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Urban Logistics: Generating Solutions to Create a Better Environment for Commercial Logistic Activities: A Case Study of the Historic Center of Quito

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RESUMEN

Hoy en día América Latina presenta la mayor tasa de crecimiento poblacional y de urbanización. En consecuencia, la demanda de productos / servicios se ha incrementado, lo que ha generado la creación de sistemas de suministro complejos y por lo tanto ha aumentado las actividades logísticas. La ciudad de Quito en especial el Centro Histórico se enfrenta a los problemas logísticos mencionados anteriormente. El objetivo de este trabajo es mejorar las actividades logísticas comerciales relacionadas con bienes de carga y descarga en una zona comercial densa del Centro Histórico de Quito, Ecuador. Como una posible solución a este problema urbano de transporte de mercancías, se propone el cálculo del número óptimo y ubicación de bahías de carga y descarga. Mediante una encuesta de proveedores de la zona se recogió datos relativos a la frecuencia y cantidad de las entregas. Sobre la base de esta información se propuso un modelo de optimización para determinar el número óptimo y la ubicación de las bahías de carga y descarga. Por último, se realizó una simulación del proceso de entrega para reajustar el número óptimo de bahías. Un total de 75 bahías de carga y descarga se calculó para servir a los almacenes del kilómetro cuadrado (km2) del Centro Histórico. Esta solución minimizará el tiempo de entrega, la distancia para las entregas, mejorará el transporte urbano de mercancías y reducirá el tráfico. Este estudio puede ser utilizado como guía para nuevas investigaciones en logística urbana, especialmente en América Latina, donde la logística urbana está todavía en estudio. Este documento es parte de un proyecto de investigación de logística urbana en Quito, dirigido por la Universidad San Francisco de Quito (USFQ), en asociación con el laboratorio de mega ciudades del MIT.

Palabras clave: logística urbana, bahías de carga y descarga, actividades logísticas comerciales, transporte urbano de mercancías.

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Urban Logistics: Generating Solutions to Create a Better Environment for Commercial Logistic Activities.

A Case Study of the Historic Center of Quito

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Abstract

Nowadays Latin America presents the highest rate of population and urbanization growth. Consequently, demand for goods/services has increased, leading to the creation of a complex delivery system and thus increased logistical activities. The city of Quito especially the Historic Center is facing the logistics problems mentioned above. The objective of this paper is to improve the commercial logistic activities related to loading and unloading goods in a dense commercial area of the Historic Center of Quito, Ecuador. As a possible solution to this urban freight problem, the calculation of the optimal number and location of loading and unloading bays is proposed. A delivery survey of the zone collected data regarding frequency and amount of deliveries. Based on these information an optimization model was proposed to determine the optimal number and location of loading and unloading bays. Finally, a simulation of the delivery process was performed to readjust the bay´s optimal number. A total number of 75 loading and unloading bays was calculated to serve the total shopping stores of a representative square kilometre (km^2) of the Historic Center. This solution will minimize the delivery time, distance for deliveries, improving the urban freight transportation and reducing traffic. This study could be used as guideline for further investigations in urban logistics, especially in Latin America where urban logistics is still under study. This paper is part of a Research Project of Urban Logistics in Quito, led by Universidad San Francisco de Quito (USFQ), in association with the Megacity Logistics Lab of MIT.

Keywords: urban logistics, loading/ unloading bays, commercial logistic activities, freight urban transport.

Introduction

Urban logistics is a trending topic because of the considerable population growth in all major Latin American cities. For example Latin America is more urbanized than any other region in the developing world with 80 percent of young population living in cities. A yearly growth of 65 million persons living in urban areas is expected (Blanco, Merchán and Bateman 2015).

As cities grow in size and complexity, the demand for goods and services and on time deliveries increase. This phenomenon generates a complicated and oversaturated distribution network worsening city externalities such as congestion, infrastructure degradation, pollution, and noise (Blanco, Merchán and Bateman 2015). As a consequence "Last-mile distribution networks need to evolve to provide enough efficiency, flexibility and resilience to operate in such multifaceted urban settings" (Blanco and Merchán 2015).

Description of Historic Center of Quito, Ecuador

Ecuador has a population of 15.52 million people and more than half of the Ecuadorian population lives in urban zones. This urbanization is expected to increase in the future. According to the last census Quito has 2,781,641 inhabitants and an annual population growth rate of 2.18% (INEC 2015).

The Historic Center is one of the most important commerce areas of Quito. The Historic Center is a tourist zone characterized by the presence of several historical monuments, which contain the majority of Quito´s artistic and cultural works. Furthermore, this area is full of food services and drinking places, clothing stores, hotels and grocery stores. Besides that, the Historic Center has mostly narrow lanes and one-way streets which complicates the delivery service causing an oversaturated transport system and infrastructure, vehicular congestion and complex delivery networks.

Application of urban logistics

Although urban logistics appears to be a good proposal for freight activities problems, there are three main reasons that hinder its application. First, urban logistics is highly dynamic due to agent interaction. Second, there is lack of knowledge and methods to solve urban logistics problems (Galelo, Macário, and Martins 2008). Third, freight transportation is not considered an important problem for urban planning (Blanco, Merchán, and Bateman 2015).

In order to tackle the problems mentioned above an efficient urban transport system and distribution process are required to satisfy consumer's needs (Galelo, Macário, and Martins 2008).

Blanco, Merchán and Bateman propose an "Urban Logistics Atlas" approach which is based on a set of metrics, methods and tools to inform city planners about the drivers of urban freight efficiency. These could be used to design better urban freight policies and facilitate goods movement in the city while reducing externalities imposed on urban life. They propose to measure these metrics in a representative squared kilometer (km^2) of the city because the daily delivery operations, behavior and needs of each sector are different from one sector to another.

First, a representative area of the city is selected based on retail density, area relevance and feasibility to execute the data collection. After that, the specific area is characterized and data of this zone concerning shop inventory, roads and regulations, delivery operations, disruptions, and traffic are collected. Information about delivery and disruptions should be taken solely from the most representative street of the km^2 based on the retail density of the street. Urban freight activities depend on the area that is being studied so it is necessary to record information about road networks, city parking capacity, storage areas, loading & unloading bays, as well as retail and restaurant spaces (Blanco, Merchán and Bateman 2015). This data will provide insight into the urban freight logistical activities for the different shop types of the km^2 and is the key to potential solutions that can help to improve the distribution system.

Galelo, Macário and Martins propose a similar methodology to solve urban freight problems based on the execution of a "Logistic Profile" (LP). "The LP is a tool that allows to identify homogenous groups of logistics needs regarding the urban characteristics of the zone, the requirements of the logistic agents and the characteristics of the products being transacted" (Galelo, Macário and Martins 2008). For these homogeneous groups, urban logistics processes could improve the use and consumption of resources (space, vehicles) because they will be assigned according to the needs of each group.

Based on the data collected from either "Logistic Profile" or "Urban Logistics Atlas" approach proposed by Blanco, Merchán and Bateman of the Megacity Logistics Lab of the MIT, future studies of modeling techniques such as gravity models, models of aggregated and disaggregated analysis, vehicle routing and timing simulation of dynamic flow, terminal or loading and unloading bays location models, multiagents systems and network models may be used in order to optimize usage of resources like space and vehicles. (Galelo, Macário, Martins 2008).

Experimental test-rig, measurement techniques, methodologies

The aim of this paper is to improve the efficiency and efficacy of the distribution of goods to each shopping store of a representative km^2 of the Historic Center by establishing the *optimal number and location* of loading and unloading bays. First, through a shop census and delivery survey of the zone data regarding frequency of deliveries, good distribution, loading and unloading activities was collected. Secondly, the data was analyzed to understand the delivery activities of the Historic Center km^2 and descriptive information of the same area was obtained. Third, an optimization model was proposed to determine the optimal number and location of loading and unloading bays. Finally, a simulation of the delivery process of each bay location was performed to readjust the bay´s optimal number.

Data collection and preparation

An establishment-deliveries survey was carried out which collected data on frequency, quantity and schedules of deliveries, along with descriptive data regarding daily activities of each store. The sample size of stores that participated in this survey was calculated with Formula 1. The total store population required for Formula 1 was obtained from a previous research work done by USFQ and MIT. The research selected a representative km^2 of the Historic Center of Quito, and collected data concerning shop inventory, roads and regulations, delivery operations, disruptions, and traffic for the km^2 based on the “Urban Logistics Atlas”

Next, the Monte Carlo method was selected for the extrapolation of survey data. The variables used for the extrapolation were as follows: number of deliveries per store, number of trips needed to discharge a truck, transport mode and schedule of deliveries per store. This method was selected because "it is more advanced since it is able to sense, learn, and calculate order in seemingly random data by modeling different outcomes in a process that cannot easily be predicted due to the intervention of random variables that does not allow the usage of deterministic models“(Whiteside, J. 2008). The distribution function of each variable was obtained and random numbers were generated to obtain the data.

Finally, a descriptive data analysis was carried out in order to understand the distribution and loading and unloading systems for the km^2.

Optimization model

An optimization model was run in order to determine the number and optimal location of each bay based on three variables (distance, streets and store weights). The objective of the optimization model was to minimize the distance between possible bays and stores by taking into consideration the stores and streets weights. The objective function of the model was defined as the minimization of the ratio of distance over stores and streets’ weights.

The distance calculation was made under two assumptions. First, the center of each street was considered the possible bay location. Second, the distance between bays and stores was calculated as the shortest walking-street´s path.

The streets’ weights were calculated by means of the Analytical Hierarchy Process (Formula 2). Four critical factors were considered for these weights: number of driving lines, number of bike lines, width of sidewalk, and the presence of a loading area on the street. The idea behind streets’ weights was that the streets with higher scores have better conditions to construct a bay and thus will also have less impact on externalities such as congestion, traffic disruptions, etc. Streets that scored over the median based on these four factors were accepted as feasible bay locations for the optimization model.

The stores’ weights were calculated by means of a multi criteria analysis evaluating each of the following criteria: commercial density around the store, number of deliveries per store, number of trips needed to discharge a truck, transport mode and presence of a private loading area. A higher score indicates that a store may receive more deliveries, need more trips to discharge a truck, not have a private loading area, and may be placed on a highly density commercial zone. Therefore, such store requires a closer bay than other stores in a similar area.

The optimization model is presented in Formula 3. The first restriction of the optimization model guarantees that at least one bay is assigned to each store. The second restriction assures that the distance between loading and unloading bays and stores does not exceed an acceptable amount.

The d value (maximal distance acceptable) was set to 300 meters. According to Blanco, Merchán and Bateman, the maximal manual delivery distance in Chile is 150 meters. This value was readjusted for the model to 300 meters because by measuring the walking-street path between two blocks, between block halves, between corners and block halves, and between opposite corners of the blocks, it was determined that the maximum distances are around 300 meters.

Simulation model

A simulation model of the delivery process of each bay determined by the optimization model was performed. The distribution process for each bay and its stores assigned was simulated based on the data of delivery times, service times, delivery schedules, and the number of deliveries for each bay. The service time was calculated as the travel distance time from each bay to a specific store plus the time needed for the delivery transaction. A simulation model of the delivery process is suggested because it considers key performance indicators such as utilization, waiting time, and queues for each bay, so that the number of bays will not depend solely on the minimal distance and number of stores, but also on the delivery rate and service rate of each bay. Furthermore, the simulation could calculate a better estimation of the maximal number of stores that each bay can serve by analyzing the utilization of each bay.

Mathematical modelling

Formula 1: Sample Size

To determine a statistically significant sample size for finite populations Formula 1 is used. This formula was selected because the Historic Center km² has a total store population of 3975 (less than 100 000). Accordingly, the store population is considered finite (Kleinbaum 1982).

$$(1) \qquad n = \frac{NZ_{\frac{\alpha}{2}}^2 p(1-p)}{Ne^2 + Z_{\frac{\alpha}{2}}^2 p(1-p)}$$

$n = the\ sample\ size$
$N = the\ population\ size$
$Z = the\ selected\ confidence\ level$
$p = the\ probability\ of\ ocurrence$
$e = the\ precision\ or\ error$

In order to achieve the largest sample size and assure that the sample is statistically significant a p value of 0.5, an error of 5% and a confidence level of 95% was set (Kleinbaum 1982).

Formula 2: Analytical Hierarchy Process

For the calculation of the streets' weights the following Formulas 2 and 2.1 were used. (Ghiani 2013)

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

$a_{kj} = relative\ importance\ of\ criterion\ k\ with\ respect\ to\ criterion\ j$
$m = number\ of\ selection\ criteria$

The weight for each factor was computed using Formula (2.1)

$$(2.1) \qquad w_k = \frac{\hat{w}_k}{\sum_{i=1}^{m} \hat{w}_i}, k = 1,2,\dots,m$$

Once the weight was calculated, the importance of each street was computed as in Formula (2.2)

$$(2.2) \qquad r_i = \sum_{k=1}^{m} w_k s_{ik}\,, i = 1,2,\dots,n$$

$r_i = total\ score\ of\ bay\ i$
$s_{ik} = score\ associated\ with\ selection\ criterion\ k\ for\ bay\ i$
$w_k = weight\ of\ factor\ k$
$m = number\ of\ selection\ criteria$
$n = number\ of\ bays\ evaluated$

Formula 3 Optimization Model

The optimization model used is an adaptation of the CPL Model (Capacitated Plant Location Model) structure (Hillier 2010).

$$(3) \qquad Min\ Z = \sum_{j=1}^{n}\sum_{i=1}^{m}\frac{x_{ij}d_{ij}}{w_i w_j} \qquad \forall i = 1,2,\ldots,m;\ \forall j = 1,2,\ldots,n$$

$$(3.1) \qquad \sum_{i=1}^{m} x_{ij} = 1, \quad \forall j = 1,2,\ldots,n$$

$$(3.2) \qquad x_{ij}d_{ij} \le d, \quad \forall i = 1,2,\ldots,m;\ \forall j = 1,2,\ldots,n$$

$$(3.3) \qquad x_{ij} = binary, \quad \emptyset\forall i = 1,2,\ldots,m;\ \forall j = 1,2,\ldots,n$$

$m = total\ number\ of\ feasible\ bay\ locations$
$n = total\ number\ of\ stores$
$x_{ij} = binary\ decision\ that\ represents\ the\ assignment\ of\ bay\ i\ to\ serve\ store\ j$
$d_{ij} = shortest\ street\ path\ distance\ between\ bay\ i\ and\ store\ j$
$w_i = weight\ of\ street\ i$
$w_j = weight\ of\ store\ j$
$d = maximum\ allowed\ distance\ between\ a\ store\ and\ its\ assigned\ bay$

Results and Discussion

Data collection and preparation results

The Historic Center km^2 has a total store population of 3975. The shop density for each shop type and for the entire km2 is showed in Figures 1 and 2. However, for the survey analysis, the public shopping centers with a private parking lot were excluded because their freight distribution system was dissimilar to the other sectors of the km2. Furthermore, stores without a name or identification were also excluded since these stores could not be found for the survey analysis. Because of these two reasons the number of total stores available for the survey was reduced to 788 stores.

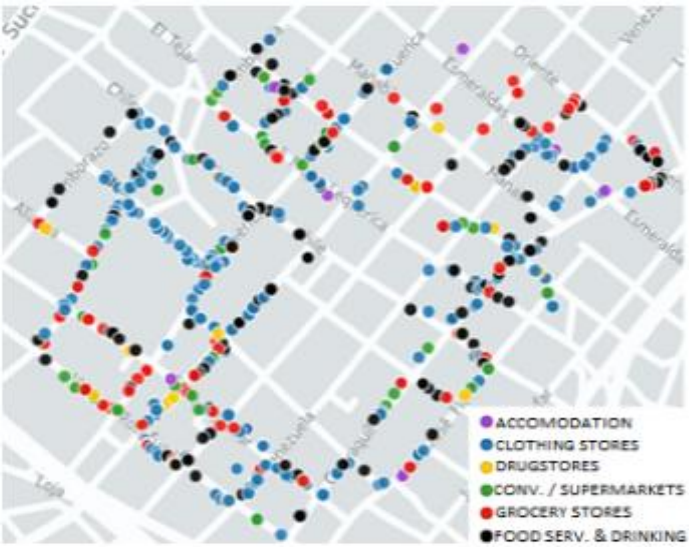

Figure 1. Shop density for each shop type.

Figure 2. Shop density for the entire km2.

After solving Formula 1 a sample size of 265 was obtained. Due to the lack of collaboration of the shop owners, a total of 230 surveys were taken in the Historic Center km^2. Even though, this sample size is still statistically significant for a confidence level of 90%. The results of the shop inventory show that the zone is composed of 59% clothing stores, 20% food services and drinking places and 10% grocery stores. After the survey analysis, it was established that the number of deliveries, number of trips needed to discharge a truck, frequency of deliveries and schedule of deliveries all depend on the shop type. The number of deliveries and trips for the entire population, excluding shopping centers with own parking, is presented in Table 1 below.

Table 1: Number of stores, deliveries, trips needed to discharge a truck and delivery frequency for each shop type.

Shop Type	Stores		Daily Deliveries		Daily Trips	
	Number	Percentage	Average	Percentage	Average	Percentage
Clothing Stores	701	60%	428	53%	1794	59%
Food Services and Drinking Places	230	19%	181	22%	596	19%
Grocery Stores	118	10%	127	16%	376	12%
Convenience Stores and Supermarkets	79	7%	22	3%	119	4%
Drugstores	37	3%	30	4%	124	4%
Accommodation	15	1%	13	2%	52	2%
Total	1180	100%	801	100%	3061	100%

Based on the information from Table 1, it can be concluded that clothing stores receive the highest number of deliveries at 53% and need an average of 59% of total daily trips to discharge the truck. Even though the delivery frequency of clothing stores is only once per month, the number of clothing deliveries is still the highest, since clothing stores represent 60% of the total amount of stores. In contrast, food services and drinking places have a delivery frequency of several days per week. However, the amount of deliveries is only 42% of the total number of deliveries to clothing stores.

In regards to the frequency of deliveries, accommodation places, food services and drinking places, drugs and groceries receive products with a range of several days each week to every day due to the fact that their products or services are made daily. According to the kind of product delivered, clothing stores receive their products weekly or more commonly, monthly.

Because the Historic Center is a tourist and dense commercial area, most of the deliveries activities occur during the day. Figure 3 shows that the delivery rush hours are between 7am and 11am. The Historic Center has an average of 800 deliveries per day. Most of the deliveries are made from Monday to Friday.

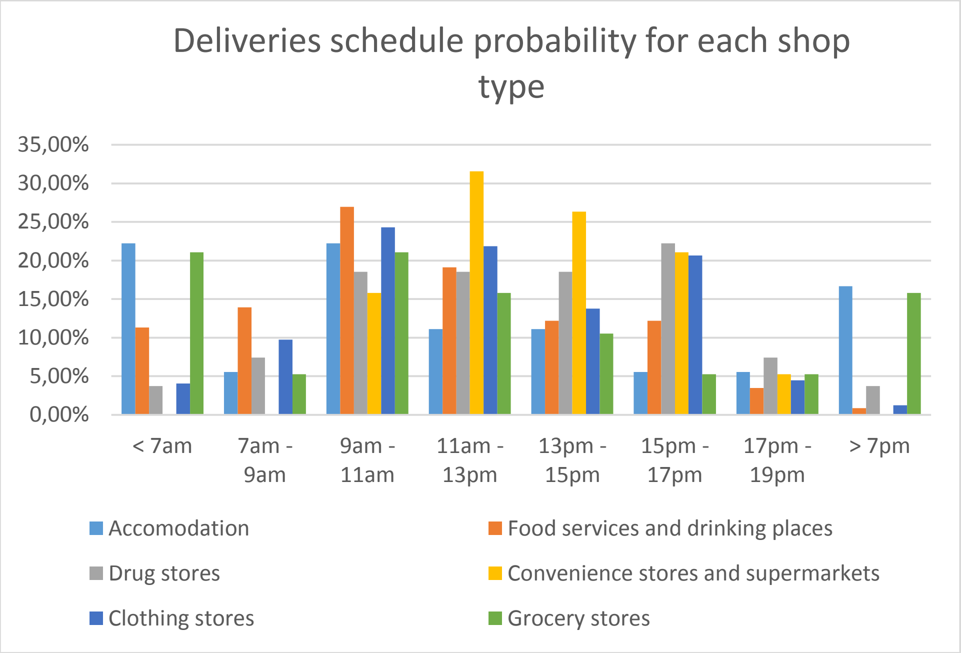

Figure 3. Deliveries schedule

Due to the urban infrastructure of the Historic Center and the lack of parking zones: three main freight unloading methods are currently performed. First, trucks park on the sidewalks interrupting pedestrian flow. Secondly, trucks park on the street causing more vehicular congestion. Third, trucks drive around the streets and discharge merchandise on each trip. This last method increases the time spent by each truck on the area and causes pollution and traffic.

The main findings of the data analysis indicates that the Historic Center has a complex delivery system in the early morning because of the lack of loading and unloading bays or any other discharge zone. As a result vehicular congestion is generated affecting the living conditions of the citizens of this zone.

Optimization model results

After running the optimization model for the entire population, except for shopping centers with parking lots, the following solution was obtained: the objective function of the model indicated that the sum of minimal distances between feasible bays and stores was 50622,615 meters. In fact, by analyzing each distance the maximal feasible distance between bays and stores was roughly 283 meters and the average distance, 44 meters. These values indicated that the constraint of maximal distance was not violated.

Considering the streets' weights streets that scored over the median a total of 78 feasible bay locations was obtained. Regarding the optimal number of loading and unloading bays, the results showed that 66 bays from a total of 78 feasible bays are needed in order to satisfy each store of the km2.

Figure 4 shows the optimal bay´s locations and the stores that each bay will serve for the areas with highest commercial density. Black points indicate the location of the bay and colored points the stores assigned to each bay. Based on this figure it can be concluded that most bays are concentrated in the zones with highest clothing stores density.

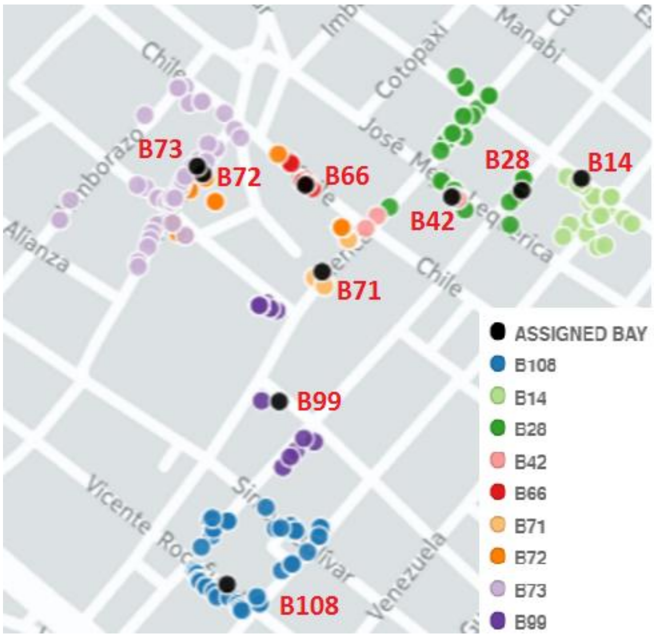

Figure 4. Store assignment for the highly commercial density areas.

Simulation model results

Based on the optimization model proposed and its results, a simulation model was performed. According to Taniguchi, the solution to the problem of urban logistics is the combination of several methods, including location models and timing simulation of dynamic flow. (Galelo, Macário and Martins 2008). Regarding the waiting time nobody waited more than 5 minutes in queue and the average number in queue is cero so that traffic congestion and externalities were reduced in order to accomplish these goals some bays had more than one bay at this location. The delivery process simulated for the 66 bays locations showed that based on the restrictions of waiting time, utilization and number in queue a total of 75 bays should be open in the Historic Center km^2 in order to fulfill the distribution process of the entire km^2. The optimal number and location of the feasible bays is are illustrated in Figure 6. Most of bay locations had just one bay but zones with higher clothes and food services and drinking places had more than one bay per location.

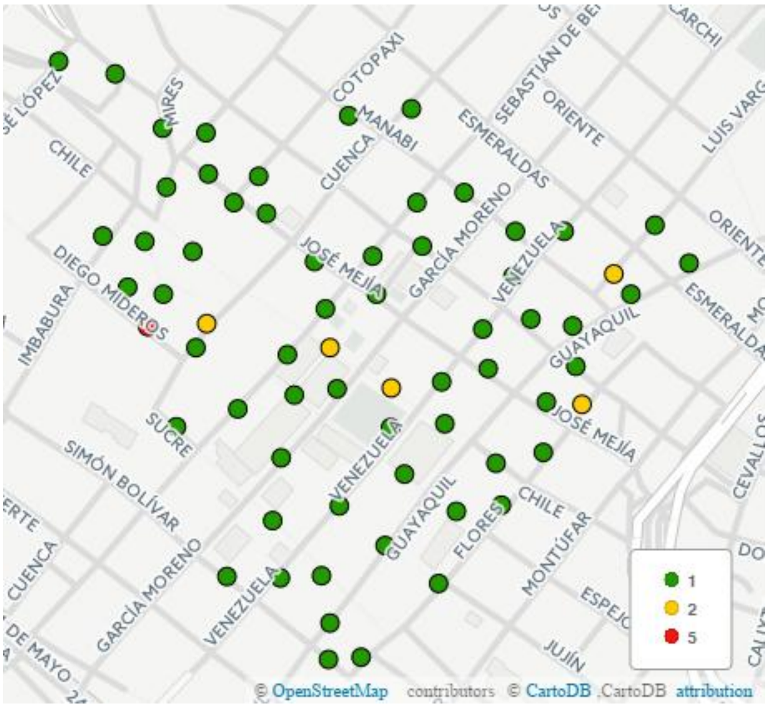

Figure 6. Number and location of feasible bays.

Based on the waiting time, queues, entities in and out and utilization of each bay the following open order prioritization for each bay was recommended. The idea behind of the prioritization allowed to open the bays that have a higher utilization and a higher shop density assigned to them. Then these bays have a higher demand and are more needed than others. As it can be seen the bays located in higher density clothes areas and near food services and drinking places should be open first because of the higher delivery volume. This open bay prioritization is recommended because the Historic Center is recognized as cultural heritage so that its infrastructure is protected. The open bay prioritization is illustrated in Figure 7 where bays with higher scores should be open first.

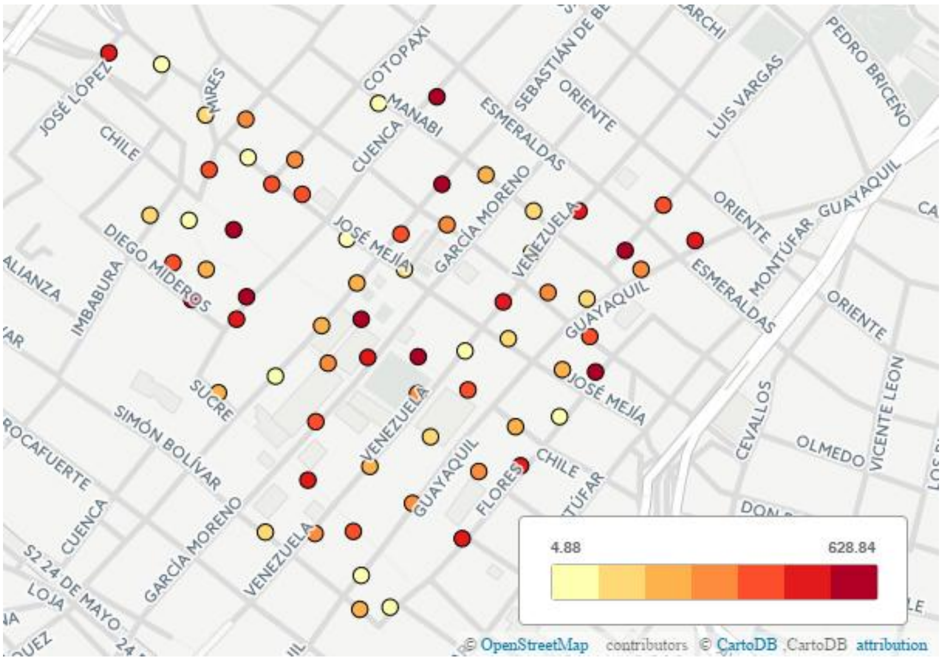

Figure 7. Open bay prioritization.

Conclusions

After analyzing the loading and unloading activities of the Historic Center km2, it has been established that this presents an urban freight problem. Because it is a tourist and historic area, there is a high concentration of product distribution. The Historic Center is a vehicular congestion zone primarily early in the morning because of the delivery activities of this sector. The main problem can be attributed to the lack of public or private parking zones, causing vehicles to park on the sidewalks and generate more traffic. Due to the Historic Center's narrow lanes and one-way streets, it is not possible to park on the sidewalks.

The problems mentioned above and the high commercial density of this area prove that an urban freight distribution solution is needed. As a possible solution, an optimization model was run and it was determined that a total number of 66 loading and unloading bays are required in order to serve the total number of shops of the Historic Center. The fact that 66 bays were selected from a total of 78 feasible bays showed that loading and unloading bays is a primary necessity in this area.

By running the simulation model the optimal bay number for the Historic Center km^2 was set to 75 bays in order to limit the waiting to less than 5 minutes and the number waiting to cero. Based on these results and regarding the utilization and number of deliveries performed on each bay the bays nearest the clothes shops and food services and drinking places have a higher open priority than other bays.

The results of this proposal will alleviate the following problems of the Historic Center km^2. First, the delivery freight system will be more efficient and effective because the delivery time will be shortened. This implies less costs for loading and unloading activities. Secondly, sidewalks and streets will not be used as loading and unloading zones. Third, traffic congestions will be reduced since trucks will spent less time performing loading and unloading operations in the km^2. Finally, the living conditions of the citizens of this zone will be improved due to less pollution, less traffic congestion and a more structured loading and unloading operations in the zone.

In conclusion, urban logistics is still a new approach to solve urban freight transportation problems that should be kept under study. Even though there is not enough knowledge of methods for applying urban logistics (Galelo, Macário and Martins 2008), there are alternative proposals such as the Logistic Profile or the Urban Atlas Platform that are good guidelines for solving urban logistic problems. This investigation may be considered as baseline for future urban logistics studies in Quito because no public evidence of similar works in Quito was found (Planificación C.M 2011).

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