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ORIGINAL PAPER

Action Research in Reverse Logistics for End-Of-Life Tire Recycling

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Abstract At the end of their product life cycle, tires require special handling and treatment in order to avoid damaging the environment and society. Reverse Logistics (RL) is necessary to manage this type of solid waste. In Brazilian cities, collection is one of the bottlenecks. One of the main difficulties in this process is enabling joint-action between the main stakeholders: Final consumers, the government and private companies. The main objective of this paper is to identify e implement opportunities for improvement in the collection phase of end-of-life tires through action-research, involving simultaneous participation between public and private organizations. The motive for this is that the knowledge generated can serve as a basis of information and references which aid in decision-making for public authorities who need to start similar programs or improve existing ones. The Action-Research occurred in a Brazilian city with less than 100,000 inhabitants, which fits the profile of 94.91% of the country's municipalities. Final results proved the efficiency of the action-research proposal; after implementing the changes, the monthly collections grew by 50% (action), and the Action-Research team was able to generate and document knowledge which can now help other cities to improve their own processes.

Keywords Action-research · Waste management · Reverse logistics · End-of-life tires

Introduction

Population and economic growth have generated greater consumption of a vast selection of products. When products reach the end of their life cycle, these items (or what is left of them, i.e. packaging, manuals) end up in the environment. Due to this situation, there is a greater interest in development of techniques and tools for managing solid waste. Reverse Logistics

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(RL) stands out as one of the most promising; it is defined as the movement of products or materials in the opposite direction of traditional logistics with the objective of creating and recapturing value, or to correctly dispose of different types of products (Demirel et al., 2014; Das and Dutta, 2013; Tibben-lembke and Rogers, 2002). The importance of RL is emphasized by Demirel and Gökçen (2008), who cite growing environmental concerns, the reduction of natural resources and limited capacities of landfills in most countries as justifications for the use of RL strategies.

Certain solid waste materials demand special attention during disposal. Tires are a perfect example of that, presenting challenges to their recycling due to their structure and complex composition (Sienkiewicz et al., 2012). According to Kannan et al. (2014), the definition of a tire at the end of its life cycle can be called an end-of-life tire; the World Business Council of Sustainable Development (WBSCD): a tire that can no longer be used for its original purposes. Incorrect disposal can damage the environment and society as a whole. For this reason, tires must receive adequate treatment when identified as end-of-life, and this is done through Reverse Logistics.

In Brazil, special attention has been paid to end-of-life tires since the 1990s. The National Environmental Council (CONAMA) has demanded that tire manufacturers and importers correctly dispose of their end-of-life tires, prohibiting landfills as a disposal option, since 1999. These laws influenced the current situation, especially because RL processes are not completely carried out in conformance with current legislation. However, there are many opportunities for improvement in small- and medium-sized cities, which generally do not have reverse logistics implemented and, by improving the initial phase – Collection – the processes will become more efficient.

Due to the practical nature of this investigation, action-research was the ideal method to help respond to the research question: Which actions can be implemented in order for Reverse Logistics processes for end-of-life tires to improve?

The objectives refer to the execution of actions to resolve the problem and respond to the research question. Thus, the general objective of this study is to identify and implement opportunities for improvement for end-of-life tires through action-research. Thus, specific objectives are: *(i)* Gain greater understanding for end-of-life tire RL processes and implement improvement actions; *(ii)* Contribute to effective forms for reducing environmental liabilities generated by incorrect end-of-life tire disposal. The knowledge generated can serve as a basis of information and references which aid in decision-making for public authorities who need to start similar programs or improve existing ones.

First, the article presents a bibliographic revision about the topic and contextualizes the studied scenario. Then the action research methodology's application is shown. A diagnosis of the current situation and the most important points for improvement are reviewed, according to two fundamental actors in the supply chain: Government Entities, which manage the end-of-life tire Collection points, and the Generation Points (tire stores, tire repair, and scrap). Finally, results are presented and reviewed.

Reverse Logistics

Concern about solid waste management has been growing since the 1990s; currently, it is a global topic of great importance (Kannan et al., 2014). Many studies confirm this by showing actions in the literature aiming to reduce the quantity of solid waste sent to landfills and, at the same time, increase recycling and reutilization of post-consumption material (Lederer et al., 2015; Danubianu and Teodorescu, 2015; Gutberlet, 2008). One of the main justifications for the growing interest in this area is that, with technological advances and rapid changes in demand, products are going onto the market faster, and with an ever-decreasing life-cycle, which generates a greater quantity of material disposed. Demirel et al. (2014) and Das and Dutta (2013) warn that the management of end-of-life products is important not only for environmental questions related to increasing amounts of solid waste, but also due to economic factors and obligations imposed by legislation.

One of the most effective avenues for effective solid waste management is the adoption of increasingly severe legislation. Lavee et al. (2009) cite the establishing of minimal urban solid waste (USW) recycling in Germany and France. The same authors describe cases in which countries adopted policies to subsidize recycling, such as the United States of America, which created programs known as deposit refunds.

The Brazilian National Policy for Solid Waste (PNRS - *Política Nacional Resíduos Sólidos*) outlines principles, objectives, instruments and other guidelines in reference to integrated and solid waste management, along with the responsibilities of generators, public entities and the applicable economic instruments (Brasil, 2010). According to the policy, it is up to manufacturers, importers, distributors and retailers to take the necessary measures to ensure implementation and operationalization of reverse logistics systems, for the following six product types:

- Pesticides and insecticides, their waste and packaging, as well as any other product which, after use, could present an environmental or health risk;
- Batteries;
- Tires;
- Lubricants, their waste and packaging;
- Fluorescent light bulbs (sodium and mercury vapor and mixed);
- Electronic products and components.

The current study focuses on RL in end-of-life tires. Thus, the next item makes a case for the importance of RL for this specific solid waste category.

Environmental Problems Caused by Incorrect Tire Disposal

According to the Brazilian National Transport Confederation (CNT, 2015), 61.1% of the country's cargo and passenger transportation occurs on roadways. The predominance of road transportation and, in turn, the great demand for tires, helped consolidate the national tire market.

While there is a great economic importance related to tires at the beginning of their life-cycle, end-of-life tires transform into an environmental concern. According to the Brazilian National Pneumatic Industry Association (ANIP, 2016), the raw material for tires are natural rubber, synthetic rubber, petroleum derivatives, soot, steel cables, cords from steel or nylon, and chemical products such as sulfur. Proportions for each component vary according to the use of the final product. According to Dhouib (2013), due to the complex composition, there are certain difficulties faced related to the final disposal of tires for recycling.

In Brazil, it is illegal to throw tires into landfills (BRASIL, 2009), since they cannot be easily compressed and are not biodegradable. Furthermore, they absorb gases liberated during decomposition of other waste products, causing them to swell, sink and even explode, which can damage the landfill coverage and shorten the lifespan of the physical space (FERRÃO et al., 2007, BLUMENTHAL, 1993). Consequently, tires are many times left in open-air environments, attracting animals and enabling gas leakage from the landfill. Aside from these drawbacks, rain water infiltrates the soil and increases the formation of leachate.

According to Subulan et al. (2015), significant environmental problems have caused the increase in the volume of end-of-life tires generated each year. Souza and D'Agosto (2013), Chan et al. (2011), Chang (2008) and Ferrão et al. (2007) cite the following environmental problems originating from incorrect tire disposal:

- Potential breeding grounds for rodents and mosquitos, such as *Aedes aegypti*, which transmits the Zika virus, Dengue Fever, and Chikungunya virus.
- Soil and air contamination via emission of toxic gases during fires: tires incorrectly disposed in the environment can turn into fire hazards, as their material does not have any filtering system, generates black smoke, toxic gases and carcinogens, as well as oils which contaminate the soil and groundwater (SIENKIEWICZ et al., 2012). Based on the examples and information provided above, end-of-life tires must receive an environmentally friendly disposal. To incentivize this, laws have been passed in order to obligate manufacturers and tire importers to promote waste management and return these products at the end of their lifecycle. Other stakeholders in the tire logistics chain were made responsible for the process. RL plays a fundamental role in guaranteeing adequate disposal which does not harm the environment or public health.

Reverse Logistics Actions in Brazil for End-Of-Life Tires

The National Pneumatic Industry Association founded the "National Collection and Disposal Program for End-Of-Life Tires". In 2007, this program was substituted by Reciclanip (ANIP, 2016); the organization's objective is to guarantee correct environmental disposal of end-of-life tires.

According to Reciclanip (2016), this nonprofit organization was created in March, 2007, by the manufacturers Bridgestone, Goodyear, Michelin and Pirelli. Currently Continental and Dunlop have come to be part of the same entity, having joined in 2010 and 2014, respectively. Regarding their results, Anip (2016) reported that since 1999, when end-of-life tire collection started, more than 3 million tons of end-of-life tires (equal to 625 million average-sized car tires) were collected and properly treated. Furthermore, the manufacturers declared that they invested almost US$ 270 million to collect and dispose of end-of-life tires.

Reciclanip depends on help from municipal governments to install and administer RL collection points (CP). According to the organization, CP are locations where end-of-life tires should be taken for public sanitation. They must have safety and hygienic regulations, especially related to overhead coverage. When a city hall opens a CP through a partnership, Reciclanip is responsible for logistics management and providing adequate disposal methods for the tires in companies which are credentialed by environmental organs and qualified by the Brazilian Environmental and National Resources Institute (IBAMA). For every 2000 car tires or 300 semi-truck or bus tires, a pick-up request is made from the CP manager to Reciclanip. All involved parties must use their own financial resources to complete their portion of the operation. According to Reciclanip (2016), the main final destinations for end-of-life tires are: co-processing, lamination, rubber artifacts and rubber asphalt.

Action-Research

Action research is the most suitable method for RL applications related to end-of-life tires, since it acts on an existing problem through implementation of improvement solutions, with an overarching goal of gathering scientific knowledge. According to Thiollent (2011), action research is social research with an empirical base, which is conceived and carried out in strict association with an action or resolution to a collective problem and in which the researchers and participants of the situation or problem are involved in a cooperative or participative way. This research method has proven to be efficient in RL problems, according to studies by Paes et al. (2016), Cullen et al. (2013) and Hameri and Paatela (2005).

According to Westbrook (1995), there is no standard to be followed for action research; however, there are some basic steps for conducting the research. In general, an action research cycle requires planning for the study, along with data collection and analysis which will aid in action planning. In turn, the actions provoke changes on the study object, and these changes are evaluated in a final stage which serves as a reference for previous cycles. These steps are shown in Fig. 1. Analyzing Thiollent (2011), Coughlan and Coughlan (2002) and Westbrook (1995), the current action research project was divided into five stages: Planning the Action Research (1), Collecting and Analyzing Data (2), Planning Actions (3), Implementing Actions (4), Evaluating Results and Generating Reports (5).

The methodology, shown in Fig. 2, was used in the development of this study.

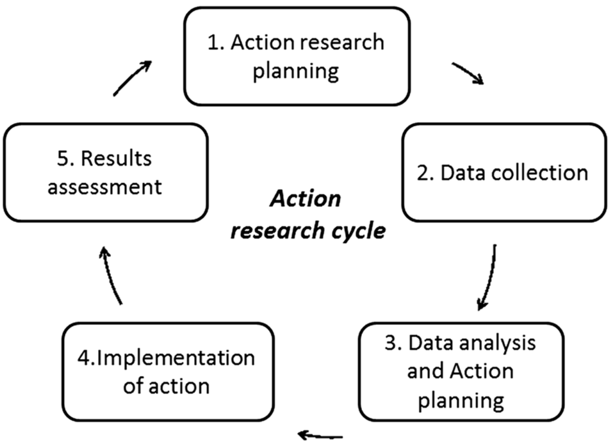
Action Research Execution

The steps shown in Fig. 1 are presented below.

Planning the Action Research

The planning phases action research involves two phases: selection of the unit under study and definition of the team.

Fig. 1 The steps utilized in action research. Source: Adapted from Mello et al. (2012), Thiollent (2011), Coughlan and Coughlan (2002) and Westbrook (1995)



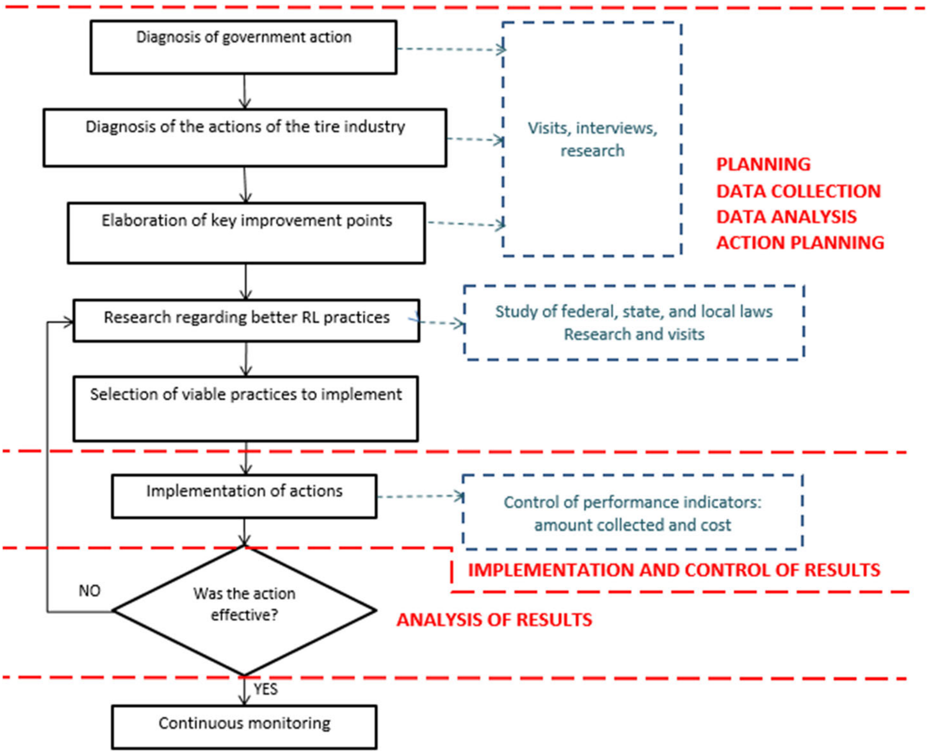


Fig. 2 Methodology for the improvement of RL for Scrap Tires

Selection of Unit Under Study

The criterion established for choosing the study object was that it needed to be a municipality where interest existed from local government for research and, preferably, where there was concern about environmental and solid waste issues. The city which fit this description was Tres Coracoes, in the state of Minas Gerais. One important characteristic which led the action-research team to choose the city is that there is a collection point for end-of-life tires, in spite of the fact that the city is not obligated to provide space for such use, since there are fewer than 100,000 inhabitants.

The studies undertaken in this part of the municipality are coordinated by the Municipal Environmental Secretary (SEMMA), which is responsible for promoting investigations and environmental projects, legislation proposals and environmental norms, partnerships with entities, companies and other groups interested in environment.

To diagnose the situation and gain a greater understanding about the end-of-life tire management in the municipality, a meeting was conducted with the SEMMA. Aside from the AR Team, SEMMA leaders and the city's landfill technical leader participated.

In this next research phase, the following information was obtained:

- Since 2010, the municipality maintains a partnership with Reciclanip to promote proper end-of-life tire disposal. Through this partnership, a CP must be established to receive the tires and promote its use with the companies in the region which generate unusable tires. No taxes nor fees are charged to the companies who drop off their tires at the CP.

- There was no active collection system at the generating points; that is, each generating point had to deliver the tires to the CP, dealing with the costs related to transportation.
- When the tires are dropped off at the CP, the business must also deliver a Transportation Declaration, where the quantities delivered are detailed. The tires must also be piled correctly (in an interlaced pattern). The tires are then collected by Reciclanip, who is responsible for final destination of the material.
- The tires are stored in the CP until a sufficient quantity is collected to fill a truckload. Once the quantity is reached, SEMMA solicits a pick up through an e-mail, which is sent by Reciclanip.

With the information obtained during this first meeting, the research-action team mapped the RL process for end-of-life tires in the municipality, according to Fig. 3.

Action Research Team Definition

After reviewing the literature, defining the object under study, getting to know the local reality and those involved in the management, the action research team concluded: From the CP on, the reverse flow of end-of-life tires functions well in the activities related to Reciclanip, complying with the responsibilities in the partnership. This can be seen by the fact that Reciclanip meets the national goals for discarding tires from manufacturers. On the other hand, the organization depends on the tires actually being dropped off at the CPs. This is the main problem, because there is no municipal instrument capable of guaranteeing that the tires arrive at the CP, or that keeps them from being abandoned in the environment. For this reason it is essential that actions be developed at the municipal level to increase the amount of tires collected, avoiding inadequate disposal and all of the negative impacts associated.

This study relates to the initial phase of end-of-life generation to the delivery at the collection point. It was defined that the analysis unit would be the municipality of Tres Coracoes, which is made up of the city hall, represented by SEMMA, and the companies which are active in the tire market. The team responsible for conducting the action research was made up of this paper's authors, specialists in Reverse Logistics. For the means of the

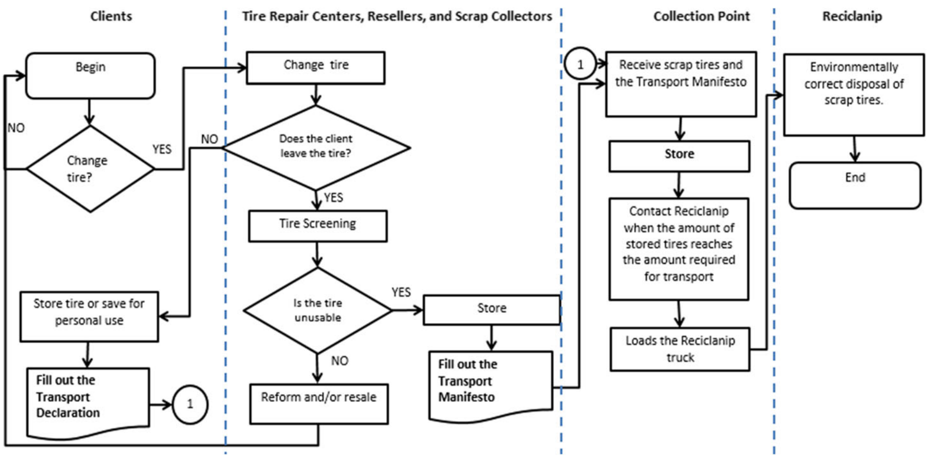


Fig. 3 Reverse Logistics flowchart for end-of-life tires in Tres Coracoes

study, the development team will be called the Action Research Team (AR Team). Two representatives from the municipal government participated, as well as stakeholders from the commercial establishments which serve as collection points (CPs). The experience promoted cooperation between the interested parties. The AR had the opportunity to put conceptual knowledge into practice on a real study object and the RL stakeholders were able to take advantage of the results which improved the process.

Data Collection

In the data collection stage, the action-research team sought to capture information about opportunities for improvement in the RL process for end-of-life tires.

For data collection, participant observation techniques, individual interviews and questionnaires were used in a combined fashion neste trabalho.

Data collection of the actions carried out by SEMMA happened in parallel with the planning stage through meetings with the City Secretary, along with visits to the collection points. During meetings with the city administration, the AR team was able to better understand the work developed by the Secretary, as well as the difficulties surrounding RL for end-of-life tires. Multiple visits were done at the collection points to gather information about the evolution of tire delivery and storage at these locations.

The second step in data collection was to diagnose the situation faced by the most common CP users: businesses, resellers and retailers. Interviews and visits were conducted to better understand these points with twenty companies (10 resellers, 9 repair shops and 1 scrap collector). These companies were identified using a control list which SEMMA maintains.

The interviews were done on site and individually, where the interviewees had the opportunity to clear up any doubts. The information obtained in this step is shown in Fig. 4.

The difficulties identified by the AR team during the meetings were:

- The business registration done by SEMMA was, in many cases, out of date and some companies' addresses were not up to date or not even in business any longer;
- While the Tres Coracoes municipality is not geographically dispersed, the distance between the businesses presented some challenges in conducting the interviews; if one business owner or manager was not available, the researcher continued to the next company. This reflected in the total amount of time to carry out the diagnosis;
- A certain level of distrust on part of some business owners to participate in the study. Some thought that the interview was part of a government regulatory agency, or that the researcher could have been sent by some new business that wanted to establish itself in the region. Once all explanations were made by the researchers, all business owners participated.

Data Analysis and Action Plan

In this phase, the main goal of the AR team was to compile the most relevant information observed by SEMMA and then at the EOL tire generation points.

Once the meetings were conducted with the public officials, it was possible to highlight qualitative information about the process shown in Fig. 2 and identify the lack of commitment

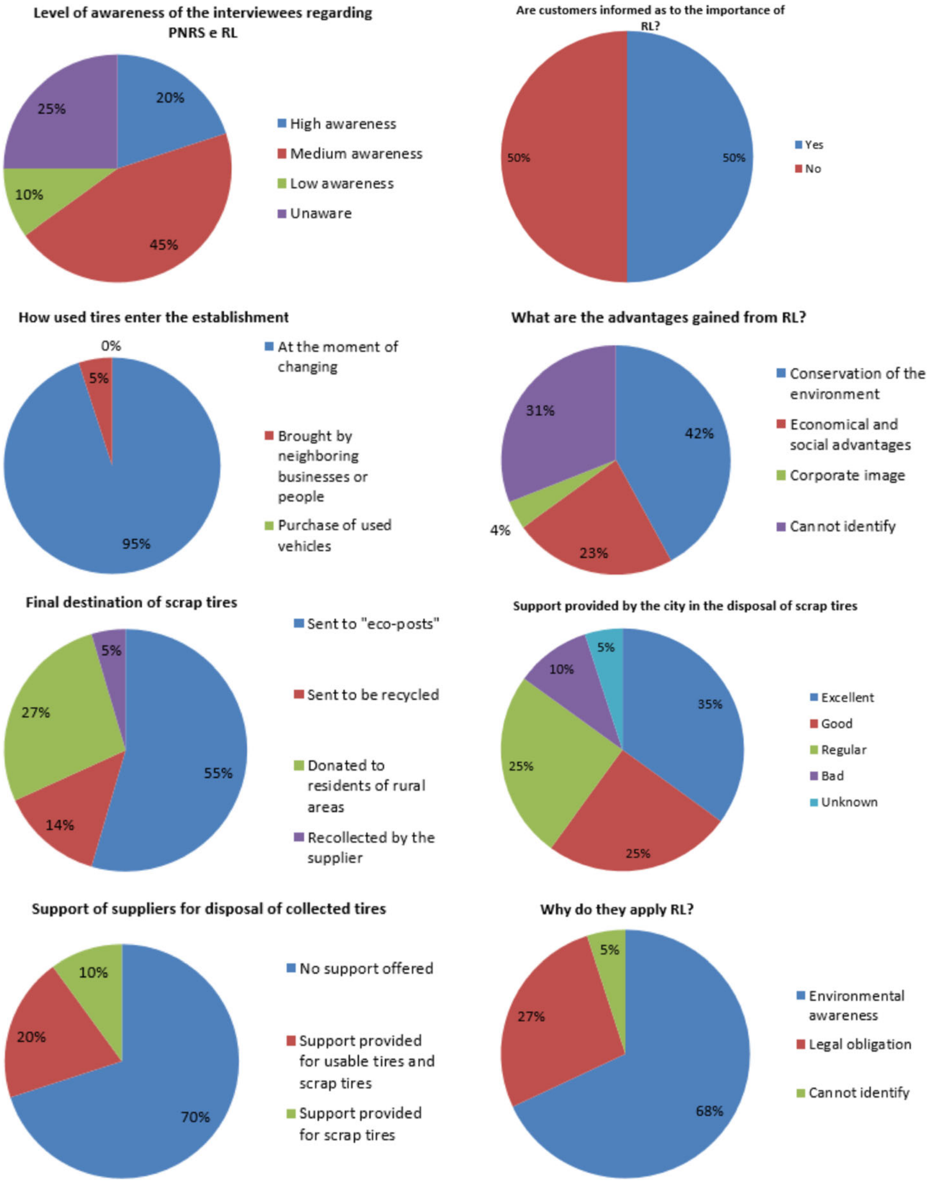


Fig. 4 Data Collection

on part of some of the generation points. Two points are worth mentioning for system improvement:

- Correct disposal of the tires, using an intertwined pattern, is not done by most of the stakeholders who deliver to the CP. Generally the tires are thrown into a disorganized pile. This causes some disadvantages surrounding the necessity for more storage space, difficulty in management and handling, and enables water accumulation;

- Despite using the Transportation Declaration, quite often it is not filled out correctly nor delivered. In turn, there is no control over the quantity of end-of-life tires. Verification of quantities is done visually and based on experience.

During data collection at the generating points, the two main questions for the AR team were:

- *What is the main difficulty for the generating points to correctly dispose of the EOL tires?* The answer obtained at the generating points was the cost of transportation to the collection points.
- *What improvement could the city government implement so that EOL tires are delivered to collection points?* The business owners believe that the main improvement which the city hall could provide is implementation of a regular collection program, which would go to the generating points. In this scenario, the collection would be scheduled and a single truck would run a route to cover all the generating points per the schedule.

According to the agreement between the action-research team and the SEMMA representatives, the improvement actions were defined based on the diagnostics done with the business owners and the operational difficulties faced by the city hall related to RL.

After this analysis was finished, another meeting was scheduled between the AR Team, SEMMA leadership, and the landfill technical lead. All attendees received a copy of the report, which provided the complete RL analysis and opportunities for improvement.

Based on the findings, the following action plan was proposed:

1. Create municipal legislation to regulate the disposal of end-of-life tires, using benchmarking with other municipalities.
2. Create and maintain regular communication mechanisms which would raise awareness about the importance and environmental impact of tire disposal with the generation points and general public.
3. Implement a regular collection system in the municipality at the end-of-life tire generation points, with fixed dates and at no initial cost to the participating businesses.

Implementation of Actions

Once planning was completed, the AR team placed their plan into action. In some moments, more than one action was put into place simultaneously. The three main actions are described below; to aid in the understanding of each action, they will be presented separately.

Proposal 1 – Creation of Municipal Legislation

A Legislation Proposal was created by the AR Team, based on 17 laws already in effect in 14 other Brazilian municipalities of varying sizes and populations. The bill proposed for Tres Coracoes establishes procedures for RL processing and environmentally-friendly disposal of end-of-life tires. The following items detailed and defined:

- Clear definitions of responsibilities: Commercial establishments, made up of distributors, tire repair shops, scrappers, service providers and tire handlers, must possess safe locations to store end-of-life tires, according to applicable norms and legislation. Individuals and companies must use these locations to discard their end-of-life tires.

- Environmental education: the City must organize and execute a campaign to raise awareness about the risks end-of-life tires pose to the environment and public health, focusing on the importance for correct disposal.
- Necessary physical structure for temporary storage, and correct piling and storage methods: end-of-life tires shall be stored in an organized manner, in piles, in order to ensure a safe environment which could be audited by relevant entities. The temporary storage place shall be compatible with the volume and safekeeping of the material to be stored and must not have water drainage systems linked to the sewer or rainwater systems. The tires shall be kept in an environment covered by tile roofs or some other hard surface, and cannot be covered by plastic tarps or similar materials, which are subject to eventual deterioration.
- Provision of Penalties for Lack of Compliance;
- Norms for incinerations: Burning of these tires will be authorized by the Municipality only for duly authorized establishments which carry out this service with permission from the Brazilian Institute for Environment and Renewable Resources (IBAMA) and the Municipal Environmental Council (CODEMA).
- Provision for Eventual Partnerships: the Municipality may establish partnerships with public or private entities to aid in the collection process for generation points, through mutual cooperation and partnerships.

Proposal 2 – Education and Communication

During the research for the elaboration of the legislation, the second opportunity for improvement was explored: creating and maintaining regular communication mechanisms regarding the importance of RL and the project developed for end-of-life tires.

The action-research team raised questions which were important to be communicated to the population about EOL tires and created releases. The first release provided an overview of the project carried out with SEMMA, details about the partnership with Reciclanip and the amount of end-of-life tires which had received proper disposal up until that moment. The overall aim was for the population to have recurring information about the treatment given to the tires in Tres Coracoes; the concept being that once the project was more well-known, the population would become more involved and cooperative with the initiative. The other two releases sought to inform the public about the collection process, partnership with the local businesses, and the specific impacts of proper tire disposal on health and safety preservation.

In all cases, the bulletins were elaborated by the AR Team and sent to the Municipal Communication Secretary for analysis and publication in the city hall newsletter.

Proposal 3- Active Collection

The third improvement proposal was the insertion of an active end-of-life tire collection process in the companies which participated in the assessment. The implementation happened simultaneously, in conjunction with the other two proposals.

With SEMMA's authorization, an autonomous service was hired to collect the tires, financed by the AR Team. To facilitate the trajectory and economize time, the AR Team created routes which covered all the generation points. The routing proposal was submitted to SEMMA for analysis, and once validated, the pick-ups were scheduled. A member of the secretary accompanied the pickup process throughout the entire route. Six active collections were done over the course of seven months. During the collections, SEMMA delivered ordinances, informing the necessity to correctly store and deliver the tires.

Results Analysis

After implementing the action plan, the analysis moved on to the next phase: analysis of results. The report involved a reflection about the results of each action, including results foreseen and unexpected, and a review of the process for future planning and action cycles to verify how they can benefit the complete cycle.

Regarding the foreseen results, the AR team met the goal proposed of identifying and implanting opportunities to improve the efficiency of RL for EOL tires, proposing and generating knowledge.

At the end of the six pickups done by the AR Team, 28.45 tons of end-of-life tires were collected. Table 1 shows the results of the scheduled, active collections.

Table 2 shows a quantitative comparison between active collection (from this investigation) and passive collection, which started in 2010.

Through July 2014, 109.71 tons of tires had been disposed over the course of 53 months, representing a monthly average of 2.07 tons. The active collections happened throughout a 9-month period and represent a monthly average of 3.16 tons, which reinforces the effectiveness of active collection, along with the other actions, to enable correct tire disposal. In the first four months, the value charged for freight was approximately US$125.00 per month, and was adjusted to US$150.00 from the fifth month on.

Throughout the action research, the team perceived multiple need for unforeseen actions to complement and support the actions. A truck route was mapped for the active collection; a simplified spreadsheet was created for use at the collection points, which would substitute the Transportation Declaration; and a disposal manual was created and distributed for instruction of EOL tires disposal.

Table 1 Results of active collection

Type of Tire	2014		2015				
	COLETA (em unidades)		COLETA (em unidades)				
	SEPT.[a]	DEC.[a]	JAN.	FEB.	MARCH[b]	APRIL	MAY
Agricultural	–	–	–	–	–	–	–
Automobile	–	–	718	435	–	734	510
Cargo	–	–	40	26	–	80	40
Motorcycle	–	–	92	46	–	100	80
Bicycles	–	–	–	–	–	–	–
Weight/month	6410	8613	3860	2710	–	3630	3230
Cost/month	R$ 400.00	R$ 400.00	R$ 400.00	R$ 400.00	–	R$ 450.00	R$ 450.00
Total Weight	28.453 kg						
Total Cost	R$ 2.500,00						

[a] During these months, there was no control for tire types

[b] Unauthorized collection due to lack of space at collection points

Table 2 Results comparison between passive and active collection

Agent	Type of Collection	Total Collected	Months	Monthly Average (Tons)
City Hall[a]	Passive	109.71	53[b]	2.07
Research	Active	28.45	09	3.16

[a] Data provided by SEMMA

[b] From January, 2010 to May, 2014

Conducting the action research enabled knowledge generation which aided other cities to implement and improve their own RL processes for EOL tires. The mapping shown in Fig. 5 summarizes the knowledge constructed during the study.

Discussion

End-of-life RL operations require joint endeavors between city halls, manufacturers and other members of the supply chain. The fact that multiple entities needed to participate in the process generated some practical difficulties. This complexity is highlighted in studies which proposed improvements which can be obtained with alterations in the RL systems, but which are mostly based on simulation and forecasting techniques (Diabat et al., 2015; Suyabatmaz et al., 2014; Golebiewski et al., 2013; Lehr et al., 2013). This is a differential in the current study, which aside from proposing improvements, these are also placed in practice through the use of action research; for this reason, the action-research methodology stood out as a desirable method for dealing with the challenging situation in which analysis and process improvement involve

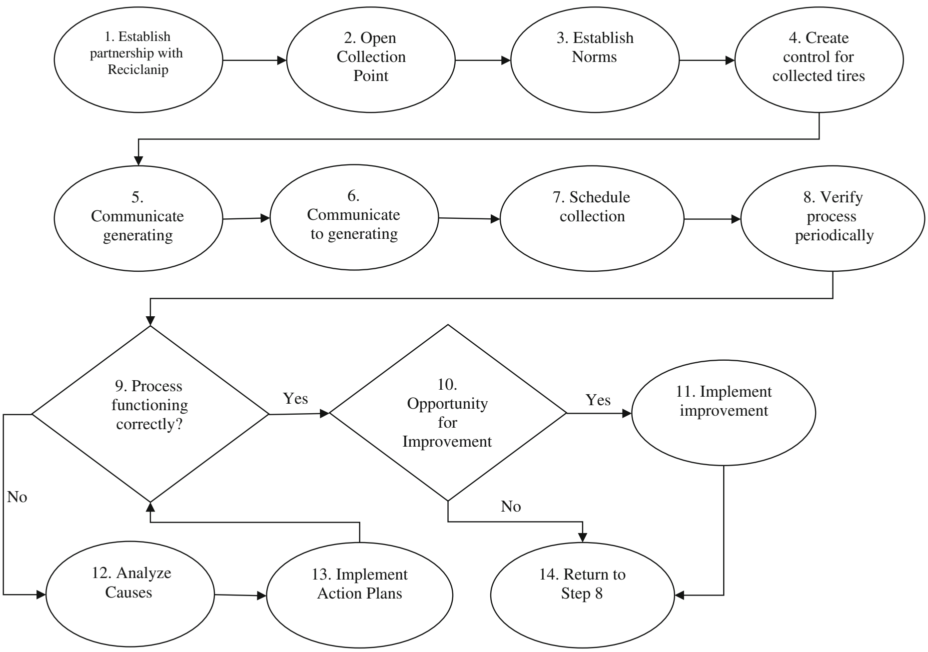


Fig. 5 Model for implementation or improvement in RL of EOL tires

different environments and each one has its own distinct characteristics. The success of the application of this method can be seen because it enables the creation of practical knowledge and also brought about positive changes in the situation under study, which according to Bhatnagar (2016), are the two main objectives for action research projects.

Throughout the development of the investigation, no serious hurdles were encountered which could have compromised the action research. However, simultaneous research with the public institution and private businesses demanded special attention. Holgersson and Melin (2015), García-Unanue et al. (2015) and Paes et al. (2016) mentioned that bureaucracy and in turn, lack of flexibility, make practical research in public organizations very difficult. This latter statement was confirmed in this study. The AR Team needed to finance the active collection with their own resources because waiting on local government approval for such resources would substantially extend research time. The investment was considered very low for the results obtained (approximately US$ 800.00).

Due to the large number of stakeholders and entities involved in this study, only one cycle of action-research was conducted. However, the study produced satisfactory actions and it was possible to evaluate the implemented actions in a way that future applications may apply the cycles to gain greater results in less time.

Conclusion

The use of action-research enabled improvements to be attained for the reverse logistics process for end-of-life tires, for both successful actions and knowledge generation. The changes implemented in this specific RL chain can be considered positive due to the significant increase in monthly collection. It should be mentioned that the measurements adopted to improve the process were defined while taking into consideration the negative points identified between the city government and the business which generate the tires. Practical knowledge was created and disseminated during the awareness campaign with each generating point and final consumer, in which releases reinforced RL importance and helped explain how the process works.

Due to the fact there is a clear need for improving end-of-life tire RL processes in small- and medium-sized cities in the material collection phase, this study could be replicated in succession in other municipalities, increasing efficiency and diminishing environmental liabilities.

Finally, it is worth highlighting that this action research was a valuable method for the present situation and it is recommended that action research be used again in reverse logistics for different types of items. The practical focus of this method carries with it benefits for society in leading with solid waste management. The unique characteristics or institution should not be limiting factors; as was seen in this study, for both public institutions and private businesses and even in projects between the two types of entities, it is possible to obtain satisfactory results.

The most important conclusion from this action-research study is that the success of any initiative to improve the RL process must go through a political analysis. If the process can generate real public support, the chances of success grow. Even though legislation does exist to promote reverse logistics, which is not sufficient guarantee that solid waste is correctly disposed of (many times the case in Brazil). Conditions must be created so that the process is not only good in theory, on paper, but also actually happens in practice, which was shown to have worked using action-research in this paper.

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