PRACTICAL SOLUTIONS TO ENHANCE THE PRODUCTIVITY OF WASTE PICKER ORGANIZATIONS THROUGH THE APPLICATION OF *LEAN* TOOLS

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ABSTRACT

Purpose: The aim of the research is to improve the productivity of a Waste Picker Organization using lean tools.

Introduction: Waste Pickers Organizations (WPO) play a key role in the circular economy and in the Brazilian recycling industry, but several organizational structure inefficiencies hamper productivity. One way to understand how these inefficiencies occur and how to eliminate them is through the application of *Lean thinking*.

Methodology: Lean tools (SIPOC, process modelling, *Value Stream Mapping*, spaghetti diagram, activity value analysis, and spatial rearrangement) were explored for the analysis of operational activities, focusing on elimination of unnecessary activities and *layout* changes, and to measure the improvements.

Results and Conclusion: After the implementation of the suggested improvements in the WPO waste selection macro process, several productivity enhancements were noted, including a reduction of initial stock (59%), a decreased *lead time* (41%), lower processing times (57%), and improved cargo handling (17%). These findings clearly indicate how the application of *lean* tools can improve overall productivity in Waste Picker Organizations being practical solutions that only require human resource.

Research implications: *Lean* tools to enhance the productivity of WPO were applied as practical and inexpensive solutions to identify and describe the main flows and *layout* types at Waste Picker Organizations (WPO).

Originality/value: Practical solutions are the most request issues regarding improvement actions implementations in waste management, but especially when the focus is the waste picker organizations due to the government's financial dependence as the main economic source and difficulties in self-management.

Keywords: *Lean Thinking*, Waste Pickers Organizations, *Value Stream Mapping*, Spaghetti Diagram, Business Process Modelling Notation, Productivity.

SOLUÇÕES PRÁTICAS PARA AUMENTAR A PRODUTIVIDADE DAS ORGANIZAÇÕES DE CATADORES ATRAVÉS DA APLICAÇÃO DE FERRAMENTAS *LEAN*

RESUMO

Objetivo: O objetivo da pesquisa é melhorar a produtividade de uma organização de catadores usando ferramentas enxutas.

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Introdução: As organizações de catadores de materiais recicláveis (OCMR) desempenham um papel fundamental na economia circular e na indústria de reciclagem brasileira, mas várias ineficiências organizacionais prejudicam sua produtividade. Uma maneira de entender como essas ineficiências ocorrem e como eliminá-las é por meio da aplicação do *Lean thinking*.

Metodologia: Ferramentas enxutas (SIPOC, modelagem de processos, *Value Stream Mapping*, diagrama de espaguete, análise de valor da atividade e rearranjo espacial) foram utilizadas para a análise das atividades operacionais, com foco na eliminação de atividades desnecessárias e mudanças de layout, e para medir as melhorias.

Resultados e Conclusão: Após a implementação das melhorias sugeridas no processo macro de triagem de resíduos da OCMR, várias melhorias de produtividade foram observadas, incluindo redução do estoque inicial (59%), redução do *lead time* (41%), menores tempos de processamento (57%) e melhor movimentação de carga (17%). Essas descobertas indicam claramente como a aplicação de ferramentas *lean* podem melhorar a produtividade geral nas organizações de catadores, sendo soluções práticas que requerem apenas recursos humanos.

Implicações da pesquisa: Ferramentas enxutas para aumentar a produtividade do WPO foram aplicadas como soluções práticas e baratas para identificar e descrever os principais fluxos e tipos de *layout* nas Organizações de Catadores (WPO).

Originalidade/valor: Soluções práticas são as questões mais solicitadas na implementação de ações de melhoria na gestão de resíduos, mas principalmente quando o foco são as organizações de catadores devido à dependência financeira do governo como principal fonte econômica e dificuldades na autogestão.

Palavras-chave: *Lean Thinking*, Organizações de Catadores de Materiais Recicláveis, *Value Stream Mapping*, Diagrama de Espaguete, Modelagem de Processos, Produtividade.

1 INTRODUCTION

Early, the waste picker workers were marginalized and its activities were only associated, around the world, to "dumpsites mining" without decent working conditions. The prohibition of uncontrolled landfills (dumpsites) in some countries, such as Brazil, initiated an integration and formalization movement of the waste pickers, and in 2010, the Brazilian federal law, which formed the National Solid Waste Policy, explicitly included them in the municipal solid waste management strategy. From that, waste pickers can work independently or associated with a member-based organizations like cooperatives, associations, networks, unions or small enterprises (Gutberlet, 2021), and be considered in this study as Waste Picker Organization (WPO).

The number of Waste Picker Organizations increased over the years, which is associated to the many advantages provided by working in the WPO, such as: reduce of social vulnerability, economic support, increase capacity of waste processing and storage compare to pickers working individually, and reduce the vulnerability to middlemen trader's exploitation (Kain et al., 2022; Dutra et al., 2018). Zampier et al. (2022) point out the importance of WPO actions in the market applying cooperative principles and values which also is related to Sustainable Development Goals (SDGs).

However, there is a long way for WPOs to move from the current point, where they need welfare policies and government subsidies, to the point where they become self-sustaining endeavors. Waste Picker Organizations still face difficulties in obtaining the maximum added

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value from their product; and consequently lack optimal economic efficiency (Fidelis and Colmenero, 2018; Siman et al., 2020). The low economic efficiency is due to the lack of standardization in traded products; a low degree of organizational structure planning; the presence of middlemen in marketing with recycling industries; the lack of public incentives; and low waste picker productivity (Tackla et al., 2017).

Regarding waste picker productivity, the research conducted by Zon et al. (2020) evaluated sustainability indicators of 23 WPOs and concluded that only 13.04%, from Espírito Santo (Brazil), presented ''very favorable" results, with values higher than three tons.month^{-1}/ waste picker^{-1}, which directly impacts on average income per member, being an indicator classified as emergency term and related to almost all necessary practical solutions.

The practical implications of waste picker productivity intrinsically depend on two factors: the amount of solid waste received by the WPO and the waste pickers capability to sort and separate the recyclable materials. That is, if the receipt of waste is greater than the sorting capacity of the waste pickers, the waste will be accumulated in the receiving yard, hence the need for studies aimed at improving the waste pickers capability.

This gap is also highlighted by Pinha and Sagawa (2020) that demonstrated through a modular model for the simulation of waste management scenarios that the increase in the operations scale, investments in training and process improvement are fundamental to increase the productivity. The authors described the productivity of the sorting activity as low due to lack of standardization of work routine and the unfavorable work conditions in terms of available tools, layout, ergonomics, among others.

In view of the above, it is clear that in order to improve the productivity and economic efficiency of WPOs, it is necessary focusing on how to improve process efficiency of sorting recyclable materials. In this sense, it is essential to pay attention to the dysfunctions identified by Tackla et al. (2017), especially those of the structural type: irregular delivery of recyclable materials, dysfunctional training programs, and management practices which interfere with the quantity and quality of the material produced. Taken together these flawed strategies ultimately hamper the economic efficiency of WPOs.

Understanding how these maladjusted practices occur and how to eliminate them is the purpose of the lean thinking philosophy, which has been shown to be paramount to an organization's competitiveness, whatever its field of action (Picchi, 2017).

2 MATERIALS AND METHODS

2.1 Case Study

A WPO case study was used to demonstrate the process improvements promoted by application of lean tools. Espírito Santo (Brazil) has currently 72 operational WPOs (ADERES, 2020). The Instituto Sindimicro (ES), that has been working with all WPOs through technical cooperation term, was consulted and one of the organizations was selected for this case study. The Institute Sindimicro-ES provided the most viable WPOs for the purposes of this research.

The Waste Picker Organization ABRASOL (Associação Banco Regional Ambiental Solidário de Planalto Serrano) was receptive to procedural change and consented to the implementation of process improvements using lean tools. The ABRASOL we worked with is located in Serra city (Espírito Santo, Brazil), with total area of 1,000 m^2 containing a warehouse with 258 m^2. There were 12 waste pickers when the research was conducted, and average received monthly was 11 tonnes of recyclable materials in 2018.

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2.2 Proposed Methodology

Proposed methodology was developed in four steps and the main purpose of the lean tools application was to improve the waste pickers productivity. Several lean tools were explored for the evaluation of the WPO economic efficiency and the analysis of operational activities, and then, focusing on elimination of unnecessary activities and layout changes, lean tools were applied to measure the improvements.

2.2.1 Step 1 - Identify essential products from a customer perspective (lean Vision) at WPO

In Step 1, the inputs and outputs of the recyclable materials selection macro process were identified by process modeling, as well as the customers and suppliers. This was achieved through SIPOC (Supplier, Input, Process, Output, and Customer) and *in situ* observation (October to November 2018). Additionally, WPO total income, sorting productivity, and the average value per associate were calculated. SIPOC was adopted based on studies performed by Lima et al. (2015), and Lobato and Lima (2010) about process modeling of urban solid waste management. The goal was to create a macro process overview, and to identify which products are essential from the point of view of WPO customers, i.e. which ones are marketable.

2.2.2. Step 2 - Apply lean tools to define Initial Scenario

The lean tools applied to define Initial Scenario of ABRASOL WPO were Business Process Model and Notation (BPMN), Value Stream Mapping (VSM) and spaghetti diagram. The purpose of this step was to understand and to model the macro process of recyclable material selection during the Initial Scenario (October 2018). This includes determining what steps are involved, their temporal duration, their place of accomplishment, and relevant stocks and flows.

The macro process of recyclable material selection, excluding the administrative activities, was modeled using the BPMN methodology, in conjunction with Bizagi Process Modeler software version 3.3.0.072. BPMN was adopted for being a well stablished standard language to self-learning the knowledge organizational structure (Banu, 2018; Salvadorinho and Teixeira, 2021).

In the VSM, according to Librelato et al. (2014), value chain is every necessary action to produce a product or a service within the workflow that aggregates a value as result of specific activities that companies can develop instead of an isolated product or service, and in the case of WPOs, most aggregating value activity is the sorting process. So, for the construction of VSM, information was collected through *in loco* data collection (with photographic record) and a time collection worksheet. The flow defined by Rother and Shook (2003) was adapted to the assignment of aggregation value, as well waste identification (Dieste et al., 2019).

VSM with the aggregation value evaluation has been useful to implementation of eco-efficient practices and reduction of cost (Narke and Jayadeva, 2020; Salvador et al., 2021). For the construction of the spaghetti diagram, the spatial localization of each relevant step and its associated flow of materials was identified. The objective of it is the evaluation of physical process flow which allows several betterments such as improve ergonomics and safety (Havard et al., 2019), uncover wasted movements (Falconer et al., 2018) and enhancing the material handling productivity (Mahajan et al., 2019).

The analysis of these lean tools allows together the identification of unnecessary activities and layout limitations in order to propose improvements for a future WPO scenario.

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2.2.3 Step 3 - Propose improvements for a future WPO scenario

The third step consisted of analyzing the Initial Scenario using lean tools in order to propose improvements. Through it, the following was identified: the presence of redundancy, rework, the lack of labor integration, error sources, delays, bottlenecks, and added value. Best practice analysis and benchmarking identified opportunities for improvement in order to propose changes to enhance WPO productivity.

Following this, the Initial Scenario was redesigned with the application of two improvement proposals for ABRASOL using the VSM tool and spaghetti diagram. These proposals included an Ideal Scenario and a Proposed Scenario. The latter was accepted and implemented by ABRASOL and this Improved Scenario was compared to Initial Scenario in Step 4.

2.2.4 Step 4 - Deploy and measure the magnitude of proposed improvements from the application of lean tools

The improvements were implemented according to the Proposed Scenario with the participation of all WPO employees. After a one month observing the following implementation, a new evaluation of the WPO macro process was conducted in February 2019. VSM was reapplied and a new spaghetti diagram was constructed in order to quantify operational productivity improvements.

3 APPLICATION

3.1 Identification of Essential Products from a Customer Perspective (*Lean* Vision) at WPO

In order to identify the essential products from a customer perspective, the SIPOC tool was utilized to define the macro process of recyclable materials selection from ABRASOL, as shown in Table 1.

Table 1. SIPOC of macro process of recyclable materials sorting from ABRASOL

Supplier	Input	Process	Output	Customer
Collection Sector	Material collected Manpower Truck	Raw material reception, inspection and storage	Identified and stocked material	Sorting Sector
Collection Sector	Material collected Manpower	Sorting	Separate material	Weighing Sector
Sorting Sector Weighing Sector	Material sorted Manpower Weight machine	Weighing	Weight material	Pressing and baling sector Expedition Sector
Weighing Sector Pressing sector	Material weighed Manpower Press	Pressing and baling	Baled material	Expedition Sector
Pressing and baling sector Expedition Sector	Material baled Manpower Truck	Expedition	Baled material on the truck	Final costumer

Source: Elaborated by the authors (2023).

The macro process mapped by SIPOC (Table 1) are similar to the one that was reported by Lima et al. (2015) and Lobato and Lima (2010), since operational activities performed in waste picker organizations usually comprises ''Collecting DSRW'', ''Receiving DSRW'',

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''Sorting solid waste'', ''Pressing and baling DSRW'' and ''Commercializing DSRW'' as detailed by Siman et al. (2020). Variations can be observed in WPOs, mainly in the mechanized activities due to electrical machines used in the sorting, pressing and baling, but it's important to highlight that WPO in low and middle income countries, in general, are not mechanized and structural investments are one of the main needs (Dutra et al., 2018).

Despite the variations that can be found in WPOs, main contribution of mapping the macro process with SIPOC focusing on the waste picker productivity analysis is the identification of suppliers, because impacts on the amount of solid waste received by the WPO, that consequently implicates in a low productivity when below the sorting capacity. Additionally, SIPOC helped to diagnose the current scenario of ABRASOL regarding waste quality, recyclable materials sold, waste picker income, among others.

In this sense, in addition to the inputs and outputs of the recyclable materials shown in Table 1, 26 suppliers were identified in ABRASOL. In 2018, more than 130 tons of waste were processed, with 19% of tailings and glass. However, 61% of the sorted materials were supplied by just three sources: Serra city, Vitória Environmental Company, and a sample collected by the local WPO.

These concentrated suppliers indicate a dependency, especially involving the city, which together with the tailings rate demonstrated the need of new partnerships with private companies, for example. Solid waste donated by companies usually presented lower tailings rate and more homogeneous composition increasing the quality of recyclable materials commercialized.

Zon et al. (2020) considered quality and diversification of partnerships as an indicator of sustainability of the waste picker organizations due to partnerships with the most diverse actors giving support to obtain resources. With regards to the outputs of the WPO operation, the 35 types of recyclable materials sold by ABRASOL are acquired by 7 customers: BioMarca, Ciclo Companhia de Reciclagem, Corona & Pasolini, Ecomax Reciclagem de Eletrônicos, Nunes Reciclagem, V. F. Reciclagem e Vitória Comércio de Aparas de Papel.

Paper, cardboard, high-density polyethylene (HDPE) and polyethylene terephthalate (PET) represent 58.2% of the material sold by ABRASOL. By contrast, tailings and glass account for about 19% of total processing and less than 1% of revenue.

Regarding glass, according to CEMPRE (2020), almost 25% of Brazilian WPOs didn't commercialize glass mainly due to low price, which in 2019 the average price was US$ 0.02. On the other hand, tailings mean cost with landfill. Tailings rate from city selective collection program was even higher (34%) because of the lack of adherence population and education programs.

In brief, the identification of outputs and customers allowed diagnose two important aspects of ABRASOL: low variety of recyclable materials absorbed by regional market which is concentrated in only 4 from 35 the types of waste sorted and a considerable tailings rate. Sorting process can be improved focusing on materials more sold avoiding waste time sorting low marketable materials as suggested by Kain et al. (2022).

It's highlighted, as described by Siman et al. (2020), that markets vary among regions for some materials and waste that is deemed tailings to some markets is marketable to others, as well price discrepancy by the same buyers or product can be found. So, the SIPOC tool can be applied to any WPO, but data analysis should be performed individually to each organization according to local market characteristics.

Regarding tailings rate, besides the waste market variation, main reason is contamination of organic or hazardous waste due to improper disposal or incorrect separation made by the population, and according to Pinha and Sagawa (2020) this amount can reach 50.43% of the collected dry waste impairing the quality and quantity of the marketable

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materials. Fidelis and Colmenero (2018) described that a higher sorting quality, associated to lower tailings rate, consequently, also involve sending less waste to landfill.

Customers are responsible to define quality and quantity of the recyclable materials sorted by the WPO, so the productivity need to be planned according to the local market standards and demand. In this sense, a lack of customers to a sorted material implicates in waste of sorting time and storage. Because no definitive difference in marketability was detected across all WPO products, it was decided to consider the materials as a single class and, thus, strive to improve the overall WPO macro process.

Regarding sorting ability, based off the activities of 12 WPO members (October 2018), an average of 506.5 kg of sorted solid waste per day and an average productivity of 42.2 kg/day/waste picker were determined to ABRASOL.

For comparison purposes, the average amount suggested by Ministry of the Environment is 200 kg/ picker/day (MMA, 2010) and the average of sorting productivity reported by Dutra et al. (2018) was 109 kg/picker/day, which demonstrated that ABRASOL average productivity is very low, and this is reflected in the income per waste picker.

The commercialization of recyclable materials generated in 2018, produced an average income per waste picker of US$ 88.3 per month (conversion rate US$ 1 – R$5.73) below of the Brazilian minimum wage (BMW) of US$ 166.7 in the same year. According to CEMPRE (2020), which consulted 549 Brazilian WPOs, in 2019, the average income of 43.72% of waste pickers was between ½ and 1 BMW and 10.56% receiving less than ½ BMW.

The collected data of average income and sorting productivity from ABRASOL along with half Brazilian WPOs reinforced the necessity of interventions to improve economic efficiency. The reason to the low income/productivity is multivariate, so it is clear that a set of measures are necessary to achieve an optimal arrangement of the macro-process of recyclable materials sorting. Different studies defended the positive effects of some measures on productivity such as provide motorized vehicles, tools and machinery (Campos, 2014) and childcare facilities (Navarrete-Hernandez and Navarrete-Hernandez, 2018), educacional campaigns (Calabrò and Satira, 2020) and increase of selective collection and work processes improvements (Pinha and Sagawa, 2020).

In relation to the last one, work processes improvements, analyzing different scenarios Pinha and Sagawa (2020) concluded that higher profits are achieved involving the increase in the selective collection together and considering a theoretical increase of 40% in the waste picker productivity in the waste sorting and separation activities.

However, practical propositions to improve waste sorting and separation activities are still unexplored, so, as innovative way this research explore the lean tools to improve these processes efficiency. Thus, after diagnosing the situation at ABRASOL based on most representative recyclable materials sorted and what are the main responsible to revenue, lean tools were applied to define an Initial Scenario.

3.2 Current and Future State

The diagnosis of the productivity of Initial Scenario determined waste sources, operational activities and process efficiency. The macro process of recyclable material selection of ABRASOL was modeled using BPMN methodology allowing the identification of waste sources and the operational activities. The results were compared to reference models of operational activities produced by Siman et al. (2020), which also applied BPMN to model 10 WPOs from Espírito Santo (Brazil) in January 2018.

The BPMN was adopted in this study also due to potential of enhance process communication between users, as reported by Banu (2018), that defined it as a tool for

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"integrating all process data, human and financial resources and basic time elements to be unitarily represented, processed and communicated to process users and stakeholders".

The comparison of the modeled activities from ABRASOL and WPOs of Espírito Santo showed several similarity points: waste source is from municipal selective collection program or is collected with own vehicle, control of material sold, sale after material accumulation to the minimum quantity required by buyers, and experience-based operation of the press. As well know, the waste type source such as selective collection door-to-door, Small Volume Delivery Stations (PEVs), private companies and collection by WPO present different quality regarding tailings rate which impacting on working time.

According to CEMPRE (2020), 52.64% of Brazilian WPOs have links established with the government through contracts or agreements to receiving waste from selective collection door-to-door and PEVs, while waste collected by WPOs vehicle is less representative, since only 16.44% of Brazilian municipalities has WPO as agent responsible by selective collection. In fact, main supplier of ABRASOL is Serra city (26%), however presented the worse waste quality (34% of tailings or glass), which corresponds to 47% of the total tailings or sorted glass.

Thus, regarding waste source, literature suggest new partnerships and continuous educational campaigns as strategies to reduce tailings rate from selective collection, and although it is not the focus of this study, it's important to highlight that only process improvements are not sufficient to maximize productivity and income.

Some divergent points from reference models (Siman et al., 2020) were detected in the comparison of the modeled activities from ABRASOL (Appendix A); (i) the operational activities do not occur in the same sequence which implicate in presence of redundancy; (ii) manual sorting is performed without ramp or pre-sorting and consequently implicate in rework and the lack of labor integration; (iii) many different types of recycled materials are sorted reflecting in error sources, delays and bottlenecks; (iv) and the sorting process presented different sub process due to the region's consumer market which is related to added value process.

It was noted that the sorting process occurs inside the ABRASOL shed, which is on the same level as the reception yard, which makes it difficult to supply the sorting table due to the need to place the material on the floor and after, in the sorting table, implicating in movement excess and layout changes. Also, this movement excess reflected a non-ergonomic work condition and that waste pickers are generally aware of overly demanding physical efforts that negatively impact health.

Inside the shed, noble area production since it's covered and used to storage, there is a smaller capacity press unused blocking the workflow. It is also worth mentioning that this press wasn't isolated, so can be accidentally turn on affecting work safety. On the other hand, there was some undefined areas with disorganized sorted materials without identification which makes the management and control of materials difficult.

Finally, stock excess and rework due to material insertion in weighed bags were also identified. More than a third of the time spent in the macroprocess of recyclable materials selection (37.1%) is from activities that do not add value and consequently reduce the productivity and income, mainly due to excess handling (60 m/bag). Based on the analysis of operational activities and sorting process in comparison to reference models, excess movement and need of adjustments of layout were identified, so from the point of view of the process improvements two scenarios were suggested: an Ideal Scenario and a Proposed Scenario, as show in VSMs of Figure 1.

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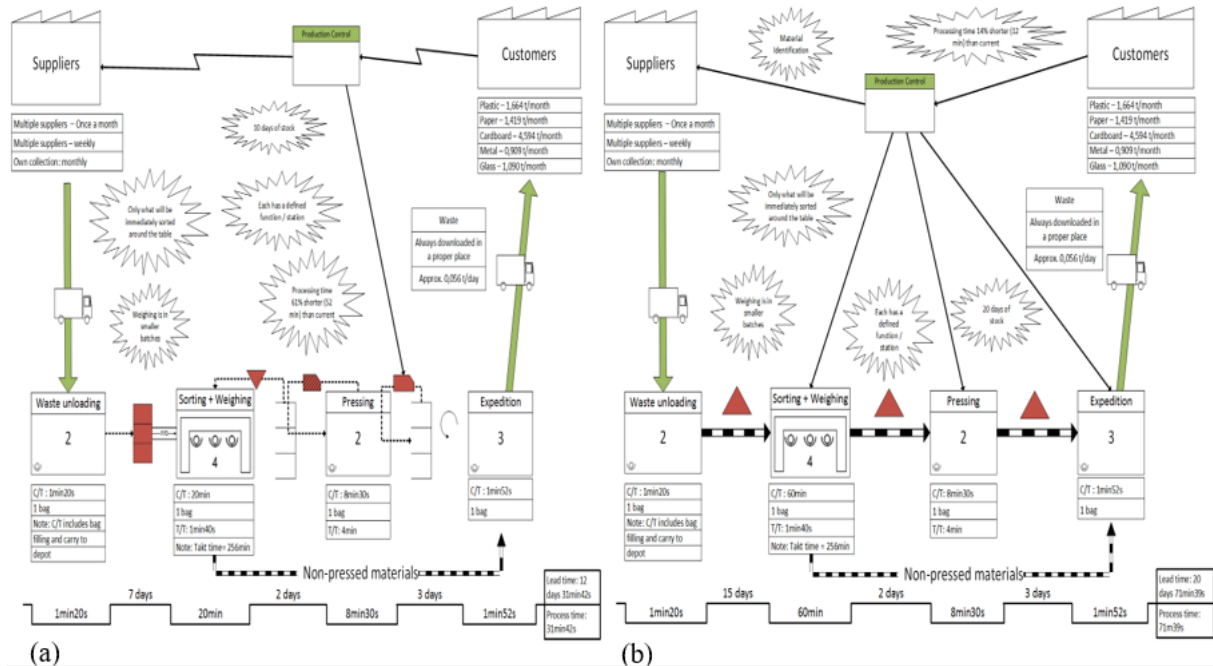
Figure 1. Value Stream Mapping of ABRASOL Waste Picker Organization (a) Ideal Scenario and (b) Proposed Scenario.

Legend: ◡ = number of people performing the activity; ▲ = intermediate stock; C/T = cycle time, T/T = transportation time. 1 Bag = 1.87 m³ e 430.1 kg.
Source: Elaborated by the authors (2023).

As can be seen in Figure 1, considering the Ideal Scenario (Figure 1a), there is an opportunity to gain around 78% in lead time (43 days), 34% in initial stock (6 t), 86% in bag handling (43 m/bag) and 3% (1 min) in activities that add value compared to Initial Scenario (Figure 1a). These results demonstrate that the WPO is able to process more waste and generate higher financial returns after the application of lean thinking.

However, the Ideal Scenario required drastic changes, such as overhauls of the WTO physical structure, change in the position of the press, and the acquisition of more equipment. This would also require new investments and a long execution time. Due to the limited financial resources of the WTO, this scenario was viewed as largely impractical. So, from the identification of essential products from a customer perspective, a Proposed Scenario (Figure 1b) was developed analysing the macro process modelled, the waste movement and the aggregate value activities.

The Proposed Scenario (Figure 1b) has a 20-day lead time, 71-minute bag processing time and a two-week initial inventory. With the implementation of the improvements suggested in the Proposed Scenario, productivity gains were observed in a 17% reduction in handling distances (10 m/bag) and a 58% increase in value-added activities (43 min).

The Proposed Scenario involved moderate changes related to the organization, cleaning, and layout of the WPO. This scenario was considered to be more feasible, while still offering significant productivity improvements. The improvements of the Proposed Scenario were a remotion of smaller capacity press, production area organization, reduction of the number of intermediary stocks and also stocks approximation of related activities improving workflow fluidity. Spaghetti diagram and VSM were applied before any improvement to be used as reference base (Initial Scenario), and to further understand where and how each process/subprocess occurs. Spaghetti diagram and VSM of Initial Scenario are presented in the next topic in comparison with Proposed Scenario.

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4 RESULTS AND DISCUSSION

In order to evaluate the Improved Scenario, initially spaghetti diagrams were used to compare operational process before (Initial Scenario) and after improvements suggested in Proposed Scenario, as presented in Figure 2.
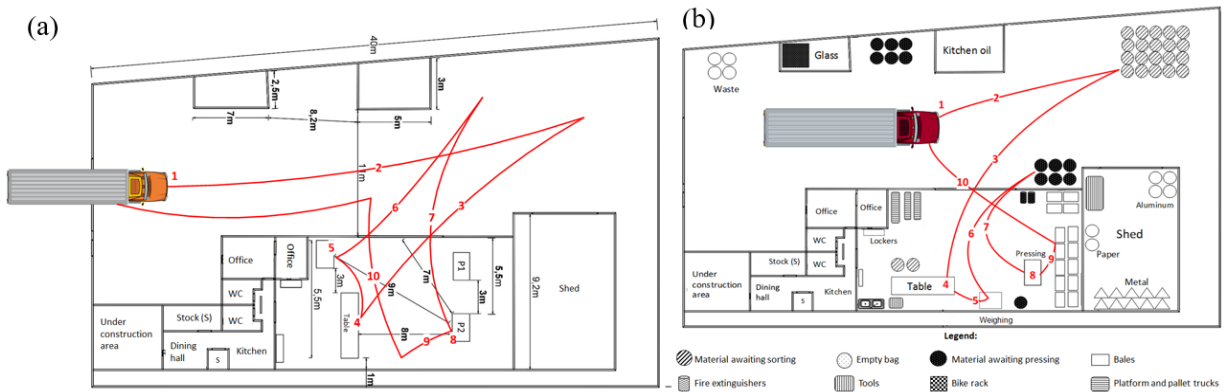
Figure 2. Spaghetti diagrams of ABRASOL Waste Picker Organization (a) Initial Scenario in October 2018 and (b) Improved Scenario on February 2019.
Legend: 1) Waste reception, 2) Waste unloading, 3) Transport to the sorting table, 4) Sorting, 5) Weighing, 6) Transport to storage, 7) Transport to the press, 8) Pressing, 9) Transport to stock and 10) Expedition.
Source: Elaborated by the authors (2023).

Figure 2a indicates the existence of 5 points where the flow lines intersect. These points demonstrate that a worker passed the same point twice, representing unnecessary movement. During the elaboration of the spaghetti diagram (Initial Scenario), it was noted that the same type of waste was redundantly stored in different locations, causing rework and excessive processing. This ultimately reduces the rate of material selection in the WPO.

Despite the simplicity of this tool and the potential increase of fluidity, the application of spaghetti diagram in WPOs are still unpublished, but it can be found in literature the adoption of this type of diagrams as one of lean methodology to improve workflow in several areas such as industrial, commercial and also health, e.g., shop floor layout (Havard et al., 2019), motor factory (Mahajan et al., 2019) and patient triage process in emergency services (Falconer et al., 2018).

The improved organization shown in the spaghetti diagram (Figure 2b), could be noted on time spent in operational activities before and after improvement as presented in Table 2.

Table 2. Comparison of time spent of each activity in Initial Scenario and Improved Scenario and respective classification of the activity regarding value aggregation.

Activity	Time spent in Initial Scenario (h:min:s)	Time spent in Improved Scenario (h:min:s)	Value aggregation
Receiving waste	-	00:00:17	NVM
Unload waste from vehicle	00:09:00	00:05:05	NV
Transport to the storage	00:00:50	00:00:35	NV
Select bag for sorting	00:04:57	-	NV
Transport to the sorting table	00:03:30	00:00:15	NV
Search empty bag for sorting	00:00:38	-	NV
Sorting	01:05:42	00:22:30	VA
Weigh	00:05:41	00:00:43	NVM
Transport to the storage	00:05:32	00:00:35	NV
Transport to the press	00:00:17	00:01:17	NV
Burden preparation	00:07:45	00:04:00	NV
Press	00:08:30	00:08:30	VA
Transport to the final stock	00:05:32	00:01:39	NV

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| Total	01:57:54	00:45:26	-

Legend: NVN — no value aggregation but necessary; NV — no value aggregation; VA — value aggregation.
Source: Elaborated by the authors (2023).

The total time spent in operational activities reduce to 38% in the Improved Scenario and evaluation of value aggregation of each activity allowed eliminated two unnecessary activities. This showed how a practical solution based on layout changes, organization and elimination of unnecessary no value aggregation activities can strongly impact on WPO productivity.

Modelling by mapping wastes has been applied to reduce them (Belvedere et al., 2019; Fercoq et al., 2016; Sutharsan et al., 2020), including in urban solid waste management (Lima et al., 2015). Figure 3 shows the Value Stream Mapping of the Initial Scenario and Improved Scenario for comparison purposes.
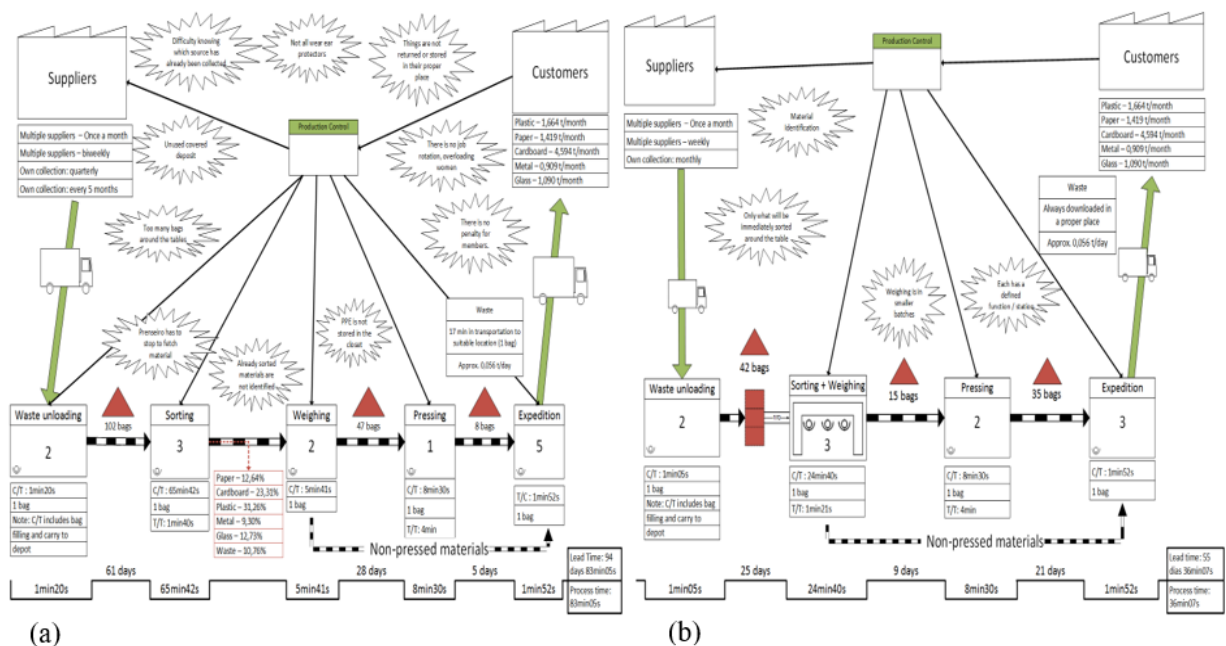
Figure 3. Value Stream Mapping of ABRASOL Waste Picker Organization (a) Initial Scenario in October 2018 and (b) Improved Scenario on February 2019.
Legend: ⌣ = number of waste picker performing the activity; ▲ = intermediate stock; C/T = cycle time, T/T = transportation time.
Notes: The percentages indicate the composition of the sorted waste (kg) based on the quantity sold between January and September 2018 and the others refer to October 2018. 1 Bag = 1.87 m³ and 430.1kg.
Source: Elaborated by the authors (2023).

It is noted in the VSM of the Initial Scenario (Figure 3a) that the waste flow in material selection is moved manually (striped arrows). Waste accumulation was observed in the sorting yard (43.87 t), stored at random, with waste older than 3 months, making it difficult to trace its origin. Moreover, other materials, equipment, and tools are spread throughout the WPO. This situation hinders the transit of people, vehicles and equipment within the WPO, increases the space required for storage, lengthens the reception and sorting process, causes ergonomic and accident risks, and favours the contamination of recyclable materials with organics, thus reducing the quantity and quality of the product (Castilhos Junior et al., 2013; Zon et al., 2020). In the shed, a small capacity press stood out for being disused.

The flaws in productivity encountered at the WPO were excess inventory, unnecessary movement and transportation, non-continuous flow, rework due to the addition of waste to already sorted materials, underutilized and disorganized areas, and mismanagement.

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Oliveira et al. (2022) describe as challenges for the work of waste pickers related to the physical structure: the lack of coverage of areas for separating and storing materials; absence of draft in the environment, separate space for having meals and storing documents.

Comparing the results of the Improved Scenario (Figure 3b), the movement reduction target was achieved; and the goal of valued-added activities was exceeded by 56% (40 min). On the other hand, the reduction in the initial stock decreased by 59% (25.8 t), 110% above the target (10 t), negatively impacting the lead time, which, despite having a 42% (39 days) gain compared to the Initial Scenario, was 175% above target (35 days).

Sutharsan et al. (2020) also used Value Stream Mapping obtaining similar achievements, but in a pump manufacturing industry, due to the potential of this tool in uncovering waste in manufacturing, production, or business processes, which allow increase the throughput speed as can be seen in the improved scenario of WPO (Table 3). The organizational structure changes implemented within the WPO, such as sorting one bag at a time (unit flow) and awareness of which waste brings the most revenue, also enabled the improvements described in Table 3. Production and availability of area were not estimated in the Proposed Scenario.

Table 3. Earnings from improved deployments (Improved Scenario)

Items	Unit	Initial Scenario	Proposed Scenario	Improved Scenario	Earnings*	Earnings (%)
Lead time	days	94	20	55	39	41.5%
Sorting stock	bag	102	20	42	60	58.8%
Sorting stock	ton	43.87	8.60	18.06	25.81	58.8%
Sorting stock	days	61	15	25	36	59.0%
Movement	m/bag	60	50	50	10	16.7%
Activity that adds value	(h:min:s)/bag	01:14:12	01:11:00	00:31:00	00:43:12	58.2%
Non-value-added activities but is needed	(h:min:s)/bag	00:22:26	00:15:00	00:10:05	00:12:21	55.1%
Non-value-added activities (movement)	(h:min:s)/bag	00:00:38	00:00:00	00:00:00	00:00:38	100.0%
Non-value-added activities (processing)	(h:min:s)/bag	00:04:57	00:00:00	00:00:00	00:04:57	100.0%
Non-value-added activities (transport)	(h:min:s)/bag	00:15:41	00:05:00	00:04:21	00:11:20	72.3%
Time to elaborate production report	h/month	36	-	6	30	83.3%
Area	m²	-	-	54.75	54.75	-

Legend: *Comparing the Initial Scenario and Improved Scenario. Bag = 1.87 m³ and 430.1 kg.
Source: Elaborated by the authors (2023).

With the implementation of the suggested improvements of Proposed Scenario, such as the removal of the press and reorganization of stocks to bring them closer to the place of use, there was a reduction of 16.7% per bag (vide Table 3).

The only metric that did not reach the expected improvement was the lead time. This can be justified due to the fact that ABRASOL's overall workforce was reduced by one driver during the experimental period; and the hiring of a replacement was considerably delayed.

There is an observed downward trend in sorting stock, which coincides with the increased, post-improvement monthly processing capacity. Moreover, the improved organization of sorted materials greatly reduced the time required to compile a production report for the relevant waste supplier, an 83.3% reduction from 36 hours a month, to just 6 hours a month. Furthermore, the work week was reduced from 40 hours to 36 hours, not accounting for occasional overtime. This reduction to 8 hours a day, with additional time off on Fridays, demonstrates a significant improvement over the 16 hours a day that some waster collectors have previously been reported to work (MNCR, 2018).

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Taken together, these improvements in overall organization efficiency illustrate that profitability can be increased while also easing the labour burden on WPO workers. Visual perception of the work environment improvement could be also perceived. The Figure 4 shows the difference in WPO organization before and after the improvements.

Figure 4. Configuration of ABRASOL Waste Picker Organization in Initial Scenario and Improved Scenario. Legend: (a) Internal shed area for press and stock in Initial Scenario; (b) Internal shed area for press and stock in Improved Scenario; (c) Sorting table in the production area in Initial Scenario; (d) Sorting table in the production area in Improved Scenario; (e) External stock area in Initial Scenario; (f) External stock area in Improved Scenario. **Source:** Elaborated by the authors (2023).

Due to the lack of studies applying lean tools in WPOs, it wasn't possible to compare the results obtained in ABRASOL illustrated in Figure 4 with other organizations. Checking out the novelty of this research, improvements in layout, productivity, lead time and earnings are usually reported by manufacturers, although the potential application in other areas as demonstrated in this study.

According to Huo et al. (2019), lean tools improves economic performance (from customer and supplier side), and social and environmental performance from customer side. The social performance is the least studied, but the positive effect in the employee satisfaction as reported by Henao et al. (2019) gain more importance in WPOs due to historical marginalization of waste picking activity (Silva et al., 2019).

The main contribution of this study, to both scholars and practitioners, is to propose a practical intervention to help WPOs to improve the economic sustainability and the ergonomic conditions that only require human resource, based on lean philosophy. This is in line with the recommended by Zon et al. (2020) that estimated a cost of US\$ 664,717,743.94 until 2040 for better waste collection practices in Espírito Santo (Brazil), but it is highlighted that some costs are still unknown and the practical options that only require human resource would better support low-income countries. Leong et al. (2019) also reported the need of these improvements solutions in industrial scale and environmental performances.

5 CONCLUSIONS

The application of lean tools at the WPO, ABRASOL, demonstrated that the low productivity was due to 32% (14 min 26 s) of initial activities, either not adding value or promoting waste such as: excessive handling and transportation due to inefficient layout, a disorganized working environment, and poor management. Taken together, these factors decrease operational efficiency and economic performance. With the application of the proposed lean tools, these inefficiencies were addressed and corrected, resulting in: a decreased

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organizational structure labour expenditure for a given quantity of recyclable materials, an overall greater production capacity, an increased profitability, and an increased market presence due to greatly improved throughput.

The lean thinking tools proposed in this study have great feasibility in simple enterprises such as Waste Pickers Organizations. These operations play a fundamental role in the circular economy, especially in low- and middle-income countries; however, they have very low efficiency because of dysfunctions that prevent their economic sustainability. The main goal is to reduce the effort required to select recyclable materials that allow for increased productivity and revenue.

In general, it is recommended to replicate the methodology used in this research in different WPOs in order to i) identify essential products from the point of view of WPO customers (recycling companies); ii) apply lean thinking tools to production in its current state; iii) propose improvements for future scenarios; and iv) implement and measure improvements to evaluate the effect of applying these lean tools in other scenarios. This methodology can be applied to others WPO with similar characterizes, especially in developing countries, considering that the low productivity is not a common reality exclusive to Brazil, since the initial scenario of ABRASOL can be found to many WPOs from other locations abroad. However, the results cannot be generalized since some WPOs process different types of waste materials and have different levels of automation, and these may have different requirements, and different methodologies for performance improvement may be needed.

It is important to highlight that for the development of the research, a special attention was given to the people involved to explain that the purpose of the work was to improve the productivity and revenue of waste pickers, in addition to the fact that the changes would occur only with their acceptance. Notably, the results would depend on the engagement of all WPO members. Finally, in line with the research gaps point out by Agyabeng-Mensah et al. (2021), which highlighted the need to exploring the impact of lean management practices on performance and intra and inter organisational learning, this research contributes with the organisational identity of WPO and their circular economy target performance applying easy implementation tool without cost. Other Lean Tools such as 5S, Poka-Yoke, Kaizen can also be explored in WPOs in further studies.

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