XVIII ICIEOM 2012
International Conference on Industrial Engineering and Operations Management
Guimarães - Portugal
July 9 - 11, 2012

Using Discrete-Event Simulation in Urban Solid Waste Selection

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Abstract

Adequate management of urban solid waste (USW) is beneficial to the environment, cities and people who depend on the income generated from collecting this waste material to survive. Due to the level of complexity of these processes involved in recyclable USW sorting, management tools which enable systemic studies become valuable assets by evaluating the effects changes may cause on the organization. This paper presents a case study in which a USW collection process was evaluated using computational simulation. The study was conducted in conjunction with the USW trash gatherers association of Itajubá, Minas Gerais, Brazil, and used both quantitative and qualitative methods. Data were collected via observation, interviews and questionnaires. Computational simulation enabled the visualization of the flow of materials in the process, the bottleneck indication and the experiments to simulate scenarios in order to increase the association's productivity.

Keywords: Urban Solid Waste (USW); Simulation; Productivity; Aiding Decision-Making.

1 Introduction

In the past, urban solid waste (USW) was largely organic and, due to its quick degradation, the population's production of USW did not cause much adverse impact on the environment (CAVALCANTE, 2002). Currently, packaging used for product distribution and protection offer practicality to costumers; however, this only increases USW production (GRADVOHL, 2001). Thus, adequately treating and disposing USW are necessary processes and offer many benefits, such as: improving environmental and sanitary conditions within the municipality, diminishing waste volume, saving energy and raw material and, furthermore, both directly and indirectly creating jobs by generating income from treating recyclable waste.

As to not miss out on the opportunity, in Brazil and other developing countries, organized recyclable material gatherers associations have utilized an ever increasing amount of discarded materials in order to create new products by treating and, in turn, selling them. However, managing collected and separated material in these associations' deposits still needs to be improved (OLIVEIRA, LIMA and LIMA, 2009). On the other hand, tools are needed which can aid in improving these productive processes, such as the use of conceptual and computational modeling by means of process mapping and simulation, respectively. According to Spina (2007), simulation not only enables the analysis of results of a solution without having to implement it in real life, but it also makes possible the testing of many scenarios of action which, implemented in real life, would incur elevated costs without knowing the results of its implementation. Simulation allows for the adequate comprehension of all of the activities which participate in the process, thus helping identify the system's bottlenecks. Once these observations are made, action can be taken to improve the process.

This investigation aimed to examine alternatives which increased the productivity of recyclable materials selection in the Association of Recyclable Materials Gatherers of Itajubá (ACIMAR) in Itajubá, Minas Gerais. Computational simulation was chosen as the research method, starting with the project's conceptual modeling phase (IDEF-SIM technique), upon which a computational model was built and tests were conducted to aid decision-making. A literature review was carried out to characterize recyclable material selective collection in Brazil and contextualize computational simulation's relevance in this research

question. Data were collected by means of observation, interviews and questionnaires in order to model the materials separated by the association under study and, in turn, study scenarios.

Within the selective collection process, USW treatment implies job creation and income for thousands of people. Nevertheless, in 42% of Brazilian cities, there are still no USW selective collection initiatives (ABRELPE, 2010) due to the cost involved for the municipalities (O'LEARY and WALSH, 1999; MONTEIRO *et al*., 2001). Another factor that complicates recycling in Brazil is the lack of correctly dimensioned systems in relation to storage capacity and waste treatment in sorting areas (SIMONETTO and BORENSTEIN, 2006). Because this deals with businesses competing for profits, trash gatherers' associations need structures capable of efficiently managing all steps of the process and, thus, turn into sustainable enterprises.

In spite of the cited problems, according to D'Almeida and Vilhena (2000), a sorting and compost system, when well-operated, can diminish solid waste volume by 50%, which is otherwise destined for landfills. This in turn reduces the landfill's cost of services and increases its lifespan. Productive chain sustainability is maintained when selective collection diminishes solid waste volume destined for landfills, or when USW is sent to sorting centers maintained by gatherer cooperatives, which have a much more respected job than when searching through dumpsters.

In general, the processes related to USW treatment ranges from collection phases, which involves collecting the material from the street; separating and cleaning organic residue off, which would be the adequate treatment of collected material; and finally disposing of the waste through recycling or compost processes; are transformed into raw material and return to the productive chain. According to Simonetto and Borenstein (2006), in the recycling stage, the materials are transported to a sorting center where a thorough sorting of the materials is done in order to put it back on the market. The sorting units must possess industrial presses in order that the recyclable material, such as paper, cardboard, aluminum and plastic, may be baled in order to ease storage, transport and resale. Obviously, there are many processes involved from generating the solid waste until its final destination. For the gatherers' associations, much importance is given to the processes of USW treatment, as this composes the organization's structure. Along this chain, the association's productive process consists in materials collection, box distribution, sorting, pressing and tying the bales for storage and resale. Thus, in order for the enterprise to succeed, an organization must manage its processes in an organized fashion, utilize techniques to analyze its bottlenecks and seek productivity improvement with frequent analyses of activities to identify those which do not aggregate value and may be eliminated, simplified or combined.

Bottlenecks may be present in any link of the productive chain, and may be due to material causes (such as low quality production inputs or equipment), organizational causes (such as organizational structure), labor organization, or even the procedures adopted and personal motivation factors, such as salary and effort (PARREIRA, OLIVEIRA and LIMA, 2009). The dynamic nature of bottlenecks is worth mentioning. Upon discovering a bottleneck in a productive process, decision makers should search for the cause(s) for low productivity and seek solutions for the problems located. However, after having taken care of the bottleneck problem, another activity may then turn into the new bottleneck, necessitating new studies to continue improving the system.

2 Simulation Projects

Computational simulation of productive systems is used as a powerful tool for planning, designing and controlling complex productive systems (SILVA, 2006). According to O'Kane *et al*. (2000) some manufacturing simulation applications are: Aiding in layout dimensioning; planning factories and helping in decision-making about necessary plant capacity; define intermediate stock size and analyze effects caused by the passage of time in the plant; guide process development; and evaluate impacts of manufacturing strategies. Banks *et al*. (2005) assert simulation's greatest benefit is being able to visualize the effect of a small change on the global system.

In general, the simulation is divided into three phases: conception phase (conceptual model), implementation phase (computer model) and analysis phase (operational model). Figure 1 clarifies the conceptual model importance, which is not only for the conception phase, but also to obtain the operational model (the verified and validated model that can be used to run scenarios), in the analysis phase. During the conceptual model creation, the main issue that might occur is the use of process mapping techniques, which were not developed focusing on simulation projects. This issue might prevent the conceptual model from entirely doing its objectives.

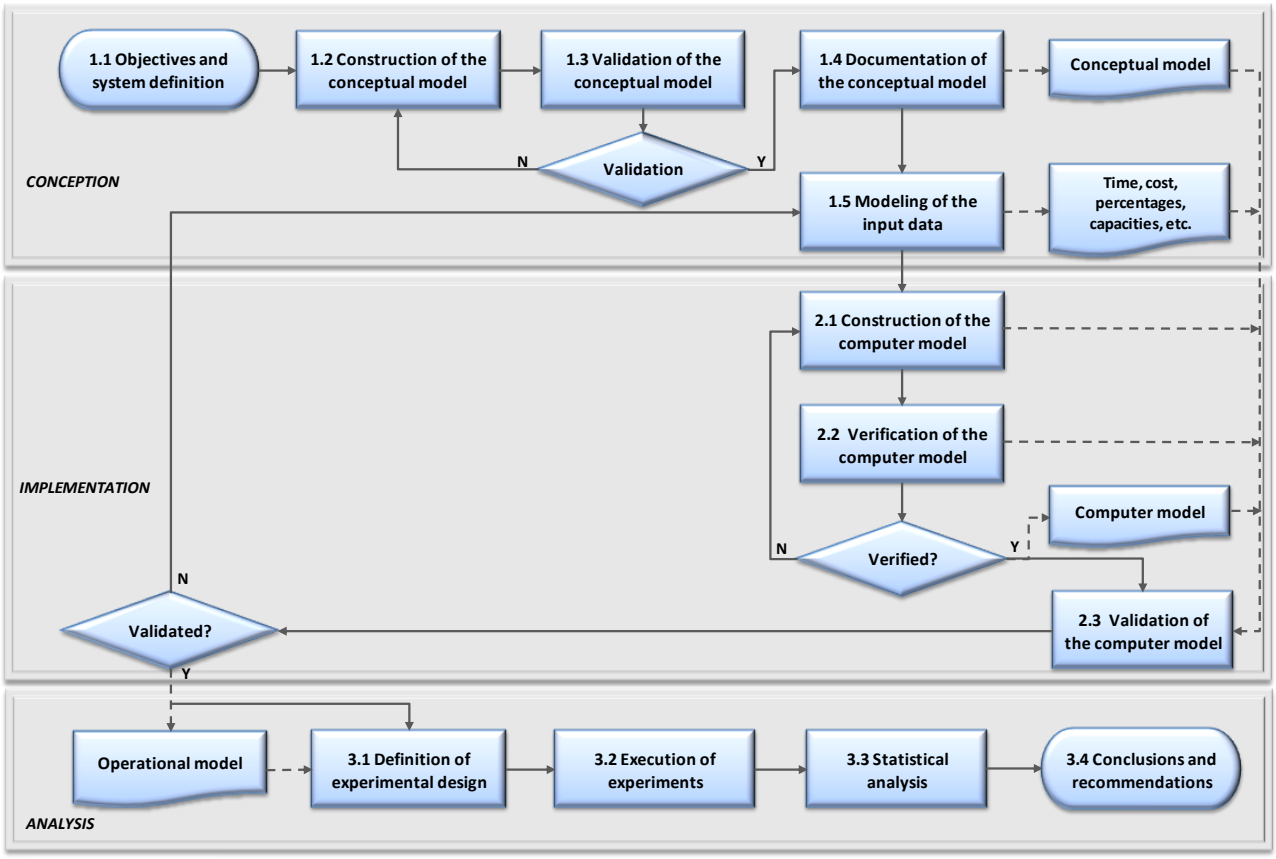

Figure 1 – Simulation study phases [Adapted from Montevechi *et al.* (2010)]

According to Moreira (2001), in the first step (Conception), simulation objectives must be clearly defined in order to establish the study's amplitude, guide the modeling process, and determine the level of detail of the analyses and resources available. This initial problem definition may be altered during the simulation as needed. Pereira and Chwif (2010) warn that a building a simulation model should never be the final objective of the study, but rather a means by which to achieve those goals. Some simulation objectives examples include: bottleneck identification, excessive lines, low productivity, inadequate service levels, productivity or service level goal verification (regardless in an existing or new system designs).

In the conceptual modeling phase it is important to avoid complex models with irrelevant details which do not completely encompass the fundamental system questions. To avoid these errors, the abstract model must be developed using some kind of representation which aims to make it more representative to reality so that other people can understand it (PINHO *et al.*, 2009). Some techniques that can be used in this phase are: value stream mapping (ABDULMALEK and RAJGOPAL, 2007), process mapping (GREASLEY, 2006), flow chart and IDEF-SIM (Integrated Definition Methods – Simulation). Other techniques are used mostly for modelling business processes, as the Event-Driven Process Chain (EPC) and the Business Process Modeling Notation (BPMN), but do not yet include any means for modelling process goals and their measures (LIST and KORHERR, 2006). The conceptual modeling technique used for this article is IDEF-SIM (Integrated Definition Methods – Simulation), which was proposed by Leal *et al.* (2008). The conceptual model evaluation phases aims to verify if the model meets the simulation

objectives, correctly representing the studied system. As the model will be utilized in the following phases of the simulation process, this stage is decisive since model incoherence may harm the subsequent stages' development (LEAL, 2003). The elements used to compose the IDEF-SIM technique, were selected from the already acclaimed modeling techniques IDEF0 and IDEF3 (NIST, 1993) and flowchart (AGUILAR-SAVÉN, 2004).

The data collection phase is one of the most difficult simulation aspects due to the level of quality, the quantity and variety of data needed to obtain reasonable and reliable analyses (VICENT, 1998). Data treatment involves techniques to identify possible problems with the sampled values and increase the knowledge about the phenomenon, resulting in a probabilistic model which will stochastically represent the phenomenon by incorporating data which describe its behavior (PINHO *et al.*, 2009). According to Pereira and Chwif (201), dedicating time to conceptual modeling becomes necessary, as the inexistence of the conceptual model or the use of a poorly constructed model will lead to the computational model demanding more time and rework and not being able to meet simulation objectives.

In the computational modeling phase, care must be taken to maintain the balance between creating models which are not too complex while still meeting the initial simulation objectives. Finally, the analysis and scenario study phases allow for programmers to use validated computational model to carry out experiments which seek solutions related to the objectives. It is important to highlight the benefit that brings to the analyzed process, since there are no necessities for physical alterations in order to envision the results generated and thus, spare the organization the trouble of convincing change-resistant workers to adapt to (potentially) inefficient problem resolutions.

3 Methodology

This research utilizes modeling and simulation as quantitative research methods and qualitative methods for the bibliographic review and data collection. Observation, interviews and questionnaires were the means of collection, enabling the elaboration of the conceptual and computational models and the scenario studies.

The case study focused on the Municipal Trash Gatherers Association of Itajubá (ACIMAR) – MG, Brazil. The city is situated southern portion of the state Minas Gerais, 418 Km from the state capital of Belo Horizonte; it is considered a typical city by Brazilian standards, with approximately 100,000 inhabitants and a population density of 402.7 inhabitants/km^2. In the ACIMAR municipality, the Itajubá Recyclable Materials Gatherers Association, is one of the groups responsible for selective collection and counts on support from the city's office of the Secretary of Environmental Affairs (OLIVEIRA, LIMA and LIMA, 2009).

Previous research (LOBATO and LIMA, 2010) showed that in relation to the volume collected, plastic materials are the most common and are composed of green, transparent, and oil PET; Tetra park; and white and colored PEAD, taking up a great amount of space in the ACIMAR installations. However, when the number of bales produced and stored is considered, the quantity of cardboard is rather dramatic and makes up the most commonly stored material when compared to papers and plastics. However, just paper, plastic and cardboard are baled by ACIMAR. Aside from collection of material in the streets, ACIMAR counts on donations from businesses in the region. Among the received materials, cardboard and plastic are the most donated, representing 80% of all donations. The profit originating from these material donations is divided among all the associations.

3.1 Conceptual Modeling

The first stage of the project was to establish the project's objectives in order to orient the following steps. Thus, this project's objective was to seek alternatives for the productive system which would enable an increase in quantity of bales produced daily and increase the salaries received by the ACIMAR members.

To develop the concpetual model, the recyclable materials selection process developed by Lobato and Lima (2010) was used as a base. The map presented seven activity flows divided by each type of material (Plastic Material – PM; Cardboard – CB;; White paper – WP; Cans – C; Glass – G; Metals – M; Electronic Materials – EM). The mapping information served as the basis for the conceptual model which was developed using the technique IDEF-SIM, as presented in Figure 2.

The conceptual model developed using IDEF-SIM is restricted to the process of USW selection of plastic and cardboard. The model was limited to these two materials due to their importance to the entire process, as they represent the greatest contribution to the organization's profit. Analyzing the process via the conceptual model, one can see the productivity is limited by weighing and pressing, since the entities already separated by the conjunction "OR" (the box with the X) in different routes, need to resume the single path to pass through these resources, forming lines and consequently wasting time and, thus, harming productivity.

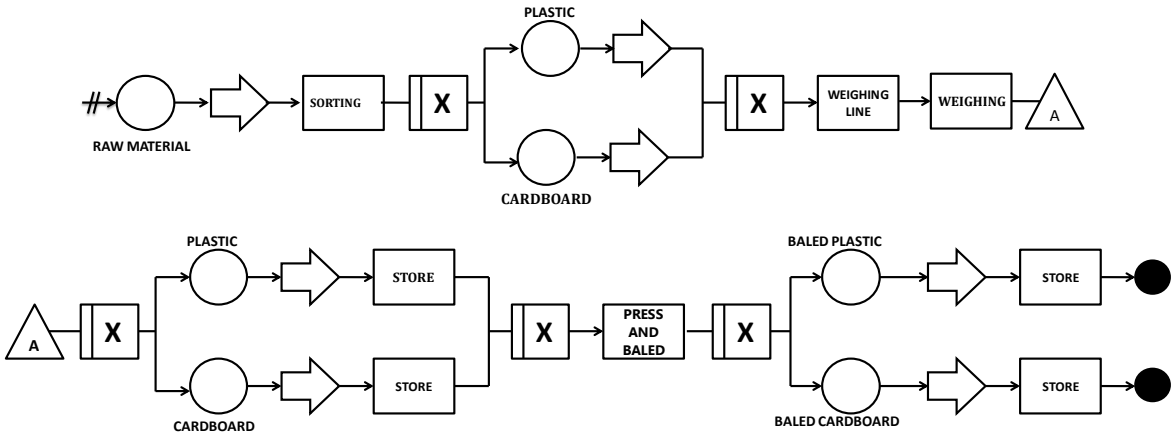

Figure 2 – Conceptual model using IDEF-SIM

Once the conceptual model was developed, the following stages are collection and input data alaysis. The analysis consists in statistically evaluating the data collected, verifying the existence of outliers and the type of probability distribution in which the data fit. For this investigation, the input data are based on time collection and interviews with the process's actors.

The variables were represented in the form distributions with the aid of the software Stat:Fit®, that statistically fits to data the most useful analytical distribution. It provides relative comparisons between distribution types, and an absolute measure of each distribution's acceptability. The export function translates the fitted distribution into specific forms for simulation software. Features include descriptive statistics, parameter estimates, goodness of fit tests, graphical analysis, random variate generation and more.

3.2 Computational Model

The computational model was developed using ProModel 2011®. Functions were used within the parameters defined according to the process's reality, demonstrated in the input data. The input data relied on: distances and times in queues waiting for materials transportation, the measurement of stock areas and the unit capacity of each piece of equipment (scale and press). The system entities are: raw material (material collected in bags from the streets), cardboard and plastic after sorting and cardboard and plastic bales (simulation output entities). Figure 3 shows the environment in which the simulation was developed.

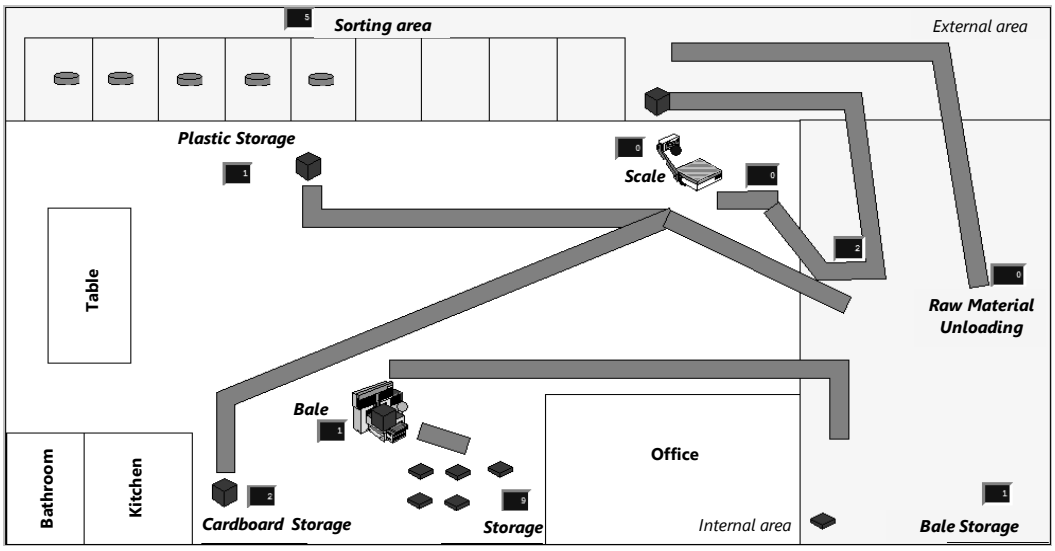

Figure 3 – Simulated Area

The simulation was run for 10 days according to the frequency of shipments of the baled material, thus enabling the verification of the quantity of bales produced. The process's starting point is defined as the arrival of material collected from the street, being directed to the sorting activity. Each gatherer is responsible for sorting and moving the collected material, and the material donations are moved by those associates who do not take part in street collection. The process then procedes to the balance, press and baling before terminating with the baled and stocked material being ready for shipping.

In order to validate the computational model, Kleijnen's (1995) method was used. It is described in Equation 1. The data corresponding to the quantity of bales produced daily are shown in Table 1. The model was validated, with the zero value contained in the interval [-1,7187; 3,0186] obtained by Equation 1.

$$X_s - X_r \pm t_{2n-2,\propto/2}\sqrt{\frac{s_s^2+s_r^2}{n}} \quad (1)$$

Where: X_s: Average simulated results
X_r: Average real results
s_s: Standard deviation of the simulated results
s_r: Standard deviation of the real results
$t_{2n-2,\propto/2}$: Student's t distribution for 2n-2 degrees of freedom and a significance level of $\propto/2$

Table 1 – Computational model validation data

	Average (X)	Standard Deviation (s)	t2n-2, α/2	n
Real [r]	X_r = 6,017	S_r = 1,360	2,776	3
Simulated [s]	X_s = 6,667	S_s =0,577		

3.3 Scenario generation

The analysis stage deals with the development of scenarios for the verification of productive bottlenecks and proposal of process improvements. The first scenario represents reality, which was simulated using the computational model using time data, and information obtained from interviews and observations. Figure 4 presents the output results generated by the software.

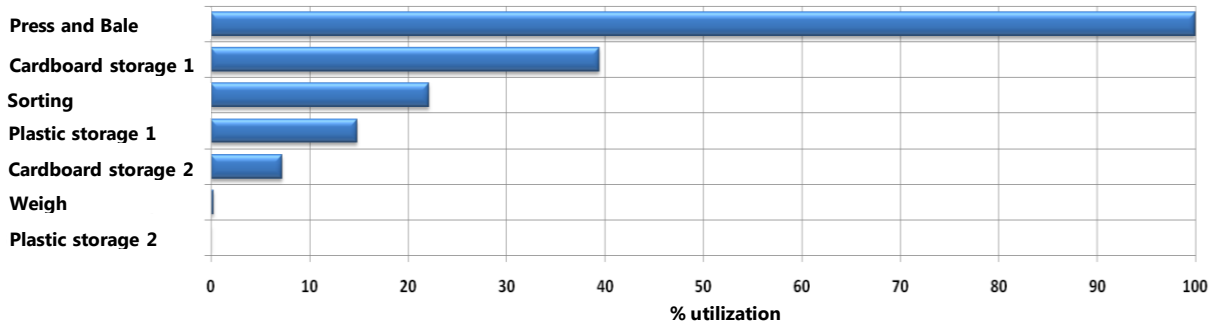

Figure 4 – Real Scenario: Model Outputs

The graph in Figure 4 emphasizes the problem verified during mapping developed in previous research (Lobato and Lima, 2010) in which the pressing stage is a bottleneck and, therefore, the daily production of bales is limited by equipment availability. The press is in operation the entire workday. It is observed that 23% of the maximum capacity is used in sorting, coinciding with reality, since the rest of the shift is directed to material collection throughout the city. It can be seen that the storage areas used for plastic material and cardboard, before pressing (storage1_plastic and storage1_cardboard) are also occupied after the sorting due to the material collected in the street and, principally, to the donated material. As the press is not able to process this material, there is an accumulation of material in the storage area prior to baling. This scenario has a daily production of 6 bales.

In the mapping, a large distance was noted inside the shed for the gatherers and associates to carry out their activities. Nonetheless, this stage does not appear as a bottleneck since the utilization percentage is low. In relation to the storage area, cardboard takes up around just 8% of the area available for this material and the area's low utilization might be an indication of poor dimensioning of the space, thus indicating a necessity for the improvement of the shed's layout.

Three scenarios were simulated as described in table 2.

Table 2 – Summary of evaluated scenarios

Scenarios		Description
Real	1 press 1 operator	Current situation: one press and one operator who feeds the equipment the material, operates the press and wraps the wire around the bale
A	1 press 2 operators	Scenario which simulates an assistant aiding the press operator, helping him/her to load the press with material and in the baling phase
B	2 presses 1 operator	Scenario that simulates the process with an additional press with a single operator
C	2 presses 2 operators	Scenario which simulates the use of two presses and two operators for each

In scenario "A", a model was created in which two operators worked the press, thus simulating a situation in which the operator's assistant aids in loading the press with the material to be processed and wrapping the bale with wire when the pressing is finished, thus reducing the total time of operation of this equipment, as shown in Figure 5.

By utilizing an operator and an assistant in the press, the time to carry out the activities of pressing and baling falls by approximately 50%. There is a considerable reduction in the cardboard storage area's use due to the presses greater processing capacity. In turn, there was also an increase in the utilization of the baled cardboard storage area by about 13%, due to the greater production of bales, which rose to an average of 11 bales per day. This represents a productivity jump of 83% when compared to the real scenario.

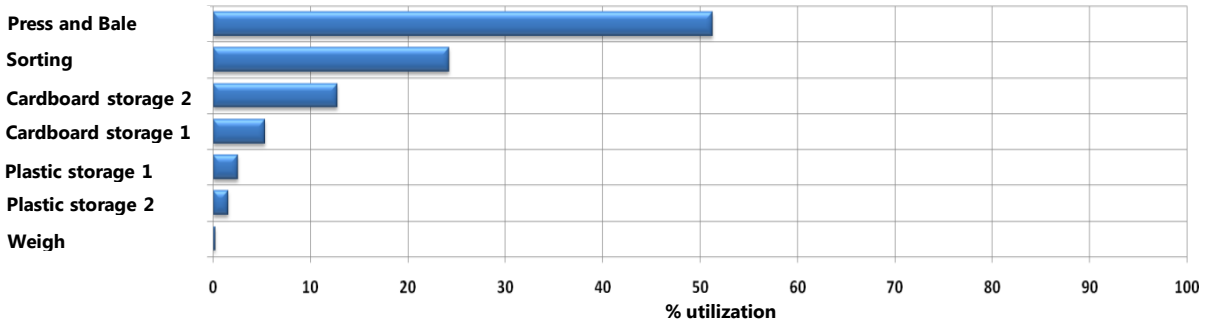

Figure 5 – Scenario A: Model Outputs

In scenario B, two presses are used with two operators without any assistants. Thus, the operator would be responsible for operating the equipment, loading the material in the press and wrapping the bale. Figure 6 presents the output data for Scenario B, which showed utilization of the two presses around 80% of the time (Press and Bale). The daily production attained a value of 12 bales, which represents double the bale production when compared with the real scenario, but has little variation when compared with scenario A.

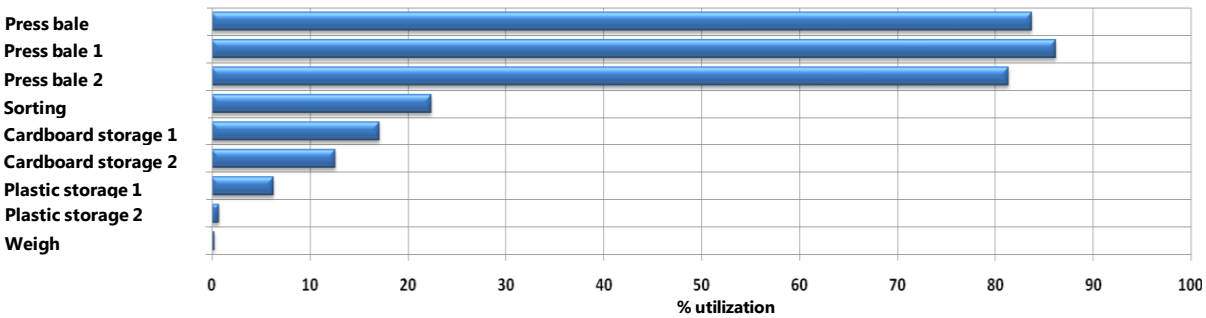

Figure 6 – Scenario B: Model Outputs

Finally, the last scenario reflects a situation with two presses and two operators for each. In this experiment the bale production reached an average of 12 per day, equal to the previous scenario. However, this value is limited to the sorting processing capacity since the presses were utilized just 13% due to the lack of material to be processed. Figure 7 represents the utilization of each function in scenario C. This scenario also validates the study of other authors (PARREIRA, OLIVEIRA and LIMA, 2009), in which one of the principal bottlenecks related to the waste treatment was sorting the material which arrives at the shed mixed and dirty with organic material.

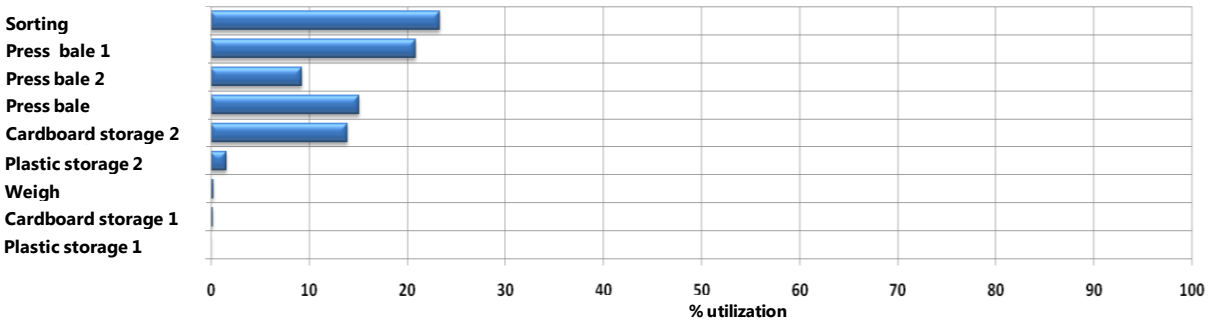

Figure 7 – Scenario C: Model outputs

Considering the three plausible scenarios being executed, if there were no investments for improvements in the sorting phase, the acquisition of another press would not bring about many benefits for the process. The scenarios with two presses (scenarios B and C) would not present great increases in daily productivity due to the limitation in the quantity of material to be pressed. Thus, in order to effectively increase the association's daily productivity it becomes evident that a greater investment is needed in

manual labor in order to improve sorting. Figure 8 shows a graph with each scenario, comparing utilization of the press and the number of bales produced.

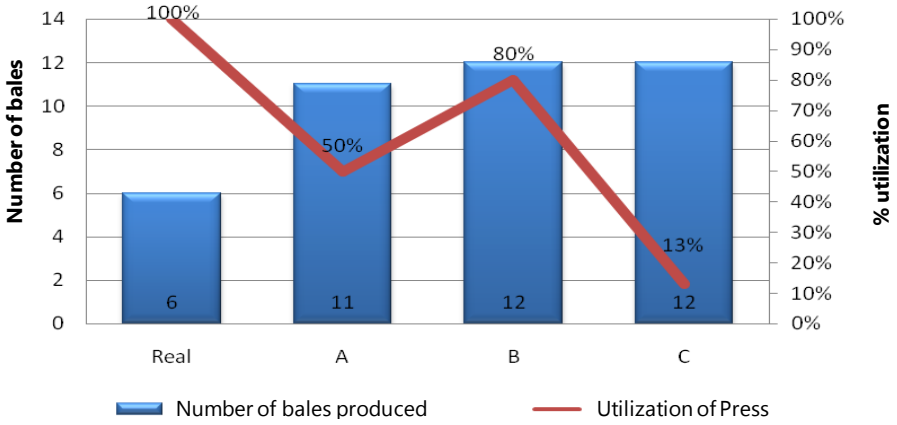

Figure 8 – Press Utilization and Number of Bales Produced in Each Scenario

Scenario A requires the allocation of manual labor while scenario B requires the investment in new equipment. However, scenario B does not demonstrate a significant productivity increase. Scenario C does not initially show itself compatible with the association's reality, since the association would have to increase its materials gathering and/or donations in order to make the investment in equipment (2 presses) and manual labor (4 operators) worthwhile. Moreover, sorting time would have to be improved, which ended up becoming the new system's bottleneck. Thus, scenario A, which involves allocating one more operator in the pressing activity, is the most appropriate for the gatherers' association's reality. This would increase the press' productivity by 50% and enable increased productivity in the case of an increase in raw material.

4 Final Considerations

This work aimed to study a USW selection process by means of computational simulation. The project reached its global objective since the method utilized enabled the proposal of improvements for the Recyclable Materials Gatherers Association (ACIMAR) in Itajubá, Minas Gerais, Brazil.

Aside from proposing improvements, it also fell within the scope of this article to present the application of mapping and simulation techniques applied to a problem of USW treatment. It is well-known there are many hurdles for trash gathering associations, principally in terms of process management and administration. However, the research shows that it is possible to intervene and improve the recyclable treatment processes without harming the system's functioning.

The simulation developed enabled the perception of some particularities, such as the inadequate use of the press, proving to be the process's current bottleneck. However, with two presses and two operators, the new bottleneck would be the sorting activity, which would not be able to meet the demand necessary to feed the ideal press operation. The scenario that simulated two operators with a single press is the one which best adapts itself to the association's reality, as it would bring about a reduction in material processing time and a daily productivity increase of 85%, thus leaving room for an increase in the amount of material collected or received from donations.

In conclusion, the research enabled the most detailed look yet at the association's USW treatment process and, as a product of the investigation, operational improvements were suggested. This should not, however, be the concluding study for this line of research, and for future opportunities, the authors recommend a standardization and rationalization of the activities performed by the gatherers and associates, aside from the possibility to use quality techniques, such as 5S in order to redo the simulation project with the aim of refining its analysis.

Acknowledgements

The authors would like to thank CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) and FAPEMIG (Fundação de Amparo à Pesquisa do Estado de Minas Gerais) for their continued financial support for the projects which have helped develop this project.

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