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Urban Logistics Solutions in Latin America: A Study of a Modern Commercially Dense Neighborhood in the City of Quito-Ecuador

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Omar Esteban Aguirre
José Javier Muñoz

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Omar Esteban Aguirre

José Javier Muñoz

Calificación:

Nombre del profesor, Título académico   Cristina Camacho, MSc

Firma del profesor   ______________________________

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Firma del estudiante: _______________________________________

Nombres y apellidos: Omar Esteban Aguirre
Código: 00107392
Cédula de Identidad: 1714279328
Lugar y fecha: Quito, mayo de 2016

Firma del estudiante: _______________________________________

Nombres y apellidos: José Javier Muñoz
Código: 00107372
Cédula de Identidad: 1718948134
Lugar y fecha: Quito, mayo de 2016

RESUMEN

La población en América Latina ha ido aumentando su tasa de crecimiento a lo largo de los años. A medida que las ciudades crecen y las personas se trasladan a zonas urbanas, las diferentes empresas y negocios tienen que luchar con importantes retos logísticos y dependen en gran medida de la entrega oportuna y eficaz de los recursos para poder cumplir con la demanda de los consumidores. La ciudad de Quito, en Ecuador, actualmente está enfrentando los retos logísticos mencionados anteriormente. Para poder tratar y reducir estos retos logísticos, conceptos y técnicas de logística urbana son propuestos y desarrollados en la literatura. El objetivo de este estudio es entender las actividades logísticas de carga y descarga en uno de los barrios comercialmente más densos en la ciudad de Quito llamado "La Mariscal". Un modelo de optimización fue utilizado para determinar el número de bahías de carga y descarga, y su ubicación óptima, que deberían implementarse con el objetivo de permitir a las empresas de transporte movilizar y entregar los recursos de manera más eficiente y efectiva. Esta investigación es parte de un proyecto de logística urbana más grande que se desarrolla en la ciudad de Quito, y que actualmente está dirigido por la Universidad San Francisco de Quito (USFQ), con el apoyo del Laboratorio de Logística de Mega Ciudades del MIT (MIT MLL). Este estudio tiene como objetivo proponer soluciones a los principales retos de la logística urbana mediante la metodología del Atlas de Logística Urbana desarrollada por el MIT MLL.
Como lo muestra el siguiente estudio, con soluciones de logística urbana, modelos de simulación y optimización, es posible hacer que las ciudades en América Latina mejoren su movilidad, se vuelvan más sustentables, y, sobre todo, se vuelvan más habitables.

Keywords: logística urbana, transporte de recursos, bahías de carga & descarga, simulación, optimización, movilidad, América Latina.

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Aguirre, E[1]., Muñoz, J.[2]

1: Department of Industrial Engineering, Universidad San Francisco de Quito, Ecuador
2: Department of Industrial Engineering, Universidad San Francisco de Quito, Ecuador

Abstract

Population in Latin America has been increasing its growth rate through the years. As the cities expand and people move to urban areas, businesses have to struggle with major logistics challenges and rely heavily on timely and effective deliveries of resources in order to cope with consumer demand. The city of Quito, in Ecuador, is currently facing the logistic challenges mentioned above. To address these logistical challenges, concepts and techniques of urban logistics are proposed and developed in the literature. The objective of this paper is to understand the loading and unloading logistic activities in one of the most commercially dense neighborhoods in the city of Quito called "La Mariscal". An optimization model was used to determine the number of loading & unloading bays, and their optimal location, that should be implemented with the goal of enabling transportation companies to transport and deliver resources in a more efficient and effective way. This investigation is part of a bigger urban logistics project in Quito that is currently being led by Universidad San Francisco de Quito (USFQ), with the support of the MIT Megacity Logistics Lab (MIT MLL). This project aims to propose solutions to major urban logistics challenges using the Urban Logistics Atlas methodology developed by MIT MLL.
As the following paper shows, with urban logistics solutions, simulation and optimization models, it is possible to make cities in Latin America become more mobile, sustainable and above all, livable.

Keywords: urban logistics, resource transportation, loading & unloading bays, simulation, optimization, Latin America.

Introduction

Over the last years, Latin America has been experiencing an important growth in population and an increasing demand for an efficient urban freight transportation. In fact, projections suggest that by 2030, cities around the world will house about 66% of the world's inhabitants (UN Department of Social and Economic Affairs, 2014). In addition to this, Merchán et al. highlights that, on average, the rate of population living in urban areas grows by 65 million every year (Merchán, Blanco and Bateman, 2015).

One problem with the non-stopping increase in Latin America's population and people moving to urban areas is that companies that perform urban logistics operations are facing serious challenges to transport their goods on a time and a cost effective manner. As urban population grows, logistics operations must rely on already congested infrastructures, and without a proper urban planning, they are worsening city externalities such as congestion, pollution and noise (Merchán, Blanco and Bateman, 2015). In fact, the increasing logistic activities in the major urban areas of Latin America are jeopardizing the sustainability of these regions (Macário, Galelo, Martins, 2008).

The problem that urban freight policy makers are dealing with has to do with the lack of tools, techniques and knowledge needed to deploy effective measures regarding urban logistic problems (Macário, Galelo, Martins, 2008). At the same time, one of the main reasons of why urban logistics problems in Latin America have not been solved properly is because urban freight is often considered a nuisance from the public perspective (Blanco, 2014). In fact, urban planning has not properly considered the importance and intensity of urban freight needs in their mobility plans (Merchán, Blanco and Bateman, 2015).

Merchán et al. suggests that there are a variety of reasons of why the role of logistics in supplying urban needs has been ignored in urban plans. One of the reasons is that freight movement has been historically perceived as dirty, noisy and polluting (Hall & Hesse, 2013). Another reason is that modern perspectives on sustainability have shifted planners' interest away from polluting industries like freight movement, despite their importance to urban life (Berke, Godschalk & Kaiser, 2006).

Cadena et al. agrees with this by stating that Latin American cities are falling short on providing coordinated urban planning and sufficient infrastructure and services needed for efficient and livable cities (Cadena et. al., 2011).

As can be seen, cities around Latin America are experiencing major logistic challenges regarding the efficient transport of merchandise because there has not been an appropriate development of urban logistic solutions. In addition, the need for mobility in developing cities is increasingly important in urban areas since private and public transport demand is rising rapidly, producing more traffic congestion (Macário, Galelo, Martins, 2008).

The most recent census developed in Ecuador was in 2010. Results showed that the city of Quito has a population of 2,781,641 inhabitants (INEC, 2015). In addition to this, experts have made the estimation that the city of Quito is one of the cities in Latin America that has more rapidly increased its population growth rate (Ecuador Explorer, 2015).

One of the most commercially dense areas in Quito is called La Mariscal. Since this area is full of bars and restaurants, it is one of the areas in the city with the most traffic and congestion problems. Now, suppliers have several drawbacks when delivering merchandise in La Mariscal. One of the drawbacks is that they do not have a designated area to park their vehicles while delivering merchandise, which forces them to keep driving around until they find a parking space. Another drawback currently present in La Mariscal is that suppliers have to park their vehicles either on the sidewalk or in a traffic lane, producing congestion and traffic jams. By being one of the neighborhoods that performs most of its commercial activities mainly during the night, and because it contains a variety of logistics challenges for the suppliers from the different shops, bars and restaurants, La Mariscal is an area that requires the application of urban logistics tools and techniques. This will help to improve the city's mobility and will enable suppliers to transport their goods on a time and a cost effective manner.

Methodologies

The Urban Logistics Approach

Macário et al. discusses that the first step into taking a urban logistics approach to solve freight delivery challenges in a neighborhood like La Mariscal is to understand how the area behaves regarding frequency of deliveries, commercial density, existence of delivery bays, restrictions of hourly and weekly periods of delivery, etc.

A logistics profile is a tool for urban logistics management that encompasses three key points: urban characteristics of the area, requirements of logistics agents, and characteristics of the products being transported (Macário, Galelo, Martins, 2008). The idea behind creating a logistics profile of an area is that it will be possible to adjust urban logistic services, which will later optimize the consumption of resources such as space or vehicles (Macário, Galelo, Martins, 2008).

Therefore, one of the main approaches of this paper was to come up with a solution that will help suppliers deliver merchandise in an easier way by understanding urban freight delivery and creating the logistic profile for the area of La Mariscal. By doing this, it was possible to determine the commercial density of the area, which is shown by the number of shops per block. In addition, it was possible to obtain the frequency of deliveries. Creating the logistics profile for La Mariscal was the first step into determining the optimal location where suppliers' loading & unloading bays should be placed.

There is another urban logistics approach that has been developed by Merchán, Blanco and Bateman, which focuses on obtaining specific metrics about a delimited area. They argue that urban freight delivery often operates on a weekly schedule and therefore the scale that matters for understanding urban freight is commonly a neighborhood (Merchán, Blanco and Bateman, 2015). This means that to better understand movement and transportation of merchandise, data should be collected and analyzed at these levels instead of citywide. These authors suggest that a square kilometer (Km^2) is an appropriate size for subareas in the city (Merchán, Blanco and Bateman, 2015).

Merchán et al. suggest that even though urban freight is diffused throughout cities, it has specific interactions with various land use types (Merchán, Blanco and Bateman, 2015). This means than an appropriate focus should be placed on studying road networks, city-parking capacity, storage areas, loading & unloading bays, as well as retail and restaurant spaces (Merchán, Blanco and Bateman, 2015). For this paper, the focus was the implementation of loading & unloading bays in the delimited Km^2 of La Mariscal.

Therefore, the first urban logistics approach that was used in this paper in the area of La Mariscal was an establishment-based freight survey suggested by Romano et al, which helped to create the logistics profile for the area. The purpose of this survey was to obtain information about weekly deliveries, retail area, supplier information, shop inventory, schedule information, among other metrics. Shopkeepers answered the survey.

Part of the objective of performing the survey was to develop the logistics profile of La Mariscal, but at the same time, we wanted to realize if there was a relationship between total weekly deliveries and independent variables such as retail area, total number of employees, industry type, etc. (Romano et al., 2015). For example, in the study made by Romano et al., the establishment-based freight survey showed that in Lisbon, employment, industry type and their interaction significantly contribute to the prediction of weekly deliveries (Romano et al., 2015).

In their paper, Merchán, Blanco and Bateman explain that metrics that capture the availability of parking spaces can inform if an area has the proper infrastructure for freight activities (Merchán, Blanco and Bateman, 2015). In addition, during their research, they found that in the centric areas in Mexico City, Santiago and Rio de Janeiro, the inventory of parking revealed a minimum number of parking spaces available for freight transportation (Merchán, Blanco and Bateman, 2015). This means that a common feature across cities in Latin America is the limited provision of delivery bays.

Based on the findings of Merchán, Blanco and Bateman, the goal of this paper was to determine the number of loading & unloading bays, and their optimal location, in the delimited Km^2 of La Mariscal. The idea behind establishing the best location for the loading & unloading bays is that they will enable transportation companies and suppliers to transport and deliver goods in a more efficient and effective way, since they will have a specific physical space to park and serve as many shops, bars and restaurants as they can, in a minimum amount of time. At the same time, by determining the location for the loading & unloading bays, other externalities are to be treated such as lines of cars waiting for suppliers to finish delivering merchandise and traffic jams.

Sample Size

In the delimited Km^2 of La Mariscal, there are 1536 businesses that were classified under the following categories: accommodation, food services and drinking places, drugstores, clothing stores, convenience stores and supermarkets, grocery stores and other retail. A statistically significant sample of this population was obtained in order to perform an establishment-based freight survey.

Formula 1 in next section shows the expression used to obtain the sample size. In this formula, the confidence level (α) chosen was 95% and the precision (e) chosen was 0.05. The sample sized obtained to conduct the survey was 308 stores. During the study, because of time constraints, 200 surveys were conducted.

Establishment-based Freight Survey

An establishment-based freight survey was carried out in order to obtain businesses characteristics to create the logistics profile for the area of La Mariscal. The purpose of this survey was to obtain information about weekly deliveries, retail area, supplier information, shop inventory, schedule information, among other metrics. Therefore, by constructing a logistics profile for each store surveyed, it was possible to understand the logistics requirements of every store of the sample.

Logistics requirements of a store are based on how often do the major suppliers of the store deliver goods through the week, at what time do they arrive, the type of vehicle they use and the amount of products they deliver. Therefore, by defining the logistics requirements of the stores, it was possible to understand which blocks in La Mariscal have major logistics requirements based on the stores they contain. Knowing which blocks are the most important ones in the area gave the first indicator of where the loading & unloading bays should be located.

Extrapolation of Logistics Profile Characteristics

Since only a sample of the total number of stores in La Mariscal was surveyed, an extrapolation was performed to the rest of the stores of the area in order to obtain their logistics requirements.

In order to extrapolate logistics requirements to the stores that were not surveyed, the Monte Carlo Method (or simulation) was used. By performing a Monte Carlo method, it was possible to stablish characteristics such as delivery frequency, type of vehicle used and number of trips needed to deliver all of the merchandise to one store, to all of the stores that are part of the Km^2 of La Mariscal.

In order to perform the Monte Carlo method, probability distributions were obtained for different characteristics of the logistics requirements of the stores using the results obtained with the establishment-based freight survey. Distributions were obtained for the type of vehicle that the major suppliers use, the time of delivery, number of trips needed for supplier to deliver all of the goods to the store that gives an idea of the volume delivered, and the frequency in which they deliver goods to the store through the week.

Once probability distributions were obtained for these characteristics, the distributions were used to perform a Monte Carlo simulation so that the type of vehicle used, the time of delivery, number of trips needed to delivery all of the merchandise and frequency of delivery were extrapolated to all of the businesses of La Mariscal according to the type of business.

After the extrapolation was performed, it was possible to determine which blocks in the Km^2 have the largest logistics requirements, and this gave an initial idea of where should the loading & unloading bays be located.

Stores and Streets Weights

Once the logistics requirements were determined for every business or store in the delimited Km^2 of La Mariscal, the next step was to assign to every business and street of the area an importance weight factor. The importance weight factor for each business was calculated based on the logistic requirements of each business and a relative importance weight of each logistic requirement over another. In contrast, the importance factor given to streets was calculated based on the actual characteristics of the street, and the objective of doing this was to determine which streets are the most appropriate for the location of the loading & unloading bays.

The logistics requirements for businesses that were taken into account in order to calculate their weight were: type of delivery vehicle, number of trips needed for supplier to deliver all of the goods to the store, weekly delivery frequency and presence of private parking area. Each logistic requirement category was rated on a six-point scale, being six the most important factor and one the least important factor.

The characteristics of streets that were taken into account for weight calculation were: presence of bike lanes, presence of parking lanes, dedicated public transport lanes, number of crosswalks and if there is a parking area on the street. Each characteristic of the street was a binary variable indicating the presence (1) or absence (0) of each characteristic, except for the number of crosswalks which took the value of the actual number of crosswalks in the street.

Then, in order to calculate the relative importance of one logistic requirement over another, an analytical hierarchic process was used (see formula 2). This relative importance is a number between 0% and 100% where the larger the number the more important the logistic requirement is. The same process was used to determine the relative importance of a street characteristic over another.

Finally, a sum of the products (see formula 3) between the rating of each logistic requirement category and the relative importance of the logistic requirement was performed. This result reflects the total importance of each business according to its logistics requirements. The same process was performed to determine the rating of each street but the difference in this case is that the sum of the products (see formula 3) was done between the value of each characteristic of each street and the relative importance weight of each characteristic.

After obtaining the total importance weights both for businesses and streets in La Mariscal, it was possible to obtain two important inputs for the optimization model. On one hand, the total importance weights for businesses of the area gave the optimization model the information needed to know which businesses or stores have the greatest need for a loading & unloading bay. On the other hand, the total importance weights for the streets gave the optimization model the information needed to know where the most suitable places to locate the bays are.

Optimization Model

The idea behind the optimization model used was to minimize an expression that depends on three factors: the distance between each potential bay and the businesses from the area, the importance factor of each business and the importance factor of each street. This model was able to determine the optimal locations to implement loading & unloading bays, which minimizes the distance between each assigned bay and the business, while maximizing the product of the importance factor of the business and the importance factor of the street.

The constraints of this model are set to assure that the model does not give infeasible solutions regarding the assignations of businesses to loading & unloading bays.

The first constraint (equation 4.1), related to distance, states that a bay cannot be located further than 300m from a store or business. The reason for choosing a maximum distance of 300m is that an average person walks at a speed of 5 km/h; therefore, with a distance of 300m, the time spend walking will be less than 4 minutes, which is a reasonable travel time for the supplier. The second constraint (equation 4.2) is related to the number of stores a loading & unloading bay can serve. Finally, the last constraint (equation 4.3) states that each business has to have at least one loading & unloading bay assigned.

After running the optimization model, we were able to determine the optimal location where the loading & unloading bays should be placed in the area of La Mariscal. These locations enable suppliers to park their vehicles in bays that are closest to the most commercially dense blocks in the delimited Km^2, which will help them to transport and deliver goods in a more effective and efficient way.

Mathematical Modelling

The following equation was used to calculate sample size for the number of businesses surveyed in La Mariscal (Kleinbaum, 1982):

$$(1)\ n = \frac{N(Z_{\alpha/2})^2\ p\ (1-p)}{N\ e^2 +\ (Z_{\alpha/2})^2\ p\ (1-p)}$$

Where:

$n = sample\ size$
$N = size\ of\ the\ population$
$\alpha = confidence\ level = 95\%$
$Z = standardize\ normal\ distribution\ value\ for\ \alpha\ level$
$p = probability\ of\ occurrence\ (0.5\ if\ p\ is\ unknown\ to\ maximize\ n)$
$e = precision\ or\ error = 0.05$

The following equations were used to determine the businesses and streets importance weights:

$$(2) \quad \widehat{w}_k = \sqrt[m]{\prod_{j=2}^{m} a_{kj}}, \; k = 1, \dots, m$$

$$(2.1) \quad w_k = 100 * \left(\frac{\widehat{w}_k}{\sum_{i=1}^{m} \widehat{w}_i}\right)$$

Where:

a_{kj} = relative importance of factor k with respect of factor j
m = number of different factors
w_k = relative weight percentage of each factor
$\widehat{w}_k$ = relative weight of each factor

$$(3) \quad I_i = \sum_{k=1}^{m} w_k y_k$$

Where:

y_k = value indicating the score given to each factor
w_k = relative weight of each factor
m = number of factors
I_i = importance factor of store i

The optimization model used to determine the locations of the loading & unloading bays is the following:

$$(4) \quad Minimize\ Z = \frac{x_{ij} d_{ij}}{P_i P_j}$$

Subject to:

$$(4.1) \quad x_{ij} d_{ij} \leq D \quad \forall_i \forall_j$$

$$(4.2) \sum_{j=1}^{n} x_{ij} \leq Q \quad \forall_i$$

$$(4.3) \sum_{i=1}^{m} x_{ij} = 1 \quad \forall_j$$

Where:

x_{ij} = binary variable indicating if the business j is assigned to the bay i
d_{ij} = distance between business j and bay i
$P_i = total$ weight of bay i
$P_j = total$ weight of business j

Results and Discussion

By analyzing the shops inventory information, it was possible to observe that the commercial density of the delimited Km^2 of La Mariscal is formed mainly by food services and drinking places businesses. Table 1 shows how the commercial density of the area is distributed according to the number of businesses classified by their type.

Table 1: Distribution of commercial density of La Mariscal by type of business

Type of Business	Percentage
Food Services and Drinking Places	47%
Clothing Stores	21%
Other Retail	13%
Accommodation	8%
Grocery Stores	7%
Drugstores	2%
Convenience Stores and Supermarkets	1%

As can be seen in Table 1, food services and drinking places type businesses account for almost half of the total number of businesses in the studied Km^2, followed by clothing stores with a 21% of presence in the area.

With the establishment-based freight survey, it was possible to determine the day of the week and the time at which the most important suppliers distribute merchandise to the different stores. The survey showed that the peak day of the week in which more deliveries are done in the area is Monday with an average of 115 deliveries per day. At the same time, Table 2 shows peak hours through the week when deliveries are carried out according to business type, and the number of deliveries made during that period.

Table 2: Deliveries peak hours through the week by type of business

Type of Business	Delivery Peak Hour	Number of Deliveries
Food Services and Drinking Places	9 am to 11 am	806
Clothing Stores	9 am to 11 am	204
Other Retail	11 am to 1 pm	125
Accommodation	11 am to 1 pm	84
Grocery Stores	9 am to 11 am	145
Drugstores	3 pm to 5 pm	60
Convenience Stores and Supermarkets	9 am to 11 am	18

By looking at Table 2, it is possible to establish that most deliveries in La Mariscal are performed during the morning, especially between 9 am and 11 am, for most business types.

In addition to this, the survey showed that the type of vehicle that is used the most by businesses in the area is a small truck with a capacity of approximately 14,000 lbs. or 7 tons, which has a use percentage of 42%. This type of vehicle is followed by minivans and pickup trucks with a use of 31%.

Regarding the optimization model, a linear programing solver was used to run the model and the solution showed the exact locations where the loading & unloading bays should be implemented. Figure 1 shows the delimited Km^2 of La Mariscal and the optimal location for the bays. The total number of loading & unloading bays that should be implemented is 98 bays.

Figure 1. Locations of loading & unloading bays obtained with optimization model for the delimited Km^2

As can be seen in Figure 1, the orange dots represent the location of the loading & unloading bays. Figure 1 shows that the optimization model was able to locate the bays through the entire Km^2, which means that most of the businesses of La Mariscal will have a designated bay for their suppliers.

In order to evaluate how effective this solution is, different metrics were obtained that are related to the distance between stores and loading & unloading bays. For instance, with this solution, the longest distance between a store and a bay is 275m. At the same time, the average distance between any loading & unloading bay and a store is 64m. In addition, the percentage of businesses that are located less than 100m away from their designated bay is 87%. Therefore, these metrics show that the solution obtained with the optimization model will help suppliers to deliver merchandise in La Mariscal in a more effective and efficient way, if implemented. The reason for this is that by implementing loading & unloading bays in the locations provided by the optimization model, suppliers will be able to park their vehicle whenever they are delivering merchandise for different stores. This will be an important addition to today's delivery process, especially during delivery peak hours.

It is important to understand that the idea behind the implementation of the loading & unloading bays is to assign a specific parking space to supplier vehicles during specific periods through the day. The advantage of this solution is that La Mariscal already has designated parking spaces in different streets that are being used now by private vehicles. Therefore, the solution consists of using those already existing parking spaces and designate them to supplier vehicles.

Conclusions

The optimization model that was developed gave the locations where the loading & unloading bays should be implemented, and this solution was based on the logistic requirements of the stores and how suitable are the different streets from the delimited Km^2 to support loading & unloading bays.

Now, the implementation of the loading & unloading bays should be supported by a city regulation, which specifies and controls a time during the day in which the areas designated for the bays can only be used by supplier vehicles. Based on the results obtained with the survey, the city regulation should establish that the areas dedicated to the bays can only be used by supplier vehicles during extended periods of time through the day, especially from 9 am to 11 am, since these are peak hours when most deliveries are performed in La Mariscal.

In addition, it is important to mention that the solution provided by the optimization model has the advantage that it distributed the loading & unloading bays through the whole Km^2 of La Mariscal, which means the businesses from every block will have a designated bay even though they don't have demanding logistics requirements, as other businesses do. Also, the location of the bays obtained with the optimization model will enable suppliers to walk a limited distance since the model minimized walking distance to the businesses. This will help suppliers to deliver merchandise in a more efficient and effective way.

Besides aiding suppliers in their delivery operations, the solution proposed in this study aims at improving mobility in the area by improving traffic flow and reducing congestion. If suppliers are able to park their vehicles in a designated area whenever they are performing their delivery operations, there will be a reduction in traffic obstruction, which will enable private vehicles to move faster and reduce congestion.

Regarding the limitations and possible improvements of the methodologies used, one of them has to do with data reliability. One of the limitations of this study was that all of the information regarding suppliers was obtained by a survey answered by shopkeepers of La Mariscal. The issue with this is that many shopkeepers did not know their suppliers operations and delivery information, for which many inferences were done. For further research, information about supplier's deliveries should be obtained with the aid of the store's manager or directly with suppliers.

Another limitation of this study is that traffic was not taken into account. Traffic is actually a very important factor that should be considered when studying deliveries peak days and hours since traffic jams would most likely influence supplier's routes and time of delivery. In a similar way, this study did not take into account the cost of implementing loading & unloading bays in the described locations. This means that for further studies, cost analysis will enhance a city's mobility plan.

Now, the locations for the implementation of the loading & unloading bays are definitely the start for a plan that will improve the mobility in the neighborhood of La Mariscal. To see real mobility improvements in the city of Quito, it is necessary to expand the application of the methodologies discussed to a bigger area other than a Km^2.

Finally, a further step into this study will be to develop a simulation that will enable to observe suppliers' deliveries through the week. At the same time, the simulation will help to understand how good the solution obtained with the optimization model is. By simulating deliveries in La Mariscal, and using the optimization model solution, it will be possible to obtain important metrics such as bays utilization, length of queue, and average waiting time for a supplier vehicle to use a loading & unloading bay. This will show how good the mobility proposal of this study is, and will determine the urban logistics solutions and measures to be taken not only in La Mariscal, but in the city of Quito too, to make it a more mobile, sustainable and livable city.

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