Environmental Engineering and Management Journal

August 2020, Vol. 19, No. 8, 1411-1418
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu

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EVALUATION OF NETWORKS BETWEEN PRODUCTION UNITS IN THE POST-CONSUMER PET PACKAGING RECYCLING CHAIN

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Abstract

This study aimed to evaluate recycling networks for poly(ethylene terephthalate) (PET) packaging and propose a network structure for sharing recycling routes between different production units, using the Rio de Janeiro metropolitan region as a case study. A descriptive design was used and field research conducted to gather data on the recycling process. Participants were production units, classified as distributors, distribution recyclers, intermediate recyclers, and molding recyclers. A georeferencing program established the location of these units, origin of the PET waste, its distribution, and the structure of integration networks between recycling units considering the supplier-customer relationship, in order to assess the reverse logistics of post-consumer PET. The data obtained were analyzed qualitatively and quantitatively to elucidate the current recycling scenario and propose a new network structure. The proposed framework would reduce the distances traveled by almost 50%, while maintaining the same business relationships between the production units identified. The most prominent features of the current recycling structure are that PET distributors are located near their suppliers, whereas intermediate-recyclers are close to molding-recyclers, their customers.

Key words: network, poly(ethylene terephthalate), post-consumer PET, recycling, recycling chain

Received:October, 2019; Revised final: March, 2020; Accepted: May, 2020; Published in final edited form: August, 2020

1. Introduction

Current organizational models are governed by the network concept, whereby participants (institutions, organizations, individuals, or production units) are required to use natural resources more sustainably, in line with the concept of a circular economy (Kirchherr et al., 2017). A network is a set of entities or elements (objects, people, or production units) that are interconnected in a cooperative and reciprocal relationship or alliance. Networks enable the circulation of tangible or intangible material between participants based on well-defined rules. In line with this concept, a distribution network can operate using forward or reverse logistics. Configuration of the latter depends on the mapping of reverse flows (reverse logistics), that is, knowledge of the paths the materials follow after use until being reintegrated into the supply chain (Kaynak et al., 2014; Kilic et al., 2015).

Factors that can facilitate the implementation of reverse logistics (RL) include entrance controls, mapping, formalization of processes and activities, planning and coordination of logistical integration, and establishing partnerships between customers and suppliers (Niknejad and Petrovic, 2014). The resulting benefits include increasing the amount of material handled and reducing reworking, since the parties

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involved can optimize flows according to their specific needs and practices (Richey et al., 2004).

Open (Shen et al., 2010) or closed loop (Huysman et al., 2015) reverse supply chains for recycling should be based on partnerships, in order to optimize product return and reduce transport costs (Bing et al., 2013) and waste disposal in the environment (Dutta et al., 2016; Kumar and Malegeant, 2006). Some articles on waste-related RL (Dias and Braga Junior, 2016) discuss issues such as transportation (Bing et al., 2013; Ferri et al., 2015; Niknejad and Petrovic, 2014), environmental concerns (Corrêa and Silva, 2013; Yu and Solvang, 2016), and, specifically, the impact of plastic waste (Bing et al., 2013; Bing et al., 2014; Pacheco et al., 2012).

According to Geyer et al. (2017), in 2015, 8.3 billion metric tons of plastic were produced worldwide and 6.3 billion metric tons discarded, 80% of which was sent to sanitary landfills, burying raw material with high recycling potential. One factor that discourages plastic waste collection is that a significant portion is only suitable for downcycling (Carey, 2017), that is, in plastic products of lower quality and economic value than the original material. However, post-consumer PET can be used to obtain 100% recycled bottles (Carey, 2017), in addition to textile or geotextile fibers, alkyd resins and other chemicals (Ikladious et al., 2017; Torlakoglu and Guclu, 2009), extruded sheets for vacuum forming parts, construction (Akcaozoglu et al., 2010; Frigione, 2010) and asphalt concrete aggregates or aggregate replacements (Hassani et al., 2005), among other materials (NAPCOR Report, 2015; Shukla et al., 2008). Establishing RL networks is a complex process involving a number of different elements, including collection, transport, type of products and associated technologies, and a wide range of stakeholders (government, society, companies). Bing et al. (2014) applied a linear programming model to assess decision-making scenarios, with a view to minimizing plastic collection and transport costs and reducing carbon gas emissions. To that end, sorting can be improved by creating partnerships between agents (consumers, recyclers, and the government) and establishing cooperation networks. However, the unique characteristics of each product make it important to tailor waste separation and designation to the specific product or product mixture involved (Silva and Neto, 2011).

A collaborative recycling chain can be achieved by developing connected and interdependent production units that are structured to carry out all the steps of the reverse supply chain. Reverse logistics depend on developing production frameworks and forging relationships with other actors (and/or production units) within the network (Conceição et al., 2016; Formigoni et al., 2014; Gomes et al., 2019; Niknejad and Petrovic, 2014).

Reverse logistics recycling networks typically consist of waste pickers, distributors, recyclers, and consumers that are connected based on the inherent characteristics of the product in question (Conceição et al., 2016). They are influenced by customer demand, distance between production units (Jianghong and Guihua, 2009), resources shared between network members, the environment in which it is located and the size of its members.

According to Kara et al. (2007), a network structure based on efficient collection of end-of-life products improves product recovery. Creating networks in line with the geographic, demographic, and sociocultural characteristics of each region can help establish policies and strategies for waste management and its return to the supply chain that involve shared participation. In this respect, an important obstacle to overcome is that relationships between network members are largely dictated by the market and not always entirely trusting (Guerrini and Vergna, 2011). Transportation (Daugherty et al., 2011) is one of the main barriers to successful waste recycling according to Yoon and Le (2013), due to a lack of integrated collection and intermodal waste transport systems.

Based on the aforementioned studies, this paper aims to evaluate recycling networks for post-consumer PET packaging and propose a network structure for sharing recycling routes between different production units, using the Rio de Janeiro metropolitan region as a case study.

2. Methodology

A descriptive method was applied to ascertain the characteristics of production units and their interaction. Visits and interviews took place at the production units to characterize and identify the activities involved in the post-consumption PET recycling chain. These enabled us to determine the characteristics of the post-consumer PET recycling chain in Rio de Janeiro, including distribution, processing, and recycling.

2.1. Identifying the production units

Both bibliographical and field research were conducted, the latter limited to production units in Rio de Janeiro state. The aim was to investigate the possibility of improving the efficiency of relationships between production units, primarily by reducing the distance required to transport post-consumer PET packaging. The production units in the PET recycling supply chain were first identified by consulting the databases of the Brazilian PET Industry Association (ABIPET, 2016) and the Socioenvironmental Institute of Plastics (PLASTIVIDA, 2018). The production units identified were classified as distribution (DR), intermediate (IR), or molding recyclers (MR) (Table 1).

2.2. Application of the questionnaire and field visits

The field research involved visits to 12 production units, where a semi-structured questionnaire containing 32 questions was applied.

The purpose was to gather data to identify, characterize and map possible existing networks for recycling post-consumer PET in Rio de Janeiro. Waste pickers and distributors were not visited, due to their large number, wide geographic distribution and the difficulty identifying a significant enough number to obtain a representative evaluation.

Table 1. Definitions of the production units in the PET recycling chain (Conceição et al., 2016)

Types of productive units	***Definitions***
Waste pickers	People who collect, receive, sort, classify and sell recyclable materials.
Distributors (D)	Units that receive, separate, purchase, transport and control the flow of recyclable materials (on a large scale), acting between waste picker and intermediate recyclers.
Distribution recyclers (DR)	Units that purchase, bundle, transport and resell recyclable materials, according to the specifications of the intermediate or molding recycler.
Intermediate recyclers (IR)	Units that shred, wash and dry the recyclable material, producing flakes.
Molding recyclers (MR)	Units that use recyclable materials to produce pellets for other industries or articles that will be reintroduced into the supply chain.

The questionnaire was divided into three parts: 1) the organizational profile of the production units involved in PET recycling in Rio de Janeiro (seven questions); 2) the production process (twelve questions about the material processed and production capacity) and 3) activities associated with the flow of PET (eleven questions on collection, processing, and transformation).

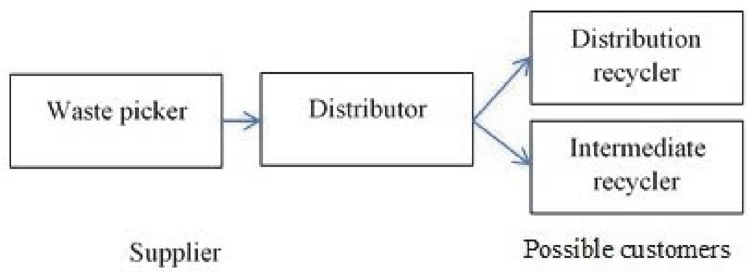
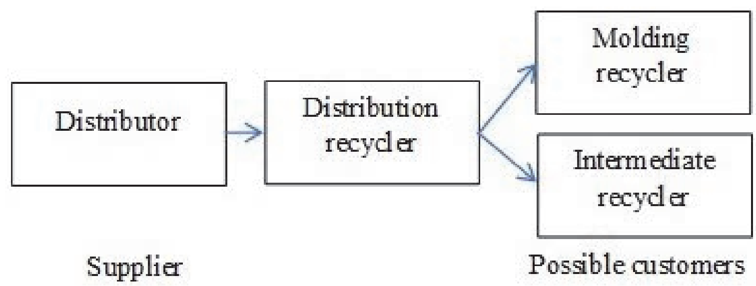
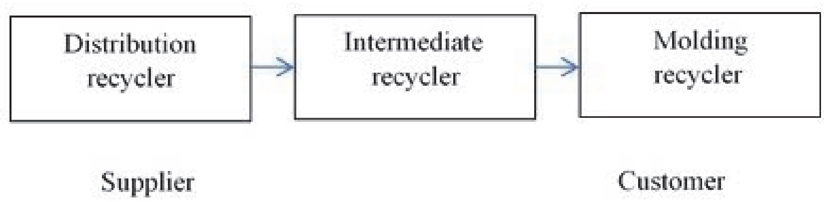
2.3. Data assessment

Based on the data obtained, the locations and flows of production units in the post-consumer PET supply chain in Rio de Janeiro were analyzed. Flows were identified according to the origin and destination of the PET.

GeoMedia Viewer software was used to visualize the location of the networks involved in recycling post-consumer PET in Rio de Janeiro. The program established a list of flows by inserting the origin and destination data into Excel. Connections between production units were established using the information they provided about their suppliers and/or recipients of post-consumer PET, considering a recycling chain beginning with the distribution recycler.

All the production units have suppliers and customers. The supplier-customer relationship was defined as a simple purchase and sale transaction, in which the seller and buyer of the material were the supplier and customer, respectively. Table 2 details the suppliers and customers for an "intermediate recycler" in the PET recycling chain.

Table 2. Business activities of the production units in the recycling supply chain

Production unit analyzed	***Supplier and customer***
Distributor	
Distribution recycler	
Intermediate recycler	

Production units were mapped based on the existing configuration of commercial relationships and information obtained during visits, using supplier-client relationships, existing production units and their geographic location as criteria. This enabled us to identify the production units, type of transport, flows, locations for mapping, and overlapping flows.

The carrying capacity of trucks is a key point in establishing the magnitude of PET flows. Medium and heavy-duty trucks were the most commonly used by members of the recycling chain. Medium-duty trucks have a cab with a single rear axle, carrying capacity up to 6 tons, gross vehicle weight rating of 16 metric tons, and maximum length of 14 meters. Heavy-duty truck cabs have dual rear axles, a carrying capacity of 10 to 14 metric tons, gross vehicle weight rating of 23 metric tons, and maximum length of 14 meters (DNIT, 1999).

2.4. Proposal for a recycling chain network

A new network structure for shared recycling routes was proposed based on the volume of PET to be transported by truck via the respective routes, maintaining current commercial arrangements between production units, and the geographic position of the units, in order to establish routes for material supply and delivery. The distance between each production unit pair was determined, namely distribution to intermediate and intermediate to molding recyclers.

In order to compare the existing reverse flows with those of the proposed system, kilometers currently traveled by production units and those to be traveled under the new shared routes were quantified. The distances between the production unit pairs were converted into percentages.

3. Results and discussion

This section presents the results obtained from the visits, the questionnaire administered to the production units, and information on their location.

3.1. Identifying the production units

Twelve production units in Rio de Janeiro state were visited to assess the PET recycling route: eight distribution recyclers (DR1-DR8), three intermediate recyclers (IR1-IR3), and one molding recycler (MR). Two distributors (D1 and D2) were also visited to clarify the current PET recycling scenario. The widespread location of the distributors made visiting them difficult. Fig. 1 shows the location of production units in the PET recycling chain in Rio de Janeiro. The only molding-recycler, all intermediate and the largest distribution recyclers were visited. In 2005, there were more distribution (Yu and Solvang, 2016) and intermediate recyclers (Shen et al., 2010) in Rio de Janeiro, but no molding recyclers, which were all located in São Paulo state (Pereira, 2006). There are also fewer production units now than there were a decade ago, in part because of the lack of policies that stimulate selective trash collection and reverse logistics (Shearer et al., 2017; Wan et al., 2017).

3.2. Current networks

The relationship networks between production units showed no commercial strategies between suppliers and customers (Table 2). The map of the production units (Fig. 1) and the questionnaire responses made it possible to locate those that buy and sell post-consumer PET, and thus identify sub-networks.

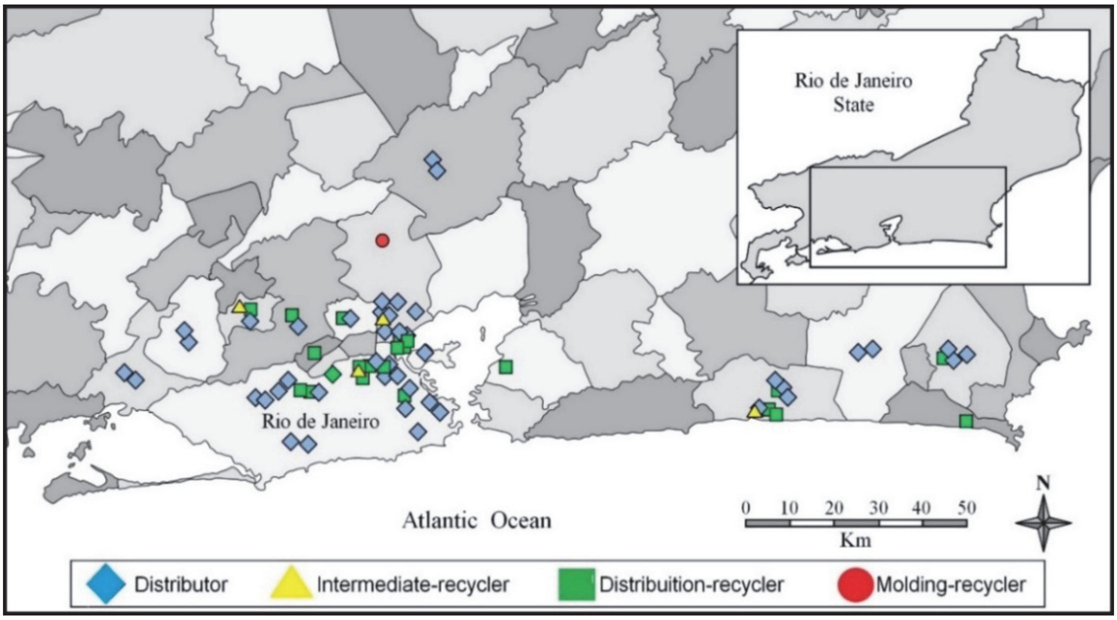


Fig. 1. Map of municipalities, highlighting Rio de Janeiro, with locations of the production units, including distributors, in the PET recycling supply chain of Rio de Janeiro state

In the current network configuration, production units use individually-determined routes, and trucks are underutilized. This strategy is flawed because the trucks cover greater distances and therefore incur higher fuel costs and more mechanical wear than if they were fully loaded. The survey results also revealed that the material is transported within Rio de Janeiro primarily as intact bottles (pressed and bundled) or flakes (shredded and cleaned), and to adjacent states (mainly São Paulo) in the form of flakes or pellets (extrusion-molded flakes). More than 50% of the flake mass from Rio de Janeiro is transported to other states, particularly São Paulo. The production units are concentrated in three municipalities: Duque de Caxias, Rio de Janeiro, and Saquarema. Most suppliers in the Rio de Janeiro PET recycling chain are located within that state. The three intermediate recyclers are in the municipalities of Queimados, Magé, and Rio de Janeiro City and largely operate within their market, as indicated by the flows between distribution and intermediate recyclers. Of these three IRs, IR2 has the highest number of PET suppliers. With respect to IR customers, most are in Rio de Janeiro state.

The delivery of post-consumer PET to states such as São Paulo, Bahia, Espírito Santo, and Santa Catarina is noteworthy. In 2005, 70% of post-consumer PET from Rio de Janeiro was sent outside the state (65% to São Paulo state and 5% to other states) (Pereira, 2006), but since 2011, more has remained in the state (now 40%), with a decline in flows to São Paulo (55%) and other states (5%). In this respect, the purchase of post-consumer PET in Rio de Janeiro by D and DR units through the existing sub-networks is more influenced by the location of material from waste picking and bundling than flows from processing. Distributors and distribution recyclers are located near material suppliers, such as waste picker cooperatives and illegal landfill operators. This is because Ds and DRs have primarily collected material from open dumps and controlled landfills and remained close to these facilities. The data indicate that material supplied to intermediate processors is collected by distributors and distribution recyclers located at a distance, which significantly influences PET flow.

The location of intermediate recyclers is linked to the flow of their output to transformers (molding recyclers), which are typically located near highways or in industrial districts. Almost all transformation flows go to buyers outside Rio de Janeiro state. Shredded, washed, and dried PET in the form of flakes is sent to companies that use it in their production lines. Current flows were individually identified based on the need for delivery from DR to IR and IR to MR (Fig. 2).

Each DR uses its own means of transport to send PET to the IRs. According to the questionnaire results, the managers of these units do not take environmental impacts such as CO_2 emissions or economic concerns into account. Material is transported with no attempt to minimize the distance traveled by trucks, increasing the costs involved. Several DRs located in the same region send their products to the same intermediate recyclers independently with no form of sharing.

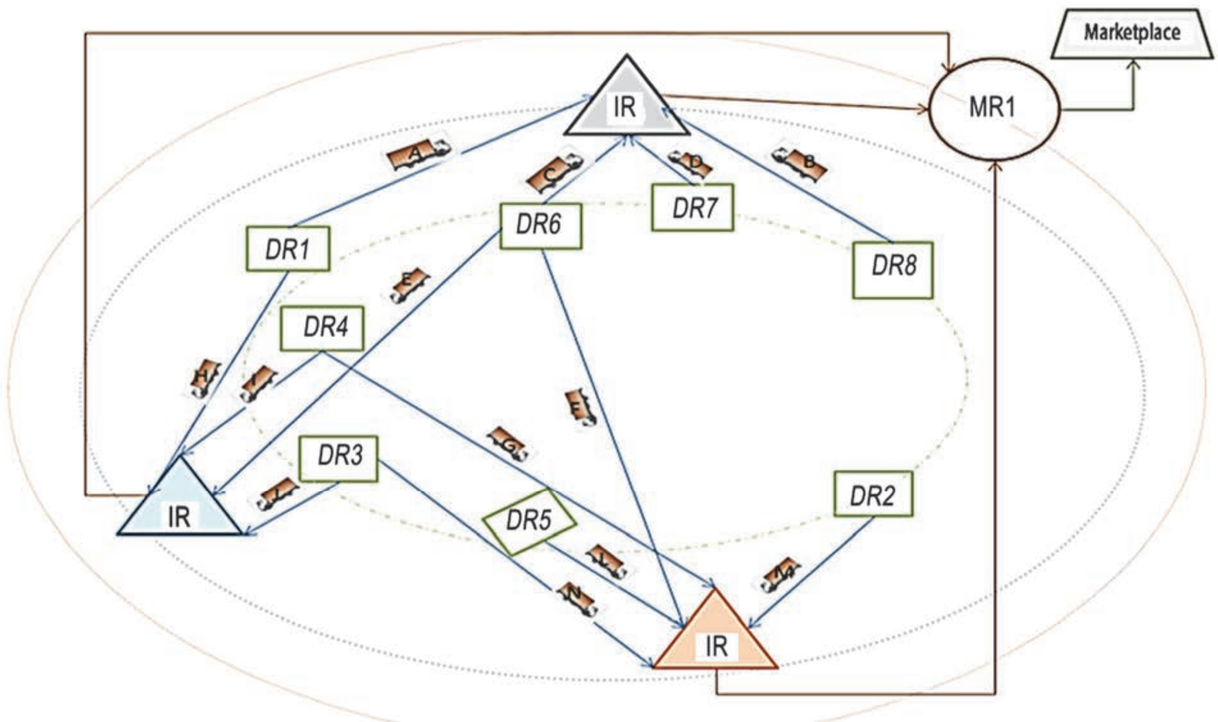


Fig. 2. Current flows of post-consumer PET in Rio de Janeiro

3.3. Proposal for a new shared network for the PET recycling chain

After identifying the locations and distances between distribution and intermediate recyclers, a new reverse flow design was proposed (Table 3), containing the 12 current sub-networks. New sub-networks were generated by superimposing the current distances traveled and routes to shorten distances of individual production units. The proposed shared transport system will optimize truck usage by distribution recyclers because all of them will be fully loaded on all legs of the journey so that each production unit makes fewer trips.

Another proposal is to use larger trucks, whereby medium-duty vehicles are replaced by their heavy-duty counterparts so that two trips by a large truck eliminate the need for one small-capacity truck (Table 3). This would reduce the number of trucks associated with the sub-networks. To reduce the distances traveled and lower fuel consumption in post-consumer PET transport, a new flow configuration was created for the supply chain, in accordance with the geographic distances between suppliers and customers.

The configuration was based on current commercial relationships and the 12 sub-networks were reworked to incorporate shared transport by the production units, reducing the number of sub-networks from 12 to 6 (Fig. 3). According to Table 3, the proposed shared route between fewer sub-networks would reduce the distance traveled by 51%. Data from the tenth recycling census, conducted in 2015 by ABIPET (2016), increase the potential of the proposed configuration, since a growing number of cooperatives (PET distributors) were identified in the PET recycling chain (58% participation) as well as concern by participants regarding the difficulty in obtaining bottles to recycle (expressed by 60% of respondents). The main reasons for this were the recession in the country, which caused a decline in consumption, and low selective collection levels, hampering the work of waste pickers (ABIPET, 2016).

As such, the simulated arrangement with larger sub-networks would give members better bargaining power, allow them to share equipment and infrastructure, and improve the quality and consistency of deliveries, corroborating the findings of Tirado-Soto and Zamberlan (2013).

4. Conclusions

It was assessed a proposed shared system for the post-consumer PET recycling chain to optimize transportation by reducing the number of trucks used. The new arrangement involves sharing large-capacity trucks to transport the material for processing and transformation. This study identified the existing reverse logistics post-consumer PET recycling chain in Rio de Janeiro, consisting of independent production units concentrated in certain regions, primarily the industrial city of Duque de Caxias.

Table 3. Distances covered in the current and proposed sub-networks of the PET recycling chain

Sub-network formed (current and proposed)	*Type of truck*	*Distance(km)*
DR1→IR2(current network)	1 medium-duty (DR1)	49.1
DR4→IR2(current network)	1 medium-duty (DR4)	32.6
DR1→DR4→IR2(proposed network)	½ heavy-duty (DR1)	21.7
	½ heavy-duty (DR4)	32.6
DR3→IR2(current network)	1 medium-duty (DR3)	38.7
DR6→IR2(current network)	1 medium-duty (DR6)	35.6
DR6→DR3→IR2(proposed network)	½ heavy-duty (DR6)	15.9
	½ heavy-duty (DR3)	38.7
DR4→IR1(current network)	1 medium-duty (DR4)	6.4
DR6→IR1(current network)	1 medium-duty (DR6)	13.1
DR4→DR6→IR1(proposed network)	½ heavy-duty (DR4)	8.9
	½ heavy-duty (DR6)	6.4
DR5→IR1(current network)	1 medium-duty (DR5)	6.2
DR3→IR1(current network)	1 medium-duty (DR3)	6.2
DR2→IR1(current network)	1 medium-duty (DR2)	6.2
DR5→DR2→DR3→IR1(proposed network)	1/3 heavy-duty (DR5)	0.3
	1/3 heavy-duty (DR2)	0.3
	1/3 heavy-duty (DR3)	6.2
DR6→IR3(current network)	1 medium-duty (DR6)	2.4
DR1→IR3(current network)	1 medium-duty (DR1)	15.8
DR1→DR6→IR3(proposed network)	½ heavy-duty (DR1)	16.5
	½ heavy-duty (DR6)	2.4
DR7→IR3(current network)	1 medium-duty (DR7)	6,0
DR8→IR3(current network)	1 medium-duty (DR8)	49.3
DR7→DR8→IR3(proposed network)	½ heavy-duty (DR7)	44.2
	½ heavy-duty (DR8)	6

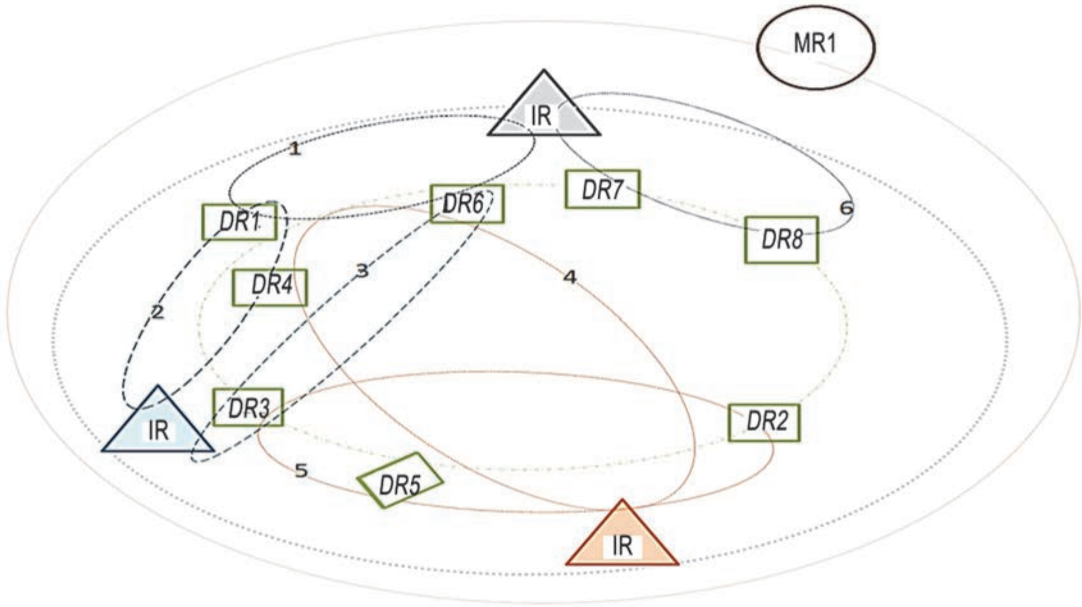


Fig. 3. Networks proposed for PET recycling in Rio de Janeiro

Most of the distribution or recycling units are located near areas where waste picking and bundling occurs and are less influenced by processing flows. Intermediate processing and transformation units have already optimized their transport to a certain extent because they are located near highways or within industrial districts. Optimizing the sub-networks would reduce the distance traveled by 51%, lower the number of sub-networks from twelve to six, and require fewer large vehicles.

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