COMPARATIVE STUDY OF THE MEANS OF TRANSPORT USED IN SELECTIVE COLLECTION

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Moises Leão Gil[1] and Giovani Manso Ávila[2]

ABSTRACT

This article aims to evaluate the economic and environmental efficiency and the impacts on urban traffic of models of door-to-door collection and transportation of recyclable materials, through the analysis of the three models in execution in Brazil, namely: compactor truck, box truck and unmanned combustion engine vehicle, associated with a support point. Due to the scarce literature found related to the transportation of selective collection, this analysis intends to contribute as a subsidy to the decision-making by the agencies and institutions responsible for the management of municipal solid waste and in the planning of the best means of transportation for this purpose, taking into account the local characteristics. The work corroborates the thesis that adequate planning for the optimization of resources, efficiency and quality in the provision of services is fundamental for the implementation and maintenance of selective collection programs, in order to comply with the National Solid Waste Policy.

Keywords: Transportation. Vehicles. Solid Waste. Selective Collection.

[1] M.Sc.
Master in Urban Engineering from the Urban Engineering Program / UFRJ
Institution: UFRJ / Urban Engineering Program
Email: moiseslgil@hotmail.com
[2] Degree and area: Doctor in Transportation Engineering / Federal University of Rio de Janeiro / Polytechnic School / Urban Engineering Program
Institution: Federal University of Rio de Janeiro / Associate Professor / Polytechnic School of UFRJ
E-mail: giovani@poli.ufrj.br

INTRODUCTION

With the growing population increase, a result of community life, and the voracious occupation of spaces, evidenced in an unbridled way from the eighteenth century onwards with the industrial revolution, one of the most serious environmental problems emerges: the constant increase of solid waste in cities. Based on this premise, garbage could be considered as one of the oldest focuses addressed in works of a social, economic and environmental nature.

The problem of urban garbage stemmed from the association between the precarious or total lack of adequate infrastructures in cities and the lack of ecological awareness, leading to a situation of chaos (SILVA et al, 2001).

Within basic sanitation, which is composed of water supply, sewage, rainwater and solid waste management systems, there seems to be a greater importance for the water supply system, relegating the urban sewage collection and treatment system to the background, followed by urban cleaning, solid waste management and urban rainwater management.

The problems caused by the inadequate disposal of solid waste are related to visual pollution, pollution of water bodies and groundwater, atmospheric pollution, degradation of ecosystems, diseases related to public health, clogging of rainwater drainage galleries and social problems.

In Brazil, the unbridled population growth also led to an increase in the number of workers, but without enough jobs to meet this demand, exposing unemployed people to inhumane situations, finding in garbage a way to support themselves and their families (MARTINS, et al., 2004).

This issue makes it essential to address the issue, both in the legislative sphere and in public policies. Bringhenti (2004) draws attention to the fact that the disposal of solid waste means a threat to public health and the environment. In this sense, it is necessary to have good planning for its management, based on knowledge of sanitary engineering, economics, administration, and other related areas, using more appropriate management techniques and avoiding high costs that make its execution unfeasible.

Thus, the present study intends to relate the adequate transport infrastructure in selective collection to the characteristics of each city, through the comparison of the costs involved, capacity and scope of each of the infrastructures analyzed.

RECYCLING AND SELECTIVE COLLECTION

Financial crisis, limitation of natural resources, associated with the damage to the environment and public health, due to the inadequate disposal of waste, made society aware of the need for recycling. As a result, the return of recyclable waste to the production chain as raw material for the production of new products was established due to occasional needs, such as in times of crisis and scarcity, experienced during the last two great wars (WELLS, 1995 apud PERIOTTO, 2013).

The first records of selective collection and recycling programs date back to the period of the Second World War, when European countries and the United States campaigned for the population to dispose of metal and paper scrap for recycling, in order to supply the war industry with raw materials (SANTOS, 1995 apud RIBEIRO, 2000).

Martins (2002), apud Besen (2006), points out that in developed countries the management of solid waste went through 3 specific moments: the first, during the 70s, centered on final disposal; the second, during the 80s, in reduction and recycling; and the third, after the 90s, with the establishment of laws and standards for the implementation of selective collection, recycling and energy use.

In Brazil, with the advent of law 12.305/2010, National Solid Waste Policy, all municipalities in the federation are obliged to close their dumps and dispose of their waste, which cannot be recycled, to landfills. The law also provides for the implementation and progressive expansion of municipal solidary selective collection with the participation of organizations of recyclable material collectors. Solidary selective collection is an environmental management instrument that must be implemented with a view to the recovery of recyclable material for recycling purposes (BRASIL, 2010).

According to Ribeiro and Besen (2011), selective collection plays a fundamental role in the integrated management of solid waste in several ways: it promotes the practice of segregating solid waste directly in the generator for later use, encourages the practice of actions to reduce consumption and waste through environmental education, promotes the socioeconomic inclusion of recyclable material collectors and provides a better organic waste for composting.

However, one of the main bottlenecks for recycling to become efficient is the collection stage of recyclable materials. Due to planning and the fact that recyclable materials have a high volume in relation to their weight, collection often ends up not being economically viable.

Grimberg and Blauth (1998) point out that in Brazil there are two basic modalities of selective collection: door-to-door, where cleaning agents and/or environmental agents walk the streets together with the collection vehicle, collecting recyclable materials previously separated and arranged in front of homes and commercial establishments; and the Voluntary Delivery Points (PEV's), in which the population travels to strategically defined locations to dispose of the segregated material at home. However, the same authors observe that it is difficult to measure the community's adherence to selective collection through PEV's, as well as the risk of vandalism that can present itself from the deposit of organic waste and/or dead animals in the collectors to their damage and destruction.

As for door-to-door selective collection, although it requires greater infrastructure and presents higher costs for collection and transportation, it provides greater convenience to the population, which results in greater participation of society in selective collection programs, in addition to enabling better control and inspection by the bodies responsible for the execution of the service, allowing the taking of specific measures to have greater popular participation (GRIMBERG and BLAUTH, 1998).

OBJECTIVES

This article aims to evaluate the economic and environmental efficiency of models for the collection and transportation of recyclable materials door-to-door through the analysis of the three models in execution in Brazil, namely: compactor truck, box truck and unmanned combustion engine vehicle associated with a support point. This last model, which is based on the unmanned combustion engine vehicle associated with a support point, has recently been used by small, medium and large cities, such as the municipality of Caetité/BA, Jacobina/BA, João Monlevade/MG and Belo Horizonte/MG.

BRAZIL AND SELECTIVE COLLECTION

Selective collection is still a recent theme in Brazil, and most of the initiatives and actions in this regard, still informal, carried out by organizations of recyclable material collectors. In the country, only 16.66% of the 5,561 municipalities are operating selective collection programs, which corresponds to 927 experiences implemented and in operation, as shown by a survey on the subject, developed by the Business Commitment to Recycling (CEMPRE, 2014).

The Ministry of Cities, through the National Sanitation Information System (SNIS), annually publishes the "Diagnosis of Urban Solid Waste Management", which in its thirteenth edition for the year 2014, points out that out of a total of 3,765 municipalities surveyed, 1,322 reported carrying out any type of selective collection, either by PEV or door-to-door. However, an evaluation of the scope of selective collection in these municipalities was not made, and it could be only in one location, in part of the municipality, or in the entire city. Of these 1,322 municipalities, 1,178 said that they carry out door-to-door selective collection, serving a total of 52 million inhabitants, a value much higher than that presented by CEMPRE (2014), which presented the number of 28 million people served with selective collection in the country.

VEHICLES USED

Selective collection can be carried out with the use of various equipment, from animal/human traction vehicles, to open-body trucks and compactors, which are capable of reducing the initial volume of waste by one third (Roth *et al*., 1999). ABNT (1993), through NBR 12980, presents two of these vehicles: Trucks with non-compaction bodywork, which are rectangular metal bodies with rear and/or side opening and their unloading occurs by tipping; and Truck with compactor, which are vehicles with closed bodies, equipped with mechanical elements that enable the compaction of the material inside, and its unloading can be done by ejection or tipping.

Recently, new technologies have been developed to reduce impacts on traffic and the environment, reduce costs and optimize the process of selective collection of recyclable materials. In 2007, through the renewable energy program of the Itaipu Binacional Hydroelectric Power Plant - ITAIPU, an unmanned electric vehicle for selective collection powered by tug was launched, with a capacity of up to 1000 kg and low operating speed, reaching up to 8 km.h-1 (LAZZARI, 2010). However, despite having a range of 30 km with a full charge, the vehicle was not very well accepted by waste pickers' organizations who, due to their experience of use, claimed that the vehicle loses power at the end of the load, running out completely before reaching the base again, causing great difficulties for its locomotion, because empty, It weighs around 400 kg and there are no points for easy refueling.

Around 2009, the company TECSCAN, created the "Collector". It is an unmanned combustion engine vehicle powered by gasoline, with a cargo cage with a capacity of approximately 3 m3 and up to 500 kg. The speed of this vehicle is 4 and 6 km.h-1 (average speed of an average person walking) and average autonomy of 30 km.l-1 (TECSCAN, 2017). The possibility of refueling with gasoline turned out to be a differential in relation to ITAIPU's electric vehicle, as it is possible to carry an extra tank of fuel next to the vehicle, or refuel it at the nearest station, being able to return to the base without major problems.

METHODOLOGY

Taking into account that there are few studies in the literature that address the transport of selective collection in Brazil, the present work presents an exploratory research of a qualitative-quantitative nature, based on the information collected from the means of transport used to carry out this collection, focusing on the truck without compaction (cage or box body), compactor truck and unmanned vehicle with combustion engine associated with a support point - Ecopoint (photos 1 and 2).

Photos 1 and 2: Ecopoint and waste pickers with mechanized collection cart in the municipality of Jacobina/BA.

Source: The author himself (2016).

It is important to mention that due to the difficulty of obtaining data, the areas of influence chosen are not the same for each case, which can generate some differences mainly in costs and routes, however, the intention of the work is to show the characteristics of the vehicles and the form of collection, observing the different case studies and areas chosen

A survey of primary and secondary data was carried out, later, the parameters to be analyzed were defined, such as; scope of collection, taking into account the capacity of the equipment and the size of the routes; occupation of spaces on public roads, with a view to the impacts on traffic resulting from different means.

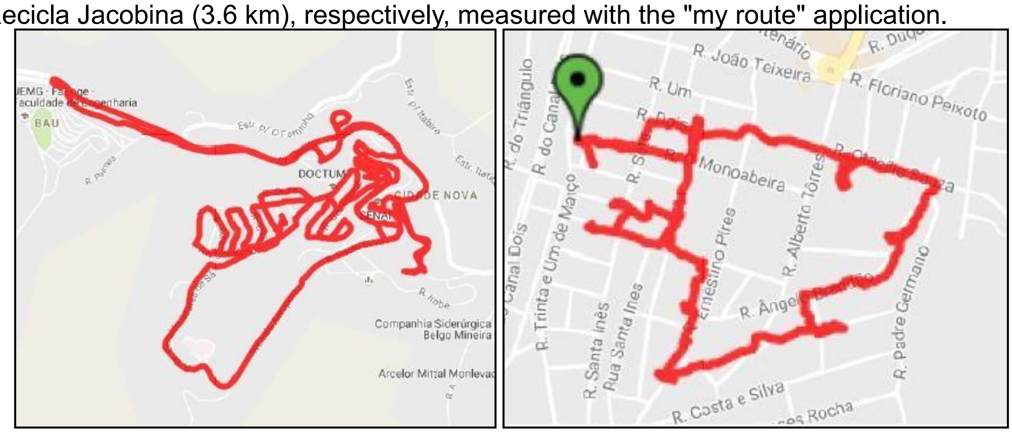
The scope of the collection was defined based on the routes and capacities of the devices of the means of transport analyzed. For this, data collection from three waste pickers' organizations and the Municipal Company of Urban Cleaning – COMLURB of the municipality of Rio de Janeiro/RJ were evaluated. Each one operates with a vehicle studied, namely: Cooperativa Popular Amigos do Meio Ambiente Ltda – COOPAMA, which receives the material from the selective collection of COMLURB, made with the use of a truck with a compactor; Association of Cleaning and Recyclable Materials Workers of João Monlevade – ATLIMARJOM, which carries out selective collection in the municipality of João

Monlevade/MG with the use of a truck with a trunk body; Cooperative of Recyclable Material Collectors Recicla Jacobina, which operates selective collection in Jacobina/BA using the unmanned vehicle with a combustion engine.

The information regarding the routes of the vehicles was obtained in two ways:

1- Through the "My Route" application, available free of charge for Smartphone devices; used for the data of the unmanned vehicle with combustion engine of Recicla Jacobina and the box truck of ATLIMARJOM. The routes of each vehicle were measured for a period of one week and the material collected during the measured route was subsequently weighed;
2- Through the form "Daily Bulletin of Operations", to obtain the route data of the compactor truck of the Municipal Company of Urban Cleaning – COMLURB, which destines the material to COOPAMA. In this form, the driver informs the schedules and mileage of the vehicle in the following situations: when leaving the garage, at the first and other collection points (roads and/or specific establishments), at the last collection point, when arriving at the road scale and when depositing it at COOPAMA.

Figure. 1 and 2: Routes of the ATLIMARJOM truck (17.1 km) and the unmanned vehicle with combustion engine of Recicla Jacobina (3.6 km), respectively, measured with the "my route" application.



Source: The author himself (2016).

Regarding the capacity of storage devices, it should be noted that according to the Ministry of the Environment (2012), the apparent density of recyclable materials is 0.25 ton.m-3, while for mixed and compacted waste, the value of 0.6 ton.m-3 is attributed.

Information regarding capacity was obtained from the manufacturers, through quotations, access to their electronic address, and data collected from the waste pickers' organizations monitored in this study. Thus, the values of maximum capacity were compared with values collected from the organizations of waste pickers studied. Another aspect considered was the depreciation of vehicles over a period of one year.

The operating costs were calculated using the simulation spreadsheet of the operating costs of road cargo transport, made available by the National Land Transport Agency – ANTT, which was prepared based on ANTT Resolution No. 4,810, of August 19, 2015 (ANTT, 2015). The spreadsheet divides operating costs into two: fixed costs and variable costs.

Fixed costs have as parameters the costs of the truck and device, the depreciation of the vehicle and equipment, monthly remuneration of the capital invested in the vehicle, cost of the driver's labor (based on the salary floor of the category), taxes and vehicle insurance. Variable costs take into account the costs of maintenance, fuel, lubricants, washing, and tires.

In the same way, the cost of the labor force of the collection agents was analyzed in parallel, where the composition of the team varies according to the means used, being considered as follows in the present study: truck with compactor and truck with box body composed of a driver and three collection agents; Unmanned vehicle with combustion engine, two collection agents.

The ANTT spreadsheet was filled with data collected in the field and market research, calculated based on the mileage driven per month, obtained by measuring the routes, also taking into account the time spent per route. It is worth remembering that due to the different capacities, there is a difference in the distance traveled between the different means.

RESULTS

The results of the information collected from each of the three media presented will be presented below. Table 1 presents a comparison of the dimensions and capacities surveyed for each means of transport.

Table 1: Comparison of the dimensions and capacities surveyed for each means of transport studied.

		Veículo		
		Caminhão compactador	**Caminhão sem compactação**	**Veículo motorizado não tripulado**
Capacidade	Peso nominal (kg)	9.000	4.860	500
	Peso aparente (kg)	3.170	500	200
	Volume (m³)	15	26	3
Dimensões	Comprimento (m)	7,9	7	1,5
	Altura (m)	3,4	3,4	2
	Largura (m)	2,5	2,1	1,2
Tempo médio por rota		6h37m	1h51m	2h27m
Km médio rodado por rota		76,0	19,5	4,1

Fonte: Elaborada pelo próprio autor (2016).

Regarding the capacity of each equipment, the information obtained by the manufacturers of the compactor, trunk and unmanned motor vehicle was 9,000 kg, 4,860 kg and 500 kg, respectively. However, the values obtained from the waste pickers' organizations showed an average of 3,140 kg per trip of the compactor, 700 kg per trip of the trunk and 200 kg per trip of the unmanned motor vehicle.

Regarding the time per trip, the compactor truck takes in the range of 8 hours per trip, resulting in only one trip per day. The trips of the box truck and the unmanned motor vehicle last in the range of 2 hours, allowing 2 to 3 trips to be made per day. Table 2 presents a comparison of the fixed and variable costs for each means of transport used.

Table 2: Comparison of fixed costs and variable costs for each means of transport used.

		Veículo		
		Caminhão compactador	**Caminhão sem compactação**	**Veiculo motorizado não tripulado**
Custos Fixos	Veículo	R$ 177.500,00	R$ 140.000,00	R$ 16.700,00
	Depreciação*	R$ 44.375,00	R$ 35.000,00	R$ 4.175,00
	Dispositivo de armazenamento	R$ 70.000,00	R$ 14.800,00	R$ -
	Depreciação dispositivo	R$ 17.500,00	R$ 3.700,00	R$ -
	Motorista	R$ 3.562,48	R$ 3.562,48	R$ -
	Tributos	R$ 7.290,38	R$ 5.790,38	R$ -
	Seguro veículo	R$ 6.100,00	R$ 4.500,00	R$ -
	Seguro dispositivo	R$ 3.000,00	R$ -	R$ -
	Custo fixo mensal	**R$ 15.594,15**	**R$ 8.538,98**	**R$ 444,36**
Custos Variáveis	Manutenção/Km	R$ 0,96	R$ 1,48	R$ 1,77
	Combustível/km	R$ 1,61	R$ 0,82	R$ 0,11
	Lubrificante/km	R$ 0,02	R$ 0,02	R$ -
	Lavagem/km	R$ 0,20	R$ 0,20	R$ -
	Pneu/km	R$ 0,22	R$ 0,20	R$ 0,40
	Custo variável por km	**R$ 3,01**	**R$ 2,72**	**R$ 2,28**

Source: Prepared by the author himself (2016).

The fixed costs used as parameters are: vehicle, storage device, depreciation, driver, taxes and insurance. It can be evidenced that the unmanned motor vehicle does not present storage device and driver costs, as it already comes with the storage device installed and it is not necessary to have a qualified professional to drive the vehicle, as shown in photo 1, unlike trucks, where the storage device is not a factory option and needs to be purchased separately from another manufacturer. The variable costs considered were: maintenance per kilometer, fuel per kilometer, lubricant per kilometer, washing per kilometer and tire per kilometer.

Regarding fuel consumption per month, the data collected from the 3 waste pickers' organizations presented the following figures: the truck with a compactor travels in the range of 76 km.trip-1; the truck with a trunk travels around 19.5 km.trip-1; and the unmanned motor vehicle travels around 4.1 km.trip-1.

Considering a monthly working day of 24 days, which compactor truck makes only one trip per day, while the box truck and the unmanned motor vehicle make 3 trips per day, we will have the compactor truck traveling 1824 km.month-1, the trunk 1404 km.month-1 and the unmanned vehicle km.month-1. It should be noted that the unmanned motor vehicle starts the collection when leaving the Ecopoint, while the compactor truck travels approximately 76 km to carry out the collection, dispose of the material to the cooperatives and return to the garage.

The information obtained from manufacturers and waste pickers' organizations indicates an average consumption of kilometers per liter of the compactor truck of 2 km.l-1, the box truck of 4 km.l-1 and the unmanned motor vehicle of 35 km.l-1. The values of the fuels found were R$ 2.79 for diesel and R$ 3.79 for gasoline.

Table 3 presents a simulation with the total costs per ton, per 10 kilometers and per trip. It is verified that the unmanned motor vehicle has the lowest costs in all three cases, followed by the compactor truck and the non-compaction truck.

Table 3: Simulation of total costs per ton, 10 kilometers driven and trips.

		Veículo		
		Caminhão compactador	**Caminhão sem compactação**	**Veículo motorizado não tripulado**
Custos Totais	Tonelada	R$ 208,49	R$ 418,94	R$ 70,96
	10 Km	R$ 86,14	R$ 150,39	R$ 35,48
	Viagens	R$ 654,65	R$ 293,26	R$ 42,58

Source: Prepared by the author himself (2016).

The unmanned motor vehicle presented R$ 70.96.ton-1, for each 10 kilometers R$ 35.48.km-1 and R$ 42.58.trip-1. Regarding the cost per ton, the compactor truck presented the value of R$ 208.49.ton-1 and the truck without compaction R$ 418.40.ton-1. As for the costs for each 10 kilometers, the compactor truck showed the value of R$ 86.14.km-1 and the box truck R$ 150.39.km-1. When analyzing the simulation of costs per trip, we see that the truck without compaction is less expensive than the compactor truck, with a cost of R$ 293.26 per trip and the compactor R$ 654.65 per trip.

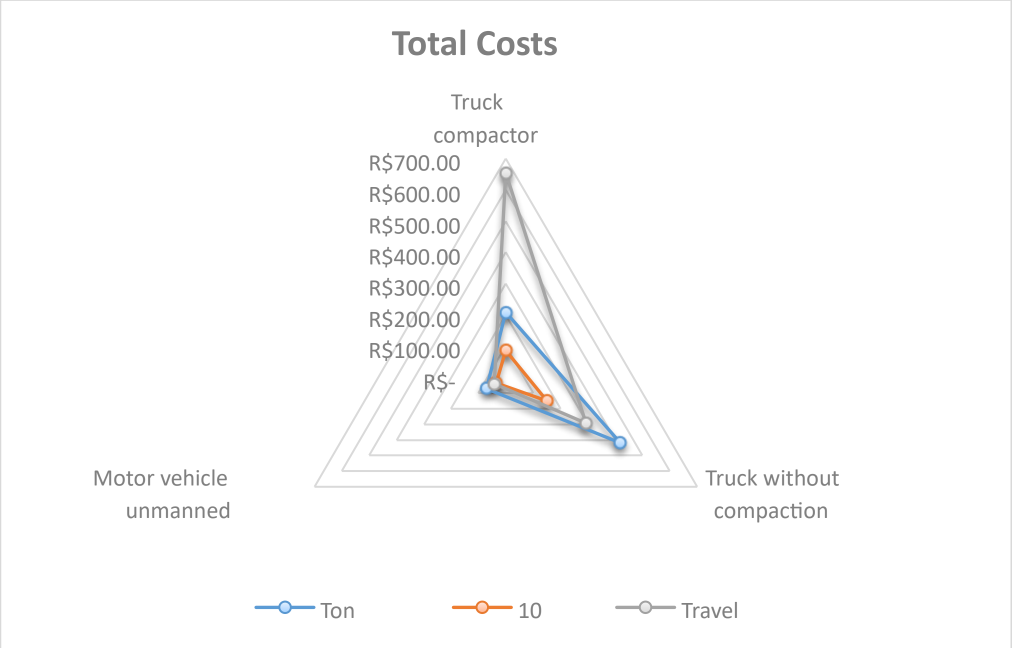
DISCUSSIONS

As shown in Table 1, the vehicle with the compactor device had a higher collection capacity, with values around 3,140 kilograms per trip, followed by the truck with a trunk body, with 500 kilograms, and an unmanned motor vehicle, with 200 kilograms per trip. However, it is worth noting that according to data from COOPAMA, the loss rate of recyclable material reaches 10.5% due to the compaction of the material. It is also noted that none of the devices were able to reach their maximum load capacity, and volume is a limiting factor for collection planning.

It is also observed that trucks, due to their size, cause significant negative interference in traffic, which does not happen with unmanned motor vehicles; which has a width equivalent to half that of trucks, with the possibility of partially climbing the curb, not causing significant impacts on traffic. It is also important to note that trucks have certain restrictions, such as the impossibility of accessing specific areas, difficulties in maneuvering on dead-end streets, and restricted circulation in some regions.

Regarding the total cost, table 3 and figure 3 present the simulation of the values of the three media studied.

Figure 3 - Comparison of total costs per ton, 10 kilometers driven and trip of the three means.



Source: Prepared by the author himself (2016).

As previously noted, the unmanned motor vehicle has lower costs in the simulations. However, in general, when analyzing the total costs, it is observed that the capacity and, consequently, scope of the compactor truck's collection ends up being higher when compared to the other means, being six times higher than the box truck and fifteen times higher than the unmanned motor vehicle.

It is verified that the highest cost is mainly due to the costs of equipment and maintenance and fuel costs, considering that the truck does in the range of 2 km.l-1, the box truck 4 km.l-1 and the unmanned vehicle 35 km.l-1.

Taking into account the differences in the study areas as well as other parameters involved in the transportation of selective collection, it is difficult to indicate only one of the vehicles as the best means of transportation, which is not the focus of this work, however, the evaluation of each case with the purpose of adaptation to other regions, represents a support for future planning.

FINAL CONSIDERATIONS

Adequate planning aimed at optimizing resources, efficiency and quality in the provision of services are fundamental for the implementation and maintenance of selective collection programs, in view of compliance with the National Solid Waste Policy.

An analysis of factors related to local aspects, population density, income and gravimetry is essential to define the most appropriate means to be used.

Although it presents lower costs and less impact on urban traffic, the unmanned vehicle with a combustion engine provides a low storage capacity, making it necessary to have a local support point (Ecopoint) for transshipment of the collected material, being a good option for regions of difficult access for trucks and more horizontal urban occupation areas, but not being a good alternative for a region of high population density.

The box truck, despite having significant costs, has an average transport capacity and a relatively lower maintenance cost than the compactor, in addition to having a greater autonomy, which can represent an alternative in regions with higher population densities, however, it is important to analyze traffic conditions.

The compactor vehicle presents better efficiency in relation to the collection coverage, being considerably superior to the other means studied. However, the use of this means requires high investments, in addition to presenting high operational costs, both in terms of fuel consumption and maintenance, as also pointed out by MILANEZ (2002).

The use of the compactor truck presents itself as a good alternative for regions with high population density, where there is a high generation of waste per area. However, according to COOPAMA data, where the loss of this material reaches 10.5%, more precise analyses are needed with regard to the quality in which this material arrives at the sorting areas, because the premise of selective collection is the return of this product to the production chain, mitigating the negative impacts caused by inadequate management and incorrect disposal of these materials in the environment, thus reducing the extraction of raw materials from nature.

Thus, the present study is important in supporting information for decision-making by the agencies and institutions responsible for municipal waste management in planning, in order to determine which would be the best option of means of transport to be used according to local characteristics.

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