The Incorporation of Eco-Friendly Light Vehicles in Logistics Distribution Models: A Systematic Review

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Abstract

The paper explores and reviews the mathematical optimization models that have been developed seeking to incorporate Light Electric Vehicles (LEV) for urban load distribution in logistics distribution models. This exploration is done through a Systematic Literature Review (SLR) with the purpose of making a deep understanding of the optimization functions, the decision variables, and the parameters that have been used in the reviewed research. In addition, this study investigates the attention that this issue has received in recent years in different optimization approaches such as distribution time, greenhouse gas emissions, or operating costs. Furthermore, this paper highlights the relevance of in-depth research that allows the development of new mathematical models that make evident the viability of the implementation of eco-friendly cargo vehicles in Latin American cities' distribution systems in terms of costs, and the need for a replicable model-construction methodology in locations with similar characteristics. The novelty of this paper, therefore, relies on the specific exploration of mathematical model-based publications, and deep analysis and comparison of their variables, parameters, and restrictions. This paper identifies the five different optimization approaches that have been used globally for the incorporation of LEV in urban logistics and compares the 25 main parameters and 7 main variables used among these models.

Keywords
Optimization modeling; Urban logistics; Light-vehicle distribution; Last-mile delivery, e-bikes.

1. Introduction
Population growth in large cities is not a new issue, as well as the migration of thousands of people from rural areas to cities in search of greater opportunities, better quality of life and greater security, among other reasons. Currently, 55% of the population resides in urban areas globally, and this percentage is forecast to increase to 70% by 2050 (United Nations, 2020). These numbers may not have a big impact at first glance, but when translating the percentages into number of people, this increase would represent approximately 2.5 billion more people living in cities, bringing with them multiple implications.

This trend can be clearly observed in the cities of Latin America, where today it is estimated that 80% of the population lives in urban areas. However, this percentage is forecast to rise to 86% in 2050 (United Nations, 2019). With this, it is very clear that more and more challenges are approaching in large cities, and one of them is related to mobility and transport because, in the words of Julián Sastre, consultant on transport and city issues, "Urbanism and mobility make up an inseparable binomial" (Sastre, 2017).

It is estimated that the transportation industry generates 24% of CO_2 emissions worldwide. This is due, in large part, to trucks and other large cargo or transport vehicles, which highlights the need for international interest and focus on the substitution of these high-contaminating vehicles. Despite rapid growth in development of electric vehicles, having today in circulation more than 6 million electric cars for personal use, the trend has not translated with the same slope to the incorporation of vehicles of this type in the last-mile delivery and distribution industry (IEA, 2020).

This paper seeks to collect the methods, variables, approaches, parameters, and restrictions that have been used and understand if they can be implemented in Latin American cities, despite the multiple differences in conditions. Under no circumstances, it intends to detract from the work carried out by the authors cited here. This is exploratory research of the work that has been developed in recent years around the world that incorporates light electric vehicles (LEV) in distribution and delivery models and has three specific purposes: (1) to understand the different optimization modeling approaches that have been given to this type of logistics problems by studying the objective functions. (2) To identify the optimization functions, decision variables, and parameters used in recent years in mathematical models that have sought to involve LEV in distribution issues. Finally, (3) to demonstrate the need to develop a mathematical model for cost optimization that incorporates LEV for urban distribution systems for Latin American cities and cities with similar characteristics.

Later in this document, the bibliographic review process followed is narrated, based on the PRISMA methodology described below. Descriptive information of the papers collected and studied is included, as well as the trends and areas of concentration identified. Finally, an overview of the published literature is added, followed by the main common findings and the conclusions pertinent to the objectives just outlined in this section.

2. Research Methodology

The growth trends in eco-friendly distribution issues have led authors around the world to mathematically evaluate the possibility of implementing LEV in distribution models. This research studies the published literature using the Systematic Literature Review (SLR) methodology known as PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyzes) (PRISMA, 2015). "PRISMA focuses on ways in which authors can ensure the transparent and complete reporting of systematic reviews and meta-analyses". (Liberati, et al., 2009) As described in the same paper, this methodology consists of a 27-step checklist grouped in seven stages that help define the scope and path of the research: Title, Abstract, Introduction, Methods, Results, Discussion, and Funding. In addition, recommendations from the scoping study stage of the SLR approach proposed by Keathley-Herring, et al. (2016) were considered in the two first steps of PRISMA.

2.1. Data Collection

Papers were searched online after the construction of a Boolean phrase formed by the following 4 groups of words: 1) logistics, distribution, delivery, routing, or freight. 2) Bicycle, tricycle, bike, light vehicle, e-bike, or e-cargo bike. 3) Urban, last mile, city, or town. 4) Optimiz*, design*, model* or network. (The * symbol is used to include all derived words with the same beginning, for example optimization and optimize). Additionally, the following keywords were excluded: air, medicine, health, train, sea, passenger, sharing, scoot*, taxi, bus*, automated, and e-scooter. The limitations of area of studies, language, type of document, and stage of publication were also added to the Boolean phrase of research.

The papers were found and obtained by accessing the digital databases of Scopus and EBSCO, through the digital library of the Universidad de Monterrey (UDEM). The decision criteria for the selection of the papers used for this research is based on the use of Operations Research (OR) techniques and mathematical modeling to identify the feasibility of involving LEV in urban mobility of loads and last-mile deliveries. Figure 1 shows the diagram of the PRISMA methodology constructed, which describes the process of filtering and selecting papers and articles from their Identification to their Screening, Eligibility, and Inclusion.

Papers with eligibility were fully contemplated and analyzed in the research, but only the publications that involved a LEV into the logistics mathematical models were included for this specific SLR publication. Those publications with different approaches and type of vehicles studied where excluded, for example those suggesting the utilization of electric cars for last-mile distribution, or those focusing in the creation process or specifics characteristics of electric vehicles.

Furthermore, Figure 2 presents descriptive information of the papers studied in the research, and those specifically selected for regarding optimization mathematical models as part of the methodology. 18 papers with optimizations models were considered, in addition to 25 publications regarding research and analysis, 7 publications with focus on simulation analysis, and 2 SLR reports. We observe also in Figure 2 that more than 65% of the papers were published in the last four years.

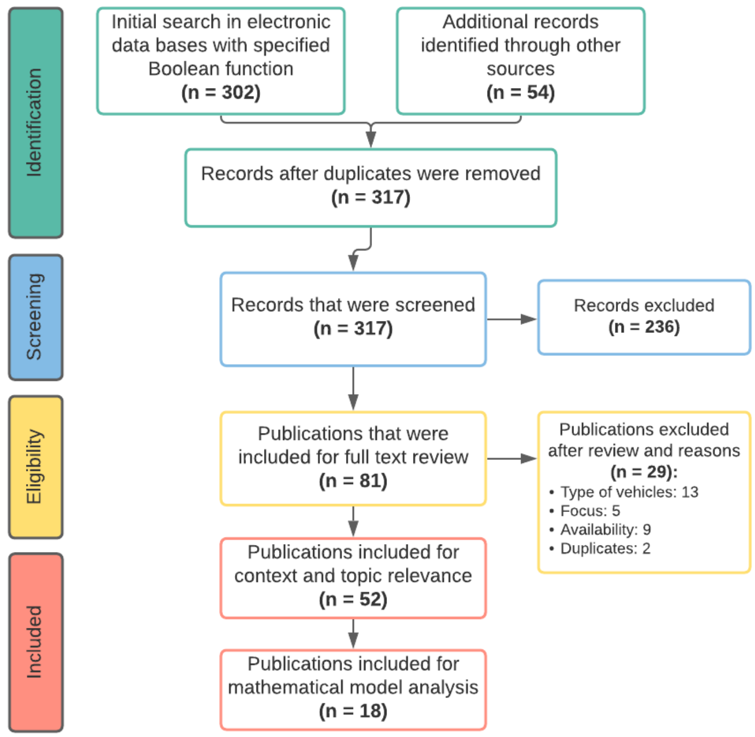

Figure 1. PRISMA methodology diagram for paper filtering (adapted from Liberati *et al*., 2009)

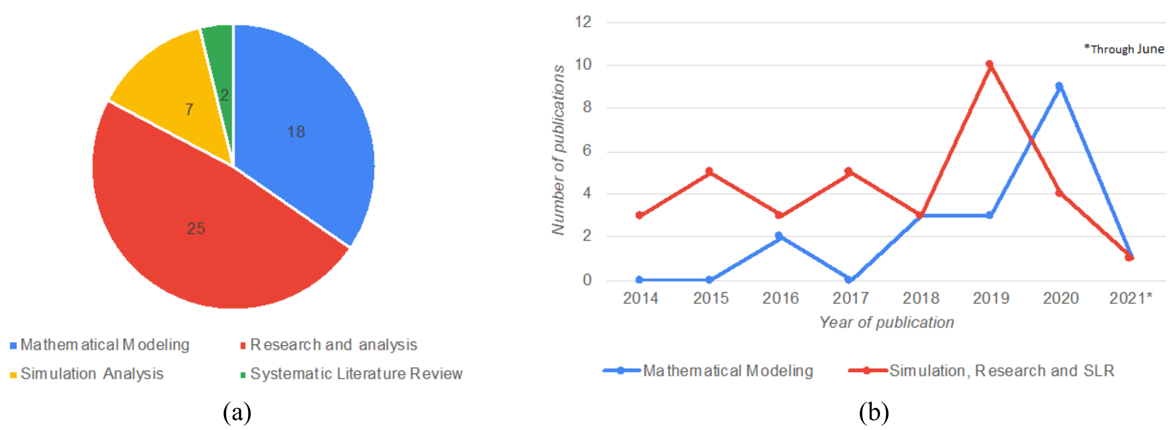

Figure 2. Descriptive data – (a) Proportion of modeling papers and other research and SLR, (b) Annual Frequency

3. Searching for alternative ways for urban distribution

Major metropolitan areas around the world have been facing incrementing vehicle congestion, and the environmental issues that come with it. It looks to be the ideal scenario to invest in logistics infrastructure and eliminating parking spaces, although it's not likely to change significantly (Sheth, Butrina, Goodchild, & McCormack, 2019). Although fragmented usage of distribution innovations can promote sustainability in the short term, operating them represents big challenges for network structure with a long-term perspective (Zhangyuan, 2020). For those reasons, and the positive tendency of e-commerce and distribution logistics that come with it, "Electric Assist (EA) cargo bicycles have been of interest to several major delivery companies as an alternative to trucks for completing urban deliveries" (Sheth, Butrina, Goodchild, & McCormack, 2019). Sharing this idea, it's understood that nowadays cargo bikes are seeing an ever-greater role in city logistics with an increasing number of deliveries, and it is essential to examine their future role in green and smart cities (Sárdi & Bóna, 2021).

Cargo bikes have been known to be a popular topic in the last-mile delivery field, where different research and findings have led to think that a collaboration between cargo bikes and other distribution innovations is possible (Zhangyuan, 2020). Different studies have been carried out to analyze this situation and determine whether EA Cargo-bikes can be a viable option for involvement in the last mile distribution models, from several different perspectives (costs, time, emissions, etc.). For example, it has been concluded that, after several studies in Porto, Portugal, the introduction of electric cargo bikes in urban logistics activities has positive effects reaching up to 25% of reductions in external costs, although not demonstrating how implement the model into the network (Melo & Baptista, 2017). Nevertheless, in other parts of the world the tricycle is blamed for reduced road efficiency and safety concerns for the drivers of such non-motorized vehicles (Zacharias & Zhang, 2015).

Although motorcycles are not the most common delivery and distribution vehicles, it's been concluded that the cost of a bicycle dedicated to delivery is 14% of that of a motorcycle. Besides this benefit, the maintenance of the bicycle is 25% of that of the motorcycle (Navarro, Roca-Riu, Furió, & Estrada, 2016). In addition to that, electric cargo bikes are perceived to have the following advantages over conventional diesel vans: taxes, insurance, storage, depreciation costs, easier to park, and consume less curb space (Melo & Baptista, 2017) (Sheth, Butrina, Goodchild, & McCormack, 2019).

3.1. Published Literature Overview

Some studies have been conducted resulting in punctual conclusions regarding the implementation of Electric Cargo Bikes into conventional distribution models for last-mile delivery, but it is yet to be found a mathematical model that reflects the cost benefits resulting in that implementation, and under what parameters can the EA cargo bikes be useful. Under the research methodology described above, 18 publications were found attempting to somehow quantify, through a mathematical model for optimization, the benefits of incorporating these eco-friendly vehicles into the distribution models in different extents. Some of them replace the conventional vans all the way, and some look to build a network with a combination of both types of transportation.

To understand each of the papers studied, an analysis was conducted to find what the objective of the model was (what are they asking themselves?), the optimization approach (what is the mathematical model optimizing?), and identify the parameters and decision variables utilized in the models (summarized in Table 1). Figure 3 demonstrates the proportion of studied papers regarding the optimization approach, where just seven (7) papers focus on costs optimization, which should be the biggest question to answer regarding this topic. This color scheme is also used on table 1 to highlight the parameters specifically used for each optimization scope. It is evident that the incorporation of LEV into the distribution models is a necessary action for the sustainability of the industry and, although models have been developed that show the reduction of emissions, travel time, distance traveled, and driver risks, cost reduction is the reason that more and more companies would start to use these innovations.

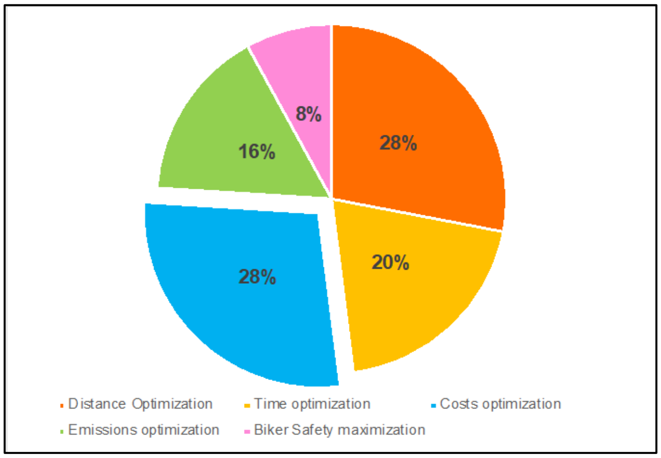

Figure 3. Proportion of optimization approach for the models included in the SLR

3.2. Discussion on Mathematical Modeling with LEV

After studying each of the 18 publications discovered to be relevant regarding the topic of this paper, several analyses can be made. The most relevant parameters have been summarized in table 1. From a total of 18 studied models, 12 (67%) utilize the demand size and the fleet size as parameters for the model. That means that they have quantified that information and introduced it to the model as given data. For example, (Figliozzi, Saenz, & Faulin, 2020) set the number of daily deliveries to 80 and the customer demand to 65 lbs., as they used continuous approximation methods for estimations that were based on the "spatial density of demand rather than on precise information about the location and demand of each customer". In another way, (Caggiani, Colovic, Prencipe, & Ottomanelli, 2021) define the demand size in terms of the demand of each vertex for each of the two echelons considered, while defining the fleet in terms of the number of stations and vehicles for each echelon. Other well-constructed models also include the demand size, in some way, as one of their parameters, like (Sheth, Butrina, Goodchild, & McCormack, 2019), (Akkad & Bányai, 2020) or (Anderluh, Hemmelmayr, & Nolz, 2017).

Some of the parameters identified in the optimization models are particularly related to one of the 5 optimization approaches mentioned above in Figure 3. (Osaba, Del Ser, Bilbao, Lopez-Garcia, & Nebro, 2018) and (Osaba, et al., 2018) consider different safety indicators per route defined, so that they're able to minimize the risk to which the driver is exposed. Another of the optimization scopes was minimizing the travel time. (Anderluh, Hemmelmayr, & Nolz, 2017), (Caggiani, Colovic, Prencipe, & Ottomanelli, 2021), (Gruber & Narayanan, 2019), and (Lee, Chae, & Kim, 2019) identify the travel time as part of their given information like average travel time per route or distance. In terms of energy consumption and non-environmentally friendly gases emissions, (Caggiani, Prencipe, Colovic, & Dell'Orco, 2020) and (Lee, Chae, & Kim, 2019) consider the CO_2 emissions per route or kilometer to be an important parameter in order to minimize the total emissions of the operation with their models.

Table 1. Identification of common parameters and decision variables of mathematical models from studied papers

		(Figliozzi, Saenz, & Faulin, 2020)	(Choubassi, Seedah, Jiang, & Walton, 2016)	(Caggiani, Colovic, Prencipe & Ottomanelli, 2020)	(Naumov, Vasiutina & Solarz, 2020)	(Naumov, 2021)	(Anderluh, Hemmelmayr & Nolz, 2016)	(Enthoven, Jargalsaikhan, Roodbergen, Broek, & Schrotenboer, 2020)	(Sheth, Butrina, Goodchild, & McCormack, 2019)	(Akkad & Bányai, 2020)	(Lee, Chae & Kim, 2019)	(Gruber & Narayanan, 2019)	(Ignatov, Baskov, Ablyazov, Aleksandrov, & Zhilkina, 2020)	(Dalla Chiara, Alho, Cheng, Ben-Akiva, & Cheah, 2020)	(Osaba, *et al.*, 2018)	(Fikar, Hirsch, & Gronalt, 2017)	(Osaba, Del Ser, Bilbao, Lopez-Garcia, & Nebro, 2018)	(Naumov & Stanczewski, 2018)	(Caggiani, Prencipe, Colovic, & Dell'Orco, 2020)
	Place of study	Portland, USA	Austin, USA	Italy	Krakow, Poland	Poland	Viena, Austria	Netherlands	Seattle, USA	Netherlands	Seoul, Corea	Germany	Russia	Singapore	Madrid, Spain	Vienna, Austria	Bilbao, Spain	Krakow, Poland	Bari, Italy
	Inclusion of Sensitivity Analysis													x					
	Scenarios analysis and simulation (no decision variable)					x			x		x	x		x	x	x	x		
Decision Variables	*Vehicles assigned to each section*					x													
	Which load to be deliver by which vehicle through which route									x						x	x	x	
	Load size to be transported by vehicle i							x											
	Variable that decides when to serve each customer				x		x								x	x			
	What vehicle assits what route / arc		x	x			x	x			x	x	x						x
	Amount of vehicles type i required	x																	
	Customers served by vehicle type	x																	
Parameters considered	*Travel cost per route*		x				x								x				
	Operational cost per hour								x		x								
	Investment and maintainance costs			x							x								
	Penalty costs for using van over bike						x												
	Vehicle and driver insurance costs						x				x								
	Vehicle life expectancy	x																	
	Materials and vehicle production emmisions	x																	
	Gas / energy / fuel consumption rate	x		x						x	x								x
	CO2 emissions per arc / route										x								x
	Safety indicators per route														x		x		
	Average vehicle speed	x		x	x	x						x				x	x	x	x
	Travel time			x			x				x	x							
	Service time	x	x	x			x		x										
	Time limits / time windows			x			x			x				x					
	Travel distance per trip / between trips	x		x			x	x	x					x		x		x	
	Covering range of the depot							x											
	Fleet size		x	x		x	x	x		x		x	x	x	x	x	x		
	Elevation											x							
	Demand size / locations	x	x	x	x	x	x		x	x			x		x	x	x		
	Package dimensions / weight				x			x	x				x	x		x		x	
	Demand density distribution							x				x		x				x	
	Traffic flow												x						x
	Warehouse capacity									x									
	Vehicle capacity (volume)				x	x	x		x				x				x		
	Vehicle capacity (kg)		x	x	x	x			x	x							x	x	
	Citation																		

Figure 4 summarizes the considered parameters by each mathematical model studied in a histogram, where the color scheme used in Figure 3 is kept for identifying the parameters that are strictly related to one of the five scopes of optimization models. The general parameters that don't fit into one of these scopes remain gray.

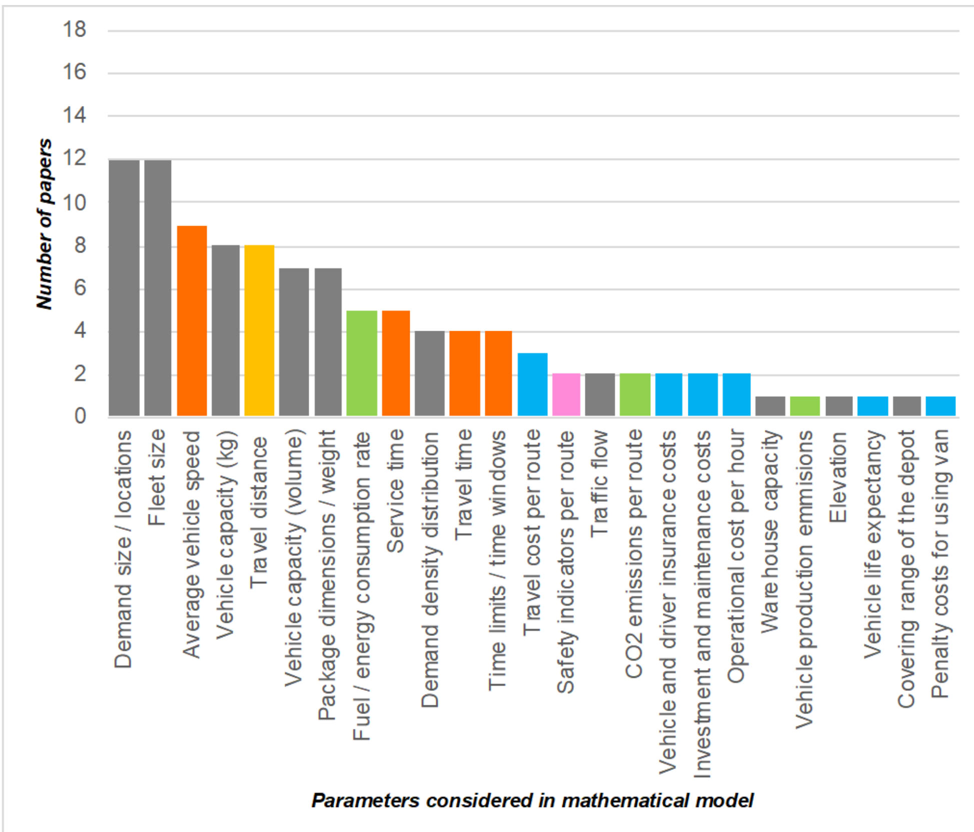

Figure 4. Histogram of the relevant parameters considered in the mathematical models

Among relevant insights from Figure 4 appears that, although it has already been specified that the most important scope of optimization should be costs minimization, the costs-related parameter have been under-utilized. For example, the only publication that considers vehicle life expectancy to distribute the investment cost and emissions of vehicle production corresponds to (Figliozzi, Saenz, & Faulin, 2020), while only (Anderluh, Hemmelmayr, & Nolz, 2017) defines a penalty cost for the instances where it's selected to use a conventional diesel van over one of the cargo bikes. The same pattern of low utilization of these parameters repeats, as only (Anderluh, Hemmelmayr, & Nolz, 2017) and (Lee, Chae, & Kim, 2019) consider vehicle and driver insurance costs. Only (Caggiani, Colovic, Prencipe, & Ottomanelli, 2021) and (Lee, Chae, & Kim, 2019) consider initial investment and maintenance costs. In terms of the costs of the operation (Lee, Chae, & Kim, 2019) and (Sheth, Butrina, Goodchild, & McCormack, 2019) consider it as an operational cost per hour, while (Anderluh, Hemmelmayr, & Nolz, 2017), (Choubassi, Seedah, Jiang, & Walton, 2016), and (Osaba, et al., 2018) add it to their models as a calculated travel cost per route defined.

For contrast, the parameters related to the time minimizing scope are way more utilized, for nine different papers consider the average speed of the vehicle to be relevant information for their models (including (Naumov & Starczewski, 2019), (Fikar, Hirsch, & Gronalt, 2017), and (Gruber & Narayanan, 2019)), and five different publications consider the service time of the delivery to be a parameter of given data to the model (including (Choubassi, Seedah, Jiang, & Walton, 2016), (Caggiani, Colovic, Prencipe, & Ottomanelli, 2021), and (Sheth, Butrina, Goodchild, & McCormack, 2019)).

Finally, in parametric issues, it is identified that none of the mathematical optimization models found and studied considers the use of exclusive lanes for bicycles as one of its modeling parameters. As previously mentioned in this document, investment in logistics infrastructure for this type of vehicle is not expected to grow significantly (Sheth, Butrina, Goodchild, & McCormack, 2019), but it is difficult to convince the corresponding authorities to make the investment without mathematical support that proves the impact of this type of infrastructure (Urban Development Institute of Bogotá, 2016). There are cities around the world with a growing urban road network of bicycle routes (dedicated or not). For example, in Bogota, Colombia it is 4% (552 km of bike routes for 14,000 km of roads), while in Madrid, Spain it is 6% (Statista, 2019) (Velásquez, 2015) (Bogota UDI, 2019). The focus is not exclusively to build new bike-exclusive routes, but also to change the use the existing bike lanes have had.

In terms of the decision variables used by the mathematical models studied, seven different decision variables have been identified . Figure 5 shows, through a histogram, the incidence of each of these variables through the 18 publications analyzed, adding those papers that did not give relevance to a decision variable and only evaluated different scenarios and/or simulated the situation of the study (highlighted in red).

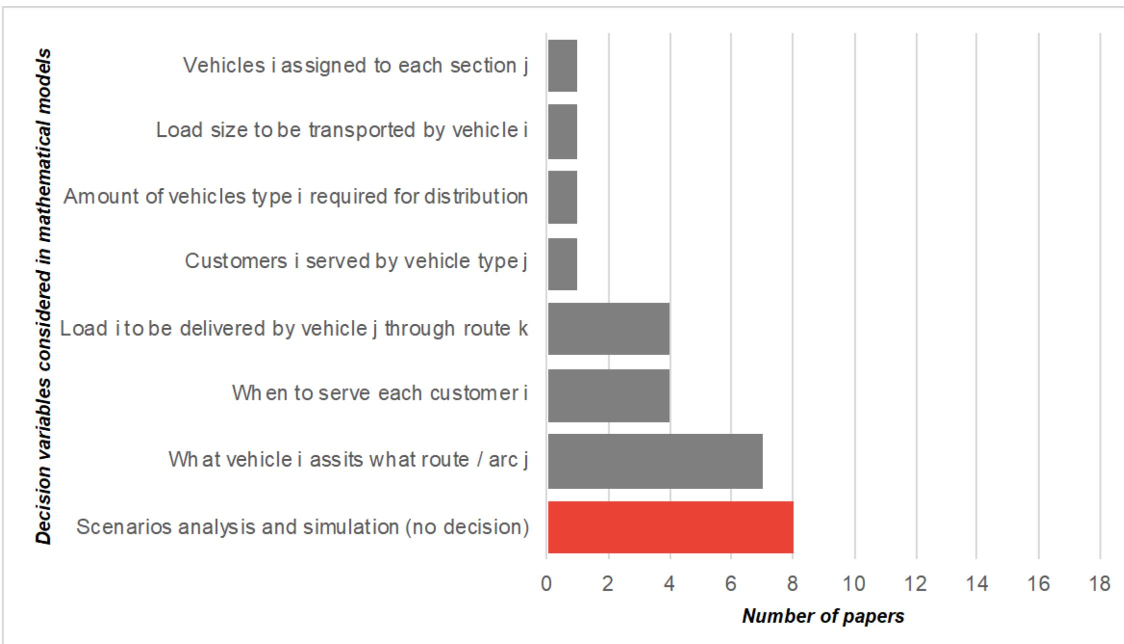

Figure 5. Histogram of the relevant decision variables considered in the mathematical models.

From figure 5 we can identify that almost half of the publications (8) found it more relevant to study their current situations or test different scenarios changing only the type of vehicle used for the particular situation they study as their decision variables. Some others define different decision variables and then test different scenarios changing the network model. Among the papers that only tested scenarios or simulations are (Dalla Chiara, Alho, Cheng, Ben-Akiva, & Cheah, 2020) and (Sheth, Butrina, Goodchild, & McCormack, 2019). The most common decision variable among papers was to define which vehicle, or vehicle type, was to be assigned to which route or arc previously defined. Seven papers use this variable, or one with the same intention, including (Choubassi, Seedah, Jiang, & Walton, 2016), (Caggiani, Colovic, Prencipe, & Ottomanelli, 2021), and (Ignatov, Baskov, Ablyazov, Aleksandrov, & Zhilkina, 2020). The most specific variable responds to defining which load will be delivered by which vehicle through which previously defined route, and there are four optimization models that focus on this variable or one similar, including (Akkad & Bányai, 2020), (Osaba, Del Ser, Bilbao, Lopez-Garcia, & Nebro, 2018), and (Fikar, Hirsch, & Gronalt, 2017).

One of the main obstacles with the use of simulations or evaluation of scenarios as decision variables, is that it limits the study to only the situation where it is carried out. The problem with this is that for the research to grow in relevance around the world, the reproducibility and use of the mathematical models created is extremely important, since the parametric conditions are not necessarily the same in all parts of the world. In fact, they change a lot. For example, the average speed in Mexico City, Mexico is 19 km/h, while in Bogota, Colombia is 14 km/h, and 21 km/h in Sao Paulo, Brazil (Hernández, 2020). Through the evaluation of 18 different papers regarding the construction of mathematical models, with different optimization scopes, none were developed in Latin America, or cities with similar characteristics. Three of the publications were carried out in or with information from the United States ((Figliozzi, Saenz, & Faulin, 2020) in Portland, (Choubassi, Seedah, Jiang, & Walton, 2016) in Austin, and (Sheth, Butrina, Goodchild, & McCormack, 2019) in Seattle). Three other publications were performed with information from somewhere in the Asian continent. Specifically, (Ignatov, Baskov, Ablyazov, Aleksandrov, & Zhilkina, 2020) in Russia, (Dalla Chiara, Alho, Cheng, Ben-Akiva, & Cheah, 2020) in Singapore, and (Lee, Chae, & Kim, 2019) in South Korea. The rest of the publications (12) were carried out in the European continent (including (Caggiani, Colovic, Prencipe, & Ottomanelli, 2021) and (Caggiani, Prencipe, Colovic, & Dell'Orco, 2020) in Italy, (Akkad & Bányai, 2020) and (Enthoven, Jargalsaikhan, Roodbergen, Broek, & Schrotenboer, 2020) in the Netherlands, and also (Osaba, Del Ser, Bilbao, Lopez-Garcia, & Nebro, 2018) and (Osaba, et al., 2018) in Spain). As stated in (Sheth, Butrina, Goodchild, & McCormack, 2019), European cities typically have narrow streets and older infrastructure as compared to American Cities, and bikes are a reasonable solution to road congestion. Table 2 lists the locations where the mathematical model development concentrates, adding the main optimization scope of the mathematical model(s) developed in each location

Table 2. Countries where the mathematical model-based papers concentrate.

Country	**Main optimization approach**
Spain	Biker Safety
USA	Costs
Netherlands	Costs
Austria	Costs
Italy	Emissions
South Korea	Emissions
Singapore	Total time
Poland	Total time
Germany	Traveled distance
Russia	Traveled distance

Finally, as can be seen in the last column of Table 1, only one of the mathematical models includes a sensitivity analysis that opens the way for future research and adaptations, being (Dalla Chiara, Alho, Cheng, Ben-Akiva, & Cheah, 2020). They performed a sensitivity analysis for what they identify as three key parameters, to better understand their contribution to the predicted total travel distance and operations time in their model. “The results for the selected parameters’ influence on total travel distance demonstrate a major effect by the assumed carrying capacity and minor effects from the assumed dwell times and delivery weight”. This type of analysis helps to understand the importance of different parameters in the mathematical model and their values, and how they affect the decision variables that are relevant to the study.

4. Conclusion

It is evident that the incorporation of LEV such as bikes and tricycles to urban distribution models will eventually be inevitable in most urban delivery operations. With the growing concern for eco-friendly alternatives for last-mile distribution, the search for what these alternatives are is studied, particularly 18 mathematical models that seek to evaluate the viability, in five different approaches of this implementation.

In this study, we identified and understood the five general optimization approaches of mathematical models (optimization of costs, emissions, time, distance, or driver safety). In addition, we identified and classified the most relevant parameters and decision variables with incidence through the mathematical models studied. Those with the highest incidence are highlighted, and clusters can be identified according to one of the five previously defined optimization approaches. Finally, this document manages to demonstrate the absence of a mathematical model of cost optimization with an adequate sensitivity analysis of parameters that allows it to be used in places outside the central place of study, without limiting the scope and reproducibility of the model despite the change in parametric conditions.

The academic contribution of this document is identified as relevant and important for the development of the matter, as this is the first document that evaluates and concentrates the different optimization models for the introduction of LEV in urban distribution models, considering their mathematical construction process. Future research should focus on the creation of a mathematical model of cost optimization, with its corresponding sensitivity analysis, that allows to identify the ranges of the parameters under which the use of LEV in last-mile urban distribution models is profitable.

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