

Evaluating the Benefits of Last-Mile Distribution with Light Electric Vehicles (LEV): A Case Study

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Abstract

The paper presents a research project where the profitability of incorporating Light Electric Vehicles (LEV) into last-mile distribution systems is evaluated, seeking to meet three particular objectives: (1) determine the benefits in terms of cost, of incorporating LEVs in the distribution of dry chain products, (2) determine the benefits in terms of cost, of incorporating LEVs in the distribution of mail packages, and (3) identify if such benefits are consistent along different scenarios of a distribution network. The research project is based on the need to promote the insertion of more eco-friendly distribution vehicles in the last-mile distribution operations, and direct data from a pilot test on the subject carried out by the Colombian research company Logyca®, based in Bogotá. This study carries out in-depth research on the subject, through an SLR, thoroughly exploring the mathematical optimization models that have been developed around the world trying to incorporate LEV into logistics distribution models to, eventually, identify the need for documentation of the building process of a model that minimizes operating costs. A sensitivity analysis is performed through the analysis of a designed experiment, which studies different conditions of last-mile distribution networks. Results show a reduction in costs of about 50% by the replacement of conventional trucks with a combination of e-bikes and e-trikes.

Keywords

Optimization; Urban Logistics; Light-vehicle Distribution; Last-mile delivery; Light Electric Vehicles (LEV).

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, among other reasons. In Latin America, it is estimated that 80% of the population lives in urban areas. However, an increase in this percentage is also forecast, up to 86% in 2050. Another interesting fact is that cities such as Bogotá, Colombia and Lima, Peru estimate that by 2030 they will have a population greater than ten million inhabitants, joining the list of other Latin American megacities such as Buenos Aires, Mexico City and Sao Paulo (Vaca 2020).

Delving into the issues of mobility and transport, some data attracts attention and creates conditions and opportunities for innovations in this sector. It is estimated that the transport sector generates 20.4% of CO₂ emissions worldwide. This is due, in large part, to trucks and other large cargo or transport vehicles, which are precisely the object of study for the change proposed in this project (Leon 2016). In Bogotá, for example, 60.3% of the pollution caused by the automobile fleet corresponds to trucks and buses. In this percentage, it stands out that only cargo vehicles generate 40%, being identified as the greatest cause of pollution within this sector (Arias-Bonafante 2020). For this reason, some cities have opted for the creation of more efficient means of transport, new types of transport and investment for infrastructure that allows new forms of urban mobility.

One of the main bets of many cities, especially in Europe, but increasingly important in Latin America, are the construction of bicycle lanes and encouraging the use of bicycles, mainly in the most densely populated areas. One city that is giving great importance to this issue is Bogotá. Today it is ranked as the worst city in the world in terms of vehicular traffic, according to a study carried out by Barria (2019), which is why the capital of Colombia needs a significant change. It is important to note that Bogotá registers the highest number of daily bicycle trips in Latin America, reaching more than 611,000 on average, followed by cities such as Santiago de Chile and Mexico City. This number of trips is possible thanks to the approximately 630 km of bicycle lanes that the city has (Alonso 2019) (Quintero 2018).

Projects of this type have been developed in different countries, mainly in Europe. Bogotá is a city that, with the data presented in relation to the use of bicycles and available bicycle lanes, presents a viable option for a project of this type, as the data seems to indicate that, with a well-defined strategy, a profitable and efficient distribution network can be created with the incorporation of LEV. For this reason, the Logyca® company decides to undertake an investigation and later a pilot test in Bogotá to verify the viability and results of a project of this type.

1.1 Logyca and their Pilot Test

Logyca® is a company based in the city of Bogotá, Colombia focused on developing logistics knowledge in Latin America. This research seeks to connect different industries and sectors to carry out collaborative research projects. To start the research project, Logyca® carried out a pilot test based on a study of the context of the logistics industry, with the objectives of gathering data, analyze the feasibility of the project, identify public policy guidelines, and study the results obtained to develop scaling strategies for the correct incorporation of LEV in traditional distribution networks.

This pilot test was carried out in collaboration with four companies with products of dry chain foods and parcels. The test had a duration of 10 months, from June 2020 to April 2021. The pilot test used two different models to diversify distribution strategies and to have a point of comparison for each model. Model 1 consisted of the distribution centers of each participating company being used with direct delivery to their customers. While model 2 used a Collaborative Cross Docking platform in a strategic area of the city.

Some opportunity areas were identified where the research team author of this document can intervene and have a positive impact: (1) there is no theoretical or mathematical foundation to support the practice that they have carried out with the pilot tests, (2) evaluating changes or modifications in said parameters or variables would be highly costly, and that (3) Logyca® and the companies that collaborate in the “*Bici-Carga*” pilot test project are looking for tangible tools that demonstrate the profitability of the operation.

1.2. Developed Methodology

The methodology used in this research project is a particular methodology built by the authors of this document, based on different research methodologies and the area of Industrial and Systems Engineering. Some of the recognized methodologies that were studied for the construction of the methodology in question are the “Preferred Reporting Items for Systematic Reviews and Meta-Analysis” (PRISMA) methodology of bibliographic inquiry (PRISMA 2015), the Define, Measure, Analyze, Improve and Control (DMAIC) methodology of interventions in industrial systems, in addition to the methodology for the preparation of a research project of Dr. Lam Díaz (2005), from the Institute of Hematology and Immunology. In a complementary manner, recommendations from the scoping stage of the study by Keathley-Herring et al. (2016).

In addition to what is involved in the different methodologies mentioned, various instances of the research project in question are taken into consideration, which are known to be necessary due to the nature of the central research question of the project: "Under what operational parameters can a company implement the light load distribution with the use of electric bicycles, reducing or equalizing the logistical costs involved in using traditional cargo vehicles? ", and the hypotheses to be tested. This involves iterative mathematical modeling, with the collection of previous information, and the corresponding subsequent analysis of the results.

The result of the investigation of research methodologies, the consideration of methodologies previously used in the study plan of the Industrial and Systems Engineering career, and the projection of research activities is a methodology

of six (6) phases, with identified tasks, milestones, and timeline for every phase. These methodology phases, mentioned next, will correspond to the sequence of the following chapters or sections of this documentation.

Phase 1: Project definition. Phase 2: Literature review. Phase 3: Collection and analysis of data. Phase 4: Mathematical modeling. Phase 5: Sensitivity analysis. Phase 6: Deliverables and conclusions.

2. Project Definition

This research's general objective is to "Define the operating parameters under which a company can implement light load distribution with the use of Light Electric Vehicles (LEV), to reduce or equalize the logistics costs involved in using traditional cargo vehicles". Following this line of research, three secondary objectives are set, which can be identified as the objective of this paper: define operational parameter for ideal scenarios in (1) dry chain and (2) mail delivery lines of business, and to identify costs differences between the two LEV studied in this document.

The scope of this project is established according to the spaces and dimensions of the areas where the Logyca pilot test was carried out in Bogotá, Colombia. These areas were selected for various factors, including their high commercial density, high demand for freight transport, and availability of bike lanes. The area where the pilot test was carried out corresponds to an area of approximately 15 square kilometers in the center of the capital city of Colombia, with small businesses with moderate movements of merchandise, short-term inventories, recurring supplies, and little storage.

An important point to take into consideration within the scope of this project is that it is intended that the data obtained, as well as the conclusions, mathematical models, simulations, and other information that is generated throughout the project can work to allow the replicability of the project in other areas of Bogotá or in any other city or area of Colombia, Latin America or the world, as long as it complies with the factors mentioned above that led to the selection of the study area. For this, it is important to define the limits of the operational parameters on which the project is replicable.

3. Literature Review

The growth trends in eco-friendly distribution issues have led authors around the world to study these concepts, analyze the different factors that have an impact on them, the possible consequences of incorporating LEV to last-mile logistics distribution models, and mathematically evaluate the possibility of implementing LEV in those distribution models. This research studies the published literature using the Systematic Literature Review (SLR) methodology Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2015).

The first activity that was carried out for the compilation of papers and relevant documents was the identification of keywords referring to the topic, to then be able to construct a Boolean phrase to carry out the formal search of the documents. The Boolean phrase for research was built with help of the Scopus digital database, from the Universidad de Monterrey (UDEM) electronic library, and was built from the following 4 groups of words, where the logical command "and" was included across groups, and the logical command "or" was included within the words of each group: 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). Word exclusions and additional filters like area of study and type of document were applied.

After the identification of documents, 302 publications were extracted from the SCOPUS database, and 54 from EBSCO. After duplicates were removed, 317 documents were left and set for the first screening or filtering. After it, 236 papers were discarded with different criteria in mind. Specifically, the research team was looking for papers, publications, documents, or research regarding LEV for distribution, so anything away from that was not desirable for the research, like electric cars, or LEV just for mobility and recreation. This activity was carried out by the three members of the research team, reading, and analyzing title, keywords, and some of the abstract. For the elimination of a document, at least two of the members of the research team needed to agree.

After only 81 documents were left, 29 more were removed because of availability, duplicate works with different names, focus, and type of vehicles studied. After all the eligibility criteria was met by every document compiled, 52 publications were left, and those are the documents that were read and studied thoroughly as part of the Systematic

Literature Review of this research project. These documents were classified in four groups of topics, as shown in Figure 1. Additionally, it is observed (in Figure 2) that the behavior of the annual publication frequency of the mathematical modeling papers on the subject has shown an upward trend over the years, and has taken on special relevance since 2020, the year in which, due to the COVID-19 pandemic, the demand for electronic commerce and last-mile logistics distribution increased notably.

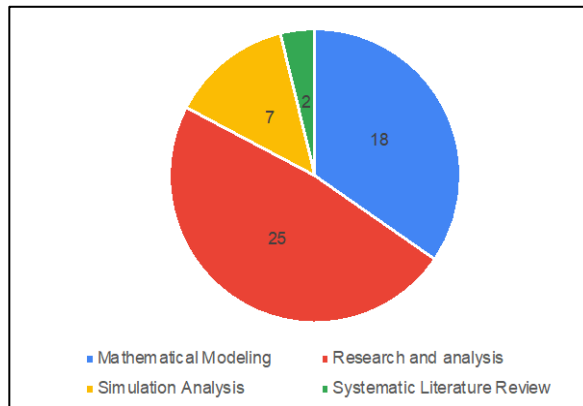


Figure 1. Proportion of documents by category

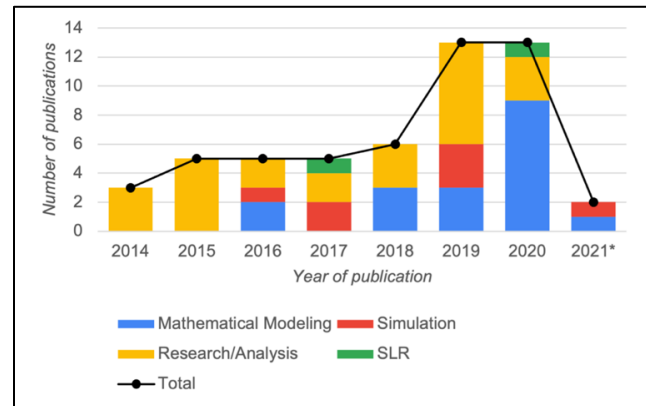


Figure 2. Annual frequency of publication by class

Costs regarding insights from the SLR note that 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 and 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 and Zhang 2015).

In the **traffic and congestion** matter, research indicate that tricycles and bicycles provide extended access to areas, like pedestrian zones, where parking is only allowed for a limited amount of time (Athanasopoulos et al. 2016). Dedicated lanes for tricycles are shown to increase overall road capacity while decreasing accident risk (Zacharias and Zhang 2015) (Garcia et al. 2015). Nevertheless, other publications state that a more than 10% increase of cargo bikes will worsen traffic (Melo and Baptista 2017), as the tricycle is blamed for reduced road efficiency and safety concerns for the drivers of such non-motorized vehicles when there are no efficient bike lanes (Zacharias and Zhang 2015).

In an **environmental** point of view, several publications agree that cargo bike delivery networks can improve urban livability significantly by improving air quality, reducing GHG emissions, and van traffic in urban districts (Melo and Baptista, 2017) (Athanasopoulos et al. 2016) (Sárdi and Bóna 2021) (Assmann et al. 2020) (Naumov and Starczewski 2019). The transport sector is responsible for 30% of the CO₂ emissions in the EU, reaching up to 40% in urban areas (Navarro et al. 2016), and urban logistics WTW CO₂ emission impacts can be reduced by up to 73%, which represents 746 kg of CO₂ avoided emissions replacing 10% of conventional vans in deliveries of no more than 2 km (Sárdi and Bóna 2021).

Regarding **infrastructure**, 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 et al. 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).

Finally, due to the crucial importance of the in-depth study of the **mathematical modeling** papers on the subject, it was decided to build a particular paper, by the research team that authored this document, for a SLR on these 18 documents that include optimization models. The research paper is titled "The Incorporation of Eco-Friendly Light

Vehicles in Logistics Distribution Models: Systematic Review” and was submitted and presented at the VI Conference on Industrial Engineering and Operations Research of North America of IEOM in Monterrey, Mexico. The project was awarded with the first place in the "Undergraduate Research Competition" with its presentation and document (Zazueta-Nassif et al. 2021).

4. Collection and Analysis of Data

The third phase in this research project consisted of the collection and analysis of the results obtained in the pilot test. The two main approaches to this analysis relate to operational indicators and cost minimization. Firstly, four key indicators are compared between participating companies: total orders delivered, average daily distance traveled, average weight of deliveries, and average delivery time. This can be observed in Figure 3, where the percentages shown on the graphs indicate the change in each indicator by company compared to their performance indicators with traditional vehicles.

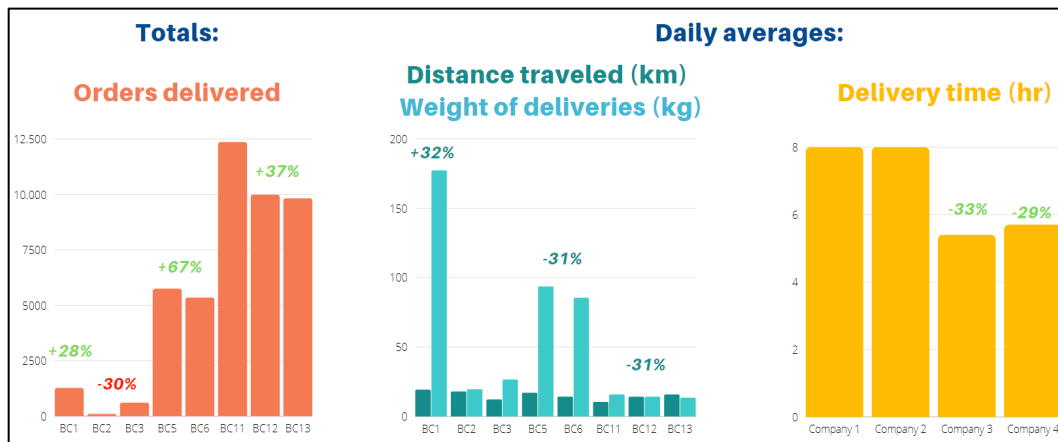


Figure 3. Key Indicators from pilot test

From these graphs, several takeaways are considered. For example, companies participating in the Model 2 with the crossdocking depot are notably superior in total deliveries and reduced their shift time by more than two hours. Additionally, the daily distance traveled was clearly impacted for most companies by using these vehicles.

The electric bicycle or e-bike consists of two wheels, a load carrier in the front, electric assistance, and an approximate capacity of 100 kg. On the other hand, the e-trike has three wheels, a load carrier at the rear, electric assistance, and a capacity of 250 or 300 kg. The set capacity for the data analysis is of 275 kg for this e-trike. Comparing these vehicles with others used in the distribution of light urban cargo, some key aspects are identified. For example, for an e-bike or e-trike a license is not required, while for a motorcycle or a conventional delivery truck it is, and this can become a limitation for companies when trying to find new drivers.

The most relevant thing, however, is whether the vehicle can use bicycle lanes or not. This is something fundamental, because being able to use these routes of circulation is a potential opportunity to avoid traffic, reduce the risk of collisions with cars or trucks and design new shorter routes for the distribution of products. It is identified, then, that the e-bike can use the bicycle lanes without problem, while the e-trike, motorcycles, and conventional trucks cannot. The e-trike cannot use the bicycle lanes due to an error in the design of the vehicle used, as it exceeds the load capacity by approximately 20%.

5. Mathematical Modeling

After studying the published literature on the subject and understanding the parameters, variables, restrictions, and various approaches of the objective functions of previous mathematical models seeking to incorporate LEV into last-mile logistics distribution systems, as well as after collecting the relevant information and data produced by the pilot test conducted by Logyca, the research team set out to build a mathematical model.

The mathematical model of optimization was constructed under three approaches: (1) minimize costs in order to achieve the replicability of cycle-logistics in other parts or areas of the world, (2) the definition of the fleet mix, that is, where the model assigns the optimal number, and type, of vehicles depending on their demand, and (3) the optimization of routes to reduce the distance traveled, the distribution time and that the demand of the clients can be met. Assumptions for the building of the model were listed and categorized in four groups: customers, vehicles, network, and costs, and they served as a guide for a consistent and cohesive mathematical model. After built, the mathematical model was tested and validated in Gams[®] software, with a hypothetical scenario of 28 network nodes, and 98 enabled arcs, to service 15 customers. An optimal solution was found and validated and, with it, the model.

6. Sensitivity Analysis

For the programming of a real scenario with more than 100 nodes and approximately 500 arcs, it was decided to use Python[®] software, as it has a higher processing capacity than the software used to validate the model and being a more popular programming language, facilitates the use of libraries to simplify the implementation of the model with large input data.

First, it was necessary to decide the nodes and arcs on which the built optimization model was to be run. To define the nodes of the operation, first the area of the city of Bogotá where the Logyca[®] company carried out the activities of the pilot test is identified and its bike lanes. The zone is an area of approximately 17 km² from the center of the Colombian capital and was split into three sections for nodes identification and arcs definition.

Nodes were assigned considering strategic points as a criterion (intersections between large streets in the area, important avenues, access to bicycle lanes, and general points in the area are specified to connect the most relevant nodes). The nodes were labeled and registered, with their geographic coordinates.

Once the work nodes had been defined, the construction and definition of the arcs that would be enabled for modeling began then. For this process, the research team considered the most direct connections between nodes, creating straight or almost straight arcs between them. After discussions with the Logyca[®] company, it was defined that all the connections are two-way, creating two arcs between nodes 1 and 2 for example (arc 1-2 and arc 2-1). Some of the delimited arcs and nodes can be visualized in Figure 5, corresponding to one of three sections of the delimited area. In addition to these arcs between nodes, which are enabled for the four types of vehicles in the model, some diagonal arcs are enabled, which are visualized in Figure 4 in green, to symbolize the movements that light vehicles can make between small streets, cross through parks or shopping centers, or general routes that a conventional cargo truck cannot do.

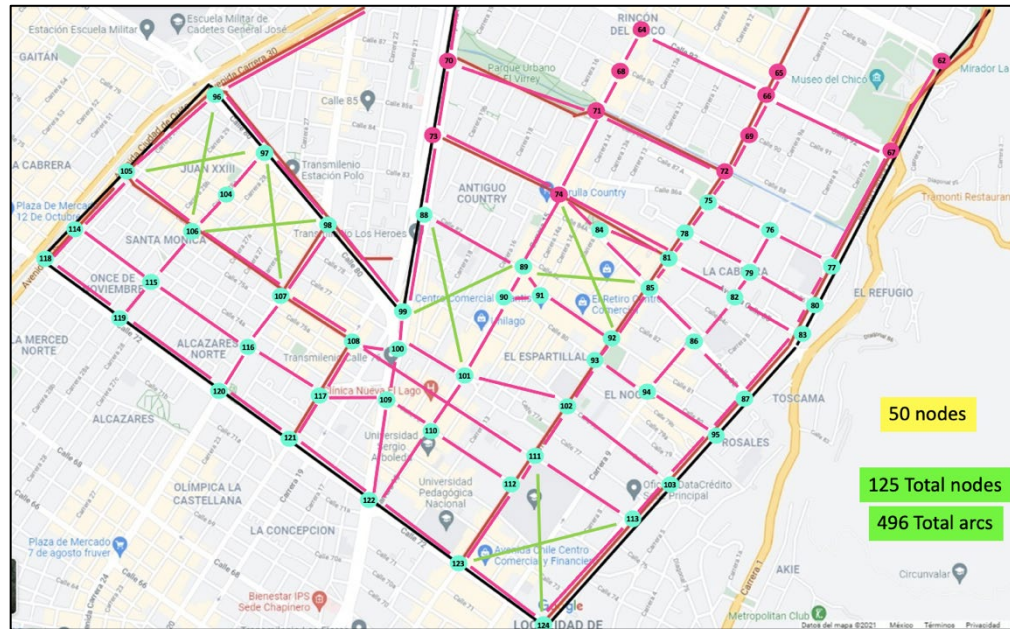


Figure 4. Arcs definition example

Subsequently, the values of each of the parameters to be used in the modeling were identified, using independent research, analyzing the data of the companies participating in the pilot test carried out by Logyca®, and calculations. The mathematical model was, then, coded into Python® programming language, using several libraries and tools like OR-Tools, Numpy, Pandas and Time. To define the running time, a convergence analysis to determine the minimum amount of time to run the model was carried out, resulting in a decision to run the model for 30 minutes per scenario, with a gap of only 4%.

After the implementation of the mathematical model in the Python® software, with the situation of the area delimited by Logyca® correctly represented with 125 nodes and 496 arcs as described above, a Design of Experiments (DoE) is carried out to evaluate the different situations and scenarios that can be presented. For this, factors and levels are identified as specified below, taking into consideration several response variables.

Table 1. Factors and levels for DoE

	Bike lanes %	Business line	Average speed	Commercial density	Transshipment depot location
Level 1	10%	Dry chain	15 km/h	Low	Centralized
Level 2	30%	Mail	20 km/h	High	Non-Centralized

The first factor, percentage of cycle paths, refers to the proportion of arches that contain cycle paths compared to the total number of arches. The arches built with the delimited area have approximately 30% bicycle lanes, and the second level is set at 10% assuming that the situation in the area in question is favorable to the use of bicycle lanes, due to the great advantage that the city of Bogotá has in in terms of infrastructure of this type, compared to the rest of Latin America. The second factor is the turn or business line of the company of the products to be distributed. This factor leads to differences in the average package dimensions, as previously mentioned in this document. Dry chain and mail delivery business lines are used because they are the turns of the companies that were successful in the Logyca pilot test.

The third factor of the DoE is the average speed of the area on conventional streets. In the delimited area there is an average speed of 17 km/h, so two levels are set that contain, in their range, this value. The fourth factor refers to the commercial density of the demand, and the levels of high density and low density are set. These terms mean different

things, numerically, for each line of business, as explained earlier in this document. Finally, the fifth factor identified as relevant for the DoE is the position of the transshipment-depot, setting the levels in centralized depot and depot at one end of the delimited area.

6.1. Response Variables

Once the influence factors and the levels of each factor have been identified, the relevant response variables are identified for the desired analysis of the mathematical model of cost optimization. The first response variable results directly since it is the cost of the operation. The following four response variables refer to the number of vehicles that the model chooses for each of the four types of vehicles enabled in the fleet. In addition to these five variables, the variables of average distance traveled by vehicle and average time of activity of each activated vehicle in each of the tested scenarios are identified as relevant for analysis. Finally, the proportion of bike lanes that each vehicle that can access bike lanes takes advantage of and is used in the scenario is identified.

6.2. Scenario Testing

With the factors, levels and response variables to study defined, the combinations to be tested are constructed. It is important to mention that the levels of the business density factor are identified as meaning different things for each of the levels of the line of business factor. For this reason, it was decided to make two independent DoE type 2^4 (4 factors of two levels each), one for each business line. The 32 scenarios to be tested with the use of the mathematical model are mentioned below in Tables 2 and 3. The customer and demand columns of the scenario are added to these tables. These data, of client nodes and demand for each change, are randomly generated independently with distributions depending on the business line and commercial density.

Table 2. DoE combinations for dry chain business line

#	Bike lanes %	Average speed	Commercial density	Transshipment depot location	Client nodes	Total Parcels
1	30%	20 km/h	Low	Centralized	10	14
2	30%	15 km/h	Low	Centralized	8	14
3	30%	15 km/h	Low	Non-centralized	14	19
4	30%	20 km/h	Low	Non-centralized	9	12
5	10%	20 km/h	Low	Centralized	12	16
6	10%	20 km/h	Low	Non-centralized	9	15
7	10%	15 km/h	Low	Centralized	10	16
8	10%	15 km/h	Low	Non-centralized	11	17
9	10%	20 km/h	High	Centralized	31	43
10	10%	20 km/h	High	Non-centralized	29	40
11	10%	15 km/h	High	Centralized	27	45
12	10%	15 km/h	High	Non-centralized	33	42
13	30%	15 km/h	High	Centralized	27	38
14	30%	15 km/h	High	Non-centralized	30	43
15	30%	20 km/h	High	Centralized	25	37
16	30%	20 km/h	High	Non-centralized	31	42

Table 3. DoE combinations for mail delivery business line

#	Bike lanes %	Average speed	Commercial density	Transshipment depot location	Client nodes	Total Parcels
17	10%	15 km/h	Low	Centralized	32	57
18	10%	15 km/h	Low	Non-centralized	29	50
19	10%	20 km/h	Low	Centralized	30	54
20	10%	20 km/h	Low	Non-centralized	34	58
21	30%	15 km/h	Low	Centralized	30	50
22	30%	15 km/h	Low	Non-centralized	25	43
23	30%	20 km/h	Low	Centralized	29	48
24	30%	20 km/h	Low	Non-centralized	28	49
25	10%	15 km/h	High	Centralized	61	113
26	10%	15 km/h	High	Non-centralized	56	102
27	10%	20 km/h	High	Centralized	59	106
28	10%	20 km/h	High	Non-centralized	60	110
29	30%	15 km/h	High	Centralized	58	112
30	30%	15 km/h	High	Non-centralized	64	119
31	30%	20 km/h	High	Centralized	61	118
32	30%	20 km/h	High	Non-centralized	57	112

As previously mentioned in this section of the document, each scenario is run for 30 minutes, after having performed a convergence analysis for the run times. This symbolizes 16 hours of computational processing. To avoid errors, and not waste processing time finding details after looking at the results, the 32 combinations were split into 4 different runs. The first run ran combinations 1-8, and so on until the fourth run used combinations 25-32. The results of each combination in terms of the cost of the operation, and the vehicles chosen for distribution are summarized in Tables 4 and 5. There's no column for motorcycles or conventional trucks because none were chosen by the model for distribution or parcels in any of the 32 scenarios tested.

Table 4. Dry chain DoE resumed results

#	E-trikes	Cost	Average distance per LEV	Average time per LEV	% of bike lane usage
1	1	\$ 28.353	13.469	1.935	0%
2	1	\$ 28.357	14.447	2.205	0%
3	1	\$ 28.378	19.564	3.021	0%
4	1	\$ 28.372	18.216	1.996	0%
5	1	\$ 28.365	16.378	2.266	0%
6	1	\$ 28.386	21.539	2.411	0%
7	1	\$ 28.363	15.897	2.480	0%
8	1	\$ 28.387	21.916	2.982	0%
9	2	\$ 56.696	12.016	2.540	0%
10	2	\$ 56.714	14.349	2.522	0%
11	2	\$ 56.689	11.165	2.746	0%
12	2	\$ 56.706	13.273	2.792	0%
13	2	\$ 56.685	10.641	2.420	0%
14	2	\$ 56.726	15.851	2.991	0%
15	2	\$ 56.696	12.046	2.262	0%
16	2	\$ 56.742	17.833	2.789	0%
		\$ 42.538	15.54	2.52	0%

Table 5. Mail delivery DoE resumed results

#	E-bikes	E-trikes	Cost	Average distance per LEV	Average time per LEV	% of bike lane usage
17		2	\$ 56.76	19.593	3.831	0%
18	1	1	\$ 50.96	22.254	7.312	8%
19	1	1	\$ 50.93	17.941	6.554	6%
20		2	\$ 56.80	24.869	3.82	0%
21	1	1	\$ 50.93	16.981	6.587	14%
22	1	1	\$ 50.97	24.372	6.834	18%
23	1	1	\$ 50.93	17.102	5.905	23%
24	1	1	\$ 50.94	19.876	6.251	21%
25		3	\$ 85.09	15.858	4.386	0%
26		3	\$ 85.11	17.462	4.172	0%
27		3	\$ 85.07	14.33	3.845	0%
28		3	\$ 85.12	18.206	4.153	0%
29		3	\$ 85.07	13.761	4.209	0%
30		3	\$ 85.10	16.968	4.636	0%
31		3	\$ 85.08	15.293	4.232	0%
32		3	\$ 85.13	18.96	4.236	0%
			\$ 68.748	18.36	5.06	5.63%

To understand which factors really influence each of the relevant variables identified, a series of analyses of variance (ANOVAs) is performed. In total, 8 ANOVAs were carried out, after defining which response variables it is considered interesting to analyze after observing the results of each business line. The analysis showed that the ANOVAs to be carried out were the dry chain combinations with the response variables of cost, average distance per vehicle, and average time per vehicle. In addition to these, it is also considered relevant to perform ANOVAs for the mail delivery combinations with the response variables of chosen e-bikes, chosen e-trikes, costs, average distance per vehicle, and average time per vehicle. The ANOVAs were carried out in the Minitab statistical software, and the 4 input factors plus the first-order interactions were considered, which means 10 factors in total for each ANOVA.

7. Deliverables and Conclusions

Regarding a deliverable in form of a strategic decision platform for Logyca®, the research team author of this project decided to enable two Python® codes on the Spyder® platform for the use of the company in the evaluation of the customer situations. A friendly Python® code has been enabled, with text notes to indicate each section, which can be edited, and run for different scenarios where the transshipment depot remains centralized. A second file was enabled with the matrices and parameters corresponding to the situation where the transshipment depot is not centralized. In addition to enabling and detailing these programming code files with the mathematical model, a manual or guide is developed to deliver to Logyca®.

To close this research project, the studies and analysis are summarized in relevant conclusions of the project, as well as the identification of interventions or future research that allows continuous impact and growing from this research. Regarding the research and systematic literature review, a series of conclusions are reached that support the idea that the subject dealt with here is a subject of international relevance, and with importance in the development of technologies and innovation in the field. of logistics distribution, particularly the last mile. It is also understood that attempts have been made to mathematically evaluate the incorporation of LEV into distribution systems, although the documentation is brief, hence the need to document the construction process of a mathematical model for the minimization of costs of this type, and its corresponding sensitivity analysis and validation.

Once the 32 scenarios were analyzed with the model, it is quite promising that the model is inclined to choose LEV in the 32 tested scenarios, especially the e-trike. These same 32 scenarios were then tested with only conventional vehicles available, and average savings of 44% and 53% for dry chain distribution and mail delivery, respectively, when incorporating LEV are very encouraging results. When evaluating the analyses carried out in this research, it is concluded that the factor of commercial density, which refers to the number of customers and packages that are demanded, is of total statistical relevance for the cost indicators, average distance traveled by each vehicle, and average

time each vehicle remains in operation or movement. On the other hand, it is identified that the average speed factor, at least at the levels evaluated, does not seem to be statistically significant, so it would be proposed to evaluate more extreme data to really conclude if it has an impact on the response variables, or not.

The research team considers that the scenario studied indicate that future research should lean towards analyzing in depth additional scenarios with the development and execution of new DoE, eliminating the factors that were identified as statistically irrelevant. Additionally, due to the overwhelming significance of the commercial density factor, two more experiments should be designed, one for each line of business, where the factor is studied in depth adding several levels for each of the two lines of business and proposing a few replicas for each scenario. Finally, it's considered that one final study should be made, where the redesign of the e-trike is taken into consideration, allowing it to use the bike lanes and, then, truly understand is bike lanes have an actual statistical impact in the costs of last-mile distribution with LEV, although it is concluded that what is analyzed here is sufficient and forceful to say that the incorporation is viable, and the future of last-mile distribution

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