Sustainable Cities and Society 52 (2020) 101844

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Measuring environmental performance of urban freight transport systems: A case study

Andrés Muñoz-Villamizar[a,b,c,*], Javier Santos[c], Jairo R. Montoya-Torres[d], Josué C. Velázquez-Martínez[a]

[a] Center for Transportation & Logistics, Massachusetts Institute of Technology, Cambridge, MA, USA
[b] Escuela Internacional de Ciencias Económicas y Administrativas, Universidad de La Sabana, Chía, Colombia
[c] Universidad de Navarra, TECNUN Escuela de Ingenieros, San Sebastián, Spain
[d] Grupo de investigación en Sistemas Logísticos, Facultad de Ingeniería, Universidad de La Sabana, Chía, Colombia

ARTICLE INFO

Keywords:
Urban freight transport
Goods transportation
Environmental performance
Optimization
Urban logistics

ABSTRACT

Environmental sustainability is a requirement for modern urban freight transport systems. On a global scale, most resources are currently consumed in cities, contributing to the economic importance of urban freight transport as well as its poor environmental performance. However, there is a lack of knowledge about how to correctly quantify the environmental efficiency of urban freight systems. In this context, this paper proposes a new methodology for evaluating the environmental performance of urban freight transport systems by applying the Overall Greenness Performance (OGP) tool. OGP is a lean-based hierarchy of metrics that uses the value-added concept to relate a company's productivity with its environmental performance. The proposed methodology uses a mixed-integer linear programming model to assess the environmental impact of the activities and/or requirements in an urban freight transportation system. This paper examines how company context, the supply chain and value stream activity types, namely value adding, necessary but non-value adding and non-value adding, affect a system's performance, operational costs and environmental impact. Real data from the city of Bogotá, Colombia, were used to validate this approach. A sensitivity analysis was performed with different companies, demands and costs in order to evaluate the trade-offs between economic performance and environmental impact.

1. Introduction

A growing proportion of the world's population is located in urban areas (Lyons, 2018). In 1950, almost 33% of the global population was urban. In 2017, around 55% of the population was living in cities, and it is projected that by 2050 the urban population will be around 68% (United Nations, 2018). However, in Latin America, around 80% of the population already lives in urban areas (Atlantic Council, 2014) and Europe is 75% urbanized (Schliwa, Armitage, Aziz, Evans, & Rhoades, 2015). Given the increase in population and the economic growth in urban areas, congestion has also increased in almost all transport modes (Kiba-Janiak, 2017), but it is in the area of urban freight transport (UFT) where congestion is a particular problem given the increase in demand for the delivery of goods and supplies (Eren Akyol & De Koster, 2018; Holguín-Veras, Amaya Leal, Sánchez-Diaz, Browne, & Wojtowicz, 2018).

While it is estimated that UFT vehicles make up only 10–20% of all vehicles, on urban roads the share is UFT vehicles is larger, constituting about 20–30% of total urban traffic (Kijewska & Iwan, 2019; Schliwa et al., 2015). And given that UFT vehicles are larger than passenger vehicles, their contribution to traffic congestion on urban roads is greater (Anand, van Duin, Quak, & Tavasszy, 2015; Coulombel, Dablanc, Gardrat, & Koning, 2018). This congestion is even worse in urban areas with one-lane roads and a deficit of parking (e.g., urban downtown areas), where UFT vehicles tend to park in active traffic lanes to perform loading/unloading operations (Pinto, Lagorio, & Golini, 2018). Another complication of increased UFT traffic is its contribution to greenhouse gas (GHG) emissions and air pollution (Forsberg & Krook-Riekkola, 2018), which accounts for 25% of CO_2 emissions and 30–50% of other transport-related pollutants (ALICE, 2015).

As the road share of UFT vehicles has grown in recent years,

* Corresponding author at: Operations and Supply Chain Management Research Group, Escuela Internacional de Ciencias Económicas y Administrativas, Universidad de La Sabana, Chía, Colombia.
E-mail address: andresmunvi@unisabana.edu.co (A. Muñoz-Villamizar).

https://doi.org/10.1016/j.scs.2019.101844
Received 4 February 2019; Received in revised form 12 September 2019; Accepted 12 September 2019
Available online 13 September 2019

researchers have begun to study the impacts of UFT (Comi, Schiraldi, & Buttarazzi, 2018), addressing the increase in urban congestion and other problems such as pollution, traffic accidents, noise disturbance, longer private and commercial journeys, etc. (Eren Akyol & De Koster, 2018; Russo & Comi, 2017; Schliwa et al., 2015; Taniguchi, 2015). All these impacts could be grouped using the triple bottom line approach, which looks at impacts from the social, environmental and financial perspectives (Buldeo Rai, van Lier, Meers, & Macharis, 2017). In the UFT context, the social perspective groups issues related to health and safety, the environmental perspective groups issues related to pollution and the use of non-renewable resources, and the economic perspective includes the cost of unreliable deliveries and time losses (Steg & Gifford, 2005).

In this context, there has been an urgent drive to develop appropriate assessment tools (Buldeo Rai et al., 2017). Furthermore, as UFT is a complex system where various stakeholders interact and individual economic interests exist, these assessment tools should: 1) holistically characterize and evaluate the UFT system in order to study the interaction between different components (i.e., stakeholders) (Kin, Verlinde, & Macharis, 2017; Lagorio, Pinto, & Golini, 2016), 2) be applicable and transferable to other cases (Gonzalez-Feliu, 2017; Kin et al., 2017) where a solid understanding of context is present (Buldeo Rai et al., 2017), and 3) consider that certain productivity factors, such as maximizing production efficiency, are the ultimate goal of almost every stakeholder (Comi et al., 2018).

To address these gaps, this paper proposes a new methodology for measuring and evaluating the environmental performance and effectiveness of logistics systems in general, including UFT systems. Our methodology combines the Overall Greenness Performance (OGP) tool with a mixed-integer linear programming (MILP) model to assess the environmental impact of the activities and/or requirements of stakeholders in an urban freight transportation system. Real data from the city of Bogotá, Colombia, are used to run numerical tests. The proposed approach is then validated through a sensitivity analysis carried out with different companies, demands and costs. Although the validation of the approach is done within a freight urban transport perspective, the methodology can be extended to other industrial contexts (e.g., manufacturing companies).

The rest of the paper is organized as follows. Section 2 presents a review of the literature on sustainable UFT. The proposed methodology is presented in Section 3 and applied to a case study in Section 4. Finally, the main conclusions of this study and opportunities for further research are presented in Section 5.

2. Literature review

There is extensive literature on what researchers understand UFT to be. However, rather than present an in-depth review, our intention is to point out some key aspects in order to highlight the gaps we have noted in the previous section. Readers interested in reviews of the literature on sustainable UFT may consult the works of Ambrosini and Routhier (2004), Anand et al. (2015), Bektaş, Ehmke, Psaraftis, and Puchinger (2019), Bibri and Krogstie (2017), Browne, Piotrowska, Woodburn, and Allen (2007), Gonzalez-Feliu (2017) and Lagorio et al. (2016). In this section, we first present a brief background to introduces the basic terminology of UFT systems. Then we present how UFT systems are addressed from the Operations Research perspective. And finally, we show how measuring sustainability presents several challenges from both UFT and Operations Research perspectives.

2.1. Urban freight distribution systems

UFT is characterized by a set of vehicle routes that carry goods from producers' sites to consumers' premises. It involves different stakeholders such as suppliers (i.e., providers of goods and/or transportation service), recipients (i.e., consumers of the goods) and governing authorities (i.e., infrastructure providers) (Comi et al., 2018). According to Freeman (1984), stakeholders are the actors that can affect or be affected by a specific system. Lindholm (2010) stated that the main stakeholder studied and discussed is the local authority. However, other perspectives are important, as conflicts among stakeholder objectives are frequent (De Brucker, Macharis, & Verbeke, 2013; Taniguchi, 2015). For instance, the freight traffic that produces congestion is the direct result of the delivery time decisions made by the receivers of supplies (Holguín-Veras, Sánchez-Díaz, & Browne, 2016). Therefore, Ballantyne, Lindholm, and Whiteing (2013) concluded that UFT can be improved by involving a wider range of stakeholders. Nevertheless, there is no broad systematic approach to incorporating these different goals in transportation systems (Kin et al., 2017; Lagorio et al., 2016).

In addition, Gonzalez-Feliu (2017) identified other components of UFT, such as organizational aspects (e.g., warehousing, inventory and routing strategies), technologies (e.g., type of vehicles, intelligent transport systems), Public-Private Partnership schemes, and regulations (i.e., restrictive policies, incentives or tariff-based regulations). Taking these additional components into consideration, UFT can be described as a system that deals with all flows of goods and materials in a city and is a key element of urban development (Kiba-Janiak, 2017).

Interest in urban freight research first arose in the 1970s, initially to address safety issues for heavy goods (Browne et al., 2007). However, no significant research activities occurred until 1990, when European and international studies on the logistics of collection and delivery in town and city centers were performed (Browne et al., 2007; Comi et al., 2018). In recent years, there has been an increasing awareness of and interest in evaluating the negative external impacts of UFT (Bektaş et al., 2019; Comi et al., 2018).

UFT is recognized as being one of the most significant sources of unsustainability in urban areas (Lindholm & Blinge, 2014; Quak, 2008; Russo & Comi, 2017). Growth in a city's population increases the demand for UFT, which in turn multiplies congestion and environmental degradation (Kiba-Janiak, 2017). When the negative external impacts of UFT became more and more evident, academics, practitioners and policy-makers likewise became increasingly interested in the issue (Karakikes, Nathanail, & Savrasovs, 2019; Quak, 2008; Russo & Comi, 2016). According to Bektaş et al. (2019), the negative externalities of UFT fall within various categories: emissions, noise, land use and safety hazards. It is also evident that, with a growing proportion of the world's population living in urban environments, cities must be economically, socially and environmentally sustainable (Lyons, 2018). However, as GHGs are directly related to global warming, reducing emissions has been the key element of international agreements, as well as a research priority (Bektaş et al., 2019).

This situation has attracted the interest of scholars, practitioners and government (Quak, 2008) in efforts to align planning, investment and policy for the sustainable development of cities (Bibri & Krogstie, 2017; Lindholm & Blinge, 2014). Within the range of disciplines (i.e., economics, engineering, physics, chemistry, etc.) that are addressing the challenge of developing sustainable cities, Operations Research (OR) has been an important contributor to accomplishing this goal (Bektaş et al., 2019).

2.2. Operations research perspective

According to Bektaş et al. (2019), within OR there are generally two approaches to addressing environmental issues in urban transportation: optimizing the design of transportation networks and/or optimizing the operation of urban transportation services. However, implementation of these and other UFT alternatives are often unsuccessful due to a lack of systematic assessment of short- and long-term effects (Anand et al., 2015; Buldeo Rai et al., 2017). Furthermore, none of these alternatives would be perceived as standard or transferable (Gonzalez-Feliu, 2017). That is, alternatives for more sustainable UFT have been studied mostly as a general overview, applied to a specific city (or region) (Kin et al., 2017) and/or are rarely used outside the context for which they were designed (Gonzalez-Feliu, 2017).

As pointed out by some reviews (e.g., Bektaş et al., 2019; Crainic & Laporte, 1997; Nenni, Sforza, & Sterle, 2019), UFT has received extensive attention in the OR community. The field of OR has developed various optimization models and solution techniques to reduce the negative impacts of UFT (Bektaş et al., 2019). As Churchman (1968) outlined, an OR approach can be helpful in characterizing a problem, its resources, its decision-makers and its environment. Consequently, OR studies have been mainly aimed at acquiring better knowledge about city logistics and supporting the policy-making process in order to improve the economy and reduce the harmful effects of goods transportation (Comi et al., 2018; Gonzalez-Feliu, 2017). These models have also been used to assess the impacts of infrastructure alternatives (e.g., consolidation centers) or regulations (e.g., pricing policies) (de Jong et al., 2007). For example, Ambrosini and Routhier (2004) provide a review of UFT modeling efforts in developed countries. The authors classify urban freight models into two families: a) systemic models that are meant for evaluating the impact of urban logistics modifications on traffic flows, and b) operational models that are primarily directed toward improving traffic flow management. Regardless, the strength of UFT models is their ability to provide insights into and managerial implications of the impact of new and different alternatives (Forsberg & Krook-Riekkola, 2018).

Within the OR field, the Vehicle Routing Problem (VRP) has been one of the most famous problems in transportation modeling (Toth & Vigo, 2014) since it was introduced by Dantzig and Ramser (1959), and it has been extensively studied in the academic literature within a large set of variants inspired by real-life contexts (Muñoz-Villamizar, Quintero-Araújo, Montoya-Torres, & Faulin, 2019). Readers interested in reviews regarding VRP may consult the works of Braekers, Ramaekers, and Van Nieuwenhuyse (2016), Cordeau, Laporte, Savelsbergh, and Vigo (2007); Laporte (1992); Montoya-Torres, López Franco, Nieto Isaza, Felizzola Jiménez, and Herazo-Padilla (2015), and Toth and Vigo (2014). It is important to note that recent developments in VRP have highlighted the importance of including environmental issues (Muñoz-Villamizar et al., 2019; Ubeda, Arcelus, & Faulin, 2011), where the reduction of CO_2 emissions is one of the main streams (Demir, Bektaş, & Laporte, 2014).

At the same time, Bektaş et al. (2019) argued that OR tools used within transportation have aimed to define efficient solutions, where efficiency is generally defined by measurable indicators. However, despite there being studies that propose assessment indicators and methods (e.g., Behrends, Lindholm, & Woxenius, 2008; Morana & Gonzalez-Feliu, 2015; Patier & Browne, 2010), there are currently no standardized (general) or systematic methods for assessing the sustainability of UFT alternatives (Gonzalez-Feliu, 2017). That is, the several methods and indicators developed so far have been based on different meanings of sustainability.

This led Gonzalez-Feliu (2017) to point out that sustainability is not perceived or measured in the same way by the different UFT stakeholders. As the author argued, stakeholders are different in nature and have different objectives and stakes. Consequently, as UFT solutions are likely to have different effects on stakeholders, it is critical to take these conflicting interests into account (Buldeo Rai et al., 2017). Similarly, Comi et al. (2018) proposed that UFT research should be evaluated according to the stakeholders and elements associated with the supply chain. Therefore, as Gonzalez-Feliu (2017) argued, the best alternatives or solutions for UFT will be the result of evaluating and considering different stakeholders' perspectives. However, to assess their potential (i.e., ex-ante assessment) to improve sustainability, it is important to use coherent and robust methods (Comi et al., 2018, Gonzalez-Feliu, 2017; Russo & Comi, 2016).

2.3. Measuring sustainability

As noted above, current methods and metrics for more sustainable UFT are mostly applied in a very specific context (Kin et al., 2017). Therefore, UFT has been defined from a mainly environmental perspective (Gonzalez-Feliu, 2017). GHG emissions, and CO_2 in particular (Kijewska & Iwan, 2019), have been traditionally evaluated within OR and other fields in order to quantify the externalities of transportation systems because there are models that estimate emissions generated by using the energy required to move a vehicle from one point to another (Bektaş et al., 2019).

In estimating CO_2 emissions, Ubeda et al. (2011) pointed out that CO_2 computation can only represent an approximation because of the difficulty of quantifying certain variables such as speed, weather conditions, driving style, congestion, types of roads, etc. Demir et al. (2014) reviewed and compared the existing emission models and found that although these models vary with respect to the input parameters and level of detail, the most common approach is the distance-based factor called the GHG Protocol (Demir et al., 2014; GHG Protocol, 2018). Nevertheless, deciding which approach to use depends on the availability of data (Ubeda et al., 2011).

However, it is important that the proposed methods be applicable beyond the specific context for which they were designed (Gonzalez-Feliu, 2017). One widely adopted methodology for assessing the externalities (e.g., resource consumption, waste emissions, etc.) in different manufacturing contexts is the Life Cycle Analysis (Ahlroth & Finnveden, 2011). Although different approaches based on Life Cycle Analysis have been implemented in different manufacturing companies (which are quite different from the UFT context), reducing environmental externalities is not enough for company managers (Muñoz-Villamizar, Santos, Montoya-Torres, & Ormazábal, 2018). Returning to the consideration of different perspectives, private stakeholders, like companies, want to provide quality products or services to their customers and reduce economic costs. That is, they seek to increase profits and promote value creation (Muñoz-Villamizar et al., 2018; Vachon & Klassen, 2008). To that end, efficiency and productivity play a crucial role in UFT systems (Pani, Sahu, Patil, & Sarkar, 2018).

The evidence presented so far suggests that there is a need for standardized and systematic methods for assessing sustainability in UFT and that these methods should consider the different stakeholders' involvement (Anand et al., 2015; Buldeo Rai et al., 2017; Comi et al., 2018; Gonzalez-Feliu, 2017). Furthermore, these methods should be replicable in other contexts in order to facilitate the applications of sustainability measures (Gonzalez-Feliu, 2017; Kin et al., 2017) and must consider certain productivity factors, given that environmental performance should not be treated independently of productive performance (Comi et al., 2018). The next section presents the methodology we propose to fill these gaps.

3. Proposed methodology

This paper presents a new methodology for measuring and evaluating the environmental performance and effectiveness of urban logistics systems. This methodology adapts and integrates the OGP tool proposed in Muñoz-Villamizar et al. (2018) within an optimization framework for assessing the environmental impact of the activities and/or requirements of stakeholders in any industrial system. A schematic representation of the proposed three-phase methodology is shown in Fig. 1. Using different versions of an MILP model, the idea is to categorize and quantify the externalities of processes and activities in order to be more effective at developing improvement alternatives that may reduce their impact.

3.1. System characterization

The first step begins by identifying the essential attributes and main

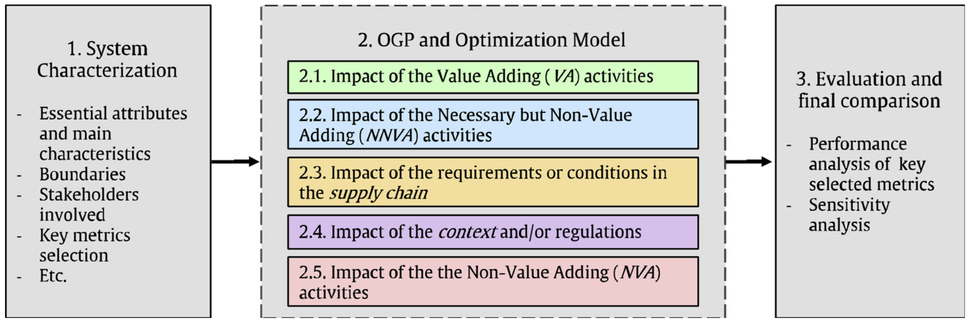

Fig. 1. Overall generic methodology.

characteristics of the system under study. Most companies' systems are defined by their essential attributes (e.g., nature, objectives, etc.). While these systems are not mutually exclusive (e.g., picking up and delivery services), each one possesses its own fundamental characteristics. Next, the boundaries of analysis must be also defined by time and place (Hancock & Algozzine, 2016). Finally, the stakeholders involved as well as the components, resources and steps of the system under study should be correctly identified by determining the key metrics that will be used to evaluate the system's performance (goal-setting) (Buldeo Rai et al., 2017; Comi et al., 2018; Gonzalez-Feliu, 2017).

Although the methodology proposed aims to be a general method that will be applicable and transferable to any context, the study presented here is focused on UFT. Consequently, UFT system characterization should include the location of delivery points (i.e., recipients) and depots (i.e., shippers), travel distances and travel speeds between nodes, time windows for delivery points and the regulated access defined by public authorities, demand at each delivery point, economic aspects (e.g., labor and fuel cost), and other relevant characteristics (Muñoz-Villamizar et al., 2019).

In addition, the key performance metrics chosen to evaluate the externalities of UFT must be defined. CO_2 emissions are the externality selected in this study. It is important to note that CO_2 emissions is one of the environmental performance key metrics in OR (Bektaş et al., 2019; Ubeda et al., 2011) and other fields (Cadarso, López, Gómez, & Tobarra, 2010; He et al., 2005; Shahbaz, Khraief, & Jemaa, 2015). However, it is important to note that other externalities (e.g., NO_x, particulate matter, energy consumption) could be evaluated with our methodology. Finally, the other selected key metrics, which are also classic in OR, are: distance traveled, economic costs, vehicle utilization rate and service level (i.e., average delivery time) (Bektaş et al., 2019; Laporte, 1992; Muñoz-Villamizar et al., 2019).

3.2. OGP and MILP model

The second step of the methodology is to integrate the OGP tool with the MILP model. Through this integration, the OGP tool allows the activities of a system to be categorized according to the generation of value and the perspectives of the different stakeholders, while the mathematical model allows the categorized activities to be quantified (see Fig. 2).

As previously mentioned, this paper uses an adaptation of the OGP tool proposed in Muñoz-Villamizar et al. (2018) (see Fig. 3). The OGP is a hierarchy of metrics that relates a company's resource consumption and waste emissions (i.e. externalities) with its production level. Using the value-added concept, the OGP classifies a company's consumption and waste processes according to the categories presented in Fig. 3 and Table 1. The most commonly employed externalities in the manufacturing context are input-oriented (resource consumption) and output-oriented (emissions, toxic waste, oil and chemical spills, and discharges that are recovered, treated or recycled) (Molina-Azorín, Claver-Cortés, López-Gamero, & Tarí, 2009). Thus, the resources/emissions that are to be measured should be defined in advance by decision-makers so the company's critical environmental aspects may also be defined.

In line with Bektaş et al.'s (2019) priority on measuring and reducing GHG emissions, in this study CO_2 emissions are the externality selected in order to evaluate the environmental performance of UFT systems. In terms of the OGP categories, the CO_2 emissions allocated to VA activities correspond to the delivery of goods themselves in an 'ideal situation'. That ideal situation consists of the CO_2 emissions generated by delivering the goods without any constraint or condition (e.g., capacity, time windows, legislation, etc.) being placed on the system. Then, the CO_2 emissions generated for extra trips due to vehicle capacity constraints are allocated to NNVA activities, while the CO_2 emissions generated by the time window constraint are allocated to the Supply Chain category, since this type of constraint is a client requirement. Similarly, the CO_2 emissions generated by adhering to regulation initiatives are allocated to the Context category. Finally, the CO_2 emissions in the NVA category correspond to system inefficiencies and mistakes commonly made in real-life operation, such as the CO_2 emissions generated by the inadequate selection of routing strategies.

All these considerations about the OGP categories, which are explained in the following sub-sections, are incorporated in our methodology by using the classic VRP model.

3.2.1. VA impact

The base MILP model employed to solve the VRP is presented below. It is important to note that, on one hand, calculating the VA impact is the least complex scenario since all the other OGP categories (i.e., NNVA, Supply Chain and Context) involve adding constraints in the UFT system. NVA impact, on the other hand, corresponds to emissions from real-life operation. The differences between each approach to measuring each OGP category (see Figs. 1 and 2) are explained in these sub-sections.

The binary variable is defined as $X_{ijk} = 1$ if the pair of customers i and j are on the route of vehicle k; otherwise it equals 0. Note that a fictitious node, i (or j) = 0, is used to represent the depot. Non-negative variables are defined as follows: Y_{ik} is the arrival time at node i of vehicle k. Other decision variables needed to calculate the selected key metrics are: TD, the total travel distance; TC, the cost of the routing process; SL, the average delivery times; and E, the total CO_2 emissions. It should be noted that the utilization rate is a non-linear expression, since it corresponds to the ratio between orders shipped and vehicles used. Consequently, this metric should be computed later. Additionally, auxiliary variables U_i are used to prevent subtours. The following notation and model are used:

Sets:

i, j Set of recipients {0,1, …, n}

k Index for vehicles {1, …, m}

Parameters:

q_i Order for recipient i

Q_k Maximum capacity of vehicle k

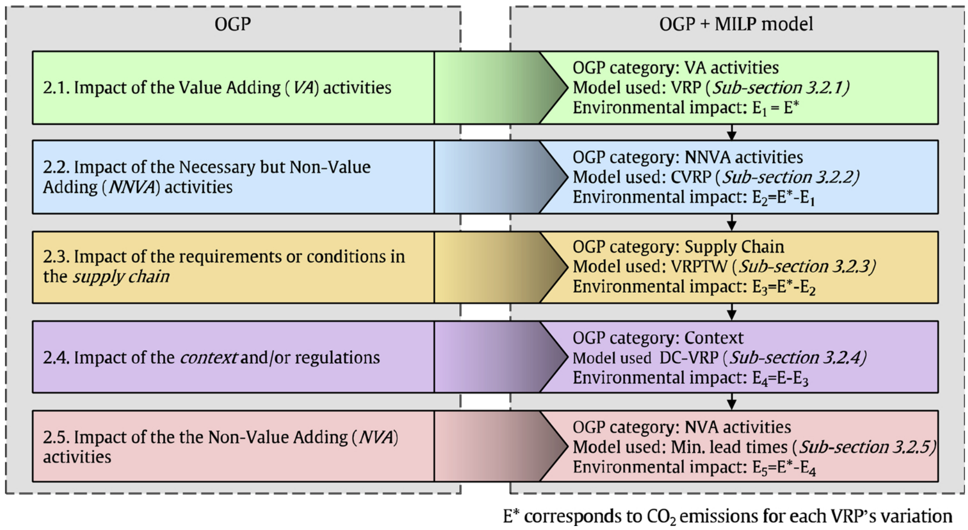

Fig. 2. Flowchart of MILP model application.

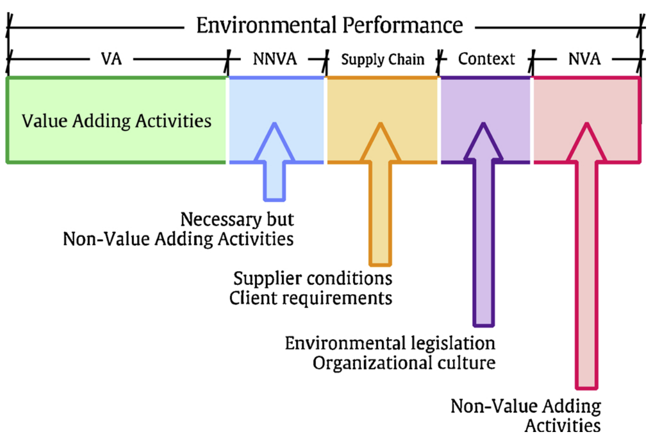

Fig. 3. OGP tool. Adapted from Muñoz-Villamizar et al. (2018).

c_{ij} Distance from node i to j
v_{ij} Vehicle travel speed from node i to j
fc Fuel cost
lc Labor cost
vc Fixed vehicle cost
ef Emissions factor
us Unloading speed
rl Maximum route length
M A large number
The mathematical model is

$$\sum_i \sum_k X_{ijk} = 1, \ \forall j > 0 \tag{1}$$

$$\sum_j X_{0jk} \leq 1, \ \forall k \tag{2}$$

$$\sum_i X_{ijk} = \sum_i X_{jik}, \ \forall \ k, \ j > 0 \tag{3}$$

$$\sum_j \sum_k X_{0jk} = \sum_j \sum_k X_{j0k} \tag{4}$$

$$\frac{c_{0j}}{v_{0j}} + q_j{*}us \leq Y_{jk} + M{*}(1 - X_{0jk}), \ \forall \ k, \ j > 0 \tag{5}$$

$$Y_{jk} + \frac{c_{ij}}{v_{ij}} + q_j{*}us \leq Y_{jk} + M{*}(1 - X_{ijk}), \ \forall \ k, \ i > 0, \ j > 0 \tag{6}$$

$$u_i - u_j + n{*}X_{ijk} \leq n - 1, \ \forall \ k, \ i > 0, \ j > 0 \tag{7}$$

$$TD = \sum_i \sum_j \sum_k X_{ijk}{*}c_{ij} \tag{8}$$

$$TC = \sum_i \sum_j \sum_k X_{ijk}{*}c_{ij}{*}fc + \sum_k Y_{0k}{*}lc + \sum_j \sum_k X_{0jk}{*}vc \tag{9}$$

$$SL = \frac{1}{n}{*}\sum_i \sum_k Y_{ik}, \ \forall \ i > 0 \tag{10}$$

$$E = \sum_i \sum_j \sum_k X_{ijk}{*}c_{ij}{*}ef \tag{11}$$

$$\text{Minimize } TC \tag{12}$$

Constraint (1) forces all recipients to be visited exactly once. Constraint (2) sets a limit of one route per vehicle. Routing continuity is represented by Constraint (3). Constraint (4) guarantees that each route begins and finishes at the depot. Constraint (5) computes arrival time for the first node visited according to travel and unloading time, while constraint (6) computes the arrival time for the remaining nodes. Constraint (10) forces the elimination of sub-sequences (i.e. subtours). Additionally, the computation of key metrics is presented in (8)–(11). Constraint (8) calculates the total distance traveled. Constraint (9) calculates the total cost based on distance-fuel consumption and time-

Table 1
Definition of OGP categories. Adapted from Muñoz-Villamizar et al. (2018).

Category	Definition
VA	Consumption/emission of the Value Adding processes
NNVA	Consumption/emission of the Necessary but Non-Value Adding processes
Supply Chain	Requirements or conditions in the supply chain (e.g., restrictions on packaging or transportation)
Context	Computes consumption/emission related to culture of working people and regulations constraints
NVA	Consumption/emission of the Non-Value Adding processes

labor cost. Constraint (10) calculates the average delivery time and constraint (11) calculates CO_2 emissions. Finally, objective function (12) calculates the classical traditional routing cost optimization in a VRP (i.e., fuel cost + labor cost + vehicle fixed cost) (Braekers et al., 2016).

The following sub-sections elaborate on the impact assessment of the four remaining OGP categories. To quantify their impact, each category is evaluated separately but compared with the previous stage. That is, the model presented above is implemented each time using the variations proposed in the corresponding sub-section, and then the E obtained in the previous category (i.e., total CO_2 emissions) is subtracted from the E value obtained in the current one. To facilitate the calculations, E_1 is defined as the emissions generated by VA activities, E_2 is defined as the emissions generated by NNVA activities, and so on.

3.2.2. NNVA impact

Our approach considers the capacity constraint to be a NNVA activity. That is, vehicle capacity is a necessary condition of UFT, but it does not add any value to the final customers. Capacitated VRP (CVRP) is also known as the classic VRP (Braekers et al., 2016), and it is solved by simply including constraint (13) in the model. As mentioned before, in order to compute NNVA impact (i.e., E_2), E_1 is subtracted from the E obtained after executing (1)–(13).

$$\sum_i \sum_j X_{ijk} * q_i \le Q_k, \ \forall \ k \tag{13}$$

3.2.3. Supply chain impact

Similar to NNVA impact, our approach considers that time windows constraints correspond to a supply chain requirement. VRP with Time Windows (VRPTW) is a popular extension of VRP, in which delivery for each recipient must occur within a certain time interval $[a_i, b_i]$ (Braekers et al., 2016) and can be solved by including constraints (14) and (15) in the model. The VRPTW has numerous applications in UFT (e.g., commercial and industrial waste collection, newspaper delivery, beverage and food delivery, etc.) (Cordeau et al., 2007). Supply chain impact (i.e., E_3) is computed by subtracting E_2 from the E obtained after executing (1)–(15).

$$Y_{ik} \ge a_i * \sum_j X_{ijk}, \ \forall \ k, \ i > 0 \tag{14}$$

$$Y_{ik} \le b_i + M\left(1 - \sum_j X_{ijk}\right), \ \forall \ k, i > 0 \tag{15}$$

3.2.4. Context impact

Environmental legislation is considered to be a Context constraint. According to Quak (2008), environmental legislation for UFT falls into one of three classes: parking and unloading initiatives, pricing initiatives and regulation initiatives. One of the most frequently used regulation initiatives is the time window regulation (Eren Akyol & De Koster, 2018; Quak, 2008). This regulation limits the routing length [rl] so that delivery occurs outside shopping hours and can be achieved with constraint (16). The regulation length varies from two to six hours and, not surprisingly, extra vehicles are needed when the regulated length is shorter (Eren Akyol & De Koster, 2018). Once more, the Context impact (i.e., E_4) is computed by subtracting E_3 from the E obtained after executing (1)–(16).

$$\sum_i \sum_j \sum_k X_{ijk} * c_{ij} * \frac{lc}{v_{ij}} \le rl \tag{16}$$

3.2.5. NVA impact

As previously noted, NVA impact corresponds to the CO_2 emissions generated for the system in real-life operation through inadequately selected routing strategies. In this context, finding a feasible schedule is sufficient for most decision-makers, who mostly prefer to use simple heuristic algorithms, such as dispatching policies, in order to facilitate replicability in real-settings (Muñoz-Villamizar et al., 2019). Therefore, it is common for decision-makers to seek to deliver the orders with the earliest due date first (i.e., reducing lead times) (Reyes, Erera, & Savelsbergh, 2018). This approach can be achieved by delivering the orders as soon as possible to each recipient i. Mathematically speaking, this could be done by maximizing the difference between the latest due date (i.e. b_i) and the delivery date (i.e., Y_{ik}). Therefore, NVA impact can be obtained by changing objective function (12) to objective function (17), and the computed NVA impact (i.e., E_5) can be obtained by subtracting E_4 from the E obtained after computing CO_2 emissions by executing (1)–(11); (13)–(17).

$$\text{Maximize} \sum_i \sum_k b_i - Y_{ik} \tag{17}$$

3.3. Final comparison and sensitivity analysis

The last step of the proposed methodology consists of a performance analysis of all the selected metrics (i.e., CO_2 emissions, travel distance, economic costs, vehicle utilization rate and service level). Economic cost is the most commonly used objective function in the literature (Montoya-Torres et al., 2015), and it is also employed in this methodology as the objective function to be minimized. Then, the other metrics (i.e., CO_2 emissions, travel distance, vehicle utilization rate and service level) are computed. That is, a single-objective optimization approach is executed, with a posteriori estimation of the other selected metrics.

In addition, VA activities are expected have a greater proportion of CO_2 emissions. However, the opposite case, meaning where the other categories (i.e., NNVA, Supply Chain and Context) have a significant proportion of CO_2 emissions, represents potential improvement opportunities for the whole system. In addition, a sensitivity analysis should be performed, varying the parameters of the problem (i.e., demands, costs, time windows, etc.) in order to evaluate their impact and the trade-offs between economic performance and environmental impact.

4. Case study and analysis of results

Case study research is a way of investigating an empirical topic by following a set of defined procedures (Yin, 2003). According to Molina-Azorín et al. (2009), research on environmental performance has been mostly theoretical and anecdotal, and more work needs to be done on the quantitative empirical side. Furthermore, the literature review by Morioka and de Carvalho (2016) on the integration of environmental performance and productivity noted that more case studies and action research are needed to promote in-depth understanding of the impact of environmental alternatives.

Following these considerations, this section applies the proposed methodology to a case study in Bogotá, Colombia. Bogotá is the capital of and largest city in Colombia. It is also the thirty-fourth largest city in the world and the fourth largest in Latin America (City Mayors, 2015). As an emerging economy—and in contrast to developed economies—Colombia and its cities are facing considerable sustainability challenges, boosted by their quick growth (Kin et al., 2017; Muñoz-Villamizar et al., 2019). Therefore, applying the case study method to Bogotá not only provides the opportunity to explore the impact of the proposed methodology in a real-life UFT context, it also provides an example of city behavior in emerging economies.

The MILP models described in this paper were implemented using GAMS commercial software version 24.1.3, with a time limit of 1000 s on an Intel(R) Core(TM) i5 personal computer with 1.4 GHz and 4 GB RAM. Furthermore, in order to carry out the sensitivity analyses, different variations and/or scenarios were evaluated. As Gonzalez-Feliu (2017) pointed out, few studies on UFT refer to the complete methodology in scenario assessment and evaluation. Therefore, sub-section 4.3 proposes different scenarios in order to evaluate the impact of different vehicle capacities, time windows and routing length policies. These analyses would allow a company to evaluate the advisability of increasing its current capacity, renegotiating new delivery dates with recipients or defining more effective legislation policies for UFT systems.

The UFT system in the case under study is characterized in sub-section 4.1. Sub-section 4.24.1. Sub-section 4.2 presents the results of applying the methodology to the initial state, and sub-section 4.34.3 presents the analysis for the UFT under study.

4.1. Characterization of UFT

This study is based on real-world data from two of the major convenience store (proximity shop) networks operating in Bogotá, Colombia. This is an extension of our previous work (see Muñoz-Villamizar et al., 2019) in that the assessment of the environmental performance of UFT systems is added. For privacy reasons, the two companies will be called Company A and Company B. Company A owns 16 stores and Company B owns 10. The initial situation for this UFT system is explained below.

The asymmetric origin-destination distance matrix for each company was obtained from the shortest path derived from Google Maps™ mapping service. The vehicle selected was the Renault Kangoo Express Van with 650 kg of payload (Q) and 0.212 CO_2 kg/km (Renault Colombia, 2018). Taking a gasoline price of 0.78 US$/L in Colombia (GlobalPetrolPrices.com, 2018) and the energy consumption of Kangoo Van (4.3 L/100 km), the assumed fuel cost is 0.034 US$/km. In addition, using a 5-year straight line depreciation method over vehicle price (16,700 US$), a fixed vehicle cost of 13 US$/route was defined.

A full month of weekly deliveries (i.e., 4 different sets of recipient orders) were randomly generated using the uniform distribution $q_i \sim U(0.1 * Q,\ 0.2 * Q)$ (i.e., 10%–20% of the vehicle payload). This assumption implies that the company with the largest number of stores (i.e., company A) will have the highest demand. Bogota's average traffic speed and its deviation are used to generate different weekly stochastic speeds between nodes i and j using the normal distribution: $v_{ij} \sim N(23.404,\ 3.986)$ (EL TIEMPO, 2016). Other parameters considered in this case are the hourly salary of the workers involved in the freight transportation process (4.26 US$/h), an unloading speed of 0.018 min kg, and the starting time (a_i) for a 3-h time window generated from a uniform distribution $a_i \sim U(0h,\ 7h)$ (Muñoz-Villamizar et al., 2019). Consequently, the companies' current routing strategy responds to the earliest due date heuristic. That is, companies visit first the recipient with the smallest time window. It was also assumed that the companies' vehicle fleets are available to deliver every order within the time windows. Finally, Colombian legislation only allows urban freight delivery between 10 p.m. and 6 a.m. (EL TIEMPO, 2013). Hence, a routing length of 8 h was assumed. The full data are available upon request to researchers who would like to replicate the experiments.

4.2. OGP and MILP model

The proposed approach (presented in sub-section 3.23.2 and summarized in Fig. 2) was implemented, and Fig. 4 and Table 2 present the average results of the OGP and MILP model in the initial situation of the companies under study. Several insights can be derived from these initial results. The analysis of these results and the sensitivity analysis of this case are presented in the next sub-section.

4.3. Final comparison and sensitivity analysis

According to the results (see Fig. 4), the size of the company has a

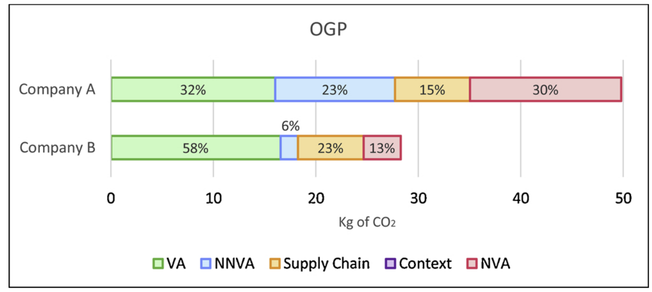

Fig. 4. Initial results per company.

major effect on environmental performance. Generally speaking, the company with the highest demand (i.e., Company A) has the poorest environmental performance, as the VA activities represent 32% of the CO_2 emissions in Company A and 58% in Company B. In both companies, the VA category (i.e., the routing process) itself makes the greatest contribution in OGP. However, Company A is the most affected by vehicle capacity. That is, the NNVA category seems to affect the company with the highest demand to a much greater extent. This suggests that it could be important to evaluate the impact of a higher vehicle capacity on environmental performance. The Supply Chain category (i.e., time windows) seems to have a similar impact on both companies. In the Context category (i.e., route length), neither company shows any impact since none of the routes exceed the 8-h length. Therefore, it would be interesting to evaluate the impact that stricter legislation would have on the companies' performance. The high contribution of the NVA category, especially for Company A, shows the inefficiency of setting reduction of lead time as the objective function (routing strategy).

At the same time, when evaluating the productivity indicators of the UFT system (see Table 2), NNVA increases the travel distance and total cost for both companies, but this implies an increase in delivery times. That is an interesting trade-off between productivity and service level. Reducing company costs could lead to lower levels of recipient satisfaction if recipients are accustomed to receiving their order in short time frames. Finally, it is important to note that every NVA overrun is an improvement opportunity since it corresponds to an inadequately defined routing process. Simply changing the objective function (i.e., reducing total cost instead of lead times) could lead to a CO_2 emission reduction of 29.7% in Company A and 16.2% in Company B. Other key indicators (i.e., travel distance, total cost, etc.) would significantly decrease as well. For example, travel distance would improve by 29.7% in Company A if the routing strategy is the reduction of UFT costs.

Additionally, for the evaluation step, we propose three scenarios (i.e., sensitivity analyses) in order to evaluate the impact of the OGP categories in the UFT system. Scenario A considers the employment of a different vehicle, specifically the 30,600 US$ Renault Traffic Van with 1274 kg of payload, 0.177 kg/km of CO_2 emissions, 7.5 L/100 km of fuel consumption (i.e., 0.059 US$/km) and a fixed vehicle cost of 24 US $/route (Renault, 2018). Scenario B contemplates the impact of recipient time windows that are 50% bigger. Finally, scenario C considers a stricter legislation of 6 h for routing length. It is important to note that in this last scenario, time windows should be also adjusted in the model (i.e., no time window can exceed the 6-h length). A sensitivity analysis was performed only for Company A, as it is the company with the lowest environmental performance and in the interest of avoiding an unnecessarily long and repetitive analysis.

The OGP and productivity results for the three proposed scenarios are presented in Fig. 5. It is important to note that the NVA category is presented in order to maintain the OGP structure. However, the NVA category could be removed by changing objective function (17) to objective function (12). These optimized results (i.e., reducing the total cost of each scenario) are presented in Table 3.

Increased capacity (Scenario A) leads to halving the NNVA category

Table 2
Initial results per company.

Company A	VA	NNVA	Supply Chain	Context	NVA
Travel distance (km)	75.65	130.655	165.25	165.25	234.9
Total cost (US$)	31.443	69.026	106.251	106.251	196.307
Average delivery time (h)	1.833	1.084	3.819	3.819	5.569
Total CO_2 emissions (Kg)	16.038	27.698	35.033	35.033	49.799
Company B	**VA**	**NNVA**	**Supply Chain**	**Context**	**NVA**
Travel distance (km)	78	86.1	116.2	116.2	138.6
Total cost (US$)	30.382	45.072	71.22	71.22	193.032
Average delivery time (h)	1.688	1.156	3.798	3.798	5.854
Total CO_2 emissions (Kg)	16.536	18.253	24.634	24.634	29.383

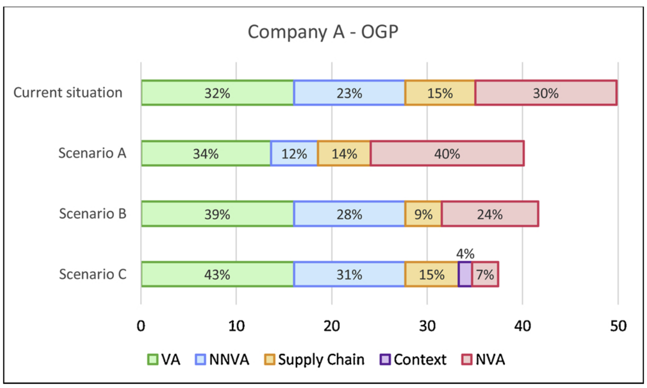

Fig. 5. OGP - Sensitivity analyses.

relative to the current situation (from 23% to 12%). The total operation cost and CO_2 emissions are also reduced. However, it is important to note that this scenario involves acquiring a new type of vehicle, where such an acquisition could be a costly endeavor if the whole fleet is renewed. However, this ex-ante analysis could be helpful for new UFT configurations in order to define the best fleet size combination.

Increasing recipients' time windows by 50% (Scenario B) leads to a 6% reduction in the Supply Chain category. Furthermore, the cost reduction seems to be very slight. Decision-makers should evaluate if these trade-offs are affordable and feasible for the relevant UFT stakeholders. Finally, reducing the routing length to 6 h (i.e., a reduction of 25% in Scenario C), adds an impact of 4% to the Context category. This result shows that, environmentally speaking, introducing stricter policies for systems can be counter-productive for UFT system configuration.

5. Conclusions and future research

This study proposed a new methodology for measuring and evaluating the environmental performance of logistics systems. This approach provides insights and highlights the characteristics that are to be considered in order to shift toward sustainable UFT systems. Furthermore, this methodology holistically characterizes and evaluates a UFT system using different stakeholders' perspectives, meaning it can be transferred to other industrial contexts, and it relates environmental performance with productivity factors (i.e., value-added concept).

Our conclusions are in line with those of Holguín-Veras et al. (2018), where the authors argued that to advance the field and guide decision-makers, assessments that take into account the complexity of impacts and the trade-offs involved are greatly needed. Certainly, as multiple stakeholders are involved in urban freight transport and these stakeholders have different objectives and different perspectives on urban freight transport, coordinating the stakeholders is needed to make progress in establishing efficient and environmentally friendly urban freight transport systems (Taniguchi, 2015).

Our methodology was validated in a practical case, demonstrating its potential for finding more effective alternatives for improvement, given the aim of reducing environmental impact through OGP categorization. In addition, this article offers interesting results for decision-makers. Stakeholders concerned about productivity and environmental issues have the chance to quantify the environmental impact of different activities in freight delivery, making it possible to use the OGP tool in an ex-ante assessment of possible alternatives such as, for example, renegotiating time windows with recipients or evaluating the impact of stricter environmental legislation. Future work should extend the proposed methodology to other contexts and explore specific supporting tools and techniques (e.g. monitoring). Additionally, different environmental metrics could be tested according to the interests of decision-makers (e.g., NO_x, particulate matter, energy and water consumption).

As we mentioned at the outset of this article, three elements are essential for the environmental assessment of UFT systems: 1) tools should holistically characterize and evaluate different stakeholders' perspectives; 2) the methodology should be applicable and transferable to other cases, and 3) certain productivity/economic factors must be considered. Therefore, the proposed approach can be extended to increase efficiency and improve the environmental performance of other logistic systems by providing a holistic measurement methodology. Our findings also provide some directions for public policies. For example, based on the current legislation in Bogotá, introducing stricter policies for systems can be counter-productive for UFT system configuration.

The limitation of our research with respect to comparability and generalizability cannot be ignored due to the specific conditions of the case under study, despite the fact that vehicles, distance and cost could be similar in other contexts. The research was based on two of the major convenience store networks in Colombia and thus the results may not

Table 3
Productivity results in optimized scenarios.

	Current situation	Scenario A	Scenario B	Scenario C
Travel distance (km)	165.25	135.95	148.65	163.65
Total cost (US$)	106.251	98.79	105.864	91.75
Average delivery time (h)	3.819	4.463	3.948	2.412
Total CO_2 emissions (Kg)	35.033	24.063	31.514	34.694
Utilization rate	79.7%	61.0%	79.7%	79.7%

be generalizable to other countries. Finally, our research was based on OR models, which means that there is a possibility that some mathematical computations may have been limited and/or can be improved (e.g., computation of CO_2 emissions, fuel consumption, fixed costs, etc.). Despite these limitations, this study has yielded some important insights and suggested potential areas for further work.

Acknowledgments

The authors are deeply grateful to the anonymous reviewers for their suggestions, which have greatly contributed to the improvement of this paper. The work presented in this paper was carried out within the framework of the LIFE MCUBO research project funded by the European Union (LIFE15 ENV/ES/000379), through the LIFE programme. In addition, the authors would like to acknowledge the support received from AdP, the Special Patrimonial Fund at Universidad de La Sabana, the doctoral grant from TECNUN Escuela de Ingenieros, Universidad de Navarra and MIT Sustainable Logistics Initiative.

References

ALICE (2015). *Urban freight research & innovation roadmap.* Available at: https://www.etp-logistics.eu/wp-content/uploads/2015/08/W56mayo-kopie.pdf (Last accessed: 4 October 2018).
Ambrosini, C., & Routhier, J. (2004). Objectives, methods and results of surveys carried out in the field of urban freight transport: An international comparison. *Transport Reviews, 24*(1), 57–77.
Ahlroth, S., & Finnveden, G. (2011). Ecovalue08—A new valuation set for environmental systems analysis tools. *Journal of Cleaner Production, 19*(17–18), 1994–2003.
Anand, N., van Duin, R., Quak, H., & Tavasszy, L. (2015). Relevance of city logistics modelling efforts: A review. *Transport Reviews, 35*(6), 701–719.
Atlantic Council (2014). *Urbanization in Latin America.* Available at: http://www.atlanticcouncil.org/publications/articles/urbanization-in-latin-america (Last accessed: 9 October 2018).
Ballantyne, E., Lindholm, M., & Whiteing, A. (2013). A comparative study of urban freight transport planning: Addressing stakeholder needs. *Journal of Transport Geography, 32*, 93–101.
Behrends, S., Lindholm, M., & Woxenius, J. (2008). The impact of urban freight transport: A definition of sustainability from an actor's perspective. *Transportation Planning and Technology, 31*(6), 693–713.
Bektaş, T., Ehmke, J., Psaraftis, H., & Puchinger, J. (2019). The role of operational research in green freight transportation. *European Journal of Operational Research, 274*(3), 807–823.
Bibri, S., & Krogstie, J. (2017). Smart sustainable cities of the future: An extensive interdisciplinary literature review. *Sustainable Cities and Society, 31*, 183–212.
Braekers, K., Ramaekers, K., & Van Nieuwenhuyse, I. (2016). The vehicle routing problem: State of the art classification and review. *Computers & Industrial Engineering, 99*, 300–313.
Browne, M., Piotrowska, M., Woodburn, A., & Allen, J. (2007). *Literature review WM9: Part I-urban freight transport. Green Logistics Project.* London: University of Westminster.
Buldeo Rai, H., van Lier, T., Meers, D., & Macharis, C. (2017). Improving urban freight transport sustainability: Policy assessment framework and case study. *Research in Transportation Economics, 64*, 26–35.
Cadarso, M., López, L., Gómez, N., & Tobarra, M. (2010). CO_2 emissions of international freight transport and offshoring: Measurement and allocation. *Ecological Economics, 69*(8), 1682–1694.
Churchman, C. W. (1968). *The systems approach* (1st ed.). New York: Dell Publishing.
City Mayors (2015). *The largest cities in the world and their mayors.* Available at: http://www.citymayors.com/statistics/largest-cities-mayors-1.html (Last accessed: 18 October 2018).
Comi, A., Schiraldi, M., & Buttarazzi, B. (2018). Smart urban freight transport: Tools for planning and optimising delivery operations. *Simulation Modelling Practice and Theory, 88*, 48–61.
Cordeau, J., Laporte, G., Savelsbergh, M., & Vigo, D. (2007). Vehicle routing. *Handbooks in Operations Research and Management Science, 14(C*, 367–428.
Coulombel, N., Dablanc, L., Gardrat, M., & Koning, M. (2018). The environmental social cost of urban road freight: Evidence from the Paris region. *Transportation Research Part D: Transport and Environment, 63*, 514–532.
Crainic, T., & Laporte, G. (1997). Planning models for freight transportation. *European Journal of Operational Research, 97*(3), 409–438.
Dantzig, G., & Ramser, J. (1959). The truck dispatching problem. *Management Science, 6*(1), 80–91.
de Jong, G., Daly, A., Pieters, M., Miller, S., Plasmeijer, R., & Hofman, F. (2007). Uncertainty in traffic forecasts: Literature review and new results for the Netherlands. *Transportation, 34*, 375–395.
De Brucker, K., Macharis, C., & Verbeke, A. (2013). Multi-criteria analysis and the resolution of sustainable development dilemmas: A stakeholder management approach. *European Journal of Operational Research, 224*(1), 122–131.
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.
EL TIEMPO (2013). *El abecé de las restricciones a los vehículos de carga en Bogotá.* Available at:https://www.eltiempo.com/archivo/documento/CMS-13202956(Last accessed: 4 October 2018, in Spanish).
EL TIEMPO (2016). *Así está la velocidad de 5 vías de Bogotá.* (Last accessed: 4 October 2018, in Spanish) http://www.eltiempo.com/bogota/velocidad-en-vias-de-bogota/16560364.
Eren Akyol, D., & De Koster, R. (2018). Determining time windows in urban freight transport: A city cooperative approach. *Transportation Research Part E, 118*, 34–50.
Freeman, E. R. (1984). *Strategic management: A stakeholder approach.* Boston: Pitman.
Forsberg, J., & Krook-Riekkola, A. (2018). Supporting cities' emission mitigation strategies: Modelling urban transport in a times energy system modelling framework. *WIT Transactions on the Built Environment, 176*, 15–25.
GHG Protocol (2018). *Calculation tools.* Available at: https://ghgprotocol.org/calculation-tools (Last accessed 16 October 2018).
GlobalPetrolPrices.com (2018). *Gasoline Prices.* Available at: https://www.globalpetrolprices.com/gasoline_prices/ (last accessed: September 13, 2019).
Gonzalez-Feliu, J. (2017). *Sustainability evaluation of green urban logistics systems: Literature overview and proposed framework. Green initiatives for business sustainability and value creation.* IGI Global103–134.
Hancock, D., & Algozzine, B. (2016). *Doing case study research: A practical guide for beginning researchers* (3rd ed.). New York: Teachers College Press.
He, K., Huo, H., Zhang, Q., He, D., An, F., Wang, M., et al. (2005). Oil consumption and CO_2 emissions in China's road transport: Current status, future trends, and policy implications. *Energy Policy, 33*(12), 1499–1507.
Holguín-Veras, J., Sánchez-Díaz, I., & Browne, M. (2016). Sustainable urban freight systems and freight demand management. *Transportation Research Procedia, 12*, 40–52.
Holguín-Veras, J., Amaya Leal, J., Sánchez-Diaz, I., Browne, M., & Wojtowicz, J. (2018). State of the art and practice of urban freight management. *Transportation Research Part A: Policy and Practice.* https://doi.org/10.1016/j.trpro.2016.02.024.
Karakikes, I., Nathanail, E., & Savrasovs, M. (2019). Techniques for smart urban logistics solutions' simulation: A systematic review. *Lecture Notes in Networks and Systems, 68*, 551–561.
Kijewska, K., & Iwan, S. (2019). The implementation of environmental friendly city logistics in South Baltic region cities. *Advances in Intelligent Systems and Computing, 879*, 599–606.
Kin, B., Verlinde, S., & Macharis, C. (2017). Sustainable urban freight transport in megacities in emerging markets. *Sustainable Cities and Society, 32*, 31–41.
Kiba-Janiak, M. (2017). Urban freight transport in city strategic planning. *Research in Transportation Business & Management, 24*, 4–16.
Lagorio, A., Pinto, R., & Golini, R. (2016). Research in urban logistics: A systematic literature review. *International Journal of Physical Distribution & Logistics Management, 46*, 908–931.
Laporte, G. (1992). The vehicle routing problem: An overview of exact and approximate algorithms. *European Journal of Operational Research, 59*(3), 345–358.
Lindholm, M. (2010). A sustainable perspective on urban freight transport: Factors affecting local authorities in the planning procedures. *Procedia — Social and Behavioral Sciences, 2*(3), 6205–6216.
Lindholm, M., & Blinge, M. (2014). Assessing knowledge and awareness of the sustainable urban freight transport among Swedish local authority policy planners. *Transport Policy, 32*, 124–131.
Lyons, G. (2018). Getting smart about urban mobility—Aligning the paradigms of smart and sustainable. *Transportation Research Part A, 115*, 4–14.
Molina-Azorín, J., Claver-Cortés, E., López-Gamero, M., & Tarí, J. (2009). Green management and financial performance: A literature review. *Management Decision, 47*(7), 1080–1100.
Montoya-Torres, J. R., López Franco, J., Nieto Isaza, S., Felizzola Jiménez, H., & Herazo-Padilla, N. (2015). A literature review on the vehicle routing problem with multiple depots. *Computers & Industrial Engineering, 79*, 115–129.
Morana, J., & Gonzalez-Feliu, J. (2015). A sustainable urban logistics dashboard from the perspective of a group of operational managers. *Management Research Review, 38*(10), 1068–1085.
Morioka, S., & de Carvalho, M. (2016). A systematic literature review towards a conceptual framework for integrating sustainability performance into business. *Journal of Cleaner Production, 136*, 134–146.
Muñoz-Villamizar, A., Santos, J., Montoya-Torres, J., & Ormazábal, M. (2018). Environmental assessment using a lean based tool. *Service Orientation in Holonic and Multi-Agent Manufacturing,* 41–50.
Muñoz-Villamizar, A., Quintero-Araújo, C., Montoya-Torres, J., & Faulin, J. (2019). Short- and mid-term evaluation of the use of electric vehicles in urban freight transport collaborative networks: A case study. *International Journal of Logistics Research and Applications, 22*(3), 229–252.
Nenni, M. E., Sforza, A., & Sterle, C. (2019). Sustainability-based review of urban freight models. *Soft Computing, 23*, 2899–2909.
Pani, A., Sahu, P., Patil, G., & Sarkar, A. (2018). Modelling urban freight generation: A case study of seven cities in Kerala, India. *Transport Policy, 69*, 49–64.
Patier, D., & Browne, M. (2010). A methodology for the evaluation of urban logistics innovations. *Procedia — Social and Behavioral Sciences, 2*(3), 6229–6241.
Pinto, R., Lagorio, A., & Golini, R. (2018). The location and sizing of urban freight loading/unloading lay-by areas. *International Journal of Production Research, 57*(1), 83–99.
Quak, H. (2008). *Sustainability of urban freight transport: Retail distribution and local regulations in cities (PhD thesis).* Rotterdam: ERIM.
Renault Colombia (2018). https://www.renault.com.co. (Last accessed: 4 October 2018).

Reyes, D., Erera, A., & Savelsbergh, M. (2018). Complexity of routing problems with release dates and deadlines. *European Journal of Operational Research, 266*(1), 29–34.
Russo, F., & Comi, A. (2016). Urban freight transport planning towards green goals: Synthetic environmental evidence from tested results. *Sustainability, 8*(4), 381.
Russo, F., & Comi, A. (2017). From the analysis of European accident data to safety assessment for planning: The role of good vehicles in urban area. *European Transport Research Review, 9*(9), https://doi.org/10.1007/s12544-017-0225-0.
Shahbaz, M., Khraief, N., & Jemaa, M. (2015). On the causal nexus of road transport CO_2 emissions and macroeconomic variables in Tunisia: Evidence from combined cointegration tests. *Renewable and Sustainable Energy Reviews, 51*, 89–100.
Schliwa, G., Armitage, R., Aziz, S., Evans, J., & Rhoades, J. (2015). Sustainable city logistics—Making cargo cycles viable for urban freight transport. *Research in Transportation Business & Management, 15*, 50–57.
Steg, L., & Gifford, R. (2005). Sustainable transportation and quality of life. *Journal of Transport Geography, 13*(1), 59–69.
Taniguchi, E. (2015). City logistics for sustainable and liveable cities. In B. Fahimia, M. G. H. Bell, D. A. Hensher, & J. Sarkis (Eds.). *Green logistics and transportation: A sustainable supply chain perspective* (pp. 49–60). Cham, Switzerland: Springer International Publishing.
Toth, P., & Vigo, D. (2014). *Vehicle routing: Problems, methods, and applications* (2nd revised edition). Philadelphia: SIAM – Society for Industrial and Applied Mathematics.
Ubeda, S., Arcelus, F., & Faulin, J. (2011). Green logistics at Eroski: A case study. *International Journal of Production Economics, 131*(1), 44–51.
United Nations (2018). Department of Economic and Social Affairs. Available at: https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html (Accessed 13 09 19).
Vachon, S., & Klassen, R. D. (2008). Environmental management and manufacturing performance: The role of collaboration in the supply chain. *International Journal of Production Economies, 111*(2), 299–315.
Yin, R. K. (2003). *Case study research: Design and methodsApplied social research methods series: Vol. 5* (3rd ed.). Thousand Oaks, CA: Sage.