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INNOVATION IN THE REVERSE SUPPLY CHAIN OF ELECTRICAL AND ELECTRONIC WASTE: A STUDY ON INFORMATION SYSTEMS AND TRACKING TECHNOLOGIES

Inovação na cadeia reversa de resíduos eletroeletrônicos: Um estudo sobre os sistemasde informação e as tecnologias de rastreamento

Innovación en la cadena inversa de residuos electroelectrónicos: Un estudio sobre sistemas de información y tecnologías de seguimiento

ABSTRACT

In this study, the contribution of information systems and tracking technologies to the reverse logistics of electronic and electrical waste chains is analyzed. The research was based on a case study in the Brazilian context, incorporating the electronics supply chain. The results show that reverse logistics do not use the technologies and systems implemented in direct logistics. Although tracking technologies can make disassembly and recycling more efficient, the possibility of increased costs remains, and does not contribute to increased sales and profitability. Furthermore, resistance by representatives of the electronics sector to adhere to the sectoral agreement—established by the National Solid Waste Policy (NSWP) in 2010 but signed only at the end of 2019—contributed to companies postponing investments in information systems and technologies tracking in Brazil.

KEYWORDS | Environmental innovation, tracking technologies, supply chain, reverse logistics, waste electrical and electronic.

RESUMO

Esse trabalho tem como objetivo analisar a contribuição de sistemas de informação e as tecnologias de rastreamento para a logística reversa de cadeias de resíduos de eletroeletrônicos. A pesquisa foi realizada por meio de um estudo de caso incorporado em uma cadeia de eletroeletrônicos no contexto brasileiro. Os resultados da pesquisa mostraram que as tecnologias e sistemas implementados na logística direta não são utilizados na logística reversa. Mesmo reconhecendo as tecnologias de rastreamento como uma alternativa para tornar mais eficientes a desmontagem e a reciclagem, prevalece uma visão de aumento de custos, que não contribui para o aumento de vendas e a lucratividade. Infere-se que a resistência dos representantes do setor de eletroeletrônicos em aderir ao acordo setorial, assinado apenas no final de 2019 e estabelecido pela Política Nacional de Resíduos Sólidos (PNRS) em 2010, contribuiu para que empresas adiassem investimentos em sistemas de informação e tecnologias de rastreamento no Brasil.

PALAVRAS-CHAVE *| Inovação ambiental, tecnologias de rastreamento, cadeia de suprimentos, logística reversa, resíduos eletroeletrônicos.*

RESUMEN

El objetivo de este trabajo es analizar la contribución de los sistemas de información y las tecnologías de seguimiento a la logística inversa de las cadenas de desechos electrónicos. La investigación se realizó a través de un estudio de caso incorporado en una cadena de electrónica en el contexto brasileño. Los resultados de la investigación mostraron que las tecnologías y sistemas implementados en logística directa no se utilizan en logística inversa. Incluso reconociendo las tecnologías de seguimiento como una alternativa para hacer que el desensamble y el reciclaje sean más eficientes, prevalece una visión del aumento de los costos, que no contribuye a aumentar las ventas y la rentabilidad. Se infiere que la resistencia de los representantes del sector de electrónica a adherirse al acuerdo sectorial, firmado solo a fines de 2019 y establecido por la Política Nacional de Residuos Sólidos (PNRS) en 2010, contribuyó a que las empresas pospusieran inversiones en sistemas de información y tecnologías de seguimiento en Brasil.

PALABRAS CLAVE *| Innovación ambiental, Tecnologías de rastreo, Cadena de suministro, Logística inversa, Residuos eléctricos y electrónicos.*

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INTRODUCTION

Obsolescence processes have encouraged consumers to change electronic equipment such as smartphones, tablets, personal computers, and electronic games more frequently, contributing to the increased disposal of these products. These products contain substances with a high potential of causing health and environmental damage in case of improper disposal. Therefore, there are laws or guidelines that require manufacturers to seek efficient solutions in the development of reverse logistics (RL) programs (Demajorovic, Augusto, & Souza, 2016).

For the implementation of RL and green supply chain management (GSCM), the process improvement is related to investments in information systems (Ajamieh, Benitez, Braojos, Gelhard 2016), which manage and share environmental information in the chain (Olorunniwo & Li, 2010). Information technology (IT) has emerged as one of the best tools for technological innovation implemented in the supply chain, constituting an emerging research theme in chain management literature (Hazen & Byrd, 2012).

The main limitation is in the reverse flow, which is the exchange of information between manufacturers and disassembly sites. The use of tracking technology, such as radio frequency identification (RFID) (Kumar, 2014), barcode (Musa, Gunasekaran, & Yusuf, 2014) or integrated chips (Um, Stroud, & Suh, 2015), contributes to the sorting and classification of equipment for reuse, disassembly, remanufacturing or recycling (Nowakowski, 2018), improving process efficiency and reducing costs.

Despite the advantages of using IT in RL programs, there remains inadequate research on this topic in academic literature (Toyasaki, Wakolbinger, & Kettinger, 2013), and few companies have systems for this purpose (Hazen, Overstreet, Hall, Huscroft, Hanna, 2015).

In developing countries, the implementation of RL is faced with much significant challenges. The absence of economic incentives, legislation or low enforcement capacity by the public sector (Li, Jayaraman, Paulraj, Shang, 2016), reverse chain conflicts, and lack of awareness among the population (Demajorovic, Augusto, Souza, 2016; Zurbrügg, Caniato, & Vaccari, 2014) discourage business investment in these countries.

In Brazil, Law no.12.305/2010 instituted the National Solid Waste Policy (NSWP), which fosters RL and a set of actions and procedures for the collection and final disposal of waste, including electronics. Accordingly, it established regulations, sectoral agreements, and terms of commitment to achieve its goals (Ministry of the Environment, 2018). The resistance of the representatives in signing the sectoral agreement favored the low interest of the members of the electronics chain in investing and implementing large-scale programs of RL systems for electronic waste (Demajorovic, Augusto, Souza, 2016). Despite the low commitment and interest of the electronics sector in promoting RL, at the end of 2019, almost 10 years after the NSWP was promulgated, the sectoral agreement was signed.

During this process, the contribution of IT towards achieving the goals proposed in the sectoral agreement received little to no attention. Therefore, the aim of this study is to analyze the contribution of information systems and tracking technologies to the RL of electronic waste chains in the Brazilian scenario.

THEORETICAL FRAMEWORK

The importance of IT and tracking technologies in the implementation of RL programs is discussed in this section. The theoretical framework presents the development of an analysis model, data collection instruments, and the analysis and discussion of the results.

Information systems and tracking technologies in the supply chain

Green Supply Chain Management (GSCM) includes product design (Gmelin & Seuring, 2014), life cycle analysis, green operations that encompass RL, and solid waste management. The products are designed taking into account the conservation of resources, use of residues in remanufacturing, reuse and recycling (Liu, Zhu, & Seuring, 2017).

Three aspects are considered limitations to the implementation of the GSCM: high costs, coordination and complexity efforts, and insufficiency or failure of communication in the supply chain (Seuring & Müller, 2008). Green information systems provide the necessary information for decisions on eco-design, in terms of material and energy consumption, reuse, recycling and post-consumption destination (Li et al., 2016). These systems provide the interface to support sustainable management in a shared environment (Yang, Sun, Zhang, Wang, 2018).

To involve various departments of the organization, the flows of goods and information in the GSCM must be interconnected and coordinated. In addition, suppliers and customers should be interconnected and coordinated to improve the performance of the entire chain (Morgan, Richey, & Autry, 2016). Currently, information flows in the GSCM are expanding, and the combination of RL and IT skills is enhancing

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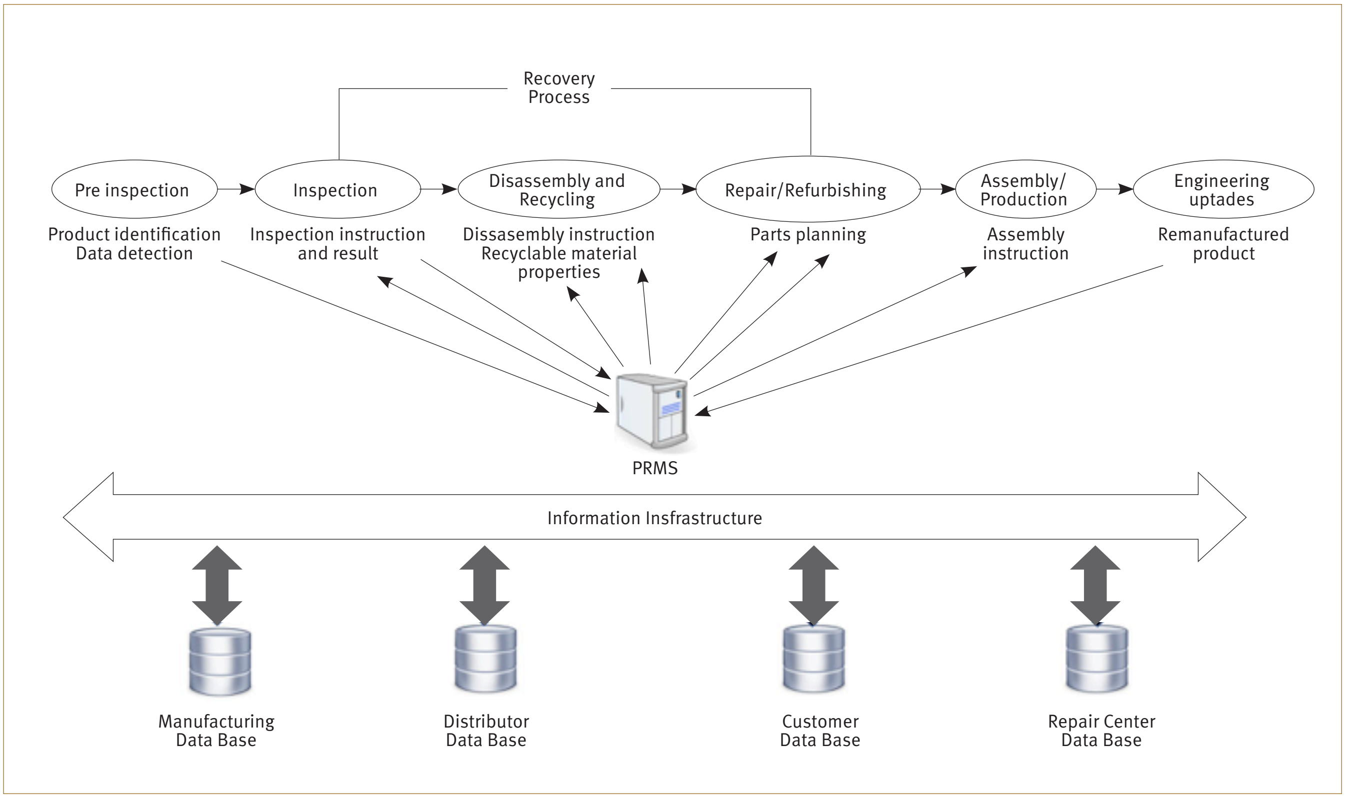
the performance of the reverse product flow (Morgan et al., 2016). Recycling processes have become more efficient and waste is being disposed of properly (Prajogo, Olhager, 2012; Morgan, Richey, Tokman, Deffe, 2018).

RL includes several activities, beginning with the return of the used product, which can be directed to resellers or manufacturers through return programs or public/private collection points. After collection, inspection is done for classification in various categories: repair, reuse, remanufacture or recycle (Agrawal, Singh, & Murtaza, 2015; Dhanda & Hill, 2005). In this area, there are several studies on the use of IT to improve efficiency in waste management (Król, Nowakowski, & Mrówczyńska, 2016). Managers can improve partner communication, integrate information about company activities and improve responsiveness (Daugherty, Richey, Genchev, Chen, 2005).

Studies show that loss of information is one of the main obstacles to recovering the value of returned products (Madaan, Kumar, & Chan, 2012). To return products at the right time and locations, IT provides accurate information on the status, location and condition of products in motion in the supply chain (Jayaraman, Ross, & Agarwal, 2008). Therefore, compatible systems that facilitate the exchange of information between organizations or units should be employed (Huscroft, Hazen, Hall, Hanna, 2013a).

In the product recovery management system (PRMS) (Toyasaki et al., 2013), there may be information-intensive product recovery systems (IPRS), which provide product information to enable recovery, automate manual processes, and reduce sorting time and costs. These systems require highly accurate information on the product identification, use and condition to enable a more efficient RL process (Toyasaki et al., 2013). Figure 1 shows the function of the PRMS in establishing the integration between databases and all activities in the RL chain.

Figure 1. **Product recovery management system**



Source: Um et al. (2008, p. 1182).

PRMS needs to be further developed to give access to databases by all stakeholders, enabling integration of systems through standardized information, and use of tracking technologies such as RFID, barcodes, or integrated chips. In disassembly, the PRMS can provide information on the materials that make up the product. Remanufacturing information must have repair and reassembly instructions

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(Um et al., 2008), and generate decision making reports that are effective in improving the chain's environmental performance as well as meeting targets (Green, Zelbst, Meacham, Bhadauria, 2012a).

These technologies, which have always been used in the automation processes of direct logistics, can now provide reverse flow information and reduce product classification time (Toyasaki et al., 2013). One of the advantages of RFID is the remote simultaneous identification of several items, without the need to target each item (Kumar, 2014; Parlikad & Mcfarlane, 2007). Although RFID tags have a higher cost, their use in assembly lines and distribution centers has increased (Um et al., 2015). The barcode is an optical technology for reading data only, which means that data cannot be changed once printed, and the barcode reader needs to be close and directed to the product or packaging. It is a technology widely used in low cost direct logistics, and is universal (Musa et al., 2014). Integrated chips are the most advanced and one of the most expensive technologies, and are present in several electronic products. The captured information can be used in research and development areas to provide more eco-efficient products (Um et al., 2015).

The most accurate decision for the repair, reuse, refurbishing, or recycling of a product depends on several parameters, including product quality, date of manufacture and sale, and the conditions the product has been subjected to throughout its life cycle. These conditions include ambient temperature, humidity, utilization rate, and maintenance (Parlikad & Mcfarlane, 2007). In the monitoring process, RFID technology begins by defining the life cycle stage of the product, that is, the beginning of life (BOL), middle of life (MOL), or end of life (EOL). Defining the stage of the product's life cycle makes it possible to select its destination among the alternatives of reuse, remanufacturing or recycling. If a product is in the BOL, it can probably be selected for reuse if repaired. If it is in the MOL, the likely destination is remanufacturing, and in EOL it would be selected for recycling (Um, Stroud, Suh, 2015).

Information sharing strategies via RFID allow for more accurate stock and inventory control, with real-time monitoring (Shin, Suh, Stroud, Yoon, 2017), which helps coordinate inventory policies between recycled material suppliers and manufacturers in the supply chain, reducing environmental and economic costs and adapting quickly to changes in the system (Green, Zelbst, Sower, Reyes, 2012b; Nativi & Lee, 2012).

Analysis model

This study assumes that the recovery systems for information-intensive products can collaborate with RL, to increase efficiency and decrease costs (Daugherty et al., 2005; Jayaraman et al., 2008; Olorunniwo & Li, 2010; Toyasaki et al., 2013). The PRMS starts by integrating the systems and databases of all those involved in the GSCM, as manufacturers, distributors, resellers, technical assistance and collection and recycling centers, and uses sensors such as RFID, or barcode, and integrated chips to identify and obtain product information. Figure 2 shows the direct and reverse flow of products, using tracking and information collection technologies, with information captured in all the main areas (Nativi & Lee, 2012; Nowakowski, 2018). The purpose of this analysis model is to present a synthesis of the application of tracking technologies and information systems in the reverse flow, as discussed in the theoretical framework.

In direct logistics, the sensors are used in the manufacturing process with the introduction of tracking technologies in products (Nowakowski, 2018; Um et al., 2015). Products are tracked and systems updated with information about deliveries in the distribution process. For the resellers, the information collected provides the systems with sale levels, which provide feedback on the stocks of distributors and manufacturers that can plan production (Um et al., 2015).

Information systems with product information collectors also contribute to the development and planning of the RL network (Green et al., 2012a; Liu et al., 2017; Müller & Seuring, 2007). In the collection, inspection and disposal centers, information systems can identify hazardous materials and the quantity and weight of various components, and provide instructions for disassembly or proper disposal (Nowakowski, 2018). These systems can also benefit from poorly automated manual processes (Nativi & Lee, 2012; Parlikad & Mcfarlane, 2007; Toyasaki et al., 2013). The information captured in the collection centers updates the databases and provides data for the development of reverse flow goals (Li et al., 2016; Olorunniwo & Li, 2010). The use of IT for tracking and capturing information, such as RFID (Nativi & Lee, 2012; Nowakowski, 2018), makes it possible to evaluate the most suitable destination according to the product's characteristics and its lifetime. It can be directed to the factory, in the case of remanufacturing, to technical assistance for repair, or to a distributor or reseller for reuse (Nativi & Lee, 2012; Nowakowski, 2018; Srivastava, 2008; Um et al., 2015).

The collected data can also be fed back to the research and development database of new products, providing important information for improving products, packaging, and eco-design (Agrawal et al., 2015; Gmelin & Seuring, 2014; Green et al., 2012a; Li et al., 2016). For this purpose, the bases shared between the main participants in the chain for decision making, and the creation of management reports must be integrated and accessible (Green et al., 2012a; Um et al., 2015).

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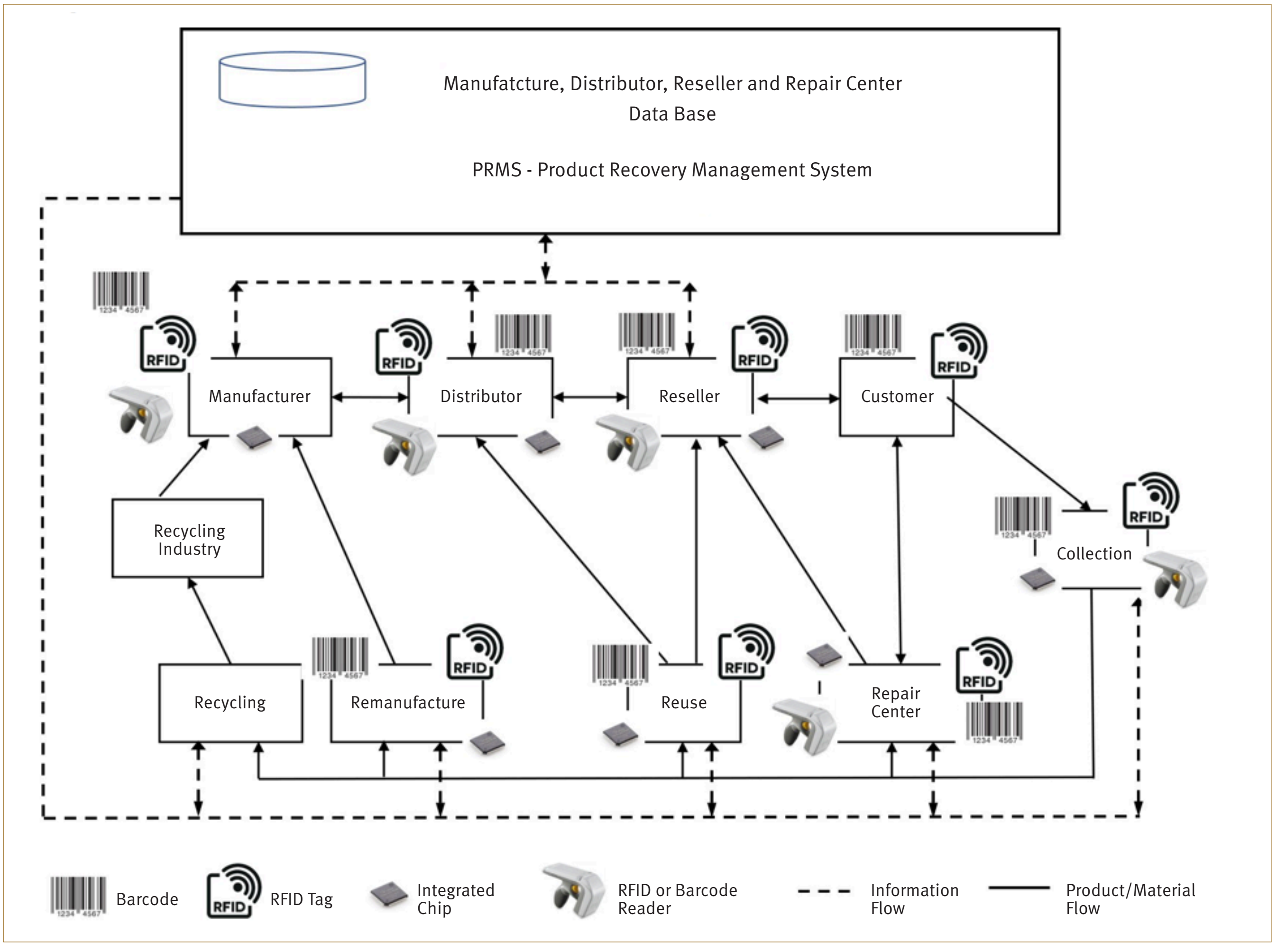
Figure 2. **Conceptual analysis model**



RESEARCH METHOD

Case studies can be used for different types of research, such as exploration, theory building, theory and extension testing, and theory refinement (Voss, Tsikriktsis, & Frohlich, 2002). In this study, the methodological approach involved a single case study integrated with several incorporated analysis units (Yin, 2017). The theoretical sample was composed of analysis units on which the study data was collected (Yin, 2017). The validity of the study requires the selection of at least four cases that should be chosen based on determined standards (Eisenhardt, 1989), with the aim of predicting similar or contrasting results (Yin, 2017). The researched organizations were chosen to represent the main participants in the reverse waste electrical and electronic equipment chain (WEEE) in the Brazilian scenario in the segments of personal computers, notebooks, tablets, and printers. Thus, the analysis units involved two manufacturers, a distributor, a retailer, an RL management company, an RL innovation center, technical assistance, a recycling company, and a cooperative. The characteristics of the companies and respondents are shown in Exhibit 1.

For all the analyzed units, the research focused on the technologies involved in capturing and tracking products for reverse flow, and the existing information systems for processing this information. Manufacturer A is present only in the corporate market, whereas Manufacturer B operates in the corporate and domestic markets. The evidence sources used for data collection were documents, semi-structured interviews and direct observation. The use of multiple evidence sources guaranteed the validity of the research construct and the different sources of information, when converging, thus contributing to the reliability of the data (Yin, 2017).

For case studies, documents are important as they corroborate and increase evidence from other sources (Yin, 2017).

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The documents used in this case study were sustainability reports, company websites, and documents provided by the interviewees. Moreover, direct observation is often useful to provide additional information on the study topic and is applied during field research (Yin, 2017). Direct observation was carried out at the cooperative, recycler, retailer, and innovation and recycling center. The semi-structured interview questions were based on the theoretical categories presented in the literature review. These include the flow of products in direct and reverse logistics; RL network; processing, storage and capture of product information; system integration between departments and members of the supply chain; use of capture technology for product information, such as RFID, barcode or integrated chips, as shown in Exhibit 2.

Exhibit 1. **Characteristics of the researched companies**

Researched Company	Characteristics
Manufacturer A	US-based company with approximately 9,000 employees worldwide. In Brazil, it has approximately 300 employees based in São Paulo and operates in the corporate market throughout the national territory. It has several distributors and resellers.
Manufacturer B	US-based company with approximately 55,000 employees worldwide. In Brazil, it has approximately 500 employees based in São Paulo and operates in the corporate and domestic market throughout the national territory. It has several distributors and resellers.
Reverse Logistics Manager	Brazilian company based in São Paulo with approximately 30 employees and national coverage. Serves major WEEE manufacturers.
Innovation and Recycling Center	Brazilian company, with the participation of multinationals in the technology area, headquartered in São Paulo, with approximately 90 employees and national coverage. Serves major WEEE manufacturers.
Distributor	Technology distributor of products based in the USA and controlled by a Chinese group, with 33,000 employees worldwide. In Brazil, it is headquartered in São Paulo with approximately 600 employees and national operations. Its customers are manufacturers in the areas of technology and electronics.
Retailer	Brazilian retailer with approximately 5,000 employees and operating throughout the national territory, it is multi-branded.
Technical assistance	Technical assistance for computer equipment based in São Paulo and operating in the greater São Paulo with approximately 60 employees, it is multi-branded.
Cooperative	Electronics recycling cooperative, with operations in Greater São Paulo, with 30 employees, and is multi-branded.
Recycler	Electronics and metals recycler with operations in greater São Paulo, and with 60 employees. Serves the cooperative market and major WEEE manufacturers.

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Exhibit 2. **Interview questions related to theoretical research categories**

Category	Questionnaire
Manufacturing	Does the production system use any tracking technology such as RFID, barcode or integrated chip?
	Which products or product lines use this tracking technology for production control?
	Is any type of recycled material used in manufacturing? If so, in which products? Are these materials from the company's recycled products or from the recycled market?
	Do the systems allow product tracking to the final customer?
	What information fed by the factory into the system can be viewed along the chain (distributor, retail, technical assistance, cooperatives, recyclers, etc.)?
	Are products with malfunctions returned to the factory by the distributor, retailer or technical assistance?
	Are damaged products recovered or discarded?
	Are there policies and processes for remanufacturing or refurbishing products?
	Are the production, and research and development control systems fed back with information on returned products or technical assistance? If so, what kind of information?
	Is the information useful for product recovery?
	Is there currently the generation of reports that enable management monitoring, decision making and goal control?
Distribution	Are systems and databases updated with manufacturer's product information?
	Are products returned from retail, technical assistance or consumers forwarded to the distribution center?
	Are they integrated with the manufacturer and supplied with distribution information?
	Is there a policy for returning products returned because of customer dissatisfaction not related to any defect or obsolescence? If that is the case, at which point in the supply chain is the responsibility for collecting these products? Is there access to product information returned by the retailer or resellers in the system?
Resellers/ Retailers	Are systems and databases updated with product information from the manufacturer or distributor?
	Are products returned from customers or technical assistance routed to resellers or retailers?
	Are they integrated with the manufacturer and supplied with distribution information?
	Is there a policy for returning products returned because of customer dissatisfaction not related to any defect or obsolescence? If yes, at which point in the supply chain is the responsibility for collecting these products? Is the product information returned by customers fed into the system?
Repair Center – Technical assistance	Is there a process for capturing product information, such as RFID readers, bar codes or integrated chips that support technical assistance?
	Is there access to systems and databases with information about the manufacturer's products that facilitate the repair process or correct destination? Are the systems integrated with the manufacturer or can they be supplied with information from the repair center?
Reverse-Collection Logistics Network – Cooperative	Are there cooperatives where customers can return obsolete/damaged products?
	Is there a process for capturing product information, such as RFID readers, bar codes or integrated chips?
	Is there access to the systems and databases with the manufacturer's product information to facilitate collection, identify product components and disassembly? Are the systems integrated with the manufacturer or can they be fed with information from the cooperative?
	Can cooperatives identify products with any of the tracking technologies, such as RFID, barcode or integrated chip?
	Can cooperatives access the systems and obtain information for disassembly and proper disposal of components and materials?
Reverse-Collection Logistics Network – Recycler	Are there recyclers where customers can return obsolete/damaged products?
	Is there a process for capturing product information, such as RFID readers, bar codes or integrated chips?
	Is there access to the systems and databases with manufacturer's product information to facilitate collection, identify product components and disassembly? Are the systems integrated with the manufacturer or can they be fed with information from the recycler?
	Can recyclers identify products with any of the tracking technologies, such as RFID, barcode or integrated chip?
	Can recyclers access systems and obtain information for disassembly and proper disposal of components and materials?

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The managers responsible for the companies' sustainability area, RL and operations were the targets for the interviews and questionnaires. The interviews were recorded and transcribed. The documents used in this case study were sustainability reports and company websites. Additionally, during the interviews, some managers completed the verbal information with records in the files of the researched company. Direct observation was carried out at the cooperative, recycler, retailer, and innovation and recycling center, applying an observation protocol developed specially for this study. The codification of the interviews, documentary analysis and direct observation (interviews, document analysis and observation) presented in Exhibit 3, allowed the chaining of evidence and contributed to the validity of the construct (Yin, 2017).

Exhibit 3. **Coding of interviews, documents and observation**

Researched Company	Interviewee	Time in the function	Interview Time	Interview Code	Document Code	Observation Code
Manufacturer A	Reverse Logistics Manager	4 years	40 min	FAB-A-ENT	FAB-A-DOC	
Manufacturer B	Operation Manager	6 years	43 min	FAB-B-ENT	FAB-B-DOC	
Reverse Logistics Manager	Sustainability Manager	5 years	49 min	GEST-ENT	GEST-DOC	
Innovation and Recycling Center	Operation Manager	6 years	42 min	INOV-ENT	INOV-DOC	INOV-OBS
Distributor	Operation Manager	5 years	35 min	DIST-ENT	DIST-DOC	
Retailer	Operations supervisor	3 years	37 min	VAR-ENT	VAR-DOC	VAR-OBS
Technical assistance	Technical Assistance Manager	20 years	29 min	ASSISTEC-ENT	ASSISTEC-DOC	
Cooperative	CEO	2 years	45 min	COOP-ENT	COOP-DOC	COOP-OBS
Recycler	Operations manager	2 years	33 min	RECI-ENT	RECI-DOC	RECI-OBS

Because the data obtaining process generates a large amount of information, the analysis allows researchers to deal with this volume of information (Eisenhardt, 1989). For this study, we used the strategy of following the theoretical categories established in the case study research.

ANALYSIS AND DISCUSSION OF RESULTS

The research indicated a gap between the analysis model that synthesized information on information systems and tracking technologies obtained in the literature review, and the empirical data. The main results of the interviews, document analysis, and direct observation are coded and presented in Exhibit 4.

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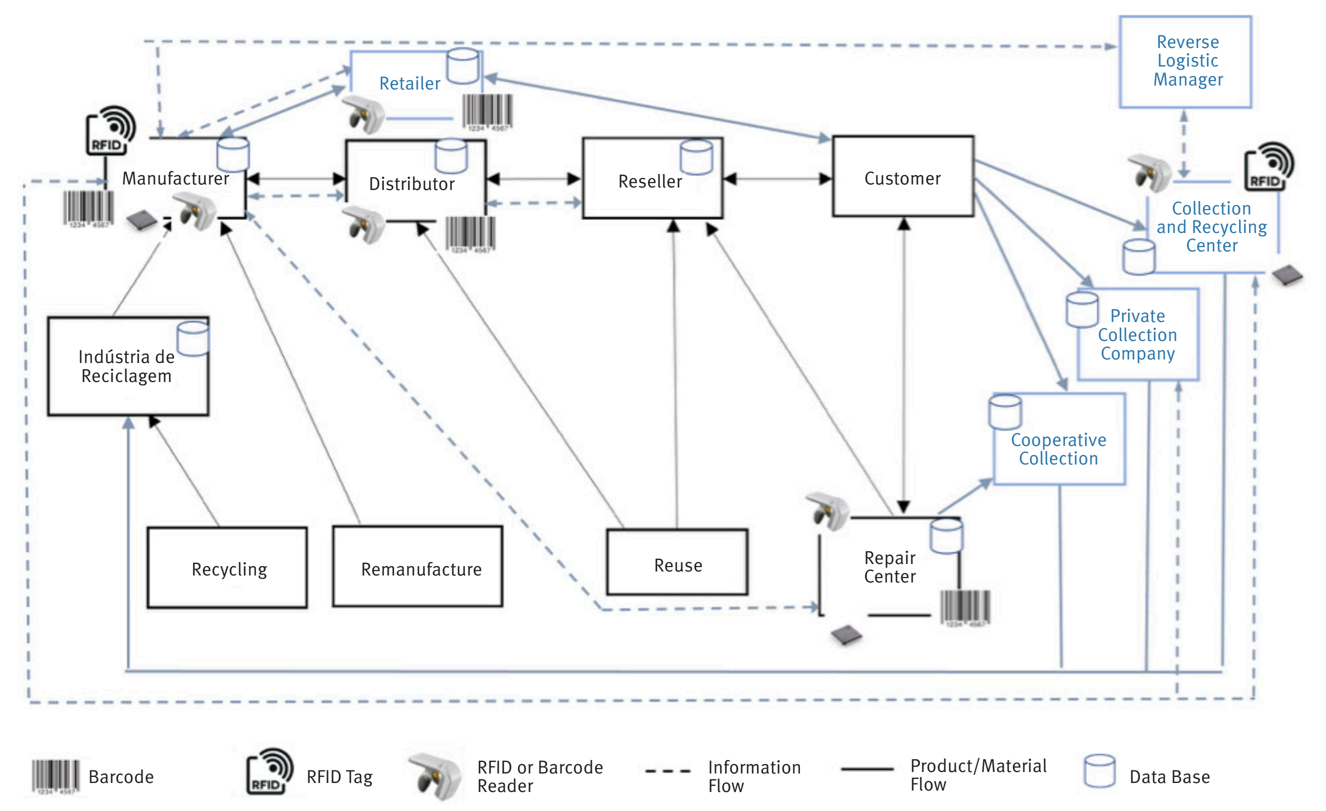
Exhibit 4. **Summary of research results in analysis units**

Category	Analysis Units and Data Collection Instruments	Summary of Research Results
Direct Logistics	**Manufacturers** FAB-A-ENT/FAB-B-ENT/FAB-A-DOC/FAB-B-DOC	It uses RFID for manufacturing process control.
		Maintains product information system but does not share information with other members of the supply chain.
	Distribution DIST-ENT/DIST-DOC	It does not use RFID but uses bar codes in packaging for inventory control. It uses product barcode when the product is after-sale or post-consumer. There is no interconnection of systems; information is shared through forms.
		It uses products returned in trade-in negotiations that are in useable conditions. It does not recondition.
	Retail VAR-ENT/VAR-OBS/VAR-DOC	It does not use RFID but uses packaging barcodes for inventory control. It uses product barcodes when the product is after-sale or post-consumer. It has a B2B system for manufacturers' access.
		It resells after-sale products in case of an incorrect sale. It does not perform post-consumer reconditioning.
Reverse Logistic	**Reverse Logistics Manager** GEST-ENT/GEST-DOC/INOV-ENT INOV-OBS/INOV-DOC	The innovation and recycling center uses the RFID and integrated chip, but does not use barcodes. It obtains information from the chips integrated in the toner and ink cartridges.
		The innovation and recycling center provides access to systems for opening collection requests and providing recycling production reports. The reverse logistics manager provides information by forms and does not have access to manufacturers' systems.
	Cooperative and Recycler COOP-ENT/COOP-OBS/RECI-OBS COOP-DOC/RECI-ENT/RECI-DOC	The cooperative and recycler do not use any tracking technology. RFID is not present in most products, and bar codes are damaged with the use of equipment.
		They do not integrate with any manufacturer's systems and have adapted market systems for use in their operations.
	Technical Assistance ASSISTEC-ENT/ASSISTEC-DOC	They do not use RFID. They use barcodes on both the packaging and product.
		Access manufacturers' systems for training, warranty calls and support. Defect information feeds the manufacturers' R&D bases.
		Reuse for rental and service contracts, without the manufacturer's participation.
		Remanufacturing or reconditioning for rental and service contracts, without the participation of the manufacturer.

Research has shown that information systems are present in all areas of the direct and reverse supply chain. However, they are still far from interconnected solutions that could allow efficient information sharing. The flow of information should provide the necessary details to make recycling processes more efficient and enable the proper disposal of waste, as indicated in existing literature (Morgan et al., 2018; Olorunniwo & Li, 2010). Figure 3 illustrates the synthesis of the results obtained in the field research.

Figure 3. **Synthesis of the results obtained in the field research**



Note: retailers buy directly from manufacturers and sell to consumers. Resellers buy from distributors and sell in all markets

In direct logistics, the distributor and manufacturers use controls, which are reports developed by the distributors. The sensors are used in the manufacturing process with the introduction of tracking technologies, such as RFID, bar codes or embedded chips, corroborating several aspects raised in the literature review (Nowakowski, 2018; Um et al., 2015). Manufacturers have developed a system for accessing technical assistance to expedite the repair of equipment under warranty. Technical assistance accesses the manufacturers' system when there is a need to purchase parts or provide support for products under warranty. These integrated systems can improve the responsiveness of partners, as mentioned in other studies (Daugherty et al., 2005).

The retailer's need to keep their inventories stocked and in the right quantity. To avoid increasing storage costs, a business-to-business (B2B) system was created for online and real-time access by manufacturers. This quickened the movement of inventory and supply of products. However, the system is still considered inefficient by users, considering the speed of current commercial transactions. Studies show that systems with information collected through tracking technologies contribute more effectively to location, delivery, and sales (Nativi & Lee, 2012; Shin et al., 2017), providing up-to-date information for enhanced inventory control (Green et al., 2012b) and production planning (Um et al., 2015).

This study demonstrated that the development of systems and their interconnection occur when there is an impact on sales. Each participant develops its own structure interconnected with other links in the chain to serve specific purposes. The databases are not yet interconnected, meaning they lose significant information to recover value as presented in existing literature (Madaan et al., 2012). Previous research shows that technological development is necessary (Ajamieh et al., 2016; Huscroft, Hazen, Hall, Skipper, Hanna, 2013b) for companies to develop skills related to the integration and dissemination of information (Huscroft et al., 2013a; Toyasaki et al., 2013), and support environmental management (Yang et al., 2018).

With regard to RL, there are no ready systems on the market, meaning every company has to adapt or create their own system. The study revealed a very early stage of adoption of these technologies in the national market. The process of controlling parts and components is not covered by the available logistics

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software solutions, hindering reverse flow and remanufacturing, which corroborates previous studies (Morgan et al., 2016). Even in these conditions, the innovation and recycling center offers online access for customers, who can request collections and have access to the weighted quantity of processed products. Additionally, the RL manager passes production information to customers in the form of reports; however, a system that allows online and real-time access is still being developed. The cooperative and recycler also adapted their systems to improve decision-making related to the reverse flow of products, as suggested in existing literature (Green et al., 2012a; Liu et al., 2017), without interconnection with the chain, which does not contribute to the efficiency of the process as a whole.

In Brazil, systems that provide information for identification and lifetime, such as PRM and IPRS discussed in the theoretical framework (Toyasaki et al., 2013), are still far from being used. According to some authors, these systems would make reusing, reconditioning, and remanufacturing programs more efficient (Agrawal et al., 2015; Dhanda & Hill, 2005). In technical assistance, repair or reconditioning is defined by the availability and cost of parts. The distributor buys and refurbishes products from corporate customers, without the participation of manufacturers. As pointed out in previous work, IT is a major obstacle for companies, owing to the lack of resources and adequate knowledge in the area (Bouzon, Miguel, & Rodriguez, 2014), which causes communication failure in the chain and inefficient processes (Seuring & Müller, 2008).

The cooperative reconditions some products in small volumes for resale or own use. Repair information that can assist in product development is provided by technical assistance. According to the Brazilian Consumer Protection Code, distributors and retailers only communicate on defect information when the product is returned within seven days. The recyclers do not provide feedback for the development of eco-design products, which facilitate disassembly and non-use of materials that contaminate others. This information feedback, unlike (Gmelin & Seuring, 2014; Li et al., 2016), does not happen between electronics manufacturers and recyclers, which increases the costs of remanufacturing and recycling. Product components that use welding or screws, for example, increase the disassembly time and, consequently, the labor employed in the process.

The study showed that the use of tracking technology like RFID for RL, presented in studies on the topic (Um & Suh, 2015), exists in only one product line from Manufacturer B, and the innovation and recycling center reads it when the product arrives at the recycling center. Manufacturers A and B use it in production; however, no other supply chain participant uses this technology for inventory control. The cost issue is still highlighted as the main limitation, and companies do not implement information systems for this purpose and do not prioritize this technology for supply chain activities (Hazen, Overstreet, Hall, Huscroft, Hanna, 2015). Other participants in the chain infer that, in the future, this technology may be used for products with greater added value, mainly because it facilitates distance reading (Kumar, 2014). Studies show that the use of RFID technology allows better control of inventories with real-time monitoring and information sharing (Green, Zelbst, Sower, Bellah, 2016; Nativi & Lee, 2012) for greater environmental and economic benefits (Jayaraman et al., 2008).

The barcode is widely used in direct logistics, mainly in packaging. The product barcode is widely used in technical assistance, and post-sale or post-consumer situations for retailers and distributors. The barcode is not used in RL. Because there is no interconnection with manufacturers' systems, the barcode does not identify the product, and consequently, there is no information, such as the model, manufacturer, weight, types of materials and disassembly information, which could be useful information for recycling, as suggested by Musa et al. (2014). Additionally, the product barcode is often damaged.

For the cooperative manager, the use of a universal barcode or RFID by manufacturers would facilitate the identification of products for recycling and help in the operation, which would increase productivity with scale gain. With quick identification, the company could obtain information on disassembly, identification of hazardous materials and components, thus reducing costs and simplifying the process, as suggested by some studies (Nativi & Lee, 2012; Nowakowski, 2018; Parlikad & Mcfarlane, 2007).

The manager of the innovation and recycling center pointed out that RFID could be used for planning the supply of recycled materials and better stock control. The manufacturer, having prior knowledge of the amount of recycled material available, adjusts the stock with the input supplier and, consequently, decreases the consumption of virgin raw material, as concluded in a previous study (Nativi & Lee, 2012).

The use of the integrated chip was observed in toner cartridges and inks. The technical assistance that provides this products to customers with a service contract or the innovation and recycling center that has a contract with Manufacturers A and B controls and audits the supplies by reading the information on the chip to pass on to manufacturers. Manufacturers have a special interest in recycling these supplies to prevent reconditioning and returning to the black market. The study did not identify the use of integrated chips in any other electronics, at least with the intention of traceability aimed at the RL, as pointed out in previous literature (Um et al., 2008).

For some participants in the chain, signing the sectoral agreement will be a catalyst for the significant expansion of investments in the structure of tracking systems and technologies implemented to meet targets, which corroborates studies on the topic (Dou, Zhu, & Sarkis, 2014; Green et al., 2012a).

CONCLUSIONS

The objective of this study was to analyze the contribution of information systems and tracking technologies to the RL of electronic waste chains in the Brazilian context. The results from the study showed that information systems are present at all points in the direct and reverse supply chain. However, the interconnection of systems is not effective in the chain, and the implementation of these technologies is still incipient in the Brazilian market. Some participants in the chain acknowledged the potential of tracking technologies with universal coding for product identification, and access to systems that give information on the model, the estimated useful life, characteristics such as weight, types of materials and hazardous components. These technologies are also regarded as alternatives for reducing costs in the process, making disassembly and recycling more efficient, as well as providing an opportunity for use in production planning and inventory control of recycled materials.

On the other hand, the main limitation identified in the study is that tracking technologies used in reverse flow are perceived quite differently from their use in direct logistics. From the case study, it is inferred that the use of such technologies in the reverse flow does not contribute to increased sales and profitability for all companies in the chain, but raises operation costs and causes a shortage of resources for investment. Additionally, because there is no system in the market that integrates the entire chain, many companies had to develop their own system. Finally, at some points of the chain, it was observed that the managers lacked knowledge regarding these reverse flow tracking technologies. These limitations hinder the flow of information and render processes inefficient, slowing the investments and strategic partnerships of companies in developing countries like Brazil.

In this regard, the identification of the main limitations of using tracking technologies in reverse flow is a significant managerial contribution of this research. The recent signing of the electrical and electronics sector agreement in October 2019 may have been an important element to enhance the benefits of tracking technologies and overcome the limitations identified in this study for the large-scale implementation of WEEE RL in the Brazilian scenario.

The theoretical contribution of this study is the analytical model, which summarizes the main elements that constitute the advantages of using these technologies and systems. The literature review showed the contribution of information systems and tracking technologies in several aspects, for the implementation of RL programs, which are already used in some countries, with the potential to increase efficiency and overcome limitations in developing countries.

Thus, for future work, the development of new research on investment and cost evaluation of information systems and tracking technologies in RL programs as an emerging and important theme is recommended.

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AUTHORS' CONTRIBUTION

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