

## THE CHALLENGE OF REVERSE LOGISTICS FOR E-WASTE IN BRAZIL – A CASE STUDY IN ELECTRONIC COMPONENTS INDUSTRY

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### Resumo

Resíduos eletrônicos (E-waste) ou equipamentos eletro-eletrônicos (REEE) é uma importante questão estratégica devido ao seu impacto no meio-ambiente. O descarte se torna mais importante quando o governo cria leis para forçar a logística reversa dos produtos para que seja descartado de maneira apropriada para encorajar o retorno destes na cadeira reversa e, então, movitando o crescimento do campo de pesquisa em logística reversa. Além disso, o crescimento mundial no consume destes produtos causa o surgimento de um paradigma relacionado ao fim da vida útil ou o fim do consume destes produtos. Como aplicação, o estudo da logística reversa do E-waste e REEE foi realizado.

Neste contexto, este trabalho utiliza a modelagem matemática e o método do centro de gravidade para projetar a cadeia logística reversa. O modelo foi aplicado no estudo de caso e resolvido de maneira ótima pelo solver comercial CPLEX. Os modelos foram resolvidos por um solucionador comercial e seu desempenho foi avaliado. O modelo apresenta viabilidade com tempo de computação suficiente para auxiliar na tomada de decisão gerencial.

**Palavras-chave:** REEE; E-Waste; Modelo Matemático.

### **Abstract**

Waste of Electronics (E-waste) or electrical and electronic equipments (WEEE) is an important strategic issue due to its impact on environment. The disposal became more important when the government creates law to force the logistic reverser of their goods to an appropriate disposal with the objective of encouraging the return in the reverse chain and, thus, motivated the growth of the research field of reverse logistics for environmental issues. Furthermore, the world growth of the consumption of these goods causes the emergence of a paradigm related to the end of the useful life or the end of the consumption of these products. As an application, the study of reverse logistics of E-waste and WEEE was carried out. In this context, this work uses a mathematical modeling and an geographic method to design of the reverse supply chain. The model was applied to the case study area and then solved with the implementation in CPLEX that was able to solve all these scenarios to the optimality. The model was solved by a commercial solver and its performance was assessed. The model presents feasibility with enough computing time to aid in management decision making.

**Keywords:** WEEE; E-Waste; Mathematical Model.

## **1. Introduction**

Electronic waste (E-waste) or waste electrical and electronic equipments (WEEE) is a major pollution concern in the contemporary global environment (BORTHAKUR, 2020).

According to the estimates by the United Nations University, 44.7 million tonnes of E-waste was generated in the year 2016 alone with a potential for further 17% growth to 52.2 million tonnes by the year 2021 (BALDÉ et al., 2017).

Electronic waste (or e-waste) are various forms of electric and electronic equipment that have ceased to be of value to their users or no longer satisfy their original purpose. Therefore, using modern tools and technologies help the supply chain in this issue (SERVARE JUNIOR et al., 2018).

There are nearly 900 different types of EEE items available in the market including information and communication technology (ICT) products (ISLAM and HUDA, 2020). Mobile phones, tablets, laptops: the proliferation of digital devices is becoming a problem for the planet because once they come to the end of their useful lives — every year almost 50 million tonnes of technological scrap is generated — their recycle rate is poor. Improving it is vital to slowing climate change and avoiding harm to the environment (IBERDROLA, 2019).

Rapid technological developments, urbanization and increased purchasing power among consumers fueled the consumption trends of various electrical and electronic equipment (EEE) all over the world (ISLAM et al., 2016; LI et al., 2019).

Managing e-waste is significantly challenging as it contains diverse range of base metals (e.g. Fe, Al, Cu), precious metals (e.g. Au, Ag, Pd), and critical and rare-earth elements (e.g. Nd, Ta, Dy etc) as well as toxic elements (e.g. Pb, Cr, As) which are detrimental for human health and environment (CUCCHIELLA et al., 2015).

Considering the common ways of e-waste disposal worldwide, it is highly likely this remaining undocumented e-waste ends up as landfill in municipal waste or is exported to developing countries, where it is stockpiled and recycled, mostly using improper and hazardous methods (BAKHIYI et al., 2018; ONGONDO et al., 2011).

The volume and the lack of accountability of large volumes of e-waste make e-waste management a global challenge of increasing significance. The issue is not just the volume of e-waste being generated upstream (SHAIKH et al., 2020). With the reduction of investments in facilities nowadays, the efficient use of the available structure or the structure to be designed is an essential factor for the competitiveness of companies (SERVARE JUNIOR et al., 2020).

In the face of challenges, the framework of the study is based on three Brazilian perspectives: analyze the drivers of Reverse Logistics (RL) regarding electronic waste, identify the dimensions of Reverse Logistics for electronic waste and evaluate the performance indicators of transport and location of e-waste using a case.

Another important part of this paper is characterized as a quantitative approach, after collecting data from a large technology company, considering the variables necessary to develop the best electronic waste collection strategy for the collection site, a study will be carried out aiming survey the difficulties and gains found in the company's reverse logistics process, through the mathematical modeling of Transport Problems with Linear Programming and the mathematical calculations performed in the IBM ILOG CPLEX® Optimization Studio 12.7.1 software and through the Center of Gravity Method and identification of the strategic point for receiving the equipment.

Is important study this problem due the complex composition and improper handling of e-waste adversely affect human health. In terms of health hazards, open burning of printed wiring boards increases the concentration of dioxins in the surrounding areas. These toxins cause an increased risk of cancer if inhaled by workers and local residents. Toxic metals and poison can also enter the bloodstream during the manual extraction and collection of tiny quantities of precious metals, and workers are continuously exposed to poisonous chemicals and fumes of highly concentrated acids. Although electronics constitute an indispensable part of everyday life, their hazardous effects on the environment cannot be overlooked or underestimated. The interface between electrical and electronic equipment and the environment takes place during the manufacturing, reprocessing, and disposal of these products.

## **2. Drivers of Reverse Logistics**

According to De Brito (2003) the drivers or motivations of reverse logistics are three: economic aspects, that is, the possibility of recovering value, governmental laws that stretch the implementation of reverse logistics and the market that adds consumption pressure (TIBBEN – LEMBKE and ROGERS 2002).

Brazil generates more than 1.4 million tonnes / year of waste from electronic equipment (e-waste) and less than 3% is recycled. It is estimated that 10% or 140 thousand tonnes / year are of computer and telecommunications equipment. Reverse logistics

receives a large part of this disposal, almost always in warehouses and places without proper environmental licensing, ignoring the necessary measures to reduce the risks of environmental contamination.

Without a structured system that receives all this disposal, much of it stops in the informal market with all the complications that this entails. Reverse logistics, as defined in the legislation itself, is an instrument of economic and social development characterized by a set of actions, procedures and means designed to enable the collection and return of solid waste to the business sector, for reuse, in its cycle or in other productive cycles, or other environmentally appropriate final destination.

It is through this system, for example, that the recyclable materials of an end-of-life electronic product, discarded by the consumer, may return to the productive sector in the form of raw materials. In order to make the reverse logistics required by the National Solid Waste Policy (NSWP) feasible, all parties related to the process must contribute to the forwarding of end-of-life products for environmentally appropriate recycling or disposal.

The legislation obliges manufacturers, importers, distributors and traders of pesticides, their residues and packaging, as well as other products whose packaging, after use, constitutes hazardous waste; Batteries; tires; lubricating oils, their residues and packaging; fluorescent, sodium and mercury vapor and mixed light lamps; and electro-electronic products and their components to:

invest in the development, manufacture and placing on the market of products suitable for reuse, recycling or other forms of environmentally appropriate disposal and whose manufacture and use generate the least amount of solid waste possible; disclose information regarding ways to avoid, recycle and eliminate solid waste associated with their respective products; to assume the commitment, when signed agreements or terms of commitment with the municipality, to participate in the actions provided for in the municipal plan for the integrated management of solid waste, in the case of products not yet included in the reverse logistics system.

The NSWP was instituted by Law 12.305, of Aug/2010 regulated by Decree 7.404 of Dec/2010. Among the concepts introduced in our environmental legislation by PNRS are the shared responsibility for the cycle product life cycle, reverse logistics and sectoral agreement.

The shared responsibility for the life cycle of products is the set of individual and linked tasks of manufacturers, importers, distributors and traders, consumers and owners of public services for urban cleaning and solid waste management, to minimize the volume of waste generated and tailings, as well as to reduce the impacts caused to human health and environmental quality resulting from the life cycle of products, under the terms of this Law.

Reverse logistics is an instrument of economic and social development characterized by a set of actions, procedures and means designed to enable the collection and return of solid waste to the business sector, for reuse, in its cycle or in other productive cycles, or other destination. Law 12.305/2010 devoted special attention to Reverse Logistics and defined three different instruments that could be used for its implementation: regulation, sectoral agreement and commitment term.

In Brazil there are instructions as NBR 16156: 2013 - Waste from electronic equipment, which requirements for reverse manufacturing activity establishes requirements for protection of the environment and for the control of safety and health risks at work in the reverse manufacturing activity of electronic waste. It is applicable to organizations that carry out reverse manufacturing activities of electronic waste as an end activity.

The emerging economies and developing countries are in urgent need of workplans and policy interventions to address their ever-increasing E-waste volume and subsequent management crisis (BORTHAKUR, 2020). The international commerce together with aspects such as depletion of resources had enforced the E-waste policies/legislation to be altered in several countries.

For the economic driver, is important identify what can be used from the waste. Maybe the polymer, any metal or glass. The Figure 1, show the e-waste composition and although had precious components, for culture reasons the e-waste are disposal the incorrectly. But if would had a structure network, the scenario could be different. Nowadays, the informal sector is more efficient than formal sector because of the costs.

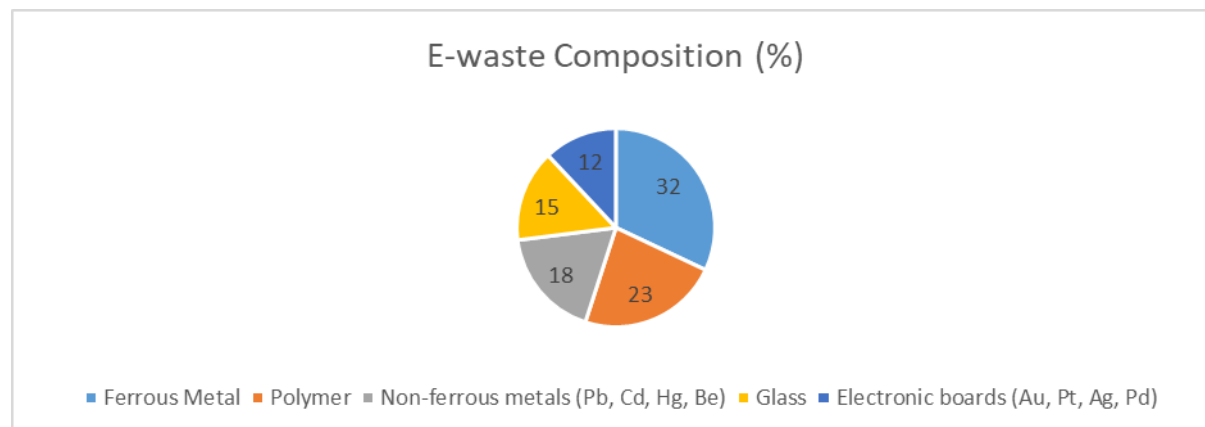


Figure 1 - Composition e-waste (adaptaded from VGResiduos)

The formal sector needs to take clue from the functioning of the informal sector and there should be greater collaboration between both the sectors for effective E-waste management. Further, there is a dearth of information on the accurate amount of E-waste generated in the emerging economies.

At present, the success of the informal E-waste collectors over the formal collectors in the emerging economies could be attributed to the fact that the informal collectors often offer more flexibility, convenience, accessibility and even financial incentives for the E-waste collected (OTTO et al., 2018).

Corporate citizenship refers to the set of values or principles that an organization holds to be responsible with RL activities. The motivations behind the implication of RL activities lay on both being legally obliged and trying to establish an image the consumers desires as an environmentally responsible organization. Better customer services such as increasing the level of customer awareness for returning and refunding options, guaranteeing better services would affect company's image positively and provide potential benefit (AKDOĞAN and COŞKUN, 2012).

### 3. Dimensions of Reverse Logistics

According De Brito and Dekker (2003) the reverse logistics includes some dimensions. These dimensions are necessary to comprehend the concept of framework RL.

Why-returning: the reasons why products are returned, product characteristics and product types. These return reasons are here presented in conformity with the usual supply chain phases: starting with manufacturing, going to distribution until the products

reach the customer. Therefore, three groups are differentiated: manufacturing returns, distribution returns and customer returns.

What: types and characteristics. An applicable viewpoint on reverse logistics can be obtained by considering what is actually being discarded or returned. Standard logistics product properties, such as size, weight, value, easiness of transportation and so on, play also a role for reverse logistics.

How are products recovered: processes and recovery options. The processes and recovery options need be discussed. Recovery is actually only one of the activities of reverse logistics. Other processes include collection, inspection/testing selection, and sorting. Collection refers to bringing the products from the customer to a point of recovery.

Who can do the recovery: the actors and their roles. Is necessary understand who could collaborate with these processes. Depending of the case, should have variation but, among them, stand out governmental institutions (national governments), forward supply chain actors, (supplier, manufacturer, wholesaler, retailer, and sector organizations) and, specialized reverse chain players (such as jobbers, recycling specialists, dedicated sector organizations or foundations, pool operators).

Why-receiving: the forces driving companies and institutions towards reverse logistics. There are many possibilities to earn money if the company receiving solid waste. This waste can be raw material to another process and, offer gains to organization.

The big challenge is structure the process showed in Figure 2. Identifying the need to collect is not difficult but, create the network to collect is so hard. In this process is necessary to set what return, how return, when return and who will return. Maybe this is one of the most difficult to do because the law gives general guidelines and the actors from the reverse logistic network needs to have initiative to work towards solving the problem.

There are difficult also to create an effective segregation process to separate correctly the good materials from the waste and identify what better way to send it. After collect and provide the segregation, is necessary the transport. In Brazil is so expansive this part because the resources are limited and the road transport cost are high. Many fees could be reconsidered to this flow (reverse) and minimize the cost but it's not possible yet.



Figure 2- Process to reverse logistic network

To recycle there are available technology, although expensive. Again, the access could be easier if there was a government action removing fees. No less important, the needs to certificate the generator e-waste is turning be ordinary in Brazil. But to ensure this practice many developments are necessary as reformulate the policy and inspection.

#### **4. Performance indicators of transport and location of e-waste – a case**

The technology company studied has a very promising scenario about reverse logistics, they have a program called Remarketing, also known as GARS (Global Asset Recovery Solutions), where they are able to collect used equipment and recondition it to the standards of remanufacturing, through policies of recycling and certification.

Remarketing products are reconditioned, tested and certified using rigorous processes and original factory remanufacturing standards, the flowchart of equipment reconditioning by the technology company is shown in Figure 5. Of all systems that qualify for maintenance, on a global scale, only 5% of used equipment is disposed of in landfills or incinerated.

The company serves different types of customers, from small and medium-sized companies to large corporations and the main reasons why customers look for used equipment are: when they don't need more advanced technology, supply temporary needs, update discontinued equipment lines or when the customer has limitations budgets.

The remarketing equipment comes from the end of the lease, that is, financial leasing, stock of new machines or customer buyback for technological updating, when the machines arrive at the technology company's inventory they undergo a technical evaluation and can be remanufactured, reconditioned, disassembled or directly sent for a new sale.

Some of the processes that are done are evaluated in two categories. Certification process for personal computers and certification processes for printers and monitors. They contain, test and verify all parts (including refurbished notebook batteries); fully loaded operating system software; cleaning of internal and external equipment; cleaning up hard risk data; 90-day quality satisfaction guarantee; rigorous testing of all functions.

In the years 2017 and 2018, around 430 tonnes of electronic waste were correctly disposed of, of which 95% were recycled, 4% reused or resold and only 1% was incinerated and the same occurred in 2016, where 99% of the products returned were recycled, reused or sold. Of these, the average of articles processed was 41,482 per week, totaling an average of 26,626 tonnes of products, parts and materials. In 2016, the Remarketing program recycled 1,036,038 units, of which approximately 373,000 laptops were included.

The transport cost is the product of the distances between nodes in the network and the transport fee, sometimes, in cases where the transport takes place between the generation zone and the transshipment facilities, a collection factor is incorporated into the transport cost, otherwise, the collection cost is defined by the market.

Servare Junior and Cardoso (2020) highlight the feasibility of using mathematical modeling as a tool to aid decision making in supply chain management for the design of a reverse logistics network considering facilities and the flow between them.

The costs of sorting and inspection come from the collection factor, sometimes being a percentage of it. Reprocessing costs include: remanufacturing and repair. This cost is calculated based on the product to be reprocessed. The disposal costs are given by the market, that is, the cost is based on the amount charged for proper disposal of the processed material. The computational modeling was performed using the IBM ILOG CPLEX® Optimization Studio 12.7.1 software, where the transportation problem described in Table 1 presented below was solved, using the linear programming methodology.

Table 1 – Transport cost and capacity

| <b>Location</b>     | <b>Cost (R\$/km)</b> | <b>Capacity (Unit)</b> |
|---------------------|----------------------|------------------------|
| Rio de Janeiro – RJ | \$7,32               | 3283                   |
| Belo Horizonte – MG | \$6,88               | 1970                   |
| São Paulo – SP      | \$18,97              | 34799                  |
| Curitiba – PR       | \$7,61               | 8535                   |
| Manaus – AM         | \$4,55               | 3939                   |
| Fortaleza – CE      | \$4,67               | 7222                   |
| Brasília – DF       | \$5,52               | 5909                   |

The model's proposal is to minimize transport costs to the verification unit located in São Paulo, Brazil, which has an average annual demand of 65,657 pieces of equipment. Thus, the objective function is given by Equation (1) below, to find the value of the minimum cost with transportation, respecting the capacities of each location and the average demand of the verification unit.

$$\text{Min } z = \sum_{i=1}^N \sum_{j=1}^N c_{ij} x_{ij} \quad (1)$$

Where  $c_{ij}$  is the unit cost of transport from location  $i$  to destination  $j$  e,  $x_{ij}$  is the amount of equipment transported from  $i$  to  $j$ .

After the execution of the program, the following results were obtained: the average annual minimized cost of transportation was R\$ 846,940.41, reaching the maximum supply capacity for each location, thus supplying the demand.

## 5. Conclusions

It is essential to deal with the increasing volume of E-waste produced, effectively and passably. Brazil have ratified and implemented legislative measures to deal with their concerns associated with E-waste.

In this paper was possible to meet some strategic reasons that drive the reverse logistic. With the three ways, is also possible structure the process to return the waste. As important also who is an agent inside the network understand your function. From that assumption, they need organize the steps of the reverse logistic network. To organize these steps as Figure 2, is necessary a discussion about the economic, legal and environmental aspects according Oliveira and Gonçalves (2016).

The companies and government must be able to create efficient forms to return the waste and inspect the process. According to Gonçalves and Chaves (2014), when is there fines, the possibility of compromise increases. Creating policies and infrastructure that allow for convenient and low-cost or free recycling of e-waste may increase consumer recycling. Policy-makers should focus on the creation of reduced financial

and other incentives to recycle may increase consumer awareness and motivation to recycle used electronics. (ARAIN et al., 2020).

Because of the increasing importance of network costs and network responsiveness in supply chain management and reverse logistics activities is important discuss the ways to reduce the necessary cost to optimize resources.

In the case studied on this paper, was possible get an important aspect that is economic, resulted from the networking reverse logistic. Not all the parameters were considered in model but it was enough to meet the challenge. It's should be used as performance indicator and establish efficient methods to this process. The transport and location are hard decisions and needs attention from managers.

Future research could be aimed at robust models to accommodate the changing parameters of the business environment of the logistics network. In addition, addressing the demand uncertainty and the supply of returned waste integrated logistics network is a promising research avenue with significant practical relevance.

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