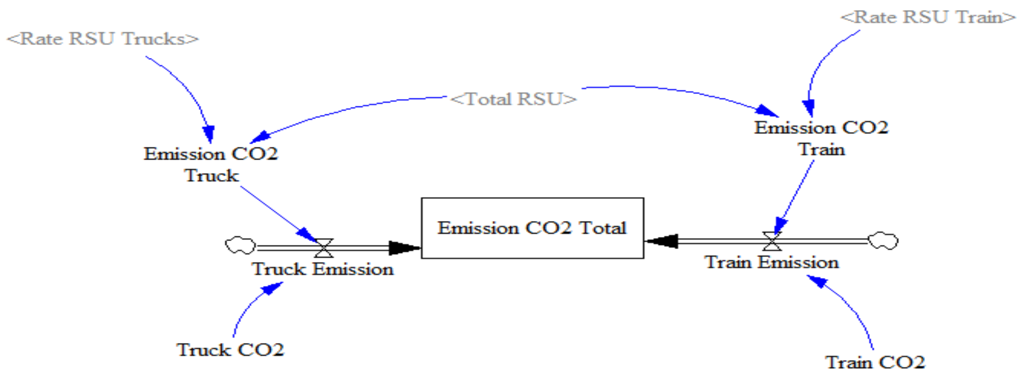
Figure 2 – Financial Model



Source: Authors (2020).

The model responsible for storing environmental behavior is shown in Figure 4 and it is composed of a stock variable ("Total Emission"), four auxiliary variables ("CO2 Truck", "CO2 Train", "EMISSION CO2 Truck" and " EMISSION CO2 Trem "), three shadow variables (" Tx RSU Truck "," Total RSU "and" Tx RSU Trem ") and to insert the input data in the stock variable, two“ arrow ”variables were generated, which replicate the data stored in the auxiliary variables "EMISSION CO2 Truck" and "EMISSION CO2 Train". It is worth noting that the shadow variables already belong to the model shown in Figure 3, thus allowing the data entered to replicate in both models equally.

Figure 3 – Modelo ambiental



Source: Authors (2020).

After defining all equations and their relationships, the model was simulated. Therefore, your experiment is described in the next section.

4.3 Experiment of the computational model

Once the three scenarios were defined, it became possible to simulate the model proposal developed in the Vensim® simulator (VENTANA SYSTEMS, 2016) on a computer, with a Pentium Core i3 processor and 4 Gb of RAM. The simulation execution time was in the order of hundredths of seconds. The simulated time horizon in the experiment was eleven years; however, the configuration of this variable is left to the designer / user, as it depends on the analysis to be made.

With the model developed, several analyzes can be performed and in the current study, the ones that seemed to be the most relevant in the opinion of the authors and the stakeholders participating in the study were selected, namely: population growth and its relationship with the generation of MSW and as a consequence the cost of transporting this waste to the landfill located in the city of Santa Maria - RS. It is important to note that the model is open to new configurations, and any and all analysis of the "what if" type is simple and easy to use, because when the rates and variables are modified, new results are generated for analysis. of users (SIMONETTO *et al.*, 2016).

The first analysis to be developed using the model refers to the number of inhabitants in the studied region. In 2018, the number of inhabitants was 80,040 people and in 2019 there is an increase of 689 people. In the eleven simulated years there was an average variation of approximately 2.89% reaching 107,977 inhabitants in the year 2029. Knowing the possible population of the region assimilating with the average generation of MSW per capita, it became possible to estimate what will be the generation of waste per capita for eleven years, Figure 4 shows this projection. Therefore, in the year 2019, approximately 30,000 tons of garbage will be produced, reaching 40,000 tons in 2029, with an average generation of MSW per year of approximately 35,000 tons. Table 8 shows population growth in eleven years of analysis in addition to the generation of MSW in the region studied.

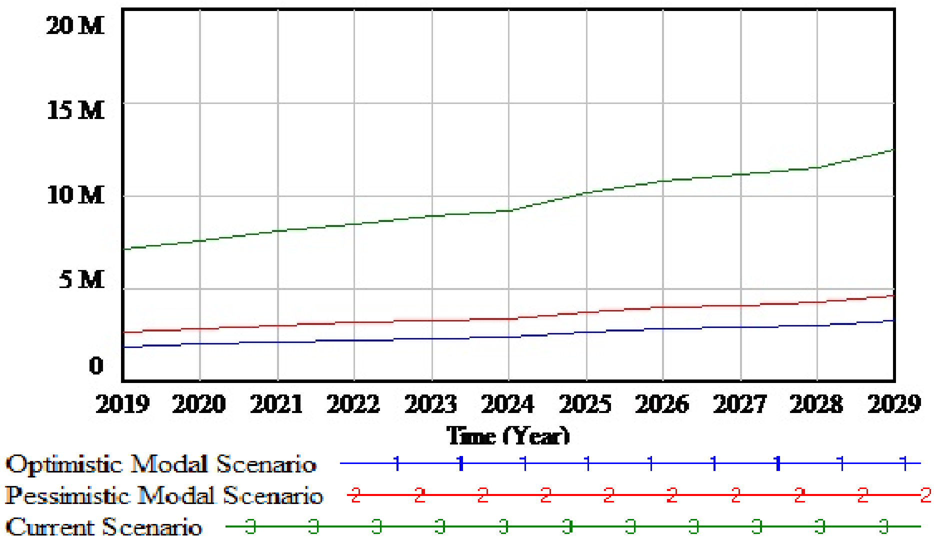
Frame 6 - Inhabitants and Urban Solid Waste

Year	Population	Solid Waste (RSU/Kg)
2019	80.729	8.173.000
2020	84.055	8.509.730
2021	87.526	8.861.180
2022	90.642	9.176.640
2023	93.679	9.484.060
2024	96.667	9.786.600
2025	99.490	10.072.400
2026	102.117	10.338.300
2027	104.598	10.589.500
2028	106.836	10.816.100
2029	107.977	11.013.000

Source: Authors (2020).

The cost to transport the urban waste shown in Figure 4 is represented in Figure 5, below, where the scenarios with transport by road and rail transport were compared. The Current Scenario - which represents collection by road (the usual means of transport these days) - is the most expensive transport: it costs R $ 1,038,000.00 per year, totaling in 2029 approximately R $ 105,154,007. The scenario with the best financial performance is the Optimistic Modal Scenario, which will save approximately R $ 7 million per year if compared to the scenario with the worst financial income. The Modal Scenario will also present savings when compared to the Current Scenario and may generate approximately R $ 4 million per year.

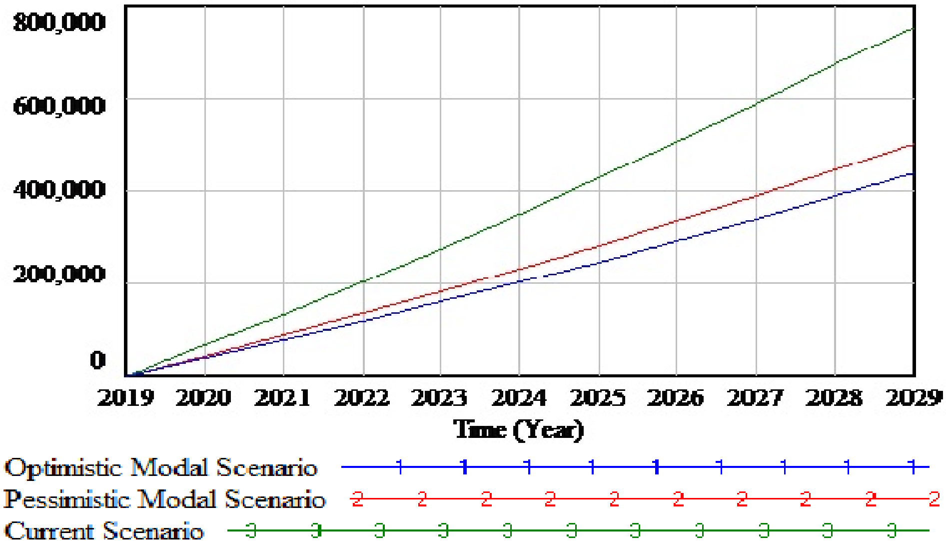
Figura 4 – Custo total da coleta dos resíduos sólidos urbanos



Source: Authors (2020).

Air pollution is one of the biggest environmental problems in the world, being considered a worrying factor both for today and for the next generations (Instituto Estadual do Ambiente, INEA, 2012). Given this fact, the second analysis of the model is related to the emission of carbon dioxide (CO2) resulting from the complete combustion of carbon, therefore, Figure 6 presents the simulation performed. It is noted that the Optimistic Modal Scenario is the one with the lowest CO2 emission index, totaling eleven years simulated here, approximately 435 tons. This represents 321 tons less than the scenario with the highest emission index (Current Scenario), since in 2029 it will emit up to 756 tons of CO2. The Modal Scenario also has a lower CO2 emission when compared to the Current Scenario, it will emit approximately 500 tons, about 256 tons less than the Current Scenario.

Figure 5 – Total de emissão de CO_2



Source: Authors (2020).

It is observed by the simulations generated in the present work that there is a big difference in financial and environmental terms between the rail and road modes. This, in addition to demonstrating the importance of valuing the railways, also presents itself as another option for managers for the purpose of transporting the waste generated in the municipalities studied, since the railway modal does not replace the road modal, but could be better explored because of the benefits generated by its adoption.

5. FINAL CONSIDERATIONS

The continuous appearance of new technologies on the market, the urbanization process and the increase in the purchasing power of individuals are some of the characteristics present in contemporary society. therefore, these factors alter and shape the current consumption practices, which means that the discussions around the generated msw are increasingly brought up in seminars, forums, lectures, as well as exposed in works and publications that address this issue.

The point is that msw has become a problem both in brazil and in other parts of the world and in addition to significant financial expenditures, it still has all the environmental damage caused by the improper disposal of this waste in the environment. consequently, everyone is affected and this requires thinking about ways to alleviate these problems in the sense of looking for alternatives in order to reduce both the negative financial impacts and the environmental impacts arising from the msw.

Thus, considering the proposal of this article and among the analyzes carried out, it was verified in the eleven simulated years that the number of inhabitants in the region considered for study purposes reaches a total of 107,977 in the year 2029. from that point on, it became it is possible to make an estimate of the generation of waste per capita in the period, where it was found that the average generation of msw per year will be approximately 35,000 tons.

As for the simulated scenarios, it was observed that modal optimista obtained the best financial performance - saving about r $ 7 million reais - when compared to the one with the worst financial performance. in addition, investigating the environmental part, it was found that the optimistic modal scenario is the one with the lowest co2 emission index in the simulated period - approximately 435 tons - a total of 320.955 tons less compared to the scenario with the highest index of issue. finally, from the research carried out it is remarkable, seen from a financial perspective, that there is a great difference between road and rail modes in the transport of msw.

At the end of this study, it is hoped that it will have contributed to managers and government officials seeking new options in the face of the problem faced with msw and, at the same time, being able to find ways to take advantage of the advantages provided by the railway modal. for that, it is necessary to resume investments in this modal with the due planning so that over time it is possible to revert to the situation experienced today - the excessive dependence on highways for the transportation of cargo - and to have an adequate infrastructure.

Furthermore, it is believed that the discussions around this theme do not end here. therefore, as a recommendation for future research, an investigation is recommended that contemplates the entire environmental part, taking into account the benefits that could be achieved with the resumption of railroads in the transportation sector in Brazil.

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