Simulation computer to evaluate scenarios of solid waste – an approach using systems dynamics

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Abstract: The article presents the development, validation and experimentation of simulation model using systems dynamics methodology, which allows users and managers to evaluate and analyse scenarios about the generation and disposal of urban solid waste. The developed model takes into account the following rates and information: rate of population natural increase (births and deaths), percentage of urban solid waste sent to each type of final disposal and the quantity of waste generated per inhabitant. The simulated scenarios take into account three distinct situations: a) current scenario with varying rates; b) current scenario with static rates; c) scenario with rates similar to the Netherlands's. The model's validation was developed through the analysis of future scenarios for a municipality in Brazil's southern region. With the generated results, the area managers may, in advance, evaluate and decide possible ways for improvements or adjustments in the management of municipal solid waste. The best simulated scenario was with rates similar to the Netherlands's. For the system modelling and development Vensim simulator was used.

Keywords: solid waste; computational simulation; decision-making process; population growth.

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1 Introduction

The environmentally correct disposal of solid waste is among the most important issues for maintaining the quality of the Earth's environment and especially, to reach an environmentally correct and sustainable growth in all countries (Zutshi and Sohal, 2002). Despite the worries of the international community with the quality of Earth's environment, what happens most of the time is a non-sustainable development in the management of municipal solid waste (MSW) because the methods of collection, that is, transportation and deposit of solid waste do not take into account the consequences that their inadequate treatment may cause to the environment in the very near future.

Solid waste, for the purpose of this work, is considered every domestic and non-hazardous waste, such as commercial, institutional and construction waste. In some countries, the solid waste management system is also responsible for human waste, such as excrements, ashes from incinerators and sewage treatment facilities (Barlaz et al., 1995).

Solid waste management is a matter that has been drawing the attention of researches in operational research (OR) and system modelling in the last few years (Bani et al., 2009). Many authors (Chang et al., 2008; Simonetto and Borenstein, 2007; Sufian and Bala, 2007; Chang and Wei, 2000; Costi et al., 2004; Weintraub et al., 1998; Tanskanen, 2000; Tung and Pinnoi, 2000; Huang et al., 1998) have used PO methods and techniques to develop studies in this specific area, although very few in Brazil. The use of quantitative techniques in solid waste management appears as a feasible alternative to the treatment of the complexity inherent to the process, for through the use of these tools it is possible to represent a real world situation, study its behaviour and make decisions based on the conclusions extracted.

The main goal of this article is to present the development and validation of a computer simulation model, which allows the managers of MSW to evaluate and analyse scenarios about the generation and final destination of MSW. Therefore, the research problem consisted on the investigation, definition and validation of the variables composing the simulation model, as well as its conception and validation. For the development of the computer model, techniques from the system dynamics field were used (Gharajedaghi, 2011; Daellenbach and McNickle, 2005). The use of such techniques has the goal of aggregating quantity to the decision process, because many decisions on the planning of solid waste management are taken based only on the managers' experience (Chang and Wei, 2000). This fact, according to this author, contributes to the high cost and low performance of the management of waste in the municipalities. For the validation of the model, possible future scenarios were analysed using real data on the generation and final disposal of MSW of a given municipality.

The paper is organised as follows: Section 2 presents the research methodology used to develop the study. Section 3 presents an introduction to computer simulation and system dynamics methodology; Section 4 presents concepts on solid waste treatment and final disposal. Section 5 describes the modelling problem, the component variables and the model developed. Section 6 presents the validation, the simulation scenarios and the experiments using the model as well as the discussion of results. The conclusions are presented in Section 7.

2 Research methodology

The research methodology adopted to develop the computational model of this work was proposed by the Law and Kelton (1991) for scientific study in operations research and consisted of the following steps:

1. exploratory studies in scientific papers, reference manuals and interviews with managers in the field of solid waste, in which the problem was characterised and structured
2. development of the solution, by the construction of formal models capable of representing the problem
3. the computational implementation of the solution, using the simulator Vensim (Ventana Systems, 2011) in the area of system dynamics
4. validation of the solution, through laboratory tests and field trials, to verify if the results obtained are in agreement with the observed reality as well as by simulating an experiment using three scenarios for doing so.

The scenarios that were used to validate the model were generated from analyses where historical data were used from the censuses of 2000 and 2010 (IBGE, 2010), the overview of solid waste in Brazil-2010 (ABRELPE, 2011), a newsletter about types of disposal in the European Community (EUROSTAT, 2011), and diagnostic of solid waste management (Ministry of Cities, 2010) and also through the participation of researchers and experts.

3 Computer simulation

The computer simulation of systems consists of using a set of methods and mathematical techniques, in order to simulate the behaviour of real systems, often using computers and software for this task (Kelton et al., 1998). It can be defined as a process of designing a model of a real system and procedures for experiments with this model to verify the behaviour of the system or even evaluate strategies for its operation (Pegden et al., 1995).

Through the use of the simulation, it is possible to simulate the behaviour of virtually any type of operation or process in the real world (Law and Kelton, 1991). One of the main steps of a simulation study is to create a logical model. Thus, a logical model consists of a set of assumptions and approximations, properly quantified and structured, designed to represent the real system behaviour under certain conditions, using it to predict and compare logical alternatives that can be simulated.

A model is also used when you want to learn something about the real system that you cannot observe or experience directly, whether because of the absence of the real system or the difficulty of handling it, or for the impossibility of subjecting it to the test without incurring high costs and time spending. The amount of simplifications imposed to the model will directly influence the distortion between the results obtained by the model and the real system. Therefore, this method constitutes one of the most powerful analytical tools available for representing complex systems (Kelton et al., 1998). The simulation has many applications in everyday life, in many different areas, ranging from the production control in the area of food (Pidd, 1987), controlling the flow of papers in an office (Davies, 1994), the traffic control in cities (Salt, 1991) to the control of surgical instruments transportation inside a hospital (Ceric, 1990). One of the techniques used for the simulation is the methodology of system dynamics, which is presented in subsection 3.1.

3.1 System dynamics

Engineer Jay Forrester of the Massachusetts Institute of Technology (MIT) developed the system dynamics (SD) methodology during the 50s. Its first application was an analysis of a US company, specifically the study of fluctuations in its sales. This study was published under the name of Industrial Dynamics.

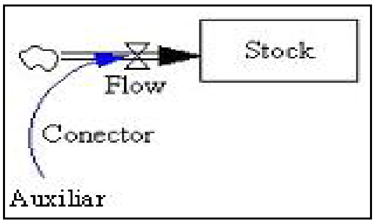
In 1969 the book 'Urban Dynamics' was published, in which the model of system dynamics applied to modeling cities is presented. This work later would serve as a basis for Meadows et al. (1972) to develop the work 'The Limits to Growth', presented to the Club of Rome in the early '70s. This work and its impact popularised system dynamics worldwide.

An SD model can be interpreted as the structure resulting from the interaction of policies. This structure is composed of two main components, which are inventory and streams. Inventories depict variables that are accumulated and flows are the decision-making functions or policies of a system. These components may be arranged in the form of circular relations of cause and effect, known as balance or reinforcement feedback, and are subject to time lags in the system. Sufian and Bala (2007) used this approach for modelling the system of solid waste management in the city of Dhaka, Bangladesh.

3.1.1 Model components

In system dynamics, a model is built with basically four components: stocks, flows, auxiliaries and connectors. Inventories are state variables and can be considered as repositories where something is accumulated, stored and potentially passed on to other elements of the system (Deaton and Winebreake, 2000). They provide an overview of how the system is at any instant of time. And any changes in inventories, which occur due to the action of streams, require a certain time, or are not instant (Cover, 1996).

Figure 1 Components of a systems dynamics model (see online version for colours)



Source: Deaton and Winebreake (2000)

Flows, in turn, are action variables, and they can change the stock, increasing or decreasing their volume. The auxiliaries are used to formulate the data to define the flow equations. They serve to combine, through algebraic operations, flows, stocks and other auxiliaries.

The auxiliaries are used to model the information, not the physical flow, being able to change instantly without delays (Cover, 1996). The connectors represent the interrelations between all of the system's components. It is these interrelationships that connect the components that form a mathematical expression (Deaton and Winebreake, 2000). Figure 1 shows each of the components of a systems dynamics model.

4 Solid waste

Disposal of waste is an operation that involves the stages of cleaning, collection and disposal. These services are considered typically municipal tasks, and are therefore organised by local governments. Among these, the disposal of waste is a concern that has been gaining importance due to its implications for the quality of people's life and the need to improve techniques for management of MSW (Monteiro, 2001).

The environmentally correct waste management must go beyond its simple disposal or recovery by safe methods; it must be sought, in the concept of sustainable development, the form of solid waste treatment, i.e., the changing patterns of production and consumption. The use of this concept (sustainable development) is a way to reconcile development with the welfare of the environment.

Garbage collection is the most developed segment within the urban cleaning system and it has increased comprehensiveness of care by the population, and it is a system activity that demands a higher percentage of investment on the part of the municipality (Monteiro, 2001; O'Leary and Walsh, 1999; Huang et al., 1998). Because the population and commerce demand, the garbage collection is carried out at regular intervals, thus avoiding the hassle of living with garbage in the streets.

However, this claiming usually has a selective effect, i.e., when the municipal government has no means of providing the service to the entire population, it prioritises business sectors, health facilities and services to the population with higher incomes. One of the major problems faced by municipalities for waste collection in their poorest areas is the lack of an adequate road infrastructure, which requires the adoption of alternative systems that have low efficiency and therefore higher cost. The final disposal of waste is one of the most critical problems faced by municipalities.

When analysing only the solid waste, it can be seen clearly that the generalised action of the government over the years was only to place the solid waste collected away from the urban areas, depositing it, often in places wholly inadequate, such as slopes and rivers, in the popular 'dumps'. Another form of final disposal of solid waste is the landfills that, in turn, are designed to minimise impacts on the population and environment.

Regarding the treatment of solid waste, composting and recycling units have been installed in Brazil; they use simplified technology with manual segregation for recyclable waste, and composting outdoors, with subsequent screening. The few existing incineration plants, used exclusively for the incineration of waste from health services and airports in general do not meet the minimum requirements of environmental legislation in Brazil (Monteiro, 2001). Moreover, according to Monteiro (2001), other units of thermal treatment of waste, such as autoclaving, microwave and others, are being installed more frequently in some Brazilian cities, but the investment and operational costs are still very high.

5 Variables and the simulation model

Over the years the dumping areas for solid waste can become scarce, forcing those responsible for its management to act in advance to prevent problems that might result from such scarcity (Monteiro, 2001; Chang and Wei, 2000). The design of the model developed in this work came after analysing the work of (Chang and Wei, 2000) in Taohsiung, Taiwan, which describes how quickly the physical storage of solid waste is reduced and also the time consumed in the process of determining the area for new landfills and construction of new incinerators. In Tahosiung, the alternative was the search for increased rates of recycling.

In addition to the recurring problem of the lack of space for final disposal of MSW, another factor that contributes to the analysis of future possibilities with respect to them is the significant increase in MSW generation rates associated with population growth. Associated with the growth of the quantity of waste generated it appears that much of this has its final disposal on landfills and even inappropriate treatment ('dumps' and controlled landfills), moreover, that the rates of reutilisation, by recycling or composting, remain as low as ten years ago (Netto, 2001).

The model developed was designed in order to assist the decision making of those responsible for management of MSW, with regard to planning for a better use and disposal of waste generated by the population, a better design of areas for the deposit of solid waste and, finally, allow the assessment, in advance, of policies for integrated management of solid waste to minimise environmental impacts caused by the rising generation of waste associated with population growth.

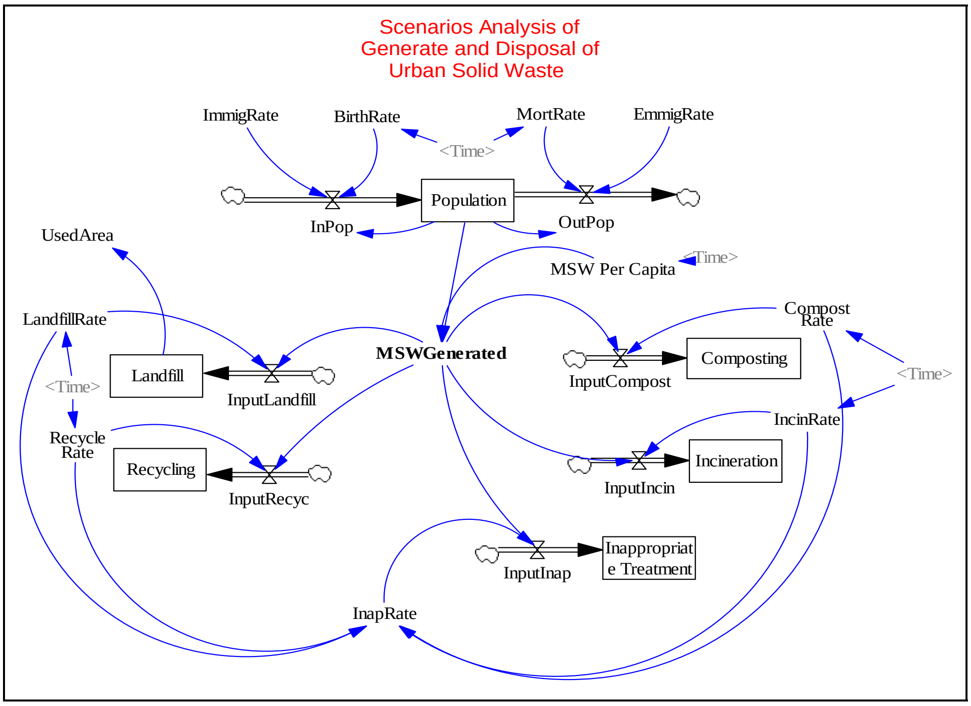
Such decisions may involve construction of new landfills, the search for a higher rate of recycling and composting, through public awareness campaigns, as well as other analyses and observations of interest to the managers, provided that they are enforceable in the model simulation developed. It is noteworthy that the model was constructed to simplify the user-machine interaction, so that 'what if' analyses, common in simulation models, are easily and simply implemented.

To construct the model, which can be seen in Figure 2, at the time of the exploratory research and development of the solution, variables were identified (validated by the experts in waste management) that influence the total values for the generation and disposal of MSW (EUROSTAT, 2011, Ministry of Cities, 2010; UNEP, 2005; Monteiro, 2001; Chang and Wei, 2000; O'Leary and Walsh. 1999), which are:

- The annual birth rate (*BirthRate)*, the annual mortality rate (*MortRate*), the annual immigration rate (*ImmigRate*) and the annual emmigration rate (*EmmigRate)*, all directly influencing the rates of input and output population (*OutPop and InPop*), which determine the total population (*Population*) of the municipality. That is, the natural growth rate was used in the model (total births – total deaths) which corresponds to the only possible way to increase or reduce world population and, when analysing the growth of specific areas, migration should also be considered.
- The average quantity of waste (*MSWPerCapita*) generated per capita multiplied by the total population results in the total amount of waste (*MSWGenerated*) of the municipality.

- The percentage rate absorbed by each waste destination (*LandfillRate*, *RecycleRate*, *CompostRate*, *IncinRate*, *InapRate*), namely, landfill, recycling, incineration, composting, and if it occurs, the percentage sent to inappropriate forms of treatment (the rate *InapRate* is dependent on the value of all other levels, for their use will occur only if the other forms of treatment can not undertake the total amount of generated MSW).
- The inflow of waste in different types of disposal (*InputLandfill*, *InputRecyc*, *InputIncin*, *InputInap*, *InputCompost*), which represent the total annual solid waste destined for each of the final destinations, and are obtained by the product of the quantity of total waste by percentage share of each destination.
- The total amount accumulated sent for each type of final destination is represented by variables *Landfill* (landfill), *Recycling* (recycling), *Incineration* (incineration), *Composting* (composting) and *InappropriateTreatment* (inappropriate treatment).
- Finally, the total area occupied by the solid waste is determined by the variable *UsedArea*, which is obtained by dividing the total amount of waste sent to the landfill by the amount of solid residue which occupies 1 m^3.

Figure 2 Simulation model developed (see online version for colours)



Source: Elaborated by the authors

6 Model validation and experimentation

The validation of a decision process support model, according to Finlay (1994), is "the process of conformance testing between the model behavior and real-world system being modeled". Finlay also states that it is not possible for a model to represent the real world system in its entirety, however, that it is possible to define relationships between model components, which allow an acceptable representation of the real world.

For Borenstein and Becker (2000) validation consists in testing the concordances between the behaviour of the system and the real world being modelled. The work of these authors refers to the validation systems. The same authors divide into two main categories, qualitative and quantitative validation. Qualitative techniques rely on subjective evaluation of the subject. The quantitative validation uses the statistics to verify the system performance in field tests. The types of validation can be seen in Table 1.

Table 1 Types of system validation

Nominal validation	Based on specialists to verify if the problem is well formulated and contains the key variables for its representation.
Predictability validation	Based on system lab tests, where the results are already known and expected.
Tracking	Impression of the variables of a programme short after the event occurred, to verify if the programme is functioning accordingly.
Turing tests	Adequate for knowledge systems. Tests the compatibility of the system result with that used by specialists.
Subsystems validation	Consists in decomposing the system into modules and its validation into parts.
Field tests	Consists in making the system work and verify the performance errors which occur.
Sensibility analysis	Consists in performing controlled alterations in the system inputs and verifying the output alterations.
Visual interaction	Consists in using the visual capacities to observe the system at work.
User evaluation	Consists in consulting the system's end users and then question them about some characteristics of the system.

Source: Adapted from Borenstein and Becker (2000)

Validation of the simulation model was made at different developmental stages. In the first validation phase (conceptual model), we used data from scientific articles, technical manuals relating to the area of integrated management of solid waste, and also with the participation of experts in the field of waste management, here is characterised the nominal validation, since experts were used to define the important variables in the model proposed. In the second validation phase, when implementing the simulator Vensim (Ventana Systems, 2011), we used historical data on the population and management of MSW (IBGE, 2002) to verify the integration between the modules of the model components, and the results generated, as we evaluate the output produced by the simulation model from actual data provided to them, this fact demonstrates the correctness of the model. In both cases the results were satisfactory and met the expectations of researchers and experts.

In the third validation phase for the construction of the experiment, we used data and real rates from a city in Rio Grande do Sul. For this end, we generated 3 (three) scenarios to be simulated in the model:

a current scenario with current rate variation

b current scenario without rate variation (static)

c ideal future scenario, which is based on rates in the Netherlands.

This type of validation can be recognised as a sensitivity analysis, since controlled variables were used in the inputs and the results variation were checked. The detail and quantification of rates for each scenario are presented in subsection 6.1.

6.1 Scenarios simulated in the model

For the validation and testing of the simulation model developed the following scenarios were generated.

6.1.1 Current scenario with current rate variation

To simulate this scenario we used the data and the rates observed in 2010 (ABRELPE, 2011), but considering their change (increase or decrease) over the years. The rates are presented in Table 2.

Table 2 Rates used in the simulated scenario with current variation

Population growth	Annual birth and mortality rates, where the average population growth of a municipality in Rio Grande do Sul was 0.7% (IBGE, 2010).
Waste generation	The average rate of MSW generated is approximately 1.213 kg/person. The evolution of annual generation is 2%.
Final destination of waste	Landfill: In 2010, approximately 53% of the waste generated in Brazil were destined to landfills. The annual evolution of the sending rate was approximately 1%. It is presumed, for the calculation of occupied area, that in 1 m^3, 700 kg of compacted MSW will be deposited.
	Recycling: Average recycling rate in Brazil is 4.3% and annual evolution is 3%.
	Composting: The average rate of composting in Brazil is less than 1%. The evolution was disregarded, as it is also low.
	Incineration: The rate considered was 0%, for this type of disposal is almost never used in Brazil.
	Inappropriate treatment: Refers to solid waste disposed of inadequately. The average rate in Brazil, in 2010, was 42.4% of the total waste. The reduction of this type of final destination was approximately 1%.

Source: Elaborated by the authors

6.1.2 Current scenario without rate variation (static rates)

To simulate this scenario we used the data and the rates observed in 2010 (see Table 3) (ABRELPE, 2011), but considering that they remained stable during the whole simulation time.

Table 3 Rates used in the simulated scenario without variation

Population growth	Annual birth and mortality rates, where the average population growth of a municipality in Rio Grande do Sul was 0.7% (IBGE, 2010). Only variable rate in this scenario.
Waste generation	The average rate of MSW generated is approximately 1.213 kg/person.
Final destination of waste	Landfill: In 2010, approximately 53% of the waste generated in Brazil were destined to landfills. It is presumed, for the calculation of occupied area, that in 1 m3, 700 kg of compacted MSW will be deposited.
	Recycling: Average recycling rate in Brazil is 4.3%.
	Composting: The average rate of composting in Brazil is less than 1%.
	Incineration: The rate considered was 0%, for this type of disposal is almost never used in Brazil.
	Inappropriate treatment: The average rate in Brazil, in 2010, was 42.4% of the total waste, therefore, in this specific scenario the rate remained static throughout the time simulated.

Source: Elaborated by the authors

Table 4 Rates used in the simulated scenario with positive outlook

Population growth	Annual birth and mortality rates, where the average population growth of a municipality in Rio Grande do Sul was 0.7% (IBGE, 2010).
Waste generation	The average daily rate considered in this scenario was initially 1,213 kg/person, where it evolved until it reached the average generation in the Netherlands of 1.466 kg/person in the 15th year of simulation. Later, it kept the same growing rate.
Final destination of waste	Landfill: In 2009, approximately 1% of the waste generated in the Netherlands were destined to landfills. In the beginning of the simulation we used Brazil's initial rate (53%), reducing it until the Dutch rate was reached in the 15th year of simulation. Later, it kept the same growing rate until the end of the time simulated. Therefore, it is presumed, for the calculation of occupied area, that in 1 m^3, 700 kg of compacted MSW will be deposited.
	Recycling: Average recycling rate in Brazil is 4%, which was used in the beginning of the simulation. It evolved until the 15th year, where it reached the Dutch average recycling rate of 32%. Later, it kept the same growing rate until the end of the time simulated.
	Composting: The average rate of composting in Brazil is less than 1%. It evolved until the 15th year, where it reached the Dutch average recycling rate of 28%. Later, it kept the same growing rate until the end of the time simulated.
	Incineration: The average incineration rates in the Netherlands is 39%, in Brazil this rate is 0%. In the simulation, this rate was reached in the 15th year and, later, it kept the same growing rate until the end of the time simulated.
	Inappropriate treatment: In the Netherlands, this type of disposal does not exist. In the model, from the 15th year of simulation, this kind of destination was disregarded, for the other types of final disposition are capable of handling the amount of MSW generated.

Source: Elaborated by the authors

6.1.3 Ideal future scenario

To simulate this scenario we used the data and the rates observed in 2010 (see Table 4), but considered that in 15 years time the rates will be equal to the Netherland's in 2009 (EUROSTAT, 2011), taking into account that these rates are considered a great parameter in the management of MSW.

6.2 Experiments

After defining the scenarios for the experiment using the model, simulations were performed using it.

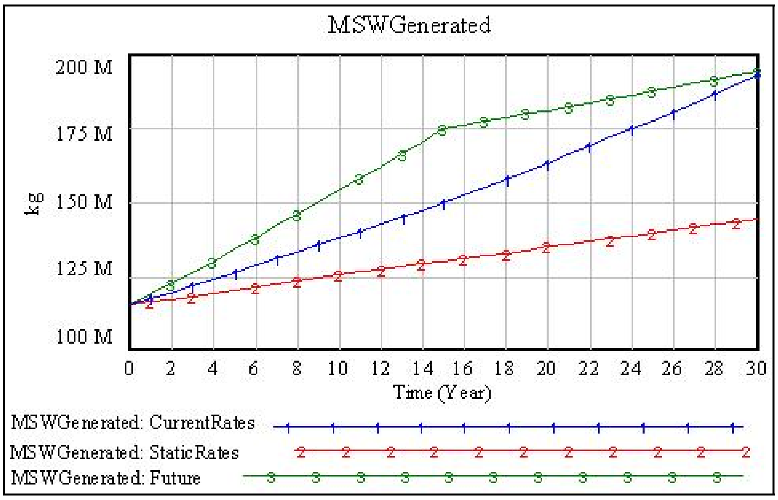
As previously mentioned, the data used in the three scenarios were from a city with approximately 270,000 inhabitants in the interior of Rio Grande do Sul, which has landfills, controlled landfillings (in the model it is considered inadequate treatment), recycling and composting facilities. The simulated time in the experiment was 30 (thirty) years, but the researcher can set this variable as he/she wishes.

For the execution of the simulations we used the simulator Vensim (Ventana Systems, 2011) on a workstation with a Pentium Dual Core processor (G630), 4 Gb of RAM and execution time of the simulation of the three scenarios was in the order of millionths of a second. The results obtained in the experiment are presented in subsection 6.3.

6.3 Results obtained

For this experiment, some results among the many generated will be presented, such as those relating to solid waste generation, land used for landfill, the amount of solid waste sent for recycling and inadequate handling.

Figure 3 Results of the variable regarding the generation of MSW (see online version for colours)

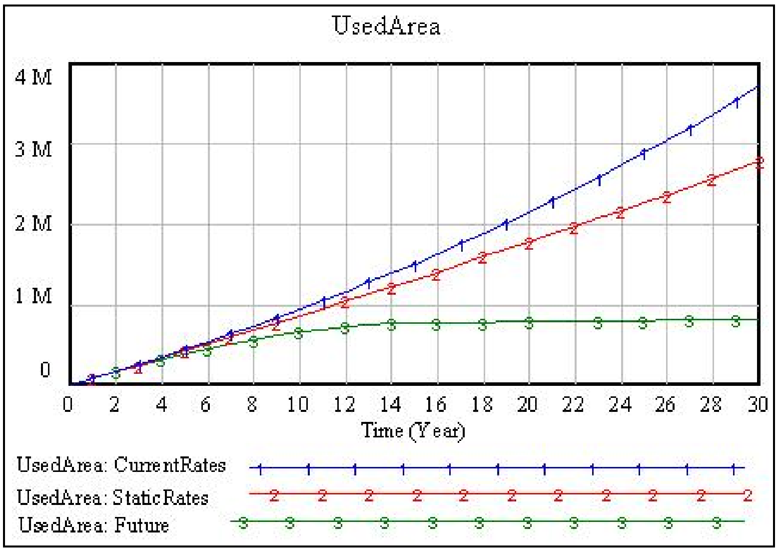


Source: Elaborated by the authors

First, regarding solid waste generation, it was found that the best scenario among those simulated is the current scenario without rate variation (static rates), because in this scenario the rate of current generation remains and the increase occurs only in the amount of waste generated due to population growth, and at the end of the simulated time (30 years) the annual generation of MSW would be approximately 145,000 tons/year. In the current scenario with current rate variation and in the ideal future scenario, in terms of MSW generated, less effective results are presented, because at the end of the simulated time in both cases the generation would be approximately 190,000 tons/year. The ideal future scenario shows poor performance in this item, because despite the high rate of MSW treatment in the country used as a parameter, the waste per capita ratio is higher than the rate recorded in the county analysed. The results can be seen in Figure 3.

Regarding the area used by the landfill over the 30 years simulated (see Figure 4), the scenario that showed the best result was the ideal future scenario, because the rate of MSW sent from the 15th year of simulation is at 1%. The estimated area at the end of 30 years for the ideal future scenario was 816,000 m^3, in the current scenario without rate variation (static rates) the estimated area was 2,780,000 m^3, and in the current scenario with rate variation the area was 3,710,000 m^3. The results generated for this particular variable, periodically and when analysed together with the analysis of the actual occupation of landfills, can be of great importance for determining the total occupation time and the execution of projects for construction of new landfills.

Figure 4 Results of the variable regarding the area (space) occupied by landfill (see online version for colours)

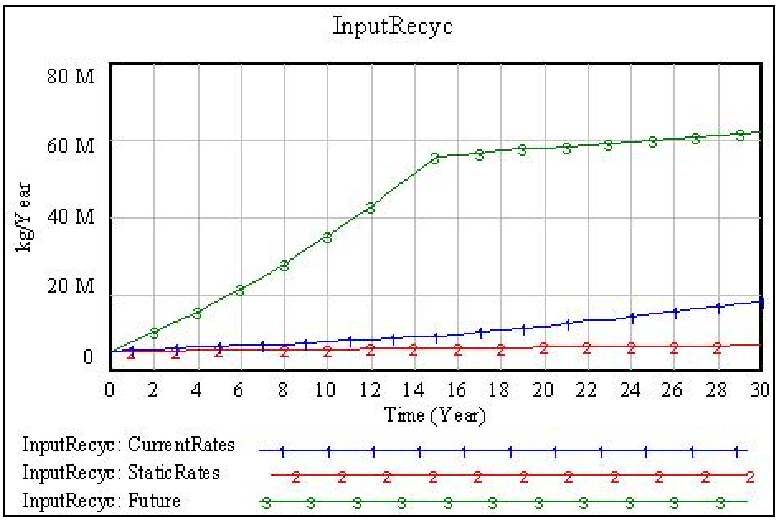


Source: Elaborated by the authors

In the case of the amount of MSW sent for recycling, it was found after the simulation that the best result was the ideal future scenario. Such estimate is justified by the fact that the country used as a parameter for setting the rates has high rates in this type of waste treatment. Another observation was that, keeping the evolution of recycling in the analysed municipality, the amount of recycled waste had an increase of 350% over

30 years. This result shows the trend in rates of waste recycling, but this result has little significance when compared to the amount of waste recycled by using the rates of an ideal future scenario. Keeping rates without variation, the amount of recycled waste would increase in line with the amount of MSW generated. The results generated for this particular variable can be used by managers in the field of MSW for the establishment of support programmes to reduce waste generation, programmes to encourage waste separation at the source, as well as recycling and reutilisation. The results can be seen in Figure 5.

Figure 5 Results of the variable regarding the quantity of waste sent to recycling (see online version for colours)



Source: Elaborated by the authors

7 Conclusions

The main objective of this study was to present the development, validation and use of a computer simulation model to aid managers in the area of solid waste in the decision making process with regard to estimates of generation and possible destination of MSW. To develop the model, variables such as population growth, average amount of waste generated per capita and rates absorbed by type of final disposition were used, and from these, the system is able to estimate the amount of MSW being sent to each type of final destination, as well as the total area of landfill to be occupied by the waste generated by the population in a given period of time (which, in the model developed, can vary from hours to thousands of years).

Through the results generated by the simulation, the city manager may, for example, estimate when the capacity of a landfill in your municipality will be exhausted and, in advance, discuss, evaluate and decide possible measures to improve the current utilisation of the landfill, such as increasing the selective collection, increasing composting, campaigns to reduce MSW with the population and even start the process to build a new landfill. By choosing the latter option, the simulation model can assist in the sizing of it, estimating for how long this new target would support the demand or what area would be required to deposit the solid waste generated through a given number of years by the population of the municipality.

In the article, three different scenarios were presented in which the model was validated and evaluated using data from a municipality in Rio Grande do Sul. The generated results were presented to experts that used the model for testing and got satisfied with the results. It should be noted that the scenarios were generated for this experiment, but the simulation model can be configured with the scenario wished by the user, that is, it is a reconfigurable and open model.

Regarding the results generated for the scenarios evaluated, the ideal future scenario was superior to the other two in almost all aspects, but in the variable on the estimated amount of waste generated by the population, the current scenario without rate variation (static rates) was better. This result is due to the fact that, although the Netherlands has advanced processes in the recovery and reutilisation of domestic waste per capita, the output of waste is very high, based on the simulation of the municipality. To obtain a significant improvement, according to the simulated scenarios, Brazil needs to improve rates of recycling, composting and reuse of solid waste generated.

For further works, it is intended to include new variables in the model, such as seasonal population and new types of destinations. Finally, we point out that the results obtained in the experiments met the expectations of city managers who evaluated them.

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