Application Guide

A path to sustainable logistics

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A path to sustainable logistics

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Presentation

This Application Guide: A Path to Sustainable Logistics seeks to fill a gap noticed long ago, which is presenting effective cases of practical application in which the performance of one of the most important logistics activities, freight transport, is assessed not only from a costs and level of service perspective, which is the usual approach and is limited to the economic and financial aspects, but also from an environmental and, whenever possible, a social perspective.

Expanding the scope of assessing the performance of freight transport under a sustainability perspective has long ago stopped being desirable and has become mandatory. It represents society's commitment to minimizing and/or eliminating the social and environmental impacts caused by economic activities and guaranteeing the survival of these activities in harmony with the environment.

The cases presented here summarize part of the last ten years of activities carried out by researchers of the Freight Transport Laboratory (LTC), reference in the training of professionals of different levels ranging from undergraduate courses to master's and doctorate courses, culminating in post-doctoral courses. LTC is a laboratory linked to the Transport Engineering Program (PET) of the Alberto Luiz Coimbra Institute for Graduate Studies and Research in Engineering (COPPE) of the Federal University of Rio de Janeiro (UFRJ), a renowned education and research institution in Brazil and worldwide.

As shall be presented, the reports presented here successfully represent the collaboration between the academy and the private sectorand show that the challenge of considering sustainability in the assessment of logistics performance may be overcome with very good results, serving as an example to those that still intend to carry it out. Do not miss the opportunity of improving your knowledge on this topic!

Have a good reading!

Márcio de Almeida D'Agosto
Coordination of LTC

Introduction

Worldwide, logistics costs, including costs with transport, warehouse maintenance and order processing, account for 7% to 9% of the gross domestic product (GDP). In Brazil, the value reaches 12% of the GDP and around 9% of the total company costs, with greater influence (around 30%) related to transport costs.

Unlike other sectors of the economy, transport is still highly dependent on petroleum as an energy source, consuming 93% of this non-renewable natural resource, whose burning significantly contributes to the emission of carbon dioxide (CO_2), the main greenhouse gas, which is associated to climate changes and poses one of the greatest challenges of humanity in the 21st century.

From 1970 to 2010, the emission of CO_{2e}[1] in transport increased 2.3 times, reaching 7.1 $GtCO_{2e}$ in 2013 and consuming 29% of petroleum production in the same year. Freight transport alone was responsible for 8% of the total emissions of these gases. In Brazil, the situation is even more serious! CO_2 emissions in transport increased 5.6 times in the same period, consuming 69% of petroleum and natural gas, since 80% of the energy used comes from these sources, resulting in the fact that this activity was responsible for 13.8% of CO_2 emissions in 2015, of which 7% is the participation of freight transport.

According to the United Nations, 54% of the world population currently live in urban areas and this is a growing trend in the 21st century. Guaranteeing sustainability in the mobility of people and freight within the cities is another equally relevant challenge for the next decades, if one considers that, according to the World Health Organization (WHO), transport is the greatest source of air pollutants in cities, being responsible for significant social damage due to respiratory, cardiovascular and neurological diseases, stress, as well as injuries and deaths caused by accidents.

In a world where petroleum reserves are becoming scarce and more expensive, climate balance is at stake and the need for guaranteeing quality of life for people that live in the cities has been growing, reverting the previous scenario is a challenge to be overcome, especially when the society faces significant changes in the way of relating, communicating, moving, producing and commercializing. The 21st century begins with a world in transformation which will promote the desired changes towards sustainability in logistics and transportation. Companies and people need to be prepared for that.

In a society where awareness about the social and environmental impacts of its economic activities is growing, these changes point to the expansion of the concept of logistics, which, be-

1 CO_{2e}: equivalent carbon dioxide emissions.

sides involving the reduction of total costs and the expansion of level of service, must also aim at the reduction of environmental impacts generated by its main activities, especially freight transport.

The expansion of this conceptual horizon leads to terms such as low-carbon logistics, green logistics and sustainable logistics, which add to the term "logistics" characteristics related to the necessary assessment of social and environmental aspects. It is worth highlighting that low-carbon logistics seeks to specifically reduce the use of fossil fuels and the emission of CO_2. Green logistics expands the scope of logistics in order to consider other environmental attributes, such as air pollutant emissions, generation of noise and vibration, water consumption and generation of solid and liquid waste. Sustainable logistics is the most comprehensive concept, since it introduces the consideration of the social aspect in the assessment of logistic performance.

In this context, it is possible to notice the potential of improving freight transport management, since it is the main logistics activity, with a consequent impact on social and environmental performance of supply chains. This is possible by introducing best practices that seek better sustainability for this activity, with the application of a set of actions oriented to: (1) reducing the activity of freight transport; (2) modal shift through the use of less energy-intensive modes, which demand infrastructure; (3) using more energy-efficient vehicles that are capable of promoting a reduction in energy intensity; and (4) using energy sources that reduce liquid emissions of CO_2, such as electrical energy of renewable sources or biofuels.

Practical examples of how this may be made are presented in this Application Guide that provides four cases of the effective application of the following best practices for freight transport: (1) using alternative propulsion systems; (2) conducting drivers training (eco-driving); (3) using different types of vehicles to carry out deliveries and collections; and (4) transferring freight transport to cleaner modes (modal shift). For all the cases, results regarding the assessment of cost and level of service measures are shown, representing the performance of the economic and financial aspects, followed by measures of energy consumption, and local greenhouse gas and air pollutant emissions, which are representative of environmental impacts. Whenever possible, social aspects measures were also introduced.

Improving the sustainability of urban waste collection

Solid waste collection in urban areas

The city of Rio de Janeiro has a population of around 6.3 million inhabitants and it is the second most populous capital in Brazil[2]. It is subdivided into five planning areas, 33 administrative regions and 162 neighborhoods[3].

Data from the Municipal Plan of Integrated Management of Solid Waste[4] show that, in 2014, approximately 9,227 daily tons of waste were generated, 53% of which was characterized as domestic waste (4,900 t/day). According to the Brazilian Association of Public Cleaning and Special Waste Companies[5], in 2015, a total of 1.342 kg/inhab.day of waste were generated in the city. In the same year, the national average of daily waste generation was of 1.071 kg/inhab. day. As a consequence, the municipality of Rio de Janeiro makes efforts to treat volumes of per capita waste generation that are 20% higher than the national average.

In this context, the collection of urban waste in the municipality of Rio de Janeiro is carried out by a municipal urban cleaning company that has a heterogeneous truck fleet, in which the choice for the type of vehicle is associated with a specific application, as shown in Table 1.

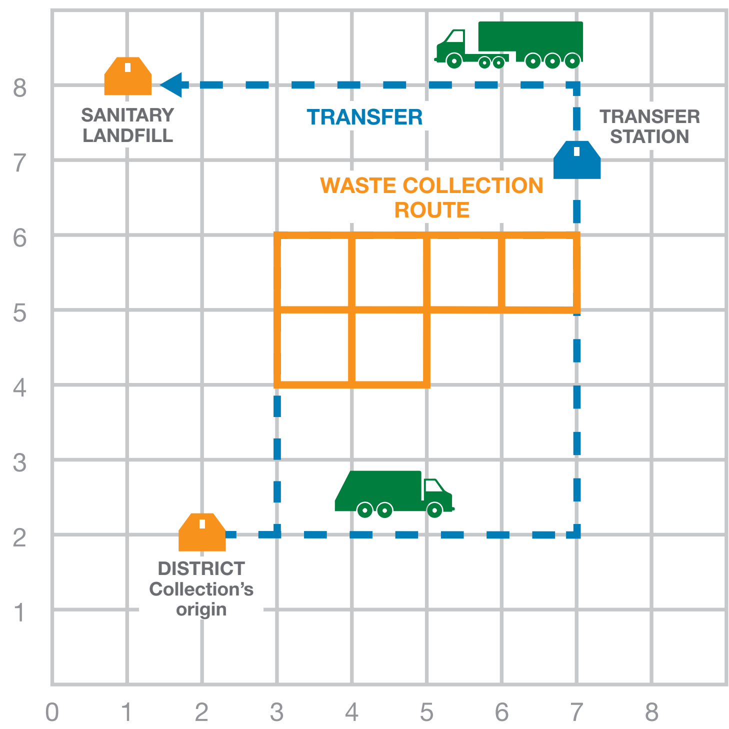
Table 1: Profile of the truck fleet of the municipal urban cleaning company

Image	Type	Description	Application
	P5	Simple truck with a $6m^3$ mini compactor	Domestic waste collection
	P5A	Simple truck with two axles and a $10m^3$ compactor	Domestic waste collection
	P6	Simple truck with two axles and a $15m^3$ compactor	Domestic waste collection
	P7	Simple truck with three axles and a $19m^3$ compactor	Domestic waste collection
	P19	Set of tractor unit and a $45m^3$ bucket semitrailer	Transfer of waste from transfer stations to sanitary landfills.
	P25	Simple truck with three axles and a $19m^3$ compactor	Collection of domestic, public and special waste

2 Brazilian Institute of Geography and Statistics. Demographic Census of 2010. Rio de Janeiro. Available at: https://censo2010.ibge.gov.br/
3 Municipal Government of Rio de Janeiro. Rio in Summary, 2017.
4 Municipal Government of Rio de Janeiro. Municipal Plan of Integrated Management of Solid Waste in the City of Rio de Janeiro. December, 2015.
5 Brazilian Association of Public Cleaning and Special Waste Companies. Panorama of Solid Waste in Brazil. 2015

Half of the activities of the municipal urban cleaning company are related to domestic collection, in which simple trucks equipped with waste compactors are used, vehicles that are classified as P5, P5A, P6, P7 and P25. Domestic waste is a Transport Service Category (CST) in which trucks perform waste collection routes in several locations distributed throughout an urban area and unload the collected waste at a transfer station located on the city's outskirts. From this point on, waste is transported to a sanitary landfill using sets of tractor unit and semitrailers, such as vehicles P19. This application constitutes another CST, in which the load is transferred from one location (transfer station) to another location (sanitary landfill). Figure 1 shows a diagram of this operation with both CSTs.

Figure 1: Illustration of the urban waste collection operation



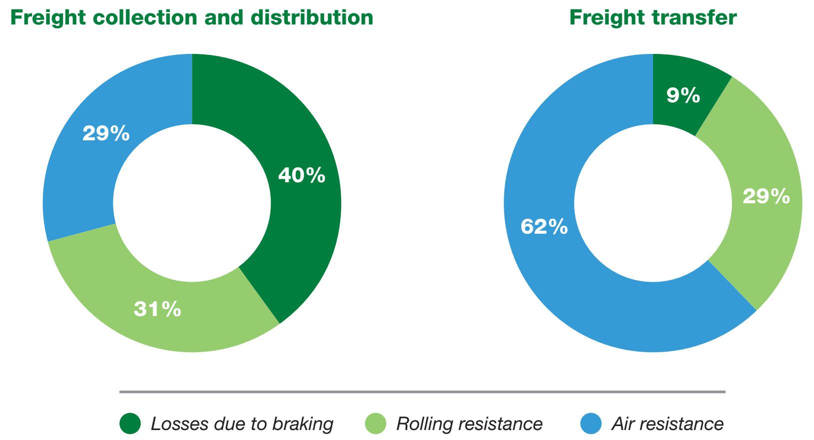
Urban waste collection trucks, equipped with waste compactors (P5, P5A, P6, P7 and P25), besides continually using part of the energy from the burning of fuel in the engine to compact waste, are subjected to a "stop and go" operation in urban traffic, since they may face traffic congestion and significant external intervention of other flows of vehicles and pedestrians. For that reason, these vehicles usually have low energy performance (Table 2) when compared to vehicles with the same total gross weight (TGW) that perform other kinds of service, such as food and beverage delivery in urban areas. On the other hand, this situation does not necessarily occur with the vehicles that transfer waste from transfer stations to sanitary landfills (P19).

Table 2: Truck fleet of the CST that is candidate to the application of the best practice

Type	Capacity [m³]	Monthly mileage [km/month]	Fuel economy [km/l]	Fleet [units]
P5	6	4,700	2.00	18
P5A	10	4,900	2.00	10
P6	15	4,300	1.75	95
P7	19	4,500	1.50	80
P25	19	4,200	1.50	18

Figure 2 properly illustrates the difference between the operational profile of freight collection and distribution vehicles (urban transport) and freight transfer vehicles (interurban transport). It can be noticed that, in the operation of freight collection and distribution, most of the energy consumed (40%) is associated to braking losses, since the vehicles are subject to a “stop and go” operation. The same is not true for the operation of freight transfer, where the greatest percentual (62%) is associated to aerodynamic resistance, since the vehicle has the possibility of traveling on roads where it can reach speeds above 80 km/h.

Figure 2: Energy use in freight collection, distribution and transfer



Furthermore, vehicles that operate at the municipal cleaning company travel average monthly mileages that range from 4,000 km to 5,000 km (Table 2), leading to high fuel consumption, which is the highest variable operational cost of this activity.

Improving the energy performance of urban waste collection vehicles is an opportunity to reduce costs, while simultaneously reducing: (1) the consumption of a non-renewable energy source, petroleum-derived diesel oil; (2) the emission of greenhouse gases (GHG), responsible for climate changes, of which carbon dioxide (CO_2) is the main component in the transport sector; and (3) the emission of local-action air pollutants (AP), which impact the health of urban populations.

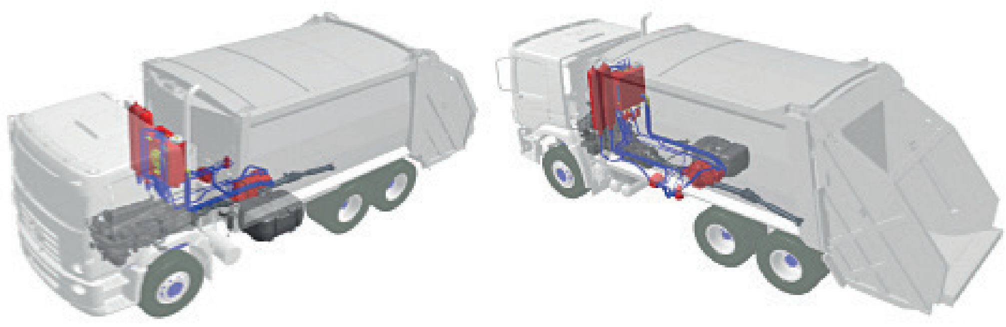
Considering the above, at a first approach, the municipal urban cleaning company identified the opportunity of improving energy performance in urban waste collection vehicles through the use of alternative propulsion systems in vehicles that could take advantage of braking energy losses.

Best Practice: use of alternative propulsion systems

This best practice consists of using a vehicle with a propulsion system different from the conventional one (internal combustion engine and mechanical transmission system). In road transport, vehicles are usually equipped with either hybrid (electric, mechanical or hydraulic) or electric propulsion systems.

The means of intervention chosen for the application of this best practice was using a vehicle equipped with a hybrid diesel-hydraulic propulsion system, as shown in Figure 3. This propulsion system is equipped with a Hydrostatic Regenerative Braking (HRB) device that enables the partial recovery of the energy lost during braking. Its goal is to improve fuel economy and, consequently, add economic, environmental and social benefits to the operation being performed.

Figure 3: Illustration of the diesel-hydraulic hybrid propulsion system



Choice of attributes, indicators and measures

It was identified that there was a potential to use this best practice in 223 trucks of the fleet of the municipal urban cleaning company (Table 2). In order to subsidize the decision of replacing vehicles with conventional propulsion systems by vehicles equipped with alternative propulsion systems, a set of attributes, indicators and measures were established so as to evaluate the economic and environmental benefits of adopting this best practice.

The economic attribute selected was cost and the environmental attributes were energy, greenhouse gases and air pollutants. It is important to highlight that, considering all the attributes of level of service[6], the truck equipped with a diesel-hydraulic propulsion system satisfactorily replaces the vehicle equipped with a conventional propulsion system.

As an indicator related to the attribute of cost, additional cost (AC) was selected, as specified in Equation 1. The environmental indicators selected were: fuel volume, in liters; the mass of carbon dioxide, in kg of CO_2 and the masses of air pollutants[7], in kg of CO, NMHC, NO_X and PM.

In order to form the performance measures to evaluate this best practice, one month of operation was adopted as a time indicator. In this way, the measures of cost, greenhouse gas emissions and air pollutants were evaluated on a monthly base.

Method of comparison

Considering that an innovative technology is being used (HRB) and that its benefits depend on the capacity this technology has of generating an effective reduction in fuel consumption, a field test was carried out to confirm the interval of economy that HRB would bring to the real operation of the urban cleaning company. The levels of fuel economy obtained through the field test were evaluated using the ANOVA[8] statistical method and compared to the data found in the literature, thus allowing the establishment of a fuel economy value ranging from 15%, a characteristic of the vehicles that have higher energy performance (2.0 km/l) because they have a lower TGW and less frequent stop and go behavior, and 25%, characteristic of vehicles that have lower energy performance (1.5 km/l) because they have higher TGW and more frequent stop and go behavior.

Since the vehicle equiped with a diesel-hydraulic hybrid propulsion system is 25% more expensive than the vehicle equipped with a conventional propulsion system, it is expected that the fuel economy compensates in the long term for this initial difference in capital cost and the periodic additional costs with maintenance (EMC) of the HRB. The economic assessment was based on the cash flow of uniform monthly costs, in which additional cost (AC) is monthly distributed as capital cost (CC) and equipment maintenance costs (EMC), as shown in Equation 1. The costs may

6 Safety, reliability, time, flexibility and capacity.

7 CO – carbon monoxide, NMHC – non-methane hydrocarbons, NO_x – nitrogen oxides and PM – particulate matter.

8 ANOVA is a statistical technique of variance analysis that enables the evaluation of statements about population means. The analysis fundamentally aims to check whether there is a significant difference between the means and whether the factors exert influence on any dependent variable.

be recovered according to the financial economy (FE) reached through fuel economy, whose total is a function of the average monthly mileage.

$$AC = CC + EMC \quad (1)$$

Where, AC is the additional cost;
CC is the capital cost;
EMC is the equipment maintenance cost;

In the case of environmental indicators, its results were reached considering that the reduction in fuel consumption proportionally reduces the emission of GHG and air pollutants.

Comparison of results

The use of vehicles equipped with a diesel-hydraulic hybrid propulsion system has the potential of reducing fuel consumption to an amount that compensates for the additional costs after a certain monthly traveled mileage, as can be observed in Figure 4.

Figure 4: Economic assessment of the use of vehicles equipped with a diesel-hydraulic hybrid propulsion system

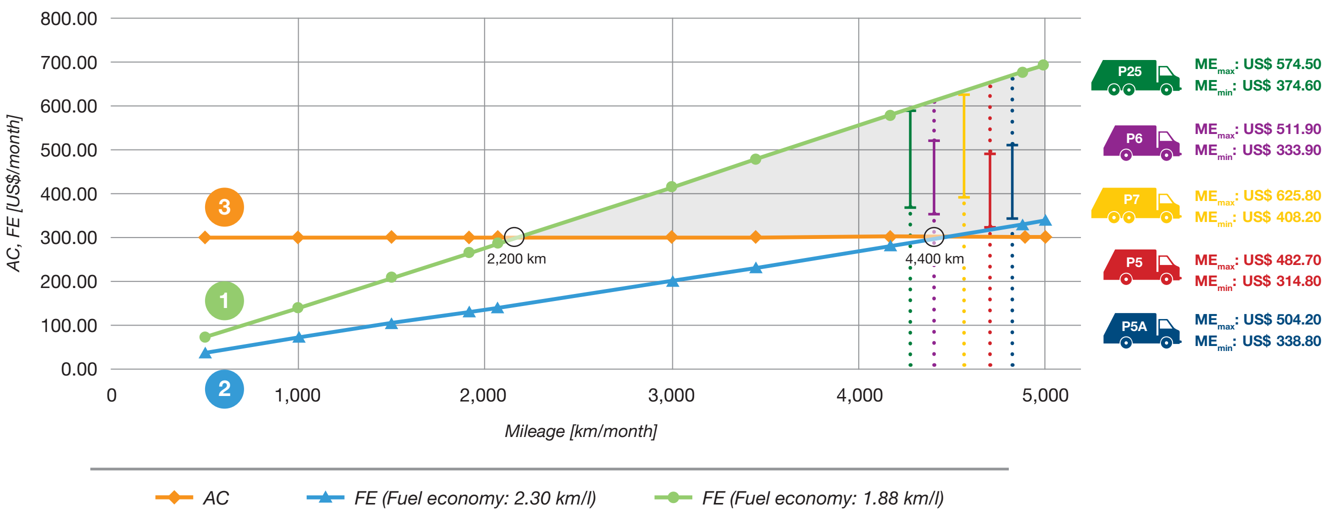


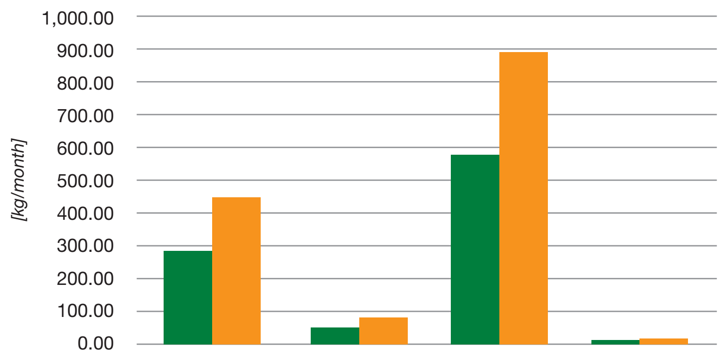
Figure 4 shows that, for the estimated economic life span of 60 months, the vehicles that have the lowest energy performance (1.5 km/l) and that could have better results (25% savings) through the use of the diesel-hydraulic propulsion system (Curve 1) would have economic viability above an average monthly mileage of 2,200 km. For vehicles that have higher energy performance (2.0 km/l) and which could have worse results (15% savings) through the use of a diesel-hydraulic hybrid propulsion system (Curve 2), this average monthly mileage would be 4,400 km. Figure 4 also shows that all vehicles of the urban cleaning company have average monthly mileages that enable the economic viability of the use of a diesel-hydraulic hybrid propulsion system, considering that in all cases the interval of financial economy (FE) is within the viability area (blue triangle) and the minimum FE is above US$ 300.00, which is the value of monthly additional costs (Curve 3).

The additional investment for applying the best practice to the fleet of 223 vehicles of the urban cleaning company would be of US$ 3,000,000.00, which could be recovered in thirty two months[9]. The estimated reduction in monthly

9 The SELIC rate used was that of 2011, time in which this case was developed.

consumption is of 107,000 l of diesel oil, which would result in avoiding the emission[10] of 265 t of CO_2 and an economy of US$ 110,000.00[11] per month. The reduction profiles of the emission of air pollutants[12] are shown in Figure 5.

Figure 5: Reduction profile of local pollutant emissions



	CO	HCNM	NO_x	MP
15% reduction in consumption [kg/month]	287.44	50.87	572.45	5.72
25% reduction in consumption [kg/month]	440.74	78.00	877.75	8.77

Legend: CO – carbon monoxide, NMHC – non-methane hydrocarbons, NO_x – nitrogen oxides and PM – particulate matter

Final considerations

Due to the specific characteristics of the activity, urban waste collection trucks have a non-continuous operation, with cycles of braking and acceleration, and face different urban situations. These are favorable conditions for the application of the listed best practice, especially within the average monthly mileage ranges practiced by the vehicles of the urban cleaning company, as depicted in Figure 4. Results showed that there is a potential for reduction in fuel consumption and in CO_2 and air pollutant emissions, in addition to economic benefits that enable the viability of the initial investment with a return in thirty two months, a time lower than the expected economic life span of the vehicles (60 months). There is still a monthly economy of US$ 110,000.00 with fuel and US$ 45,900.00 of monthly benefits after paying for the capital costs and equipment maintenance costs.

The same system is used to evaluate whether this intervention method may be used for other intervention methods for this same best practice, such as the use of diesel-mechanical hybrid propulsion systems or electric propulsion systems. This system will also be useful in the assessment of means of intervention associated with other best practices such as, for example, the use of cleaner energy sources, renovation and modernization of the fleet, use of vehicles with higher energy efficiency, use of tires with low rolling resistance, reduction of the vehicle's weight, use of additives to improve fuel energy efficiency and the installation of emission control equipment on the vehicles.

Acknowledgments

We thank the authors Leonardo Alencar de Oliveira, Marcio de Almeida D'Agosto, Vicente Aprigliano Fernandes and Cíntia Machado de Oliveira for producing the article titled A financial and environmental evaluation for the introduction of diesel-hydraulic hybrid-drive system in urban waste collection, published in the journal Transportation Research Part D, in 2014, which originated the example of best practice described above.

10 The emission factor considered was of 2.604 kgCO2/l and the diesel fossil blend used was of 95% (B5).

11 Diesel price was of US$ 1.03.

12 OThe emission factors used, in g/l, were: CO = 3.667; NMHC = 0.649; NO_x = 7.303; and PM = 0.073.

The effect of eco-driving practices in urban waste collection

Solid waste collection in urban areas

As shown in the previous section, waste collection is a common daily operation in all cities. However, the energy economy potential and, consequently, the reduction of greenhouse gas (GHG) and air pollutant (AP) emissions in this process are still not often addressed. Best practices in freight transport applied to the management of urban solid waste have the potential to contribute to an improvement in the energy efficiency (EE) of transport in cities. With that in mind, this section aims to evaluate the eco-driving technique applied to the fleet of waste collection trucks of the municipal urban cleaning company of the city of Rio de Janeiro, as shown in Figure 1 of the previous section (Use of vehicles with a propulsion system different than the conventional one (internal combustion engine and mechanical transmission system)).

For this company, a typical waste collection operation in urban area involves two operational regimes: collection and transfer. The waste compactor trucks (P6) are used during domestic collection, which involves an operation with cycles of stop and go every 50 meters. The vehicle is equipeed with a waste compactor, generating additional fuel consumption. Every time they are fully loaded, the waste compactor trucks go to a Waste Transfer Station (WTS), where they unload the waste, which will be carried in sets of tractor unit and semitrailer (P19) and transferred to the Waste Treatment Center (WTC). Although they also operate in urban areas, the transfer trucks transport waste to a single delivery point without intermediate stops.

Best Practice: driver training (eco-driving)

This best practice consists in the establishment of a continuous and periodic training program for drivers, administrative support team and vehicle maintenance team. This training aims to teach economic, safe and environmentally sustainable driving techniques. As a result, it is expected that energy consumption is reduced and, in the case of fossil fuels, that there is a reduction in GHG and AP emissions.

Eco-driving is a process of decision making that includes: strategic decisions (such as vehicle purchases), tactical decisions (such as vehicle maintenance, vehicle loading and route selection) and operational decisions (such as trip change, driving style and behavior changes).

A pilot training about eco-driving was offered to 22 drivers in a fleet of 11 trucks of the P6 and P19 types (Table 3). This training includes, at least, two days of classes. On the first day, theoretical classes are given addressing the following eco-driving techniques: (i) anticipating traffic conditions; (ii) adequately using brakes; (iii) driving at a constant speed; (iv) avoiding low engine gears; and (v) properly shifting gears. On the second day, there is a practical training in which the instructor shows how to apply eco-driving techniques and assess whether the driver properly executes the recommended driving behavior.

Table 3: Description of vehicles used in the eco-driving training

Type	Vehicle description	Capacity [m³]	Fleet	Vehicles used in the training	Fuel economy [km/l]	Average monthly mileage [km]	Use
P19	Tractor unit and semitrailer set	45	43	4	1.70	10,000	Transfer
P6	Truck with 2 axles and a compactor	15	97	7	1.21	5,200	Collection

Choice of attributes, indicators and measures

In order to subsidize decision making regarding the adoption of training on eco-driving, one should evaluate, under a strategic perspective, the opportunity of its implementation and continuity, considering whether the benefits originating from the reduction of operational cost resulting from fuel consumption economy compensate for the expenses with periodic training and confirm the expected environmental benefits. For that purpose, attributes, indicators and measures were established so as to enable the assessment of economic and environmental benefits related to adopting this best practice.

The chosen economic attribute was cost and the environmental attributes were energy consumption and GHG and AP emissions. The indicators related to total operational cost [R$] are: volume of fuel consumed [l]; distance traveled in kilometers [km]; and the emissions of GHG [kg] and AP [g].

In order to form the performance measures to assess this best practice, the period of one month was adopted as the time indicator for the average distance traveled and the period of one year for the economic evaluation. For energy performance, the measure used was km/l.

Method of comparison

The data were collected before and after the training during a period of three months. In order to estimate the gains with energy performance, data were collected regarding fuel consumption (l) and distance traveled (km). After gathering these data, a statistical treatment of the data was carried out to eliminate the outliers, adopting a conservative criterion of maintaining data dispersion within the range of three standard-deviations. Within this period, the average monthly distances traveled by the P6 and P19 trucks were of 5,200 km and 10,000 km, respectively.

The economic evaluation is based on uniform monthly cost. The capital cost (CC) is represented by the product between additional cost (AC) of eco-driving training and the capital recovery factor (CRF). The financial economy (FE) is found based on fuel economy.

The environmental evaluation is based on a bottom-up analysis to estimate emissions of: carbon dioxide (CO_{2e}), considered as GHG; and nitrogen oxides (NO_x), non-methane hydrocarbons (NMHC), carbon monoxide (CO) and particulate matter (PM), considered as AP. The emissions are calculated by multiplying the emission factor by the average fuel consumption of each vehicle running on fossil fuel used in the operation (Table 4). Due to the legislation in force at the time, the vehicles were fueled with a blend made of 5% biodiesel and 95% mineral diesel with low sulfur content (10 ppm), called S10 B5 diesel.

Table 4: Emission factors for air pollutants and greenhouse gases[13]

Model	Vehicle Type	Fuel	CO_{2e} [kg/l]	CO [g/l]	NMHC [g/l]	NO_x [g/l]	MP [g/l]
Euro 5	Truck (PBT>15t)	Diesel	2.71	3.66	0.64	7.30	0.073

Notes: 1 – this factor already considers the emission of CO_2, CH_4 and N_2O.
Legend: CO_{2e} – equivalent carbon dioxide, CO – carbon monoxide, NMHC – non-methane hydrocarbons, NO_x – nitrogen oxides and PM – particulate matte

Comparison of results

With pilot training, the increase in energy performance was greater in the waste transfer operation. Therefore, for the P6 vehicles there was an average improvement of 0.8%, while for P19 vehicles the average improvement was of 7.1%, as shown in Table 5.

Table 5: Energy performance (km/l) in pilot training

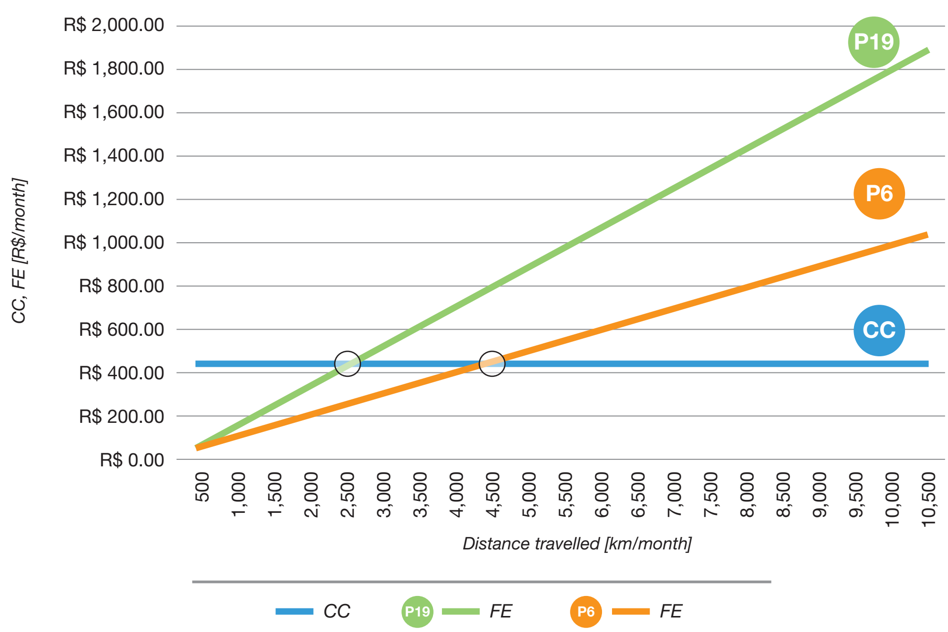
Vehicles	Before training (Scenario a)	After training (Scenario b)
P6	1.21	1.22
P19	1.70	1.83

The financial evaluation of pilot training involves an investment value to carry out two eco-driving trainings every year, during five years. So the uniform monthly cost of the training is of R$ 427.24 for one class.

For P6 vehicles, Figure 6 shows that the financial return starts at 4,500 km/month, below the average distance traveled monthly, which is of 5,200 km/month. During the whole month, a total of R$ 455,41 was saved with fuel consumption, surpassing the monthly investment of R$ 427,24.

In the case of the P19 vehicles, the application of the pilot training proved more favorable, since the average monthly mileage of the P19 is of 10,000 km/month and costs start compensating at 2,500 km/month. During the whole month, a total of R$ 1,711.79 was saved with fuel consumption, greatly surpassing the monthly investment of R$ 427,24.

Figure 6: Financial evaluation of eco-driving



13 Adapted from "Greenhouse Gas Inventory and Emissions Scenario of Rio de Janeiro City - Brazil Technical Summary" (2011).

Regarding the environmental evaluation, Table 6 and Table 7 show the GHG and AP emissions before (Scenario a) and after (Scenario b) the training for the fleet of 11 vehicles (P6 and P19), as well as the monthly benefit obtained (reduction).

Table 6: GHG and AP emissions – P6

Reference	Fuel consumption [l/month]	CO_{2e} [kg]	CO [g]	NMHC [g]	NO_x [g]	PM [g]
Scenario a	30,082.64	81,523.96	110,313.1	19,523.63	219,693.5	2,195.97
Scenario b	29,836.03	80,855.74	109.408.9	19,363.61	217,892.8	2,177.98
Reduction	246.61	668.22	904.19	160.02	1,800.75	17.99

Table 7: GHG and AP emissions - P19

Reference	Fuel consumption [l/month]	CO_{2e} [kg]	CO [g]	NMHC [g]	NO_x [g]	PM [g]
Scenario a	23,529.40	63,764.68	86,282.32	15,270.56	171,835.30	1,717.60
Scenario b	21,857.92	59,234.96	80,153.00	14,185.76	159,628.40	1,595.60
Reduction	1,671.48	4,529.72	6,129.32	1,084.80	12,206.88	122.00

Table 8 shows a summary of the financial evaluation of the implementation of the eco-driving training in the total truck fleet with compactors and vehicles of the P19 type, assuming that all of them would reach a performance improvement similar to that of the study case regarding fuel economy.

For compactor trucks, the calculation considers the eco-driving training being hypothetically applied for a fleet of 223 vehicles and 446 drivers. In order to reach all drivers, it would be necessary to form 15 classes with 30 students each. As a consequence, the total investment value to carry out two trainings each year, for five years, would be of R$ 311,273.00, which would lead to a uniform monthly cost of R$ 6,408.00.

For vehicles of the P19 type, the general case considers the eco-driving training being hypothetically applied for a fleet of 43 vehicles and 86 drivers. This situation would require forming three classes with 30 students each, which would receive two eco-driving trainings each year, for 5 years. This would lead to a total investment of around R$ 62,250.00 with a uniform monthly cost of R$ 1,280.00.

Therefore, as shown in Table 8, the general case seems economically favorable both for compactor trucks and for the P19 vehicles, since the monthly financial economy would cover the monthly expenses with the training.

Table 8: Monthly financial economy for the general case

Vehicle (general case)	Average monthly distance traveled [km]	Average monthly distance to achieve compensation [km]	Monthly financial economy
Compactor trucks	5,200	2,250	R$ 8,100.00
P19 Vehicles	10,000	500	R$ 34,161.00

When the results of the environmental evaluation of the pilot training for the whole fleet are extrapolated, due to the linear behavior with the distance traveled and the fuel economy, the percentage of GHG and AP emissions reduction both for compactor trucks and for P19 vehicles would remain at 0.8% and 7.1%, respectively Tabela 9 shows the monthly reduction of GHG and AP emissions for compactor trucks and P19 vehicles.

Table 9: Monthly reduction of GHG and AP emissions for the whole fleet

Vehicle	CO_{2e} [kg]	CO [g]	NMHC [g]	NO_x [g]	MP [g]
Compactor trucks	9,260	12,506	2,187	24,943	249
P19 Vehicles	48,695	65,765	11,500	131,170	1,312

Final considerations

Eco-driving is a practice that may improve sustainability in the collection and transfer of waste in urban areas, promoting financial return according to the mileage traveled. Considering the whole fleet of compactor trucks and P19 vehicles, the monthly financial benefits achieved by the evaluated operation reached a total of R$ 8,100.00 and R$ 34,161.00.

The best practice not only affects fuel economy, but also the reduction of CO_{2e} and AP emissions, at about 0.8% for vehicles with compactors and 7.1% for the tractor unit and semitrailer sets. For a period of 5 years, approximately 3.9 thousand tons of CO_{2e} would be avoided.

Additionally, it should be highlighted that eco-driving is a best practice that may be adopted in combination with many others, among them: the use of different types of vehicles to carry out deliveries and collections; the renovation and modernization of the fleet; carrying out night collection and distribution; and route optimization.

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An analysis of sustainability of the case of postal service in the city of Rio de Janeiro

Postal distribution in urban area

The urban population worldwide may reach 70% until 2050[14], with a potential growth in the demand for urban transport services in the cities. The activity of transport for the distribution of goods and services in urban areas is responsible for promoting social, environmental and economic impacts, especially regarding the intensification of traffic congestions, air pollutant emissions, sound pollution and greenhouse gases (GHG), particularly carbon dioxide (CO_2), besides increasing costs and decreasing population safety due to the increased number of accidents[15],[16].

The operations that take place during the last mile are responsible for aggravating these impacts. Furthermore, this is the phase in which there is evidence of the highest participation of transport costs in a supply chain[17]. Thus, the cities need to advance in their transformations and allow the innovative exploration of Urban Freight Transport (UFT) forms of operation, especially regarding the development of new technologies[18].

In this scenario, the technology of electric tricycles has been considered an alternative and sustainable solution to urban mobility, considering that it meets the sustainability expectations of the contemporary world in face of worsened air quality in the cities due to the intensive use of vehicles with internal combustion engines and fossil fuels[19].

In Brazil, the postal company practices the distribution of correspondences in urban areas by means of the so called traditional intermodal distribution (TID), which is carried out through the sequential combination of walking, use of conventional buses and the operational support of a light commercial vehicle equipped with an internal combustion engine.

14 United Nations. (2014) World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352). New York, United. doi:10.4054/DemRes.2005.12.9

15 Fernandes, V. A., D'Agosto, M. D. A., Oliveira, C. M. de, Assumpção, F. D. C., and Deveza, A. C. P. (2015) Eco-driving: a tool to improve sustainability in the transport of urban waste. TRANSPORTES, 23(2), 5. doi:10.14295/transportes.v23i2.773

16 McKinnon, A. C., Browne, M., and Whiteing, A. E. (2012) Green logistics: improving the environmental sustainability of logistics. Kogan Page

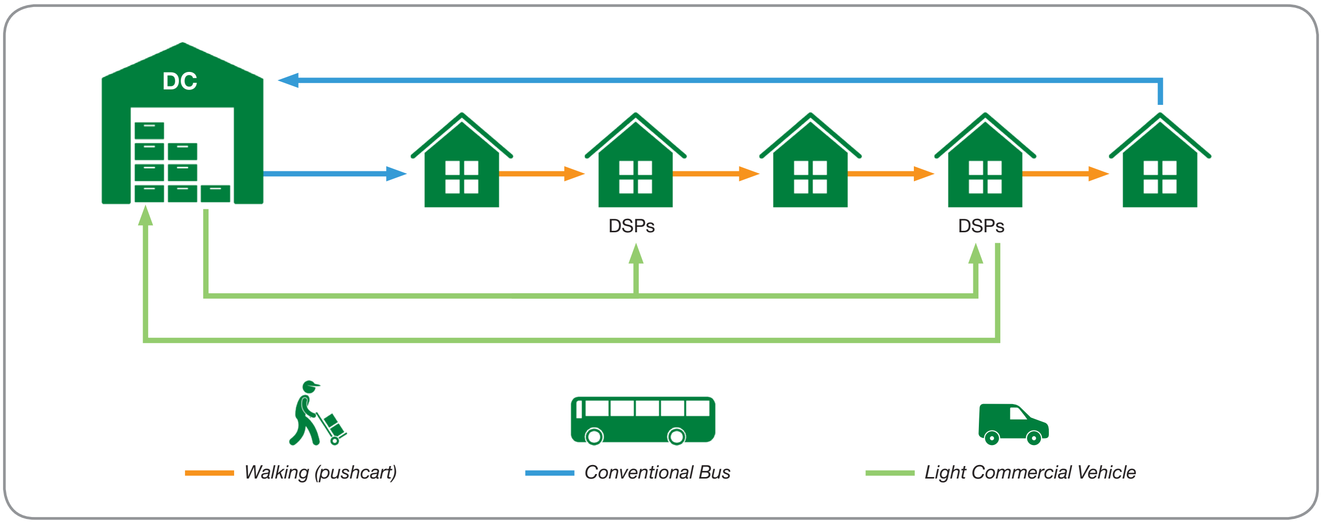
17 Roumboutsos, A., Kapros, S., and Vanelslander, T. (2014) Green city logistics: Systems of Innovation to assess the potential of E-vehicles. Research in Transportation Business & Management, 11, 43–52. doi:10.1016/j.rtbm.2014.06.005

18 Björklund, M., and Gustafsson, S. (2015) Toward sustainability with the coordinated freight distribution of municipal goods. Journal of Cleaner Production, 98, 194–204. doi:10.1016/j.jclepro.2014.10.043

19 Cherry, C. R. et al. Comparative Environmental Impacts of Electric Bikes in China. Transportation Research D, V. 14, pg. 281- 290, 2009. https://doi.org/10.1016/j.trd.2008.11.003

Due to legal limits, the weight of the mail carrier's bag, established via a collective agreement negotiated by the mail carriers union, is of 10 kg for men and of 8 kg for women. Therefore, mail carriers have the support of a light commercial vehicle with an internal combustion engine to transport the exceeding weight to predefined points in their routes, which are the distribution support points (DSP). When finishing the delivery of a bag, mail carriers go to a DSP to refill their bags and, from then on, a new distribution begin, which is carried out on foot. After finishing their route, mail carriers return to the DC using a conventional urban bus, as shown in Figure 7.

Figure 7: Traditional Intermodal Distribution



Best Practices: using different types of vehicles to carry out deliveries and collections and using alternative propulsion systems

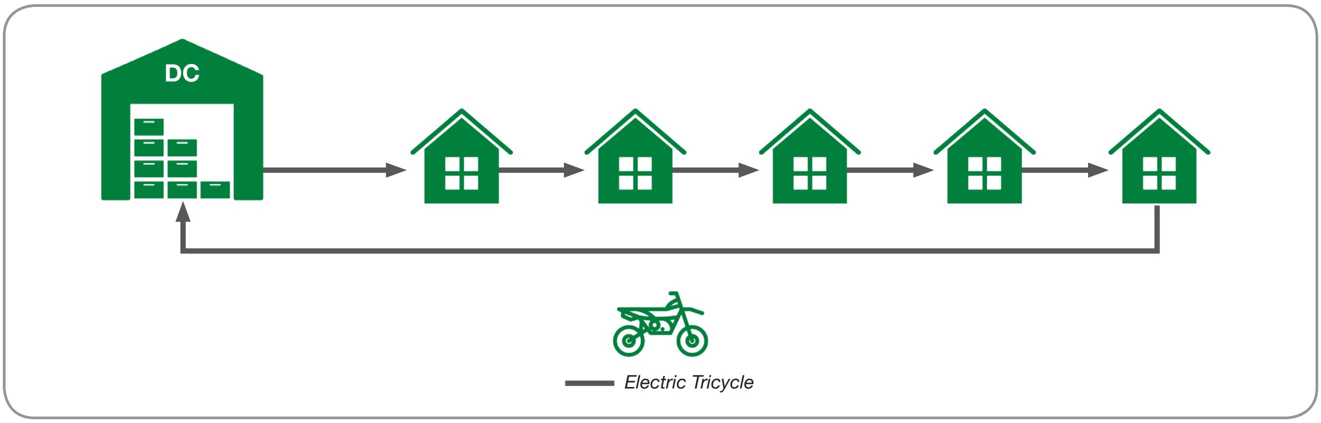
The postal company identified the possibility of implementing two best practices to improve the sustainability of traditional intermodal distribution.

- **Using different types of vehicles to carry out deliveries and collections**
  This best practice consists of using a greater variety of vehicles to carry out deliveries and collections in order to reduce delivery time and meet the needs of customers established in areas of restricted traffic for medium and large vehicles. Therefore, there is a possibility of using small vehicles, such as vans, and/or non-motorized vehicles, such as tricycles and bicycles. It is a best practice usually deployed in urban freight transport.

- **Using alternative propulsion systems**
  This practice consists of the use of a vehicle with a propulsion system different than the conventional one (internal combustion engine and mechanical transmission system). Usually, those vehicles are equipped with a hybrid (electric or hydraulic) or electric propulsion system. This best practice aims to reduce energy consumption in transport operation while impacting on the reduction of GHG and air pollutant emissions.

Thus, the proposed alternative was the carrying out of postal distribution with the support of an electric tricycle (DET). This operation is carried out with the support of the electric tricycle throughout all the route, so the weight limit becomes the capacity of the tricycle (for the case in question, the capacity of the tricycle being used is of 50 kg), instead of the legal restriction imposed by the union's collective agreement. The mail carrier performs the main displacement of the first leg, from the DC to the first point of service, using the electric tricycle. Upon arriving the delivery location, the carrier parks the vehicle and carries out deliveries in the vicinity on foot, as shown in Figure 8.

Figure 8: Distribution with the support of an Electric Tricycle (DET)



In order to evaluate DET, the tests were conducted in the neighborhoods of Leme and Copacabana in the city of Rio de Janeiro (Figure 9), Brazil. These neighborhoods have a small area (4.1 km^2), with 100 blocks, 78 streets and five avenues, and high population density (36,000 inhab./km^2)[20] and are located in a flat area between mountains and the sea. These factors constitute a scenario of high complexity for urban distribution, justifying the choice of the location to carry out the experimental test.

Figure 9: Location for the application of the best practice

Choice of attributes, indicators and measures

In order to subsidize decision making regarding the adoption of these two practices, a set of attributes, indicators and measures was established to evaluate the economic, environmental and social benefits of adopting the best practice.

The economic attributes chosen were cost and the number of clients served during the operation cycle's time (level of service). The environmental attributes considered were energy consumption, greenhouse gas emissions and air pollutant emissions. The social attribute considered was the effort made by the mail carrier measured through his/her heartbeat rate.

20 Demographic Census, IBGE. Available at: http://www. ibge. gov. br. Access on, v. 3, 2010.

The indicators regarding the cost attribute were total operation cost [R$], distance traveled [km], total delivery time [day[21]]. The selected environmental indicators were volume of fuel consumed [l]; greenhouse gas (GHG) emissions [kg] and air pollutant emissions (AP) [kg]. The chosen indicator of the effort made by the mail carrier was the maximum heartbeat rate (HR) [bpm].

In order to form the performance measures to evaluate this best practice, the time indicator adopted was one day of operation. So the cost measures have a daily basis, while the greenhouse gas and air pollutant emissions were assessed in the total period of operation.

Method of comparison

The data were gathered, from Tuesday to Thursday, during ten days, five days for each type of operation, TID and DTE. The data gathered may be grouped into the following items:

(i) time – round trip and delivery;
(ii) distance – round trip and delivery;
(iii) average speed – round trip and delivery;
(iv) number of customers served;
(v) mail carrier's heartbeat rate;
(vi) average fuel consumption; and
(vii) fuel cost.

The economic evaluation for the comparison of each distribution strategy (TID and DET) was based on the analysis of level of service and the gathering of transport costs. The level of service was measured based on the number of customers served per operation cycle time.

As for the environmental evaluation, in the TID operation the bottom-up method was adopted, so that the GHG and AP emission factors were multiplied by the average mileage traveled, except for CO_2, for which the emission factor was multiplied by the average fuel consumption of each internal combustion vehicle. The analyzed GHG were N2O (nitrous oxide), CH_4 (methane) and CO_2 (carbon dioxide). While the analyzied AP were CO (carbon monoxide), NO_X (nitrogen oxide), RCHO (aldehydes), NMHC (non-methane hydrocarbons) and PM (particulate matter).

The emission factors considered in the study were obtained from the 2nd National Inventory of Atmospheric Emissions by Road Automotive Vehicles[22], as shown in Table 10. Still, the estimation of the direct impact of the GHG deployed the conversion of emissions of CO_2, CH_4 and N_2O to CO_{2e}, considering the GWP factors of 1, 21 and 310, respectively.

Table 10: Emission factors considered in the study[22]

Year/Model	Fuel	$CO^{(1)}$	$NO_X^{(1)}$	$RCHO^{(1)}$	$NMHC_{escap}^{(1)}$	$CH_4^{(1)}$	$MP^{(1)}$	$N_2O^{(1)}$	$CO_2^{(2)}$
2013	Flex - Gasoline C	0.25	0.0030	0.0017	0.014	0.026	0.0011	0.026	2.0267
P6 and P7 PROCONVE 2012	Diesel	0.44	2.103	-	0.033	0.06	0.0200	0.03	2.5909

Note: (1) g/km; (2) kg/l, it is worth highlighting that the values presented were obtained through the weighted average of the proportion of fuels in the blend.

In the occasion of this case study, the buses were fueled with S10 B7 diesel, a blend that has 7% in volume of bio-diesel and 93% in volume of petroleum diesel oil. The light commercial vehicle was fueld with gasoline C, a blend that had 73% of automotive gasoline and 27% of anhydrous ethanol. Additionally, the data were gathered from the Union of Bus Companies of the City of Rio de Janeiro regarding the PKM[23] (1.67) and the energy performance (2.59 km/l) of municipal buses. The average performance of the light commercial vehicle was estimated based on data gathered in the operation with the same postal company (4.56 km/l). These data are shown in Table 11.

21 Business hours.
22 MMA, 2013. National Inventory of Atmospheric Emissions by Road Automotive Vehicles 2013: Baseyear 2012, Ministry of the Environment, Brasília, DF.
23 PKM – passenger kilometer indicator.

Table 11: Data regarding the vehicles used in the TID operation

Vehicle Type	Fuel	Energy performance [km/l]	IPK
Bus	Diesel S10 B7	2.59	1.67
Light commercial vehicle	Gasoline C	4.56	-

It must be highlighted that, since the DET operation is carried out only by electric tricycles and, therefore, does not emit GHG and AP, the environmental evaluation is based on the comparison of how much emission is avoided for each GHG and AP analyzed.

Regarding the evaluation of social impact, the effort made by the mail carrier in each of the distribution operations may be evaluated by monitoring the heartbeat and measured by the maximum heartbeat rate (HR), whose estimate is based on the age of the individual. According to the Americam College of Sports Medicine[24], the heartbeat rate per minute was subdivided into six percentage ranges in relation to the maximum HR, as shown in Table 12. The measure of comparison is given by the percentage of time the average hearbeat remains in each effort range while the activity is performed.

Table 12: Percentage ranges in relation to the maximum HR

HR ranges	
< 50 %	0 – 91 bpm
50 – 60 %	92 – 109 bpm
60 – 70 %	110 – 128 bpm
70 – 80 %	129 – 146 bpm
80 – 90 %	147 – 165 bpm
90 – 100 %	166 – 184 bpm

Comparison of Results

Table 13 shows details of the items considered for the composition of total costs in the analyzed route for each type of distribution (TID and DET). Based on Table 14, it is possible to see that the total daily cost of the analyzed routes for the TID and DET operations was of R$ 35.13 and R$ 26.96, respectively, with an identified potential cost economy of 23.25%.

Table 13: Details of the items considered for the composition of the total costs per type of operation (TID and DET)

Specifications of the operation	Unit	TID	DET
Number of days per month considered	unit	26	26
Average mileage traveled in the route	km	5.01	10.74
nº of trips per day	unit	2	1
average nº of bus fares	unit	2.40	-
Bus fare value in R$	R$	3.00	-
nº mail carriers served in the route	unit	10	1

24 ACSM, 1998. Position Stand. The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. Med. Sci. Sports Exerc. 30:975–991, 1998

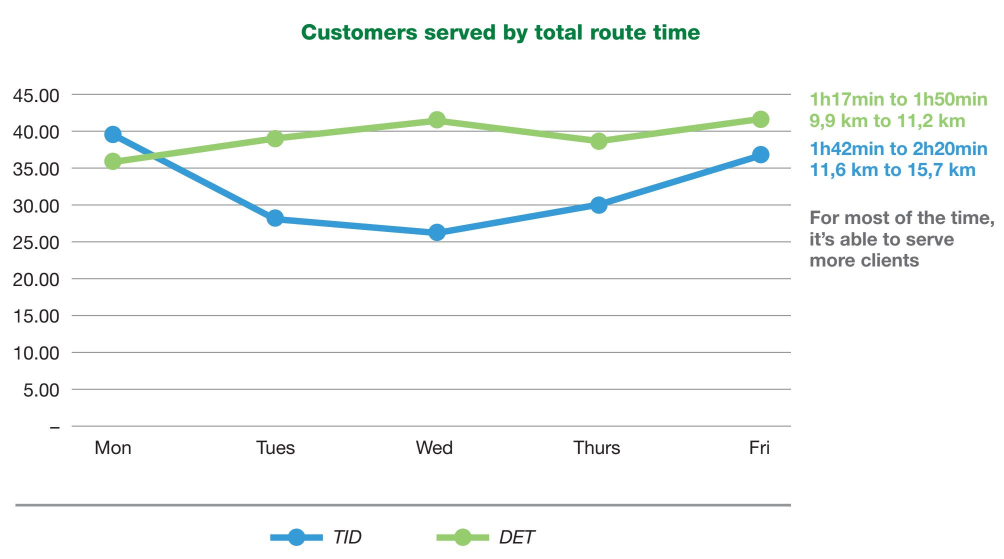
Table 14: Specification of fixed and variable costs considered in the TID and DET operations

Monthly Fixed Costs	Unit	VCL	Tricycle
Capital payment	R$	309.80	33.12
Driver salary + extra charges	R$	2,636.10	-
Mail carrier salary + route charges	R$	590.11	459.51
Workshop salary	R$	425.65	44.34
Vehicle replacement	R$	161.63	47.20
Licensing	R$	120.55	-
Vehicle hull insurance	R$	162.81	-
Optional civil liability insurance	R$	94.92	-
Total:	**R$**	**4,501.56**	**584.17**
Variable Costs per kilometer	**Unit**	**VCL**	**Tricycle**
Parts, accessories and maintenance materials	R$/km	0.7100	0.1973
Fuels	R$/km	0.7348	0.0100
Lubricants	R$/km	0.0153	-
Battery replacement	R$/km	-	0.0377
Washing and lubrication	R$/km	0.2857	0.1432
Tires	R$/km	0.0327	0.0309
Total:	**R$/km**	**1.7786**	**0.4192**

Moreover, it is important to highlight that, in the case of inserting electric tricycles in the postal distribution operation of Rio de Janeiro, public authorities would not need to adopt tax incentives. Even considering the acquisition of electric vehicles by the company, the economic analysis still showed a reduction in total transport costs in the DET in comparison to TID.

Regarding the level of service, there was a productivity increase of 26%, when comparing DET to TID. Results showed that the DET operation, besides consuming less time, was capable of carrying out a higher number of deliveries, serving more customers in the analyzed route, as can be seen in Figure 10.

Figure 10: Average number of customers served per route



Regarding the environmental evaluation, the emissions of the TID operation were the only ones estimated, as shown in Table 15, since the TID operation uses vehicles with Otto cycle and Diesel cycle engines, while the DET operation uses an electric vehicle, thus it may be considered as having null GHG and AP emissions.

Table 15: AP and GHG emission reductions

	Air Pollutants					Greenhouse Gases.			
	CO [g]	NOx [g]	RCHO [g]	NMHC [g]	MP [g]	CH_4 [g]	N_2O [g]	CO_2 [kg]	CO_{2e} [kg]
TID	10.11	32.78	0.02	0.7	0.33	1.27	0.81	20.73	21.01

Regarding the social aspect, Table 16 shows the comparison between the HR measured in TID and DET operations. The measurement was made with a 34-year-old employee, weighing 82 kg and a maximum HR of 184 bpm. Data indicate that, in TID operation, there is a greater variation of HR during the whole delivery operation (with a higher effort peak), while the DET operation showed a trend to a plateau, with constant HR during the whole operation.

Table 16: HR ranges measured in TID and DET operations

HR ranges		DTI average [%]	Standard Deviation	DTE average [%]	Standard Deviation	Variation % TID x DET
< 50 %	0 – 91 bpm	23.93	21.93	9.29	6.12	-61.17
50 – 60 %	92 – 109 bpm	52.42	15.84	84.83	2.59	61.81
60 – 70 %	110 – 128 bpm	22.01	22.09	5.88	4.85	-73.27
70 – 80 %	129 – 146 bpm	1.64	3.28	0	0	-
80 – 90 %	147 – 165 bpm	0	0	0	0	-
90 – 100 %	166 – 184 bpm	0	0	0	0	-

Final considerations

The adoption of the electric tricycle for postal distribution in Rio de Janeiro is aligned with the need for eliminating the negative impacts produced by the transport activity, especially because of the high consumption of energy from fossil origin. Results showed a reduction in costs and an improvement in level of service, considering the possibility of carrying out a higher number of deliveries per daily route performed and an increase in the number of customers served. Moreover, the insertion of electric tricycles showed positive results both from the environmental perspective, due to the emissions avoided, and from the social perspective, through the analysis of the worker's HR. This fact shows the efficiency of the alternative of adopting electric vehicles for freight transport in urban areas.

Furthermore, it is worth highlighting that using different types of vehicles to carry out deliveries and collections and using alternative propulsion systems are best practices that may be adopted in combination with: using cleaner energy sources and transferring freight transport to cleaner modes (modal shift).

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Evaluation of ecoefficiency in intermodality for regional freight transport

Intermodality in the distribution of limestone to the siderurgy industry

Despite the higher energy use efficiency with the railway mode in comparison to the road mode, the Brazilian transport matrix focuses on the latter, thus negatively impacting the performance of freight transport as a whole. Conventionally, railway and water (through vessels) services are offered in Brazil only if there is enough freight volume and a potentially profitable business for the transport operator[25].

In the last decade, the knowledge about the reduction of GHG emissions in road transport has substantially grown due to the concept of green road freight transport[26]. Therefore, the way freight is transported through the road mode has been rethought by means of the concept of ecoefficiency.[27, 28] In the primary sector, which deals with the transport of large volumes of freight that may have a low added value, such as commodities, the decision about which mode to use may not always be associated with a higher-capacity mode, in case there are no efficient intermodal platforms or the transport requires substantially longer routes.

In this context, the shipper needs a procedure to evaluate the freight transport alternatives so as to guarantee costs and level of service that are similar to the ones that would be achieved through conventional transport for commodities (which could use railways), without compromising the performance of environmental aspects associated with: (i) energy intensity; and (ii) air pollutant (AP) and greenhouse gas (GHG) emissions.

One method that may be used to evaluate the performance of specialized modes of transport and non-usual transport alternatives for the transport of products with low added value was applied at the steelmaker company Arcellor Mittal Tubarão (AMT), located in the Southeastern Region of Brazil.

25 ANTT (2016). Multimodal Logistic Corridors, Development of Transeuropean Transport Systems and Deployment of the Corridor Concept in Brazil. São Paulo, 2016.
26 Demir, E., Bektaş, T., & Laporte, G. (2014). A review of recent research on green road freight transportation. European Journal of Operational Research, 237(3), 775-793.
27 Bektaş, T., Ehmke, J. F., Psaraftis, H. N., & Puchinger, J. (2018). The Role of Operational Research in Green Freight Transportation. European Journal of Operational Research.
28 Guajardo, M. (2018). Environmental benefits of collaboration and allocation of emissions in road freight transportation. In Sustainable Freight Transport (pp. 79-98). Springer, Cham.

Regarding its productive chain, the company needs approximately 2.7 tons of input to produce one ton of steel, particularly iron ore, coal and limestone. Limestone, although essential to manufacture steel, represents a fraction of 0.04% in its composition[29], which places this product in an unfavorable position in relation to iron ore and metallurgical coal in the competition for the supply of specialized transport. On the other hand, limestone is characterized for having a low acquisition cost, which makes transport one of the most expensive and important components of the final cost of this product.

For the transport of limestone, the road mode, which has the highest costs and environmental impacts, is the most used one, followed by railway and water, which is used in combination with other land transport modes (road and railway)[30, 31, 32, 33].

Best Practice: Shifting freight transport to cleaner modes (modal shift)

This best practice consists of prioritizing, whenever possible, the use of modes of transport that consume less energy and generate less air pollutants and greenhouse gases (GHG) emissions when compared to the currently used mode of transport. Usually, this best practice considers shifting freight from the road mode to railway, cabotage and/or inland waterways modes, and it implies the replacement of a unimodal operation, when only the road mode is used, with a multimodal operation.

Choice of attributes, indicators and measures

In summary, for the economic aspect, the following attributes are considered: (1) cost, (2) time, (3) reliability and (4) safety. Regarding the environmental aspect, the attributes usually considered are: (1) energy consumption, (2) air pollutant emissions and (3) carbon dioxide (CO_2). These attributes are quantified through the identification of performance indicators.

For the economic aspect, the chosen measure was the cost of the alternative [R$/t], determined in function of: the transport cost using the mode of transport [R$/km]; the distance traveled by mode of transport [km]; the amount of product transported via the alternative [t]; the cargo handling cost at the terminal [R$/t]; and the operational cost of the equipment in each alternative [R$/t]

As for the level of service, the indicators are the average transport time for each alternative [h] and average reliability (in percentage of trip time variation). These indicators will be complemented by the measure of cost with product losses during transport (R$/t).

The environmental aspect comprises the measures of: average fossil fuel consumption per each alternative [l/t]; average energy consumption of each alternative [MJ/t]; air pollutant emission for each alternative [g/t]; and average emission of CO_2 for each alternative [kg/t]. Table 17 shows the performance measures used.

29 IAB, 2011. Statistical Yearbook 2011. Rio de Janeiro: Instituto Aço Brasil, 2011.

30 CNT, 2011. National Transport Confederation. Economic report of the transport sector, 2011. Available at:<http://www.cnt.org.br/Imagens%20CNT/PDFs%20CNT/Informe%20Econ%C3%B4mico/InformeEconomico07-2011.pdf> Access on December 3rd, 2011.

31 Poso, A. T. The process of restructuring the international and the Brazilian steel industry: the case of the National Steel Company. Dissertation of Master in Science USP, São Paulo, SP, Brasil, 2007.

32 Castro. N. Structure, performance and perspective of railway freight transport. Economic research and planning, v.32, n.2, ago.2002.

33 Coelho Neto, G.; Ribeiro, P.C.C.. "Transport in a company of the Brazilian steel industry". In: XXVI ENEGEP, Fortaleza, CE, Brazil, 9-11 October, 2006.

Table 17: Performance measures used

Aspects	Attributes	Measures		
		Description	Acronym	Unit
Economic	Cost	Cost of the alternative i (i´)	CAi (i´)	R$/t
	NS - Time	Average transport time of the alternative i (i´)	TAi (i´)	h
	NS - Reliability	Average reliability of the alternative i (i´)	VTAi (i´)	%
	NS - Safety	Cost with freight losses in the operation of the alternative i (i´)	CPAi (i´)	R$/t
Environmental	Energy consumption	Average energy consumption of the alternative i (i´)	CEi (i´)	MJ/t
	Air pollutants and GHG emissions	Average emission of air pollutant p by the alternative i (i´)	EPi, (i´)p	g/t
		Average CO_2 emission by the alternative i (i´)	ECO_2i (i´)	kg/t

Method of comparison

The method of comparison is based on an integrated approach of ecoefficiency, made of two steps.

Step 1 considers the identification of transport alternatives (Figure 11). It is our understanding that it is possible to identify a set of alternatives related to specialized transport (A_{TE}) and another set of unusual alternatives for the transport of freight with low added value (A_{NUT}). Specialized transport, in this case, is associated with transport modes of greater capacity. The unusual alternatives to transport low added value freight consider the use of other modes of transportation that enable the offer of services following the concept of ecoefficiency.

Figure 11: Illustrative diagrams (without scale) of the limestone transport alternatives

After the identification of the alternatives, it is time for Step 2, which allows the identification of a set of performance measures that relate resources and results for each alternative. It is worth highlighting that each alternative is made of a combination of modes of transport, which act in traffic segments connected through transhipment terminals.

After calculating the performance measures of each alternative, they are normalized (MNA_{TE} or MNA_{NUT}) so as to allow an isolated comparison among them. The comparison is achieved by means of Equation 2.

$$\sum_{i'=1}^{m} MN_{i'} A_{i'NUT} \; / \; \sum_{i=1}^{m} MN_i A_{iTE} > 1, \text{ so } A_{i'NUT} \text{ is better than } A_{iTE} \quad (2)$$

The results obtained through Equation 2 also enable the establishment of a hierarchy between the alternatives. In case one wishes to perform a sensitivity test, it is possible to attribute weights, ranging from 0 to 1, to the performance measures in order to value one of the aspects (economic or environmental).

In order to calculate the performance measures, it was necessary to gather data by monitoring the operation on the field throughout the year of 2014. Thus, the values of time of operation and energy consumption for locomotives, trucks, loaders and reach stacker (diesel oil) and for conveyor belts (electricity). Moreover, in this monitoring, losses were estimated by the difference between the mass of product loaded at the origin and received at the final destination. The cost values, in turn, were found through market consultation. The data are presented in Table 18 and in Table 19.

Table 18: Values of performance indicators measured on the field

Alternatives	Truck			Locomotive		
	Cost [R$/t]	Time [h]	Energy [l/t]	Cost [R$/t]	Time (h)	Energy [l/t]
A_{1TE}	8.42	1.5	0.57	47.66	109.48	2.78
A_{1NUT}	13.43	1.5	0.68	46.6	99.58	2.74
A_{2NUT}	6.01	1.77	0.16	39.33	66.81	2.51
A_{3NUT}	65.83	19.81	6.39	0	0	0

Note: A1TE, A1NUT, A2NUT and A3NUT as shown in Figure 11.

Table 19: Values of performance indicators measured on the field

Alternatives	Conveyor Belt			Loader		Container forklift	
	Cost [R$/t]	Time [h]	Energy [l/t]	Time [h]	Energy [l/t]	Time [h]	Energy [l/t]
A_{1TE}	14.89	0.04	0.32	1.44	0.12	0	0
A_{1NUT}	16.28	0.02	0.6	2.09	0.12	0	0
A_{2NUT}	20.25	0	0	0	0	1.08	0.47
A_{3NUT}	2.24	0.02	0.6	0.69	0.28	0	0

Note: A1TE, A1NUT, A2NUT and A3NUT as shown in Figure 11.

Table 20 shows the emission factors for each equipment used in the transport alternatives. The factors of energy content and CO_2 emission considered for diesel oil were of 40.87 MJ/l and 2.671 kg/l, respectively[34].

Table 20: Air pollutants and CO_2 emission factors[32, 35]

Equipment	CO_2 [kg/l]	CO [g/km]	HCNM [g/km]	NO_X [g/km]	MP [g/km]
Heavy truck	2.671	4.05	1.38	29.33	0.57
Loader	2.671	4.05	1.38	29.33	0.57
Container forklift	2.671	4.05	1.38	29.33	0.57
Maneuver locomotive	2.671	26.00	6.80	74.00	3.40
Traction locomotive	2.671	28.00	7.00	104.00	8.40

Comparison of results

Table 21 shows the values obtained for the performance measures and their normalized values are depicted in Table 22.

Table 21: Values of the performance measures for each of the alternatives

Aspects	Economic				Environmental					
Measures	CA [R$/t]	TA [h]	VTA	CPA [R$/t]	CE [MJ/t]	EP_{CO} [g/t]	EP_{HCNM} [g/t]	EP_{NOx} [g/t]	EP_{MP} [g/t]	E_{CO2} [kg/t]
A_{1TE}	70.97	112.46	0.09	33.22	126.82	22.30	5.88	92.58	5.70	9.38
A_{1NUT}	76.31	103.19	0.09	26.20	139.43	23.62	6.32	101.29	5.83	10.32
A_{2NUT}	65.59	69.66	0,03	5.91	113.06	20.98	5.43	84.50	5.60	8.39
A_{3NUT}	68.07	20.52	0.04	9.08	240.24	22.99	7.83	166.51	3.24	17.80

Note: A1TE, A1NUT, A2NUT and A3NUT as shown in Figure 11.

Legend: CA - average transport cost of the alternative; TA - average transport time of the alternative; VTA - reliability of the alternative; CPA - average cost with freight loss in the operation of the alternative; CE - average energy consumption of the alternative; EP - average emission air pollutants by the alternative; ECO_2 - average emission of CO_2 by the alternativ.

Table 22: Normalized values of the performance measures for each of the alternatives

Aspects	Economic				Environmental					
Measures	CA	TA	VTA	CPA	CE	EP_{CO}	EP_{HCNM}	EP_{NOx}	EP_{MP}	EP_{CO2}
A_{1TE}	0.924	0.111	0.333	0.178	0.891	0.941	0.923	0.913	0.568	0.894
A_{1NUT}	0.860	0.121	0.312	0.226	0.811	0.888	0.859	0.834	0.556	0.813
A_{2NUT}	1.000	0.180	1.000	1.000	1.000	1.000	1.000	1.000	0.579	1.000
A_{3NUT}	0.964	1.000	0.744	0.651	0.471	0.913	0.693	0.507	1.000	0.471

Note: A1TE, A1NUT, A2NUT and A3NUT as shown in Figure 11.

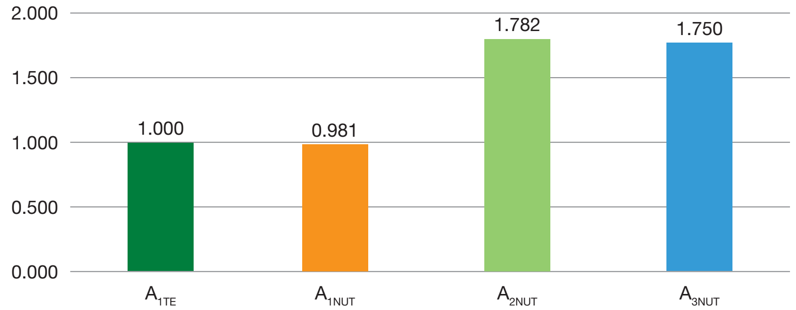
Legend: CA - average transport cost of the alternative; TA - average transport time of the alternative; VTA - reliability of the alternative; CPA - average cost with freight loss in the operation of the alternative; CE - average energy consumption of the alternative; EP - average emission air pollutants by the alternative; ECO_2 - average emission of CO_2 by the alternative.

34 MMA, 2011. 1st National Inventory of Road Automotive Vehicle Emissions, Ministry of the Environment, Brasilia, DF.

35 Lewis, P.E.; Rasdorf, W.; Frey, H.; Pang, S.; Kim, K. Requirements and incentives for reducing construction vehicle emissions and comparison of nonroad diesel engine emissions data sources. Journal of construction engineering and management. Vol. 5; pp. 341-351, 2009.

Figure 12 shows the results of the comparison of the performance measures for each of the alternatives as a group. The specialized transport alternative A_{TE} is considered as a reference adopting the value of 1.000. The higher the value found for each of the performance measures evaluated for the remaining alternatives, the better their performance, thus they become a candidate to be considered in the substitution of specialized transport.

Figure 12: Results of the comparison of alternatives as a group



Note: A_{1TE}, A_{1NUT}, A_{2NUT} and A_{3NUT} as shown in Figure 11.

Regarding the sensitivity analysis, Figure 13 shows the results found when applying a scale of weights that goes from A100 to E100. The hypothetical situation A100 considers in the performance evaluation only the measures associated with the environmental aspect when choosing alternatives. Situation E100 is a usual situation, when only the economic aspect (cost and level of service) is considered for the choice of alternatives.

Figure 13: Results of the application of weights for the environmental and economic aspects

Note: A_{1TE}, A_{1NUT}, A_{2NUT} and A_{3NUT} as shown in Figure 11.

Final considerations

The results presented with the application of the proposed procedure show that it is possible to choose an unusual alternative for the transport of a product with low added value and with superior performance when compared to the alternative of specialized transport under the perspective of the economic aspect, considering the cost and level of service indicators, without compromising the performance of the environmental aspect, which is essential to guaranteeing the current standards of environmental responsibility in companies.

The introduction of the environmental aspect in the evaluation of the performance of transport alternatives, using the proposed procedure, shows that the best choice would be A_{2NUT}, since it is the only one that maintains a level of performance superior to that of the specialized transport alternative - A_{1TE} (+8%) with the best alternative being the one in which the environmental aspect is considered in equity with the economic aspect (A100 until A50 in Figure 13).

Furthermore, it is worth highlighting that shifting freight transport to cleaner modes (modal shift) is a best practice that may be adopted in combination with: Using information systems to track and follow the fleet; Optimizing the operation of loading and unloading with the use of motorized equipment; Using vehicles with higher energy efficiency.

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Final considerations

The cases presented here show that it is possible to apply best practices that improve sustainability in freight transport as a logistics function, achieving results that guarantee good economic, environmental and, directly or indirectly, social performance.

The sustainable practice in freight transport and in logistics is no longer utopian, and it is an effective way of improving the efficiency of their primary activities. Practicing sustainability may be a very profitable business that guarantees long term social benefits. However, it is necessary to know where and how this will lead to better results.

This Application Guide proves that making these choices is possible, once there are approaches, methods, procedures and tools to evaluate sustainability in freight transport that are accessible to professionals that operate in companies, and that its use may support the adequate choice of where and how to obtain the best results in the application of the best practices presented here. It also proves that the synergy between the academy and the companies must be explored to the maximum, since it brings benefits to both sides. This is a recipe for success!

Spreading and applying knowledge is the best way to overcome the challenge of reaching sustainability in economic activities in a world that is in constant and fast transformation. Let us overcome this challenge together!