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Methodology for public passenger transport in developing countries: a survey

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Abstract

Transport is a basic and essential function in any economy or society that provides comfort in terms of travel, so the decrease in transport activity and the increase in its energy efficiency are fundamental elements in the global strategy to improve the sustainability.

In developing countries, the cities' transport systems that have a low-quality, are under the responsibility of different levels of government and are regulated in some essential aspects: vehicles, routes, and fares. However, the variety of vehicles sizes and years of use and the fact they are associated with a fragmented ownership in the hands of cooperatives or individuals makes daily operation and quality of service frequently problematic.

This paper presents a methodology that allows characterizing public passenger transport in developing countries. To know its characteristics and how they are related to energy consumption and associated emissions that serve as an instrument to support decision-making in planning.

Keywords: public passenger transport; energy consumption, simulation; developing countries

1. Introduction

Passenger transport is required to move people from one place to another, and requirements vary considerably between different places. Increases in populations in most developing countries are not proportional to car ownership, therefor this population depends on public transport and is used as an alternative for those who have private cars but due to congestion, parking difficulties or accessing problems prefer public transport use.

According to the World Bank, public passenger transport is crucial to reducing poverty, boosting prosperity, and achieving sustainable development goals, such as reducing energy consumption and emissions (TWB, 2018).

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However, the impact on energy consumption and emissions for public passenger transport in developing countries has not been extensively studied, as the characteristics of these countries are not considered (demand, type of vehicles, number of stops, age of vehicles, operation) for the implementation of improvements that minimize these consumptions and emissions. Therefore, a methodology that allows characterizing public passenger transport in developing countries is proposed. To know its characteristics and how they are related to energy consumption and associated emissions that serve as an instrument to support decision-making in planning.

2. Literature review

2.1. Public passenger transport

Transport is a basic and essential function, but it turns out to be a very energy-intensive activity dependent on oil as an energy source (Geltner, 1985). Therefore, the decrease in transport activity and the increase in its energy efficiency are fundamental elements in the global strategy to improve the sustainability of the current transport (Pérez Martínez & Monzón de Cáceres, 2008).

Concerning energy planning, the transport sector is crucial. In most regions, the transport sector is the largest consumer of liquid fuels (Wohlgemuth, 1997). Reviews show that energy-saving and efficiency measures applied to transport have not been sufficiently effective, and transport is currently the sector that consumes the most (DGIEyM, 2012). Energy consumption is measured through specific consumption, linking it to the time spent on travel or energy intensity (Trentadue & Carranza, 2014). Therefore, the phenomenon of transport and congestion that occur in large cities is a problem of energy waste (Ortúzar & Román, 2003; Moreno Quintero, 2006).

Since public passenger transport contributes to the energy use of transport in cities, it is important to carry out actions to improve its energy efficiency. The creation of strategies or policies for each transport activity, like its planning and optimization are basic steps for energy consumptions and emissions estimations (Predić, et al., 2016).

The efficient, comfortable, and safe transfer of people between the different places where they move and develop urban activities, facilitating the integration is the fundamental objective of a public passenger transport system (Jiménez Herrero, 2005). That is why the level and trends of fuel consumption in public passenger transport and the reliance on fossil fuel energy sources for energy consumption in this sector are of concern to many countries, thus making the reduction of energy consumption in this sector a political priority for governments around the world (Kenworthy, 2018).

For public passenger transport to be sustainable, it is necessary, among other activities to occupy vehicles according to their capacity and the demand they serve to fulfill their social and ecological function (Rosero Obando, et al., 2018). Most urban public transport systems depend on motor buses to provide a substantial proportion of services, and even when there is a subway or other rail system, buses often carry more than half of public transport (Michelberger, et al., 1987), (Edwards & Schofer, 1977). A sustainable transport system is based on energy efficiency and the absence of harmful effects on the environment and human beings, making necessary to optimize transport networks by planning routes that save energy, based on route planning tasks, resulting in energy savings that contribute to the sustainability of the system (Larrodé Pellicer, et al., 2014).

2.2. Characteristics of public passenger transport in developing countries

Developing countries are those countries that are in full economic and social development and in transition between developed countries and those that are less developed. To determine a country's development, the UN prepared the Human Development Index (HDI). HDI is based on GDP per capita, the degree of literacy, and life expectancy. The consideration of these factors relays on the inequality and social development of the inhabitants, even though the country shows economic development (Sánchez Galán, 2016).

This statement is directly linked to the cities' transport systems that have a low-quality, with reduced fares and discounts for various classes of users. From an institutional point of view, all public transportation systems in metropolitan areas are under the responsibility of different levels of government (TWB, 2014).

In most developing countries, urban travel is covered by around 75 percent by public passenger transport, reflecting the importance of making public transport work. Most of public transport systems in developing countries are private

and conformed of relatively small concessionaires, each serving a limited number of routes (Gakenheimer, 1998) with units that exceed their useful life, which directly impacts energy consumption and emissions. Similarly, due to the high motorization rates in these countries, it is complicated to introduce public passenger transport units in the automobile congestion that saturates the road infrastructure.

Travel demands exceed the supply of infrastructure, high levels of congestion, and the latent travel demand are the result of motorization and make unfeasible the expansion of roads, which reduces the speed (less than 10 kilometers per hour). In addition, the inadequate maintenance of streets and highways impacts public passenger transport as they are in poor condition since the streets are built by national agencies and maintained by local governments (Gakenheimer, 1998). Another factor is the weak driver discipline since the exclusive lanes for public transport are not respected and its established stops are not used. Causing unnecessary movements and generating stops along the route in unsuitable places.

The administration of public transport, especially buses, tends to be managed as a business and not as a service. Leading to mobility deterioration since they are not managed by their respective Department of Transit and/or Mobility (Celi Ortega, 2010; Cervero, 2000). Resulting in longer travel times and more transfers (TWB, 2012). Also, energy consumption estimations, the emissions associated with it, and the improvements are developed and implemented in developed countries. Making its application to the context of developing countries complex as the particularities of these countries are not considered to achieve the desired impact, so it is necessary to know the characteristics of public passenger transport in developing countries and the factors that affect them.

2.3. Factors related to energy consumption in public passenger transport

According to various authors, some variables affect energy consumption and emissions in public passenger transport. Since energy intensity, defined as mega joules (MJ) per passenger/km or ton/km, it is determined by two factors: the energy required to move the vehicle and the use of the vehicle's capacity (BMZ, 2016; Adams, et al., 2020).

The energy required to move the vehicle is determined by fuel consumption, transportation conditions (traffic and geography), and vehicle characteristics (model and size). The use of vehicle capacity depends on the occupancy and load levels of individual vehicles and the distribution of the different vehicle types in the fleet (BMZ, 2016; Mahmood Mahmoodi, et al., 2017; Cillero Hernández, et al., 2019, De Vlieger, et al., 2000). The load of the vehicle directly influences consumption since the power required from the engine increases with the weight of the vehicle due to its influence on rolling resistance. In addition, adequate maintenance on the vehicle's engine has a great impact on its consumption. (Institute for energy diversification and saving, 2005; Rafael-Morales, et al., 2010; Wu, et al., 2020).

Variations in vehicle fuel consumption and emission rates are generally associated with changes in cruising speeds, driver, acceleration aggressiveness, and road grade. Understanding the effects of different speed and acceleration profiles can help improve fuel consumption and emissions levels (Frey, et al., 2007; Wang, et al., 2008; El-Shawarby, et al., 2005; Larsson & Ericsson, 2009; Pita, et al., 2020, De Vlieger, et al., 2000). For this reason, it is important to determine the parameters that influence energy consumption such as the type of road or the orography, weather factors also affect fuel consumption.

Therefore, for the development of an accurate energy consumption model, it is necessary to consider many variables. Characterizing the vehicle fleet, the routes, and the number of buses is useful for calculating fuel consumption. While individualizing the routes can show data such as travel time, total distance for each route per cycle, the occupational rate, and the time and distance traveled on each trip by vehicles. At the same time, the number of buses determines variables such as the average occupancy rate, the daily estimation, the fuel consumption of the fleet, the number of passengers per kilometer of travel, and the number of passengers per gallon of fuel (Rosero Obando, et al., 2018; Alcántar Ruiz, et al., 2015). This shows a need to develop methods and strategies to predict fuel consumption and improve fuel economy (Wang, et al., 2008).

Therefore, a methodology that allows characterizing public passenger transport in developing countries is proposed. To know its characteristics and how they are related to energy consumption and associated emissions that serve as an instrument to support decision-making and planning.

3. Methodological proposal

A standard methodology for Energy Consumption and Environmental Inventories realization and improvement measures assessment is proposed. After estimating the actual energy consumption and emissions, improvement measures and their impact before the implementation are assessed, which will allow the design of adequate strategies and support.

The methodology designed consists of three phases (Figure 1) a report is created in each phase.

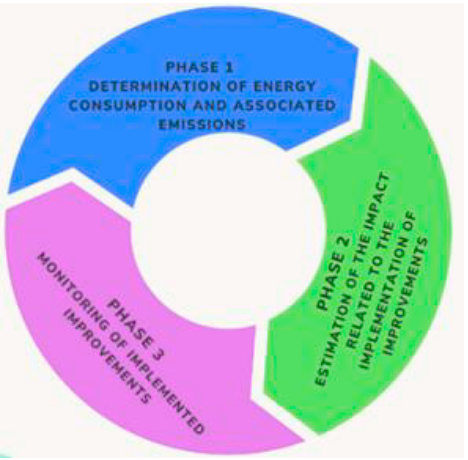

Fig. 1. Proposed methodology.

3.1. Phase 1: determination of energy consumption and associated emissions

In this phase, the identification and classification of variables are performed. Aiming to characterize the system and categorize the variables that impact energy consumption in five aspects (Figure 2).

After the determination of the variables, data collection to obtain all the information to analyze the situation of the vehicle fleet and its operation is carried out. The methodology for obtaining said information considers two types of data collection: manual and automatic and two types of data, which are shown in Table 1. The collected information allows identifying the problems of the fleet, as well as those of the environment and operation. Once the data is collected, the creation of the database and the detection of errors or inconsistencies to process, analyze, and interpret the information is made.

The databases are the basis for the analysis and diagnosis of the current situation and the creation of scenarios. This is used in Phase 2 for simulation model development to propose improvement measures and measure their implications without affecting the real system. After the information obtained has been analyzed and treated, the characterization of the route's current state is made, which will provide us with a comprehensive vision of how it operates. Making it possible to calculate the energy consumption of the route and its associated emissions, for this purpose is divided into two parts: the determination of energy consumption and the determination of associated emissions.

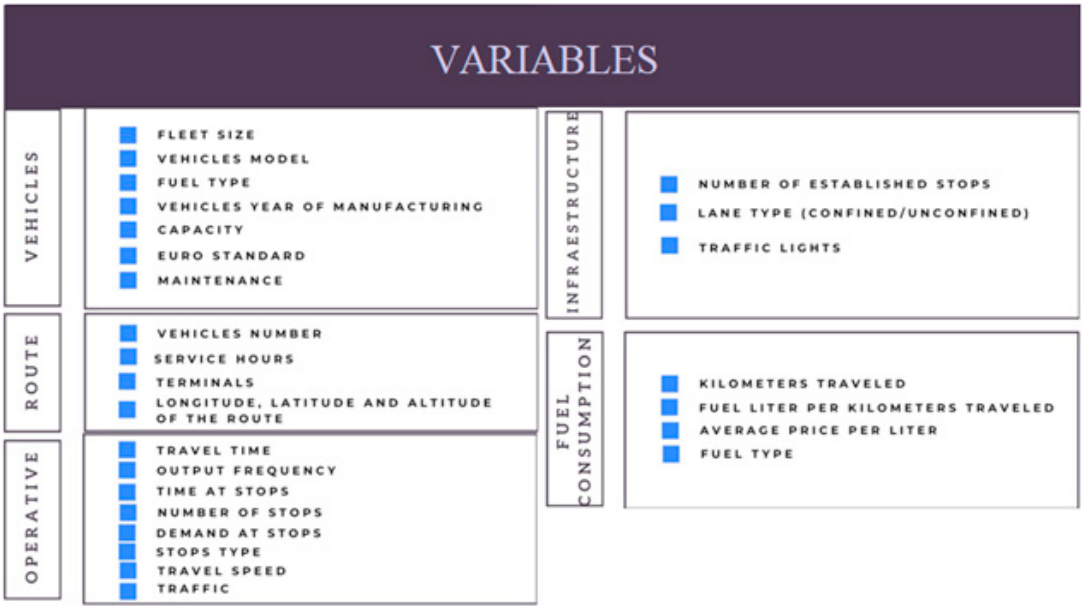

Fig. 2. Variables categorization.

Table 1. Types of data.

Data type	Description
Static	Manual registration; only once at the beginning.
	Automatic registration; once at the beginning
Dynamic	Manual registration, carried out in each tour
	Automatic registration, through devices

3.2. Phase 2: estimation of the impact related to the implementation of improvement measures

In this phase of the methodology, a simulation model is proposed. To carry out a diagnosis by feeding it with current data to identify the energy and environmental impact and subsequently that of the improvements implemented, whether in infrastructure, fleet management, improvement in operations or vehicles without affecting the real system, to implement improvement measures that have a positive impact on energy consumption and associated emissions and consider the basic characteristics of the territorial area.

The simulation is carried out under Simulation of Urban Mobility (SUMO) software. This software allows the integration of variables such as the altitude of the road, the drives expertise, traffic lights, random stops, energy consumption estimations, emissions estimations, and traffic in the study area. Since the software merges with Python, the development of the equations to estimate energy consumption and emissions with information regarding the kinetic translational and rotational energy, the energy needed for a vehicle to overcome a slope, rolling resistance, and aerodynamic resistance energy are incorporated. Also, it allows performing immediate changes in the road, traffic lights, random stops, and demand configuration, making the simulation dynamic.

The estimations of energy consumption and emissions can be analyzed on a macroscopic scale that accounts for the total results and on a microscopic scale that shows the results in each simulation step. That enables the study of the whole system or a section. So, changes for all systems or just a part where the main problems are recognized can be proposed.

For the selection of improvement measures, it is important to consider sustainability as a starting point. Each measure must be feasible and adapted to the real needs (analyzed when characterizing the route) and scope, allowing

an improvement in energy efficiency, fuel savings, and environmental improvement. The improvement measures to be implemented are selected considering the parameters of the route characterization that directly influence the improvement measure in question.

The improvement measures applied to public passenger transport are grouped into six categories (Figure 3a). After selecting the improvement measure to be implemented, the impact it represents is calculated (new inventory) and compared to the previous inventory of energy consumption and emissions. To obtain the new inventory a simulation model with the application of different improvement measures is developed (scenarios). The simulation shows the operation and its implications without affecting the real system.

3.3. Phase 3: monitoring improvement measures

In this phase, the improvement measures determined as the most suitable for application in the study route through the simulation model are applied to the real system, which allows having a reference regarding what is expected of them, for which it is possible if they meet the stated objectives.

It is considered that the improvement measures previously evaluated based on the simulation that provides an approach regarding the energy and environmental impact have been implemented. Once implemented, verification of whether the objectives are fulfilled is made. The fulfillment of the expected results is carried out by defining an indicator system that allows measuring the progress and providing information to make the pertinent modifications for the achievement of the objectives. The proposed indicator system is divided into six categories (Figure 3b).

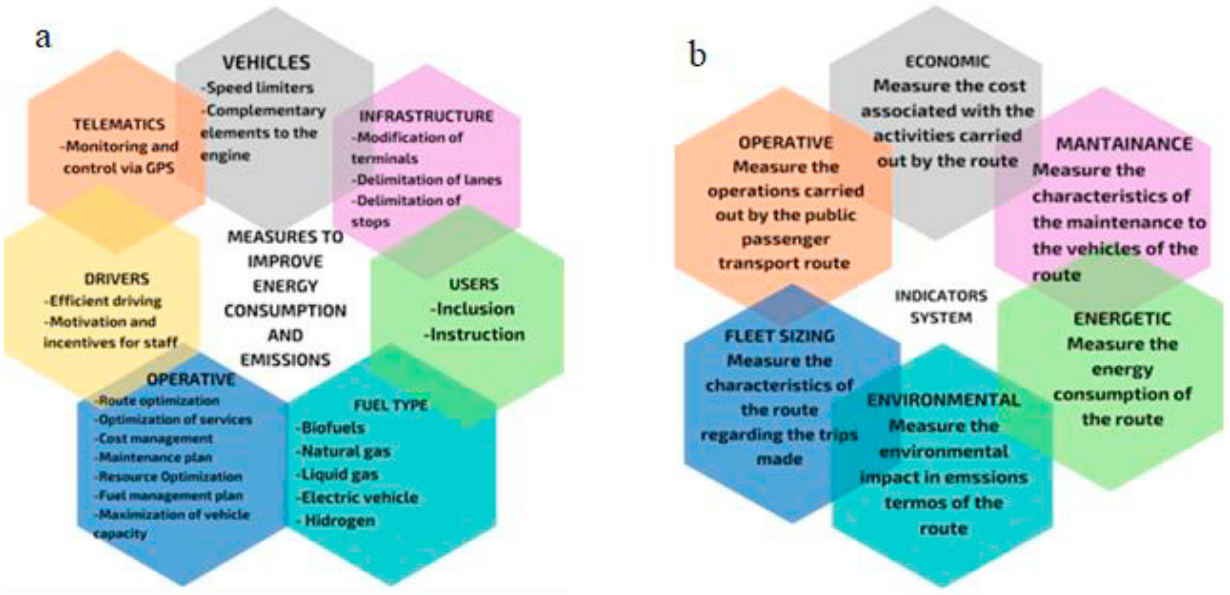

Fig. 3. (a) improvement measures; (b) indicatory system.

4. Conclusions

The literature review shows differences between public passenger transport in developed and developing countries and how these differences when proposing improvement measures are not considered. Therefore, a study that provides insight into the characteristics that influence energy consumption and emissions for public passenger transport in developing countries needs to be addressed.

This article provides a first approach on how to characterize public passenger transport in developing countries and how these characteristics affect energy consumption and emissions to propose improvement measures that reduce said

consumption and emissions. Through the characterization of the routes, roads they run through, and congestion using a methodology.

For this, it is necessary to use instruments or tools that help make decisions in accordance with the complex reality of this phenomenon like:

- Use forms to collect information.
- Models of energy consumption and associated emissions.
- Delimitation of improvement measures that reduce energy consumption.
- Simulation models to evaluate the effectiveness of the proposed measures.
- Indicators to monitor the implemented measures.

Since the lack of consideration of the characteristics of public passenger transport in said countries (demand, type of vehicles, number of stops) for the implementation of improvements for public passenger transport causes that:

- No accurate calculation of public passenger transport activity and its impact on energy consumption by not analyzing demand,
- The improvements implemented are not functional, causing in some cases higher associated costs and exacerbating energy consumption and emissions caused by not considering the type of vehicles and the number of stops they make on the route.

In future work, the verification of the functionality of the methodological proposal by collecting data for a route is proposed. With this information, the energy consumption and emissions are going to be estimated and a simulation will be generated to propose feasible improvement measures by creating scenarios and generating a new estimation.

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