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16. Abstract:

Logistics play a vital role in the prosperity of today's cities, but current urban logistics practices are proving problematic, causing negative effects such as traffic congestion and environmental impacts. This paper proposes an alternative urban logistics system, leasing hubs inside cities for designated time intervals and using handcarts for last mile deliveries. A mathematical model for selecting the locations of hubs and allocating customers, while also scheduling the optimal times during the day for leasing hubs is developed. The proposed model is compared to current delivery methods requiring door-to-door truck deliveries. It is shown that truck traveled distances decrease by more than 60%. In addition, analysis shows that in certain conditions the approach can be economically competitive and successfully applied to address real problems.

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SUSTAINABLE URBAN FREIGHT THROUGH OPTIMIZATION OF LOGISTICS FACILITY LOCATIONS

Final Report

By

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DISCLAIMER

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EXCUTIVE SUMMARY

Logistics play a vital role in the prosperity of today’s cities, but current urban logistics practices are proving problematic, causing negative effects such as traffic congestion and environmental impacts. This research proposes an alternative urban logistics system, leasing hubs inside cities for designated time intervals and using handcarts for last mile deliveries. A mathematical model for selecting the locations of hubs and allocating customers, while also scheduling the optimal times during the day for leasing hubs is developed. The proposed model is compared to current delivery methods requiring door-to-door truck deliveries. It is shown that truck traveled distances decrease by more than 60%. In addition, analysis shows that in certain conditions the approach can be economically competitive and successfully applied to address real problems.

1. INTRODUCTION

1.1. Overview

Logistics operations have become essential to the functioning of todays' economies, representing approximately 10% of the annual gross domestic product (GDP) of the U.S, and accounting for more than 37% of all jobs in the country (Harvard Business Review, 2018). Moreover, freight volumes are constantly growing and are expected to increase by nearly 29% over the next 8-10 years (American Trucking Associations, 2015).

The global use of e-commerce, with indicative examples such as Amazon and eBay, and advancing technologies implemented in the logistics operations (e.g. product tracking) are some of the main contributors to this increase, creating high expectations for "just in time" supply chain practices and home deliveries. E-commerce especially, which in the field of logistics is defined as the activity of purchasing products and conducting businesses online, has changed the way that the movement of products is organized and conducted, leading to a wide range of effects towards businesses and cities in general. **Figure 1** verifies the aforementioned increase by illustrating a freight volume projection until 2050 at a global scale.

Additionally, mitigation rates to large cities are constantly increasing and it is estimated that by 2050 more than 70 percent of the global population will live in urban areas (Lee, 2014). This relocation trends towards metropolitan areas, with all the everyday aspects it includes, such as the limited free time and fast pace in the lives of the citizens, is considered to be one of the causes for the rapid explosion of urban logistics operations, as people are leaning more and more in fast and effortless methods of acquiring necessary products.

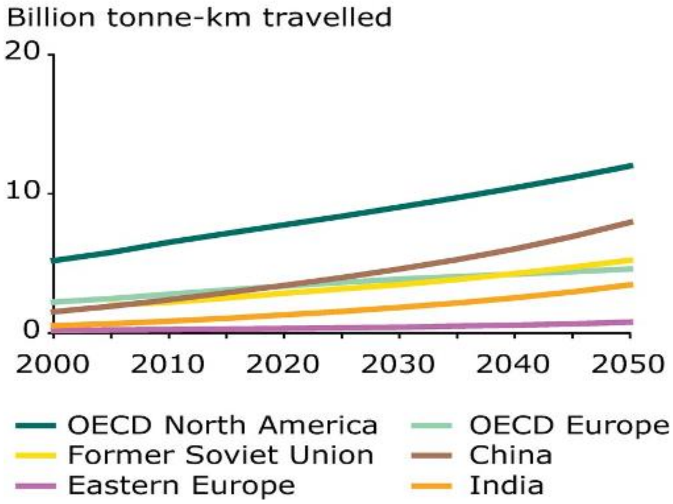

Figure 1: Projections of total freight transport activity from 2000 to 2050

Source: WBCSD World Business Council for Sustainable Development, 2004.

Therefore, due to the factors mentioned above, as the logistics operations grow both in volumes and in quality requirements, urban freight systems are required to manage and cope with these increases, and their planning and operating processes should be developed accordingly, as they play a major role in a city's development. An efficient and successful logistics system can improve the economic growth of an area, provide employment, attract foreign investments and increase awareness in important issues, like environmental impacts.

Urban logistics operations though face many challenges in their goal of delivering cargo cost effectively, timely and with the anticipated quality. Concepts such as sustainability, covering all aspects of urban freight movement, from economic, to social and environmental factors, have become a matter of constant discussion from all stakeholders involved in urban logistics operations. The requirement of addressing and solving all the negative effects associated with transportation systems is becoming more and more urgent. The main drawback in many initiatives undertaken for sustainable urban freight systems lies on the fact that they typically result in higher costs towards logistics operators. Therefore, the need for exploring and implementing alternative solutions to address such negative impacts has become a matter of utmost importance.

1.2. Problem Statement

A significant problem encountered in urban logistics relates to the last mile, as it can comprise even 75 percent of a shipments total cost (Geavers et al., 2009). The last mile in logistics refers to the final step of the delivery process from a distribution center or facility to the end user. Most often, last mile logistics involves the use of parcel or small package carriers to deliver products to consumers.

The increase of online shopping and home deliveries has led to a growth in the last mile delivery levels, which consequently leads to an ever-increasing number of vehicles occupying the streets, in order to be able to serve the demand. This high cost is affected by:

a) The high rate of unsuccessful deliveries, when the delivery vehicle cannot access the urban center due to regulatory restrictions or the customer is unavailable.

b) Traffic congestion and limited parking spaces in urban centers that leads to delivery delays.

c) Underutilization of delivery vehicle's capacity.

Moreover, another important issue encountered and has become a matter of major concern in today's urban transport and freight systems, is the increasing emission levels in metropolitan areas, which is has outlined the need for sustainable urban development. These aspects provide a clear indication on the importance of urban freight transport systems to be able to provide fast, reliable and cost-efficient services. **Figure 2** illustrates the percentage of gas emissions created by various transportation modes, pointing out the significance of truck movements in environmental impacts caused by transportation.

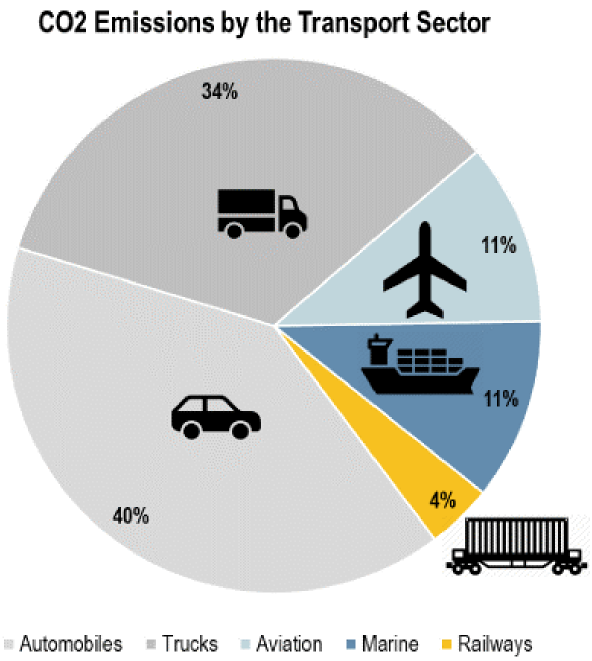

Figure 2: Transportation Greenhouse Gas Emissions by Source

Source: Source: International Energy Association

Various initiatives are constantly taken in order to increase the effectiveness and sustainability of urban freight systems. One of the most widespread is the concept of city logistics, which is defined as "the process for totally optimizing the logistics and transport activities by private companies with support of advanced information systems in urban areas considering the traffic environment, the traffic congestion, the traffic safety and the energy savings within the framework of a market economy." (Taniguchi et al., 2001). This approach incorporates all the economic and social problems encountered in large cities and requires a high level of coordination of all parties involved (e.g. freight carriers, shippers, administrators, residents) in order to be successfully implemented. Additionally, three essential components are required for the application of city logistics (Taniguchi, 2014):

a) Application of ICT (Information and Communication Technology) and ITS (Intelligent Transportation Systems) technologies;

b) Collaboration and partnerships between the private and public sectors;

c) Change in the approaches and mind-sets of logistics managers.

Logistics providers are required to address many strategic and tactical issues while designing their distribution networks. One of the most crucial ones, that can largely influence the success of their operations, is the decision of where to position their logistics (e.g. transshipment, storage, distribution) facilities, as well as which facility should serve each customer.

An important planning decision like that needs to take into consideration many different variables, goals and restrictions in order for it to be successful. In addition, it requires a large capital investment with an extended planning horizon. It has evolved into a crucial aspect of logistics business operations, especially with the current form and structure of supply chain networks. Before deciding on these matters, logistics companies are required to consider multiple aspects including economics, infrastructure, land availabilities, surrounding area, environmental impacts, competition, development strategy, logistics costs and customer service levels. A non-efficient distribution network can result to losses of millions of dollars for logistics companies. Especially in the field of city logistics, and due to the factors mentioned above, this decision has evolved into one of utmost importance.

1.3. Research Objectives

The main motivation for conducting the study lies on the fact that typically freight operators locate their distribution centers outside the cities in remote areas, where the space for warehousing, transshipping, fleet deployment is larger and the land use, operations, maintenance costs lower. Most commonly, they deliver the products using trucks and other heavy goods vehicles (HGVs), traveling "door-to-door" to all the downtown destinations in urban and suburban areas. The recent trends for "just-in-time" deliveries have significantly impacted and challenged this delivery approach, as in many cases the required level of service cannot be achieved.

More specifically, this approach results in a large fleet of delivery vehicles to be driving around congested city centers, and more parking spaces, load zones, being required by transport companies operating in cities. The aforementioned delivery method though, has proven to be causing many problems in urban areas, including traffic congestion, increasing emission levels. delivery delays. high operational costs (Oliveira et al., 2014).

The effects of urban freight mobility practices in cities have evolved into a crucial research domain, and many efforts are being conducted for quantifying the aforementioned effects, decreasing negative impacts and proposing more efficient and environmentally friendly delivery methods. This is one of the pillars where the concept of sustainability in transportation systems is based on. Global companies like UPS, FedEx, and Amazon are supporting such initiatives, as they are implementing various unconventional practices for urban deliveries, like the concepts of Bicycle Logistics, deliveries by unmanned aerial vehicles (UAV) and Amazon Locker. **Figure 3** illustrates the bicycle logistics concept that has been recently proposed.

Figure 3: Bicycle Logistics Initiatives

Source: https://mailomg.com/2017/11/09/ups-e-bike-service-begins-in-pittsburgh/

As can be easily concluded by the facts mentioned above, current urban logistics practices have proven unsuccessful. Therefore, it is essential that new delivery options are to be explored, that promote sustainable, environmentally friendly services which can help mitigate many of the negative effects of the ever-growing transportation networks. This study conceptualizes an innovative alternative supply chain method for last-mile deliveries in urban congested areas. It proposes the establishment of a set small sized logistics facilities (e.g. mini-hubs) in various places inside metropolitan areas, where trucks will directly head from the main facility that serves the whole area and unload the cargo. From there the products are further delivered on foot, using handcarts to the final destinations.

The methodology can also be applied for the case of bicycle logistics mentioned above. Essentially, this study proposes the switching of the last-mile operations from a point-to- point to a hub-and-spoke network structure. The reason behind this decision is that generally, hub-and-spoke systems minimize the distances traveled, hence the transportation costs.

Furthermore, the facilities established will provide self-pickup opportunities for customers, in similar fashion to the Locker practice mentioned above. **Figure 4** depicts an example locker practice adopted by UPS, where the last-mile delivery is conducted by the customers in a very straightforward fashion. They go to the position of the locker, insert their order number and get their products.

Figure 4: City Logistics Locker

Source: https://lancasteronline.com/news/local/lockers-from-amazon-and-ups-provide-customers-with-another-delivery/article_d54139b0-f21a-11e6-85af-9bceb64b39fe.html

Due to the fact that products will be delivered either on foot, by bicycle, or self- picked up from customers, the study focuses on less than truckload (LTL) shipments, mostly parcel deliveries, which can effectively carried by these modes with the use of company delivery personnel without the need for a vehicle such as car, minivan, truck, etc.

The main objective of the project is the development of a novel mathematical framework for the capacitated facility location-allocation optimization problem. This study proposes mixed integer linear programming models with various constraints that make the problem more complex and applicable in real cases.

Figure 5 provides an illustration of the supply chain model proposed in this study. In this method one more step is included in the whole supply chain process from the factories to the customers. The products after arriving to the distribution centers, instead of going directly to all the customers, are moved to the mini hubs established in the city centers. Then, they are transshipped to more environmentally friendly modes such as handcarts and delivered to the customers.

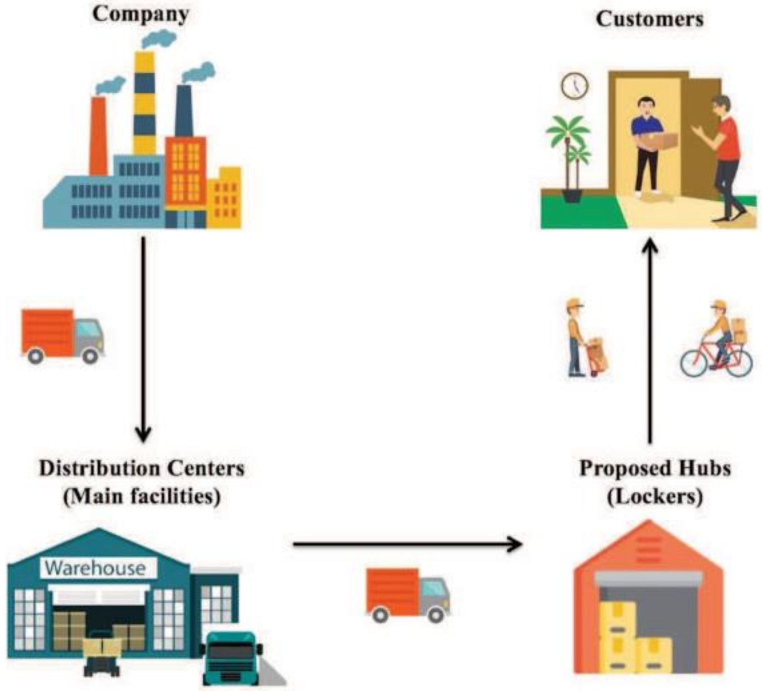

Figure 5: Illustration of the supply chain proposed in the study

An important aspect incorporated in the study and the formulation is the leasing of the hubs for a designated daily time interval, instead of acquisition of the properties. The model, apart from selecting the locations of hubs and allocating customers to hub for serving the demand, also selects the time during the day when the facilities will be leased. Each time during the day, fixed, as well as transportation costs vary, making the optimal time selection a crucial part of the formulation. In addition, since each customer has his own time requirements for delivery of cargo, the model leases each hub for a time where the allocated customers can effectively be served.

The mathematical programming model developed in this research selects the optimal number and locations of distribution hubs, out of a set of candidates, which serve the demand with the minimum operational cost, which is composed of:

- The cost for using the designated locations, as different locations are burdened by different land use costs.

- The cost for transporting cargo using a fleet of trucks from the main facility to the chosen hubs.

The constraints included in the model ensure that it is complex and realistic enough to capture all the essential variables affecting real logistics network operations. First, as mentioned before, the problem solved is the capacitated location-allocation problem, which means that each candidate facility has different capacity in terms of maximum load it can handle. In addition, the model includes time deadlines, in order to guarantee timely deliveries. Moreover, it incorporates a maximum allowed distance radius for the allocation of nodes to hubs, so each facility is guaranteed to be in close spaces with the demand places, supporting both the delivery and self-pickup functions. Finally, each facility has a maximum number of customers to be served by it, in order to make sure high service levels are provided and accommodate self-pickup from customers, since locker have a predetermined number of slots.

In order to approach the problem stated and apply the proposed method the study followed several steps:

1) First, conducted literature review on studies related to city logistics and location optimization for identifying current practices followed to solve similar problems.

2) Then, developed the theoretical conception of the problem, in order to manage and understand the important variables, objectives and restrictions that need to be taken in consideration.

3) Third, developed the mathematical formulation that accurately represents the problem and coded it using the optimization software CPLEX.

5) Fourth, conducted various experiments in different problem sizes and a case study, as well as a sensitivity analysis in order to show the robustness and effectiveness of the model developed.

6) The study finishes with the conclusions obtained from the application of the proposed approach, as well as recommendations for successful future implementation

Figure 6 provides an illustrative representation of the methodology followed for understanding, conceptualizing, formulating and solving the problem addressed in the study.

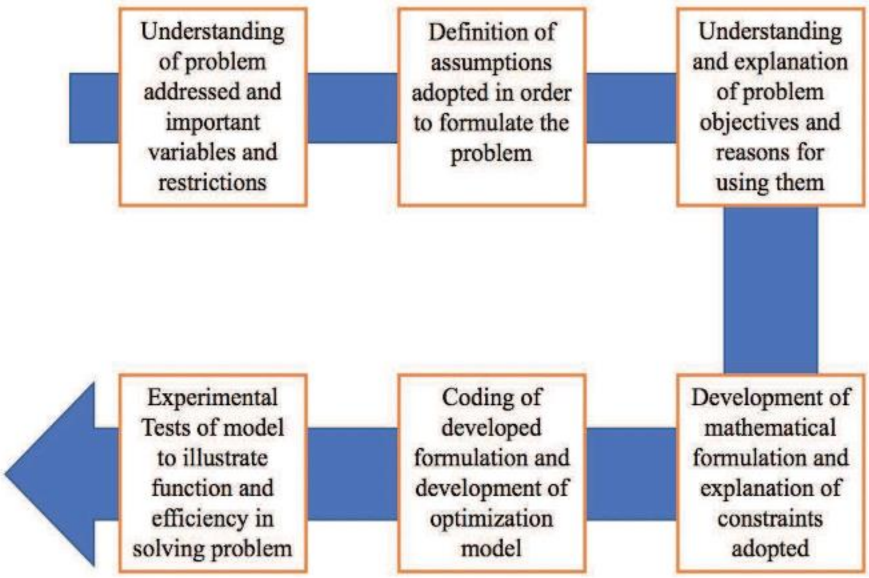

Figure 6: Illustration of the steps followed in order to solve the problem

2. LITERATURE REVIEW

The literature review conducted aims at identifying all the approaches, methodologies and practices that have been applied so far in order to solve problems similar to the one addressed in the project. The study examined research conducted in the time previous to this study, with the goal of getting a better understanding on previous works conducted in the matter. This chapter is divided into two main subchapters: (a) studies related to city logistics and urban freight transport systems and (b) studies regarding the optimal selection of logistics facility locations.

2.1. Urban Logistics Studies

The last years many initiatives are being undertaken in order to make urban freight systems faster, safer and more reliable, and negate all the negative effects that can be associated with their operations. These initiatives vary from technical, organizational, regulatory and policy alterations that aim on improving their performance.

More specifically, T. G. Crainic, et al. (2004) conducted a study in the domain of urban freight systems, proposing an organizational and technological framework for the integrated management of urban freight systems, while also identifying various important planning and operational issues encountered. In addition, they presented some corresponding to those issues operations research models, providing the exact formulation for one of them, which can help optimize the performance of these systems.

M. Browne et al. (2005) worked on a project for the U.K. Department for Transport. The projects' main objective was the identification of the potential benefits from developing urban consolidation centers, as well the determination of the viability of this initiative.

Moreover, G. Yannis et al. (2006) investigated the impacts of various regulations related to urban delivery traffic movements on urban areas. They developed traffic simulation models using data ranging from land uses, traffix mix, flows and capacities and delivery requirements for various types of services. The study concludes by stating that in order for such restrictions to be successful and provide significant improvements in urban areas, careful planning, adoption of supporting activities and gradual implementation are required.

J. Muñuzuri et al. (2010) studied the ecological effects of urban freight systems. They developed a macroscopic simulation model in order to estimate a value for the ecological footprint of urban freight deliveries. The study concluded that the ecological footprint depends on the type of vehicles used, the distances travelled by them, their average speeds and the number of stops they make. Additionally, they analyzed urban freight policies in terms of their expected influence on costs and their contribution to the sustainability of the urban area.

D. Patier and M. Browne (2010) proposed a framework for examining the effectiveness of initiatives in the field of urban logistics. Their objective was to develop a consistent methodology that can be applied in various types of city logistics experiments and pilot projects. The method considers both quantitative and qualitative performance measures, covering the economic, social, environmental effects of innovations. The study concludes by indicating that, given all the required data, the proposed methodology can provide a standardized approach that can be applied in all main types of urban freight innovations.

L. K. Oliveira, et al. (2014) investigated the effects of utilizing urban logistics facilities for freight deliveries. They developed a simulation model that represents the operation of a ULS and then generated indicators to evaluate the performance of this space according to different operating configurations. The study concludes by indicating that this approach can provide many benefits in the operations of urban freight systems, such as reductions in truck trips made, waiting and delivery times and last mile costs.

In addition, A. Alho et al. (2014) in their study focused on the analysis and modeling of logistics loading/ unloading bays. The developed model combines simulation and optimization techniques

that take into account double-parking derived vehicle obstruction. The main goal of their study was the better understanding of the relation between the factors that lead to an optimized l/u bay system, mainly the number and location of bays, enforcement outcome and size of bays.
E. Taniguchi (2014) discussed various aspects of city logistics systems. After presenting the multiple stakeholder involvement in the logistics process and their different objectives and perspectives, he focuses on the importance of collaboration between all parties for developing efficient and environmentally friendly urban freight transport systems. Later he describes the three main elements for effectively applying city logistics initiatives: (a) Application of innovative technologies of ICT and ITS, (b) Change in mind- sets of logistics managers, and (c) Public-private partnerships.
JGV Vieira et al. (2015) examined the opinions of various stakeholders involved in the logistics operations. First, they investigated some logistical performance indicators adopted by the companies with the goal of developing a profile of companies that provide the best logistical performance in freight delivery. Additionally, they aimed at summarizing the opinions of shippers, LSPs and carriers regarding regulations and issues by conducting interviews and discussed the ways freight operators address these regulations and operate simultaneously and efficiently inside and outside megacities.

2.2. Facility Location Studies

The logistics facility location problem can be classified as a special case of the well- known facility (hub) location problems. The domain of location theory has attracted much attention from the research community the last 30 years, as it comprises a complex operations decision that requires the consideration of multiple aspects including politics, economics, infrastructure, environment, competition, development strategy, logistics costs and customer service levels. Many different variations have been developed to solve the problem, like the p-median problems, p-center problems, fixed and variable cost problems, maximal covering problems, capacitated and uncapacitated problems, etc. These variations provide a wide range of different objectives, e.g. minimization of transportation or facility costs, number of hubs used, transportation times, and maximization of area coverage, among others.
More specifically, S. Abrinnour-Helm (1998) developed a hybrid genetic algorithm and tabu search optimization model for the uncapacitated hub location problem. His goal included identifying the number and location of hubs, as well as the assignment of spokes to hubs, considering minimization of the total transportation costs.
S. H. Owen and M. S. Daskin (1998) conducted a review of studies related to facility location models. They mostly focused in the strategic nature of these problems, stating the importance of an optimal facility siting in business decisions, mainly due to the high costs associated with the establishment and operation, as well as the long lasting character of the investments. In addition, due to the reason mentioned above, they argue about the importance of taking into consideration dynamic or stochastic problem characteristics while modeling the problem.
In addition, J. Ebery et al. (2000) conducted a study where they presented a mixed integer linear programming formulation for addressing the capacitated multiple allocation hub location problem, and solved it using a shortest path heuristic approach. Moreover, they developed a linear programming based branch-and-bound solution method, where they input the upper bound obtained from the shortest path heuristic. Last, they solved the problem with exact method and compared the solutions.
In a later study, Z. Yang et al. (2005) focused city logistics in their study. First, they gave their definition of city logistics terminals as warehouse, marketing, freight detaching, distributing and information centers. Then they developed a location model and a genetic algorithm in order to optimize their size and special distribution, with the goal of minimizing total freight transport costs.

Moreover, H. Topcuoglu et al. (2005) utilized the genetic algorithm framework for solving the uncapacitated hub location problem. Their model aimed at minimizing the total collection, transfer, distribution costs, as well as the costs of the hubs. They also compared their model with those of previous literature in order to demonstrate its performance and ability to extract optimal solutions in short computational times.
M.T. Melo et al. (2008) conducted a review of the literature that incorporates the facility location problem into supply chain and logistics. In their review, they dealt with the strategic nature of the problem and the basic features that need to be taken into consideration in the planning process. Furthermore, they discussed the connection of selecting a location for a facility with other operational and structural supply chain network decisions.
In more recent studies, Ishfaq and Sox (2011) emphasized in intermodal logistics. First, they described intermodal logistic networks in terms of transportation cost structure, modal connectivity, availability of transfer points and service time performance. Then, they developed a mathematical model for the multiple-allocation p-hub median problem, incorporating individual mode, modal connectivity and fixed location costs under service time requirements, and used tabu search heuristic to extract optimal solutions.
Additionally, I. Contreras et al. (2011) dealt with the uncapacitated hub location problem. In their study, they introduced the concept of stochasticity in terms of demands and transportation costs. In order to solve their problem they developed a Monte-Carlo simulation-based algorithm that integrates a sample average approximation scheme with a Benders decomposition algorithm.
J. Munuzuri et al. (2012) were amongst the first to deal with a problem similar to the one tackled in this study, as they emphasized in locating minihubs inside urban areas for freight deliveries. After stating various problems encountered in urban freight systems, they formulated their model as an uncapacitated hub location problem, with no costs associated to the hubs. The objective was the minimization of the transportation costs and the model was solved using genetic algorithms for finding optimal solutions.
Moreover, Xifeng et al. (2013) incorporated the sustainability aspect in their researcu. In their study, they solved an extension of the uncapacitated facility location problem that finds the optimal trade-off between the minimization of location and transportation costs, CO2 emissions and maximization of service reliability. In order to solve the multi-objective problem they used the e-constraint method, giving priority to the environmental aspect and then used a greedy heuristic to obtain solutions.
The same year, M. Mohammadi et al. (2014) also incorporated the aspect of sustainability in their work. Their model was based on the p-hub capacitated location problem and included two environmental-based cost functions accounting for air and noise pollution of vehicles, as well as the concept of uncertainty, as they used a mixed possibilistic stochastic programming approach for the data construction.
C. C. Lin et al. (2014) focused on solving the problem of selecting the optimal intermodal terminal locations. First, they discuss the importance of intermodal transportation in todays' freight systems. Then, they propose a mathematical programming model for minimizing total transportation and operation costs, as well as a heuristic method for obtaining solution, while incorporating the terms of collaboration of unimodal road transport with intermodal transport chains.
In addition, I. Harris et al. (2014) addressed the initiative of green logistics for solving the capacitated facility location problem with flexible store allocation. They proposed an evolutionary multi-objective optimization approach that can solve large problem instances. Their model captures flexibility in the allocation level, considering a range of tradeoffs for balancing financial costs and environmental aspects (CO2 emissions) within a multi-objective evolutionary framework at the location level.
C. Rao et al. (2015) developed a model for selecting the locations of city logistics centers while incorporating the concept of sustainability. After providing their definition of city logistics centers and their importance on urban logistics systems, they created a location selection model for

selecting the best location. Their model includes the three main aspects of sustainability (economic, environmental and social factors), capturing the problem of environmental impacts on freight mobility.

Furthermore, C. C. Lin and S. W. Lin (2016) again dealt with intermodal terminals, in their research work. Their developed model included the objective of selecting terminals that constitute an intermodal transportation network and routing freight flows with minimal total transportation and operating costs. In order to extract the optimal solutions, they proposed a two-stage programming approach along with an efficient matheuristic. This work differed from their previous due to the separation of the selection of intermodal terminals from the routing of transportation flows.

Last, M. Musavi and A. Bozorgi-Amiri (2017) created a multi-objective model for solving the hub location-scheduling problem for perishable food supply chain. Their approach included the concept of sustainability, with the goals of minimizing the transportation costs, maximizing product quality and minimizing carbon emissions, under consideration of a limited number of transportation fleet for serving the demand. They solved their problem by developing a non-dominated sorting genetic algorithm-II (NSGA- II).

The literature review indicated that although a large amount of work has been conducted in the optimization of logistics hub locations, its application in city logistics has been scarcely studied, as most studies focus either in intermodal terminals or more generally in facility locations without specifying their applications. Only one study was identified dealing with the optimal locations of inner-city hubs, that of Muñuzuri et al. (2012), which, as mentioned above, solved the uncapacitated p-hub median location problem for specified sections of curb where vehicles stop in order to make the final deliveries.

In addition, this study is the only one in the field that deals with the leasing of properties and includes this aspect into the formulation. These two factors mentioned provide evidence on the contribution of the study both in the conceptual and modeling aspects of the problem, making it a unique approach.

The fact that the proposed study is a unique approach for delivering cargo in urban areas, scarcely studied in past literature, made the theoretical and mathematical formulation of the problem much more challenging. There is no benchmark problem to take ideas, or the base of the formulation from, especially dealing with the aspect of leasing the hubs. It was crucial and necessary to manage and logically establish the problem that was conceptualized from scratch, in order to take into consideration all possible cases, problems that could arise and provide a solution that is rational and can indeed be applied in real case studies. Therefore, the large contribution of the study can be easily concluded, as it provides an innovative approach worth tested, which has not been studied before.

3. METHODOLOGY

3.1. Problem Overview

The problem addressed in the study is the design of a distribution hubs network inside urban areas in order to provide an alternative and innovative method of operating city logistics systems. Traditional practices involve the deployment of a large fleet of trucks that travel to all the downtown destinations to deliver goods. As mentioned in the introduction, a common result of this method is the illegal double parking in urban networks in order to deliver the goods. The freight parking problem has evolved into a major issue encountered in urban areas (Jaller *et al.*, 2012). It can be easily concluded that this delivery approach has proven problematic and causes various issues in cities. Some examples are (a) noise and pollutants emissions; (b) increased fuel consumption; (c) increased logistics costs; (d) delivery delays; (e) traffic congestion; and (f) deterioration of urban infrastructure (de Oliveira *et al.*, 2014). Additionally, certain policies have been adopted in many large metropolitan cities that relate to regulations regarding the entrance times of those types of vehicles to downtown areas. Usually these regulations restrict arrivals in peak hours, with the goal of reducing traffic impacts and pollution. It has been identified that this approach can have the opposite effect, as companies need to schedule their deliveries accordingly, and possibly use longer alternative routes to reach their destinations (Muñuzuri *et al.*, 2012). On the contrary, this research proposes the leasing of a number of hubs inside downtown areas. Therefore, instead of traversing "door-to-door" to all the destinations, the trucks travel to these facilities and unload the products. From there they will be delivered to the final destinations (i.e. customer locations) using handcarts. The trucks used for the product deliveries will not be traveling between all the downtown destination nodes, increasing the vehicle volumes in roads and distances traveled by trucks, but will directly head to the hubs and return to their origin from predefined, low traffic routes, allowing a controllable vehicle distribution in the network. Moreover, the proposed approach explores an alternative operating method for the last mile deliveries that can potentially prove more efficient than current practices. The facilities considered act as unloading and transshipment points. Each hub has different capacity in terms of maximum cargo volumes it can handle based on the size of the facility and different fixed operating costs, depending on the size and the land use costs. **Figure 7** illustrates the structure of the network developed in the study. Apart from the practical contribution and innovation of the supply chain method proposed, the mathematical programming model developed to extract optimal solutions presents a novel approach for solving the hub location problems as well. As mentioned above, the model selects the daily time intervals when each facility should be leased. Each time interval is assumed to be of uniform length (e.g. 2, 3 hours), and the hours of operation are split into intervals according to this length (e.g. a 12 hour work day would be divided into 6 2-hour intervals). Each time slot is defined by different leasing costs, as well as different average truck speeds (to account for the different traffic patterns during that time). For example, during peak hours, average speeds are slower than other times during the day, leading to alterations in the transportation costs.

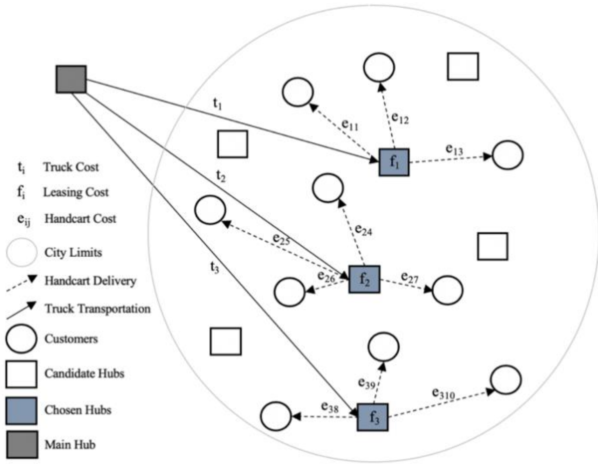

Figure 7: Schematic of Proposed Network

Then, the model chooses the time interval each hub should be leased, allowing different hubs to be leased at different times of the day in order to accommodate individual customer requirements. In addition, the study adopts a time deadlines constraint, something that has scarcely been explored in the hub location problem literature. The individual time deadlines are issued by each customer as the latest acceptable time for the package to arrive. The time required to transfer the cargo from the main hub to the mini-hubs, the time for unloading and transshipping the products to the different modes, and the time to deliver the products to the final destinations is considered when determining if time deadlines are met. Finally, the proposed approach incorporates a constraint that dictates the maximum allowable distance between a node and a hub in order to allocate the node to the specific hub, shown **in Figure 8**. Since the final deliveries are conducted using handcarts, providing as outputs locations in close proximity and easily accessible to the destinations in an important aspect of the formulation.

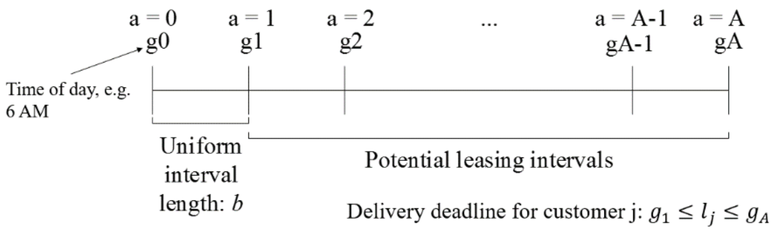

Figure 8: Time Interval Framework

3.2. Mathematical Formulation

The model is formulated as an extension of the capacitated facility location problem, with the incorporation of the scheduling aspect of the problem. A mixed integer linear programming model (MILP) is proposed, with the goal of determining the optimal number of facilities, assignment of customers to hubs and time slots to be selected in order to satisfy all customer demand with the minimum system cost. For the formulation and development of the model, some reasonable assumptions are adopted:

- A homogeneous fleet of trucks is assumed, in terms of load capacities and fuel consumption rates. The number of trucks needed is endogenously determined using the demand at a chosen hub divided by capacity per truck (it is assumed that each company can provide the amount of trucks needed);
- It is assumed that the hub locations, usage costs and demands are fixed and known beforehand;
- The values considered for the truck and walking speeds are regarded as average speeds, incorporating acceleration, deceleration, traffic delays, etc;
- The time that it takes to unload the materials at a chosen hub is less than the length of time that the hub is leased;
- It is assumed that each vehicle departs from the main hub to the chosen facility in the time period before the chosen hub is leased in order for it to have arrived at the moment the lease starts, and also that the vehicle travels back to the main hub during the chosen interval after unloading.

The complete mathematical formulation that accurately represents the problem at hand is presented below. Let:

Sets

I	Set of all candidate facilities i = 1…I;
J	Set of all destination nodes j = 1…J;
K	Set of trucking costs taken into consideration k=1…K;
A	Set of time intervals α = 0…A;

Note: Since we assume that all vehicles leave the main hub en route to the chosen hub during the time period previous to the time period of the lease, the time interval set index a runs from 0 to A—where the leasing periods are 1…A.

Parameters

d_j	Demand of destination node j;
f_i^a	Fixed cost for using facility i during time period α;
t_i^a	Transportation cost for traversing between main hub and facility i in time period α;
e_{ij}	Transportation cost for traversing between hub i and customer j;
q_i	Capacity of facility i;
c_{ij}	Distance between facility i and destination node j;
h_i	Distance between main hub and facility i;
l_j	Time deadline for cargo arrival in node j;
w	Truck capacity;
r	Maximum distance for allocation of facilities;
b	Uniform time interval length;
v^a	Average truck speed in time period α;
s	Average walking speed;
u	Unloading time per case;
g^a	Parameter referring to time of day corresponding to index value a;

Decision Variables

$$X_i^a = \begin{cases} 1, if\ facility\ i\ is\ used\ in\ time\ period\ a \\ 0, otherwise \end{cases}$$

$$Y_{ij}^a = \begin{cases} 1, if\ customer\ j\ is\ allocated\ to\ facility\ i\ at\ time\ period\ a \\ 0, otherwise \end{cases}$$

Objective Function:

Minimize

$$\sum_{a\in A-\{0\}} \sum_{i\in I} X_i^a (t_i^a + f_i^a) + \sum_{a\in A-\{0\}} \sum_{i\in I} \sum_{j\in J} e_{ij} \tag{1}$$

Subject to:

$$\sum_{a\in A-\{0\}} \sum_{i\in I} Y_{ij}^a = 1, \forall j \in J \tag{2}$$

$$Y_{ij}^a \le X_i^a, \forall i \in I, j \in J, a = 1 \dots A \tag{3}$$

$$\sum_{j\in J} d_j Y_{ij}^a \le q_i X_i^a, \forall i \in I, a = 1 \dots A \tag{4}$$

$$c_{ij} Y_{ij}^a \le r X_i^a, \forall i \in I, j \in J, a = 1 \dots A \tag{5}$$

$$\sum_{a\in A-\{0\}} X_i^a \le 1, \forall i \in I \tag{6}$$

$$X_i^a \frac{h_i}{v_{a-1}} \le b, \forall i \in I, a = 1 \dots A \tag{7}$$

$$d_j u + 2c_{ij} Y_{ij}^a / s \le b, \forall i \in I, j \in J, a = 1 \dots A \tag{8}$$

$$d_j u + \frac{h_i}{v_a} X_i^a \le b, \forall i \in I, j \in J, a = 1 \dots A \tag{9}$$

$$g_a X_i^a + d_j u + c_{ij} Y_{ij}^a / s \le l_j Y_{ij}^a, \forall i \in I, j \in J, a = 1 \dots A \tag{10}$$

$$X_i^a \in \{0,1\}, \forall i \in I, a = 1 \dots A \quad (11)$$
$$Y_{ij}^a \in \{0,1\}, \forall i \in I, j \in J, a = 1 \dots A \quad (12)$$

Function (1) represents the objective of the problem, that of minimizing the total operational costs of the developed network. Total costs comprise of three components: costs for transporting the cargo to the chosen facilities; fixed costs for using each candidate hub; costs for transporting cargo from the hubs to the customers. The fixed hub costs can vary for different daily time intervals. Transportation costs depend on the number of trucks required to transfer the allocated cargo to each facility, the distances between the main facilities and the chosen hubs, the average speeds followed in the trip time interval and the truck cost per mile. The reason for incorporating the speeds in the transportation costs is to account for the different traffic patterns during the day, which will cause the trucks to operate either longer or shorter depending on the conditions. The number of trucks required to transport cargo to each hub is calculated by dividing the total allocated demand to a hub with the truck capacity and rounding to the highest integer. The truck cost applied in the study includes fuel costs, repair and maintenance costs, tax and insurance costs, driver payments, etc. In a similar fashion, the transportation costs for delivering cargo from the hubs to the customers depends on the distances between hubs and customers, the average walking speeds and the cost per distance for transporting on foot. Since the driver payments are incorporated in the transportation costs, the main cost incurred during the final deliveries is the truck idle time cost (Dukkanci *et al.*, 2019).

Constraints (2)-(5) comprise the location-allocation aspects of the problem. Constraint (2) guarantees that each customer is assigned to only one facility. Inequality (3) states that a customer cannot be assigned to a facility unless it is used. Constraint (4) enforces the total demand allocated to a facility to not be greater that the facility's capacity, while inequality (5) ensures that each destination node can only be allocated to a facility if its distance to that facility is less or equal to its maximum range (radius). Next, constraints (6)-(10) illustrate the scheduling dimension of the problem for leasing the hubs. Constraint (6) ensures that each hub is chosen for at most one time slot. This represents choosing the best time to lease a single property. Constraint (7) guarantees that all vehicles can travel from the main hub to the chosen hub in the period before the building is leased (a-1). Inequality (8) ensures that the packages are delivered, processed, and the delivery people have time to deliver the packages and return to the facility during the time that the building is leased. Constraint (9) ensures that the vehicle has enough time to unload and return to the main hub during the chosen time interval a. Constraint (10) establishes the connection between the time deadline issued and the daily interval that the facility is leased for. It makes sure that the lease of the facility has initiated before the time deadline issued by the customer. In addition, it calculates the duration of all activities that occur once the building is leased, in order to compare it with the time deadline for each customer. The time deadline framework is shown graphically in Figure 2. Finally, constraints (11) and (12) are standard integrality constraints, stating that these variables are binary.

4. APPLICATION

4.1. Computational Tests

In this section, the performance of the proposed mathematical model is verified using various large size problems randomly generated. For the verification test, systemic parameters are proportionally increased, and the objective value and computation time are checked to verify the consistence of the proposed model, as well as its ability to be applied in real scenarios. **Table 1** summarizes the results of the various computational experiments conducted. In all the tests 4 leasing time intervals

(A=1, ...,4) are considered. The CPLEX runs are carried out in a 2.8 GHz processor and 8GB RAM personal computer. Increase in the number of locations leads to increase in the computational time, as the model has more options to explore and the problem becomes more complex. Since the number of customers remains the same though, the total cost does not increase by a large amount, as the transportation costs stay in the same ranges. On the other hand, increase in the number of customers leads to a large increase in the total cost. More vehicles are required to serve the demand and more trips are conducted, translating into higher costs. The same applies for the computational times, since the problem size (hence complexity) increases.

Table 1: Computational Experiment Results

Number of Hubs	Number of Customers					
	20		100		500	
	Obj Value ($)	CPU Time (sec)	Obj Value ($)	CPU Time (sec)	Obj Value ($)	CPU Time (sec)
10	134	11.8	696.8	28.2	3274.96	171.6
50	168.3	89.2	736.2	180.5	3607.38	312.6
100	196.7	211.6	802.9	321.9	4094.79	581.4

4.2. Application and Output Illustration

In this section, experiments are conducted using the proposed methodology and the results are presented in order to illustrate the function of the developed model. A small problem instance is generated, consisting of 10 candidate logistics facilities (I=1, ..., 10), 4 leasing time intervals (A=1, ...,4) and 20 demand nodes (J=1, ..., 20). Truck capacities are considered 50 cases, and hub capacities to be able to approximately handle the load of 3-4 trucks. The data used for the fixed hub leasing costs in the model are based on the average rent per sq. foot paid for warehouse and distribution in the U.S. in 2018 (5.5$/sq. ft) and the average size of a small warehouse, brought in to a leasing time rate (Statista, 2019). The trucking costs are 1.69$/m (American Trucking Associations, 2018), while truck idle time costs are 1.38$/hour (Center for Transportation Research, 2016). The leasing time slot was considered as 4 hours, while the maximum distance for node allocation was extracted as the average of all the distances between hubs and nodes. Average trucks speeds for each interval were chosen based on weekday traffic patterns in urban areas (e.g. 7-10 a.m. speeds are lower than 10 a.m.-1 p.m. due to peak hour). Results of the optimization process and the optimal solution that serves the network with the minimum objective function value are presented in **Table 2**. The table shows that 3 facilities are utilized in order to accommodate the network demand. Each node is allocated to one of those facilities, where the cargo volumes allocated to each facility do not exceed the capacity constraints. Regarding the optimal leasing times of hubs, a common pattern was observed in all the experiments conducted. The model tends to select the first indexes in order, those of earlier times in the day. This is a reasonable outcome, since in the first indexes the model has higher possibility of accommodating the deadline constraints. For example, if a deadline is at 15 hours (3 p.m.) and the indexes are a=1 (7 a.m.), a=2 (10 a.m.), a=3 (1 p.m.), if the facility use and transportation costs for these indexes are similar, the model will most likely select the first index. Last, it is worth mentioning that due to the linear and straightforward structure of the developed methodology, computational times required for the model to converge to optimal solution were less than 10 seconds.

Table 2: Solution Output from Optimization

Hubs Selected	Time Slots Selected	Customers Allocated	
2	1	3, 4, 6,	**Truck Transportation Cost**
		7, 16, 20	27.6 $/day
3	2	1, 8, 12, 14,	**Hub Usage Cost**
		15, 17, 19	55 $/day
6	1	2, 5, 9, 10,	**Handcart Transportation Cost**
		11, 13, 18	52.4 $/day
			Total Cost
			134$/day

4.3. Evaluation and Guidelines for Implementation

In order to test the effectiveness of the hub location model developed in the study, its performance is compared to a model that would normally be used to deliver goods in a situation where the network structure and hub establishment proposed did not exist. The model most applicable for this comparison is the Vehicle Routing Problem with Time Windows (VRPTW). This mathematical model minimizes the cost of shipment in terms of vehicles needed and distance traveled, and also ensures that deliveries are made within a certain time window (analogous to the customer time deadline parameter). Contrary to the hub location model, in which vehicles are only required to travel to the chosen hub to deliver the packages, in the VRPTW model vehicles must travel from the origin distribution center directly to each customer's location within the city limits (i.e. no buildings are chosen for leasing). We are interested in observing the performance of each model both from the freight company's perspective (total cost) and society's perspective (reduction of VMT).

The mathematical formulation used for solving the VRPTW is the one proposed by Solomon (1987). Both models are tested in CPLEX using the scenario outlined in the previous section. Since many of the parameter inputs chosen for the experiments are based on averages (or assumptions), in order for the experiments outputs to be valid and to be able to extract conclusions, we conduct multiple tests and a sensitivity analysis where we allow some parameters to vary. For each set of runs, we consider the scenario in the previous section to be the baseline scenario and then increase (or decrease) one parameter value for comparison. We observe the performance of each model both in terms of total cost and distance traveled by the trucks. This function allows us to identify the scenarios where the proposed approach results in less costs than the VRPTW.

In the first scenario, we consider the uncertainty of customer demand by allowing it to vary from +/- 30% of its original value. Results of this test are presented in **Figure 9**. The results in terms of total cost show that in the baseline scenario (100%), the VRPTW model is cheaper to implement. As demand decreases, the gap in costs between the models grows. This seems reasonable, as it would be more cost effective to deliver the goods directly under low-demand scenarios, rather than lease buildings (which could be operating significantly below capacity). When the demand increases, the hub location model becomes cheaper than VRPTW. This result can be explained in terms of both hub and truck capacities. The hubs—which operate below capacity in low-demand scenarios—have the flexibility of taking on more demand at no additional cost. In terms of vehicle costs, increased customer demand means that more vehicles are needed for delivery. This impacts the costs less severely in the hub location model, since the vehicles only need to travel to the hub locations (compared to VRPTW where more trips to and from the main hub are needed). These results show that the hub location model is more cost effective than the VRPTW in high customer demand scenarios.

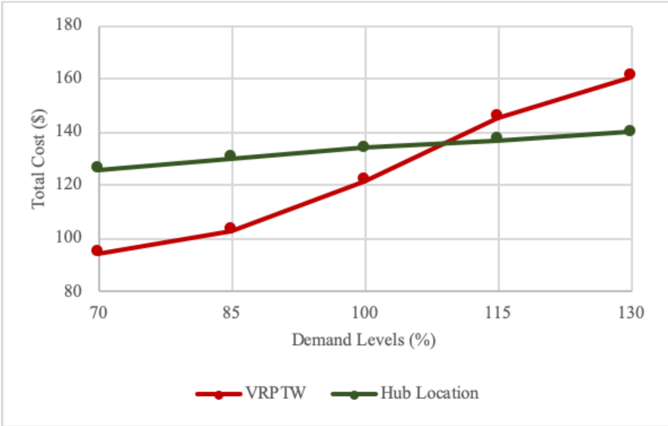

Figure 9: Sensitivity Analysis on Customer Demand

For the next set of runs, we vary the leasing time deadline for the chosen hubs to account for the uncertainty associated with the leasing times that are available. Outputs of this analysis are presented in **Figure 10**. Since no hubs are leased in the VRPTW model, the total cost for the baseline scenario is used for comparison. Here we see that for smaller time intervals, the cost is greater for the hub selection model. This makes sense, since the model would require more buildings to be leased under this scenario. With larger intervals, there is more flexibility in the hub location model to deliver within the time deadlines. It leads to the scenario where fewer buildings need to be leased, which reduces leasing costs and fixed transportation costs. This shows the value of the hub location model when longer leasing intervals are possible.

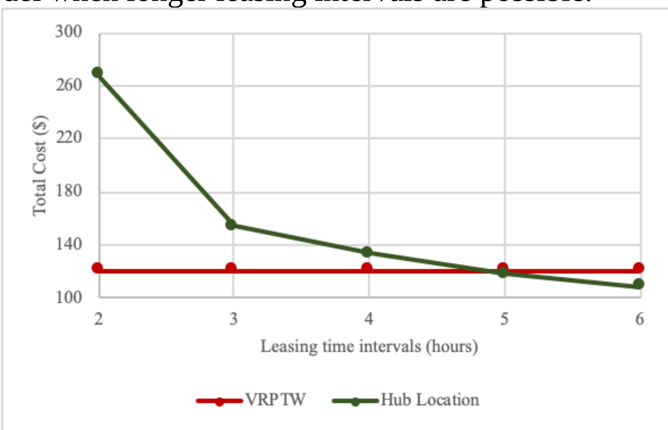

Figure 10: Sensitivity Analysis on Time Intervals

Finally, we allow the capacities of the chosen hubs to vary from +/- 30% of its original value to account for uncertainty in building size. **Figure 11** shows the results from this experiment. Again, since no buildings are leased in the VRPTW model, the baseline scenario is used for comparison. We observe that for smaller hub capacities, the cost for the hub allocation problem is much higher than VRPTW. In these scenarios, more buildings would need to be leased to handle all of the demand (which increases leasing costs). Leasing more buildings also increases the fixed transportation cost, since more main-hub-to-chosen-hub trips are needed. As the capacities increase, we see the total cost for both models being approximately the same. This is due to the reduction in leasing costs (less need to be chosen) and fixed transportation costs (less trips needed to deliver). In general, the hub location model performs about the same as the VRPTW when building capacities are high.

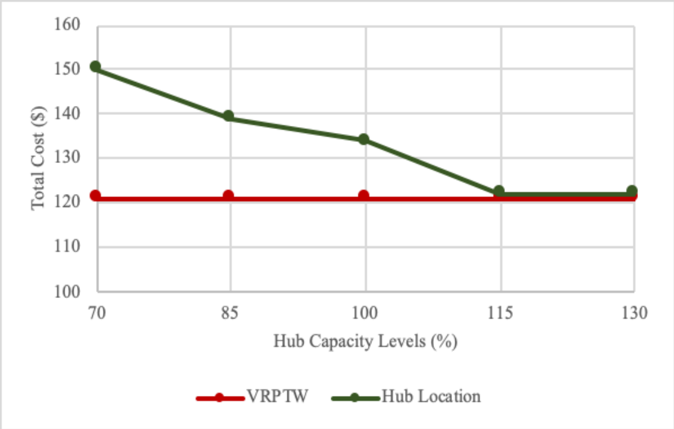

Figure 11: Sensitivity Analysis on Hub Capacities

The previous results show the scenarios where it would be cost effective to choose a hub location model over the VRPTW: high demand scenarios, and scenarios where long time-leasing intervals are available. Costs are more or less the same for scenarios where high hub capacities are available. It should be reiterated that the above results are only for situations where one parameter is changed. It is reasonable to assume that different, and more favorable to the proposed approach, cost outcomes could occur when more than one parameter is altered (e.g. high demand and high hub capacity). This analysis shows that although the proposed approach seems more costly at first sight, there are cases that can result in economic competitiveness of this supply chain method.
In the sensitivity analysis, we also observed the differences in distances traveled by trucks inside cities for each model. The results were fairly consistent for each parameter that was altered; therefore we present in **Figure 12** one general graph summarizing the results. Here, 3 represents the base scenario and the lower (higher) values represent lower (higher) parameter values. It is evident from the graph that across all different scenarios, there is a dramatic reduction in truck distances traveled when the hub location model is implemented (averaging around 60% improvement). This is a very positive result from a societal perspective, because it means less vehicle miles traveled within the city limits. While this result is expected (as vehicles are not required to go door to door in the hub location model), it is still important to observe. This result illustrates the high mobility benefits of the approach proposed and could be used to favor the hub location model when the total costs in both models are approximately the same (e.g. scenarios with high hub capacities). It is also worth mentioning that these results correspond to one company implementing the method. In the case were more companies choose to adopt it, the reduction in VMTs accumulates, and the societal benefits become much greater.

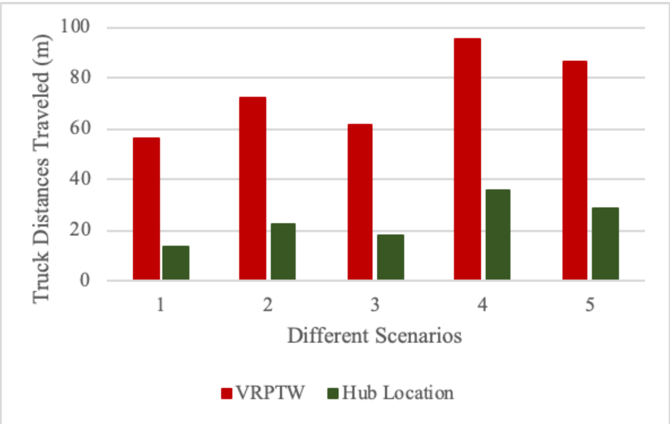

Figure 12: Distances Traveled Comparison

5. CONCLUSIONS

Urban logistics have become an integral component of today's cities and transportation systems. In order for them to provide sustainable and efficient services, innovative approaches are required as current practices have proven unsuccessful. This research provides an alternative method of delivering cargo to urban congested areas with the establishment of a network of low cost, small logistics facilities for handcart last-mile deliveries. It develops a novel mathematical programming model for the capacitated hub location-allocation problem with time deadlines and maximum allocation distance constraints, and solves it using CPLEX. In addition, it incorporates the aspect of leasing the hubs for different daily time intervals, a function not explored in previous studies which transforms the problem into a simultaneous location-allocation-scheduling one. Numerical experiments and a sensitivity analysis provide evidence of the function of the model and its ability to efficiently be used in real scenarios. The main advantage of the proposed methodology is its ability to capture the complexity in the process of selecting facilities and various issues encountered, such as high land use costs, limited facility capacities, delivery time requirements, restrictions related to handcart transportation, as well as traffic congestion issues. Moreover, the aspect of leasing the facilities can provide opportunities for collaborative supply chain systems, a function with high potential for both logistics companies as well as city authorities.

The flexibility of the model developed provides high potential for further extensions and even better solutions to the problem. The delivery cost component in the objective function can be easily modified to account for alternate delivery methods, including those by drone or robot. Additionally, since the problem of selecting facilities comprises of a long-term investment, the concept of uncertainty in some of the variables could be explored, for example, in the demand levels or land use costs. In addition, in order for the study to create a complete and more general network design, routing selection options could be investigated for truck and handcart operations, turning it into a simultaneous location-routing problem. This function would potentially help decrease network costs and make the proposed scheme an even more attractive option. Furthermore, collaborative schemes involving many companies making the same decision (where and when to locate distribution centers) is also a logical extension of this work.

Last, as the proposed approach provides a different supply chain method for city deliveries, evaluation of the method in real life situations is required. Preliminary evaluation results indicate that there are high prospects for successful implementation. The societal benefits incurred by applying the method and minimizing the truck trips inside cities are clear, including decreased fuel consumption, environmental impacts, traffic congestion, delivery delays and increased freight mobility. In addition, these benefits become of greater importance as more companies choose to apply the proposed approach for their last-mile deliveries, helping create sustainable urban logistics networks. Apart from the sustainability aspect, this study showed that there are scenarios where these benefits can be combined with economic competitiveness from a company perspective. Given the proper guidelines for problem aspects, such as the ones studied in the previous chapter, the model developed can be equally, or even less, costly than the current delivery methods applied for city deliveries. Therefore, further analysis is required to identify more variables that affect the total costs, and develop complete guidelines for successful implementation, that capture all the crucial problem aspects.

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