PROMOTING SUSTAINABLE AND INTELLIGENT FREIGHT TRANSPORTATION SYSTEMS IN THE BARCELONA METROPOLITAN AREA

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ABSTRACT

The growth of e-commerce and the on-demand economy in urban and metropolitan areas has been accelerated by the recent COVID-19 pandemic. As a consequence, logistics and transportation operators are subject to a noticeable pressure to develop efficient delivery systems. These systems are also influenced by the global trend towards more sustainable transportation and mobility, which implies changes in urban policies and technological innovations --$e.g.$, the substitution of traditional diesel petrol-drive vehicles by electric ones. This paper analyzes the current and predicted needs of logistics operators in the Barcelona metropolitan area. To do so, urban regulations are analyzed and key shareholders are interviewed. The analysis of these interviews promote a discussion on how the use of new `agile' optimization algorithms --which are based on the combination of biased-randomized heuristics, computer parallelization techniques, and IoT / 5G technologies-- can contribute to enhance urban distribution practices. Finally, we present a case study in which the effect of different configurations of working/resting times and parking areas availability on routing solutions is studied. Our research aims to provide comprehensive knowledge to managers and policy-makers, and to offer them with powerful tools capable of generating real-time solutions to complex last-mile delivery challenges under dynamic conditions.

1. INTRODUCTION

Currently, more than 50% of the world's population lives in urban areas and this figure will increase up to 68% by the year 2050 (United Nations, 2019). As the world population increases, the demand for goods and commodities will increase. The transportation and mobility sectors have become indispensable for meeting these demands.

However, these sectors emit alarming amounts of carbon dioxide (CO_2) into the Earth's atmosphere. The emitted CO_2 accounts for most transformed climate conditions in regions where climate patterns were once consistent. Respiratory and cardiovascular complications, as well as increased mortality rates have been associated with air contamination.

To alleviate this concern, an innovative paradigm for mobilizing people within urban areas, as well as for developing and sustaining healthier cities while decarbonizing and minimizing the emission of CO_2 is urgently needed. Although preventing the complete mobilization of people would be impractical, exploring environmentally sustainable alternatives such as employing zero-emission electric and unmanned vehicles, and adopting ride-sharing ordinances to reduce idle capacity could have promising results. Nevertheless, adopting technological advances for mobilizing people entails complex operations challenges that need to be properly addressed as well.

As with the mobility of people, the supply of goods is crucial to meeting the United Nations' sustainable development goals. More population implies greater flows, but it also occurs at a time of transformation of the urban business model and related supply chains.

With the emergence of e-commerce, an increasing number of consumers are switching to the online channel, and most are opting for home delivery. This means that the packaging sector is constantly booming, with more vehicles and more companies operating day after day in cities. Thus, the Urban Freight Distribution (UFD) has important implications in terms of both traffic and parking. On the one hand, it significantly contributes to congestion and the emission of polluting particles in urban environments. On the other hand, it strains the demand for parking, filling the reserved spaces and making it difficult to drive through irregular parking practices.

This work aims to investigate the problems emanating from the UFD, and in particular on the public policies imposed at the municipal level to regulate it. Each municipality has a certain infrastructure and dictates its conditions, leaving an extremely fragmented scenario that needs to be taken into account by operators.

The first contribution of this work is an analysis of the logistics conditions in the Barcelona (Spain) metropolitan area. This analysis is based on interviews to key shareholders from different sectors, which allows us to claim the need for agile optimization algorithms (Martins et al., 2021a).

These algorithms constitute an intelligent approach that relies on the combination of biased-randomized heuristics, computer parallelization techniques, and IoT/5G technologies in order to deal with the requirements of large-scale, dynamic, and complex last-mile distribution problems.

A second contribution of the paper is the inclusion of a numerical case study, which allows us to study in more detail the economic and environmental impact that a non-harmonized regulation might have on logistics and transportation operations.

The rest of the paper is structured as follows: Section 2 provides a brief review on related work. Section 3 summarizes a study in which several managers of transportation companies have been interviewed to identify their needs. Section 4 discusses how 'agile' optimization algorithms can contribute to fulfil some of the identified needs.

Section 5 describes a case study regarding the density of parking spots in the city of Barcelona. Section 6 performs a series of computational experiments over the previously described case study. Section 7 analyzes the obtained results and incorporates some managerial insights to be considered. Finally, Section 8 summarizes the main contributions of this study.

2. RELATED WORK

In recent years there has been a huge expansion in e-commerce, with high growth rates of up to two digits in most developed countries. Added to this gradual increase over time are the knock-on effects of the COVID-19 pandemic. Aside from any short-term impacts of the self-isolation and lockdown periods imposed in many countries, the very structure of the market may be undergoing a deep transformation and accelerating the digitization process (Kim, 2020). Thus, for example, in the region of Catalonia (Spain) the online purchases have grown by 27.7% compared to before the pandemic, and 44.6% more than in 2018 (Generalitat de Catalunya, 2020). This increase in e-commerce, in turn, will magnify externalities associated with urban freight logistics and transportation, i.e.: pollution, noise, traffic congestion, as well as the management of parking space.

2.1 UFD Management

Urban freight logistics are made up of the flow of goods circulating throughout a city. In general, an urban transportation system can be defined as the set of transportation elements –both public and private– that involve the mobility of people and goods within the metropolitan area: infrastructure, management, means of transport, entities, service providers, and users (Gonzalez-Feliu et al., 2018). The goal of urban freight distribution is to supply specific items on time and in the right way, guaranteeing low costs and offering good customer service. The recent boom in e-commerce has led to a sizable increase in home delivery packages, with a huge surge in the number of orders shipped and, hence, in urban freight traffic.

In addition, UFD (and especially last-mile delivery) lay bare the conflicting interests of the different stakeholders involved (Rai et al., 2017; Gatta and Marcucci, 2016; Bjerkan et al., 2014). These stakeholders can be classified into three categories: private enterprises (haulage and shipping companies, small retailers, large retailers, and logistics operators), public administrations, and citizens. Public administrations need to take on a leading role in this matter. Local authorities are the ones who have competences for city mobility.

They must have a comprehensive understanding of the complexity of city logistics to identify and implement measures, as well as to create packages of policy tools that facilitate, limit, or manage the distribution of e-goods on different levels of regulation, hence promoting a stronger link between transport planning and land use (Bjørgen et al., 2019; Kiba-Janiak, 2019). Dialogue between all the stakeholders is crucial.
Public policies should be drafted on a consensual basis, especially when logistics operators are the ones that are directly affected by them. Trying to impose specific unilateral measures tends to have unexpected and, more importantly, undesired outcomes (Viu-Roig and Alvarez-Palau, 2020).

Therefore, the goal of the city council is to regulate the use of public space in order to minimize the conflicts that might result from freight transportation in a town, and make this more sustainable (Anderson et al., 2005). The local authorities combat these negative impacts of UFD with different actions, e.g.: by preventing carriers from parking illegally, thus reducing the traffic congestion factor (Cherrett et al., 2012); by enabling enough areas for loading and unloading, thus minimizing the impact on the delivery of goods (Roca-Riu et al., 2017); by imposing vehicle size restrictions in some areas; by creating goods consolidation points or establishing distribution time windows (Rushtonet al., 2014); or by invigorating pollution restriction policies using license plate recognition to avoid the circulation of some vehicles, especially in historic quarters of the city (Liu et al., 2018).

2.2 Loading and Unloading areas

One of the main problems that council cities have to face is the dimensioning of their loading and unloading(L/U) areas, as well as the size of urban land allocated for this purpose (Muñuzuri et al., 2017). Recent researches come to the conclusion that the absence of L/U areas or their poor management causes double parking (Figliozzi and Tipagornwong, 2017).

This mismanagement can sometimes be related to non-commercial use of the L/U zones, such as the use of these by individuals. Something that required greater control for the optimization of the L/U zones (Alhoet al., 2018). In their research, the authors studied the reduction of double parking of cargo vehicles by changing the spatial configuration of the L/U areas and the level of compliance with the parking rule of non-cargo vehicles. Its conclusions show the impact that this mismanagement has on delivery delays and on slow urban traffic. Therefore, the efficiency and effectiveness in the UFD is related, among other things, to the spaces available in the towns for L/U operations (McLeod and Cherrett, 2011; Jaller et al., 2013).

2.3 Time Windows

One of the options used by the council cities to optimize the L/U areas is the implementation of time windows, thus restricting the interval in which delivery vehicles can circulate in various parts of the city (Muñuzuri et al.,2005).

As the time window pressure increases, the number of store deliveries that can be combined in one round-trip decreases, i.e.: the retail chain (who stores and sells the goods) is forced to use extra trucks and cover longer distances to accomplish the store deliveries, which results in an increase of the retailer’s cost.

Furthermore, time windows change over time, and for a retailer it is difficult and costly to accommodate to all these changes. For this reason, many retailers consider time window policies as one of the major problems in urban freight logistics (Quak, 2008). The city council determines their time windows individually, they hardly cooperate and generally copy each others’ municipalities’ regulations regardless of their characteristics (Muñuzuri and Van Duin, 2014).

Another issue that arises in vehicle routing problems or VRPs (Vidal et al., 2019) is the appearance of electric vehicles that require areas to charge the batteries (Juan et al., 2016).

The literature shows some routing examples that would minimize this problem, such as Hiermann et al. (2016) or Keskin and C¸ atay (2016). The former propose a mixed routing/location problem in which some charging stations are available to allow recharging the vehicle’s batteries during its journey. The latter present a model in which partial recharging of the batteries is assumed to save route times. More recently, Reyes-Rubiano et al. (2019) propose a model for routing electric vehicles that considers limited driving ranges and stochastic travel times.

2.4 Urban Vehicle Access Restrictions

There are many city councils that have limited the entry and circulation of large trucks or polluting vehicles in their cities, since these vehicles have a greater impact on the environment. Several studies show how these policies reduce the environmental impact (Muñuzuri et al., 2005; Anderson et al., 2005).

However, these decisions do not take into account that many more smaller vehicles will be required to transport the same amount of goods or, in the case of license plate recognition, it will force logistics companies to always have to maintain the same fleet entrance into the city, something that will difficult the management of routes (Browne et al., 2008). This will most likely increase the number of vehicles required, as well as the total number of trips (Quak and De Koster, 2005).

Major cities, such as Barcelona, face multiple problems caused by delivery operations in UFD. The urban freight distribution problem in Barcelona has been studied in some works. Thus, for example, Roca-Riu et al. (2015) used mathematical programming optimization models for solving the parking slot assignment problem in the city, while Fernandez-Barcelo and Campos-Cacheda (2012) tried to quantify the social cost (emissions, congestion, and noise)of the urban freight distribution.

As a first goal of this work, we want to analyze the needs of private and public stakeholders in the metropolitan area of Barcelona. To achieve this goal, key actors of urban freight logistics were interviewed, as discussed in the next section.

3. THE VIEW OF THE LOGISTICS SECTOR

According to Taniguchi et al. (2010), decision support tools are needed to help public decision makers and practitioners to deal with city logistics externalities (mainly traffic congestion, greenhouse gas emissions, as well as air and soil pollution). These tools can take the form of decision support systems. These systems are mainly based on modeling, optimization, simulation, and evaluation procedures. In order to devise the optimization model that we present in this research, we first need to know the opinion of the main logistics agents, as well as of the public administrations, that operate in the metropolitan area of Barcelona. Through their opinion and experience, we could know the main concerns that should be taken into account when designing the illustrative case study that considers the different urban restrictions that logistics agents face in their daily activity.

Thus, we interviewed 16 entities that intervene in the UFD in the metropolitan area of Barcelona, bringing together both private companies and public administrations. In our interviews we contemplate different sectors, including: food distribution (Condis), construction (Laymet), transportation (Transcalit), hospitality sector (ADISCAT), and the public administrations (Generalitat, AMB, ATM, or Diputació de Barcelona). We did the interviews by video-conference to comply with the restrictions derived from the health crisis caused by COVID-19. At the end, we accumulated a total of 815 minutes of recordings, with an average duration of about 51 minutes per interview. The following notes summarize the main conclusions of the interviewing process:

- The current loading and unloading areas of the towns do not contemplate the complexity and the different casuistry of each sector. For example, the time required for a parcel delivery door-to-door ranges between 20and 25 minutes, while the time required for the hospitality sector delivery person ranges between 60 and 90minutes.
- e-Commerce growth has altered UFD operations, multiplying the number of destinations and reducing the average size of the parcels.
- The lack of parking availability and its restrictions are leading to increasing illegal parking practices.
- Time windows restrictions for entering the city and for loading and unloading of goods make it difficult for the routes to be efficient.
- The lack of a criteria consensus when considering ordinances among the different towns limits the efficiency of routing plans.
- The restriction of the tonnage of goods delivery vehicles force an increase in the number of trips to make the same route.
- The public administrations recognize the above problems, but they do not have the powers to act on them. They derive this responsibility to each city council. In this sense, if each city council legislates without considering the rest, the inequality of criteria is promoted, thus entering an infinite loop.

4. AGILE OPTIMIZATION ALGORITHMS

Agile optimization (AO) algorithms allow us to process large amounts of data while supporting real-time decision making (Martins et al., 2021b). These algorithms permit a coordinated and effective use of electric autonomous vehicles in modern cities, as well as the development of concepts and solutions which contribute to transform smart cities into sustainable ones (Juan et al., 2020). Using technologies as 5G, data is gathered in real-time via electronic devices mounted onto vehicles and structures, transmitted over the Internet, and analyzed through intelligent algorithms. These algorithms predict the evolution of traffic conditions and allow for making pre-analyzed decisions. The incorporation of low-emission vehicles in last-mile delivery activities raises additional challenges from a planning, operational, and environmental perspective (Juan et al., 2016). For instance, cities are required to provide charge stations for electric vehicles. Thus, investment decisions regarding station numbers, location, and capacity must be addressed. Similarly, the limited driving range and load capacity of most electric vehicles impose additional constraints when designing distribution and collection routes (Londoño et al., 2020). Significant reductions of CO_2 emissions could be reached if carriers embrace the benefits of carefully designed strategy and mobility concepts.

Traditional optimization algorithms are widely applied for coping with optimization problems that assume a fixed time horizon and non-dynamic inputs and constraints. These particular optimization methods might sometimes be insufficient when dealing with real-time transportation problems in modern cities. With the emergence of the Internet of

Things, large amounts of data are generated in smart cities. These cities have continuously evolving conditions, such as: traffic, vehicle location, accidents, and disruptions. The lack of real-time optimization methods raises challenges on the integration of smart mobility innovations, such as unmanned and electric vehicles.

To address these problems, the AO paradigm aligns biased-randomized heuristic algorithms (Estrada-Moreno et al., 2019), which are extremely responsive, parallelizable, flexible, parameterless, effective, and accessible online. As new streams of data are provided, the AO paradigm will embrace the dynamism of real world large-scale scenarios, while offering real-time solutions which re-optimize every few milliseconds. AO algorithms will support environmentally applicable decision making, thus leading the way towards zero-emission transportation activities.

This, in turn, will generate environmental, economic, and social progress via the emergence of new business models like car-sharing and ride-sharing (Martins et al., 2021a), while improving citizen’s quality of life (Beneicke et al., 2019). Moreover, the AO paradigm will support current European strategies for low-emission mobility.

5. AN ILLUSTRATIVE CASE STUDY

In order to illustrate the concepts introduced in the previous sections, we have designed a realistic case study based on the city of Barcelona. In this example, two different carriers have to visit a series of customers scattered across the city. Each carrier has its own set of customers and no horizontal cooperation practices (Serrano-Hernández et al., 2017) –or other strategies that can speed up the distribution tasks– are considered at this time.

Therefore, vehicles from different carriers might compete for the available parking spaces in the city. Regarding the availability of these unloading areas, three scenarios are considered: low availability, medium availability, and high availability. For our numerical experiments, we have assumed that this availability level is negatively correlated with the average service time, i.e.: the more parking spaces available in the city, the shorter the average times requested to complete the delivery, and vice versa.

In particular: a low availability scenario assumes that the average service time is 15 minutes, a medium availability scenario is associated with an average service time of 10 minutes, and a high availability scenario implies an average service time of 5 minutes. For each carrier, the associated distribution process is modeled as a VRP.

Vehicle routing problems are very popular in the transportation literature, since they allow to model many different distribution activities (Faulin et al., 2008; Juan et al., 2009). Typically, the goal is to minimize total distribution costs while satisfying all customers' demands and additional capacity constraints. In this case, loading capacity of vehicles is not a constraint –i.e., the transported goods are small in size and, if necessary, they can be piled up inside the vehicles, so loading capacity is not a hard constraint. However, there is a time-capacity constraint for each route, i.e.: no route should exceed a time threshold, t_{max}, given by the carrier. In our experiments, this time threshold is a design parameter that can take different values: $t_{max} \in \{6,7\}$. Figure 1 shows a map of Barcelona together with the depots associated with both carriers and their customers. In Figure 2, a potential solution (set of routes) is drawn.

The aforementioned setting of the VRP is based on the real-life case oriented to deal with the collection of sanitary items – produced using personal 3D printers – from individual houses in Barcelona during the first months of theCOVID-19 pandemics.

The computational experiment will allow us to investigate how different levels of loading/unloading areas in the city will affect the number of trucks needed to complete all visits and, as consequence, the total time that these vehicles are circulating around the city –which is a direct cause of CO2emissions and traffic congestion, apart from being the main factor in the cost function of the carriers.

Our solving approach is based on the algorithm proposed in Tordecilla et al. (2020). This algorithm has been implemented in Python 3.7, and a maximum computational time of 60 seconds has been set for executing each instance of the problem. The experiments were run on a Windows 10 operating system using a computer with the following characteristics: an Intel(R) Core (TM) i7-8750H CPU at 2.20GHz and 16 GB of RAM.

6. COMPUTATIONAL EXPERIMENTS

The results of the case study described in the previous section are shown in Table 1. The first four columns identify the company (1 or 2), the configuration of the time threshold in hours (6+2 or 7+1), as well as the parking areas availability and the service time in minutes: high (5), medium (10, or low 15). The next six columns describe the performance of the best solution found for each case: number of routes (where each route requires one vehicle and driver), time of the longest route, distance of the longest route, total time and total distance (considering all routes), and CO_2 emissions. These emissions have been estimated using the calculator of *myclimate* (https://www.myclimate.org/), which depends on the distance, the fuel type (petrol in our case), and fuel consumption or vehicle type (van). *myclimate* is a non-profit organization and one of the world's quality leaders in voluntary CO2compensation measures. It has a large number of partners, such as *energiapro* or *WWF Switzerland*. The last row of the table shows the average measures.

Based on this data, Figure 3 displays a parallel coordinates plot of the main performance indicators. The data has been added up for each scenario (that is, for each configuration of working/resting times and parking areas availability). It can be concluded that the level of parking area availability has a great effect on the number of routes (which range around 15).

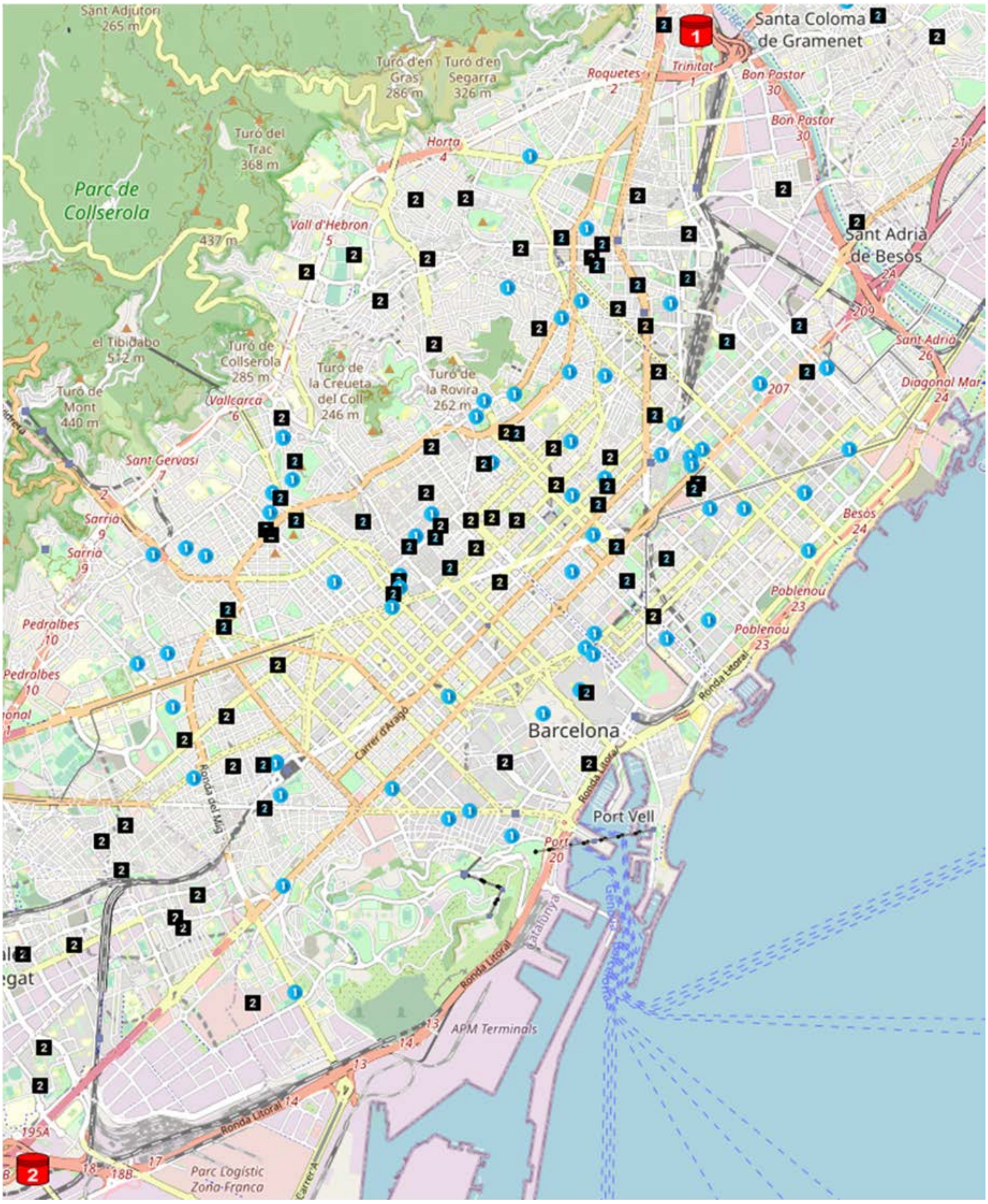

Fig. 1 – Illustrative example in the city of Barcelona. There are two depots corresponding to different carriers (represented by cylinders) and a set of customers for each carrier (represented by circles and squares).

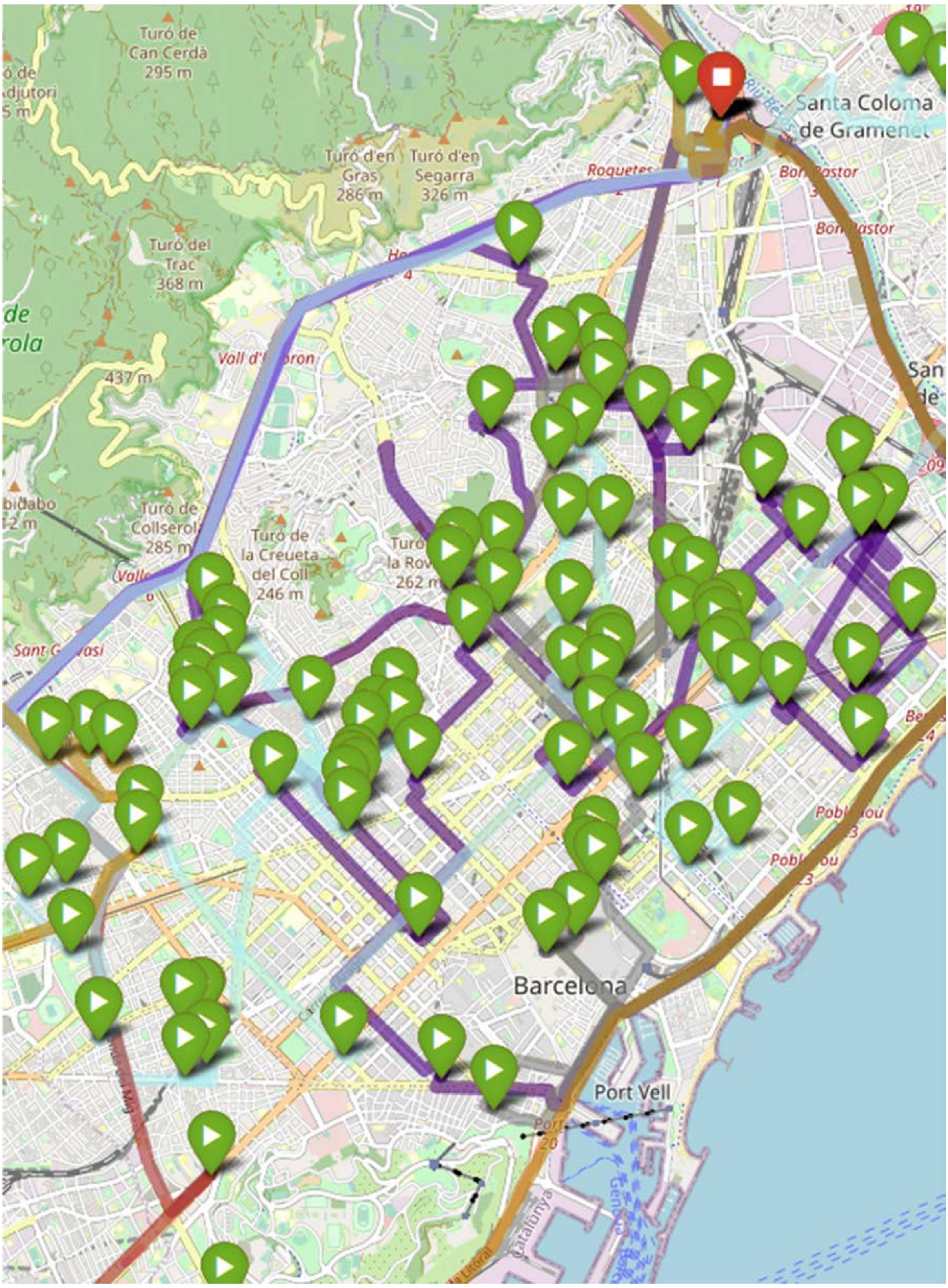

Fig. 2 – Design of routes for an illustrative case study.

Company	Timetable (h)	Parking Areas Availability	Service Time (min)	# Routes	Time Max Route (h:m)	Distance Max Route (km)	Total Time (h:m:s)	Total Distance (km)	CO_2 Emissions (t)
1	6 + 2	high	5	8	5:48	101.46	41:30:34	630.53	0.26
2	6 + 2	high	5	10	5:52	174.95	50:17:15	845.22	0.34
1	7 + 1	high	5	7	6:48	86.28	41:10:20	603.87	0.25
2	7 + 1	high	5	8	6:41	127.55	48:48:42	796.65	0.32
1	6 + 2	medium	10	13	5:45	140.74	66:19:17	843.81	0.34
2	6 + 2	medium	10	14	5:56	110.96	74:14:32	1019.38	0.42
1	7 + 1	medium	10	11	6:39	61.72	64:34:59	742.39	0.3
2	7 + 1	medium	10	12	7:00	110.47	72:19:30	913.74	0.37
1	6 + 2	low	15	17	5:54	59.44	90:24:51	1038.46	0.42
2	6 + 2	low	15	20	5:49	108.02	97:59:10	1174.85	0.48
1	7 + 1	low	15	15	6:51	50.04	87:48:21	873.43	0.36
2	7 + 1	low	15	16	6:49	102.56	95:44:40	1050.8	0.43
			Avg	12.58	6:19	102.85	69:16:00	877.76	0.36

Table 1 – Performance indicators of routes for different configurations of working/resting times and parking areas availability

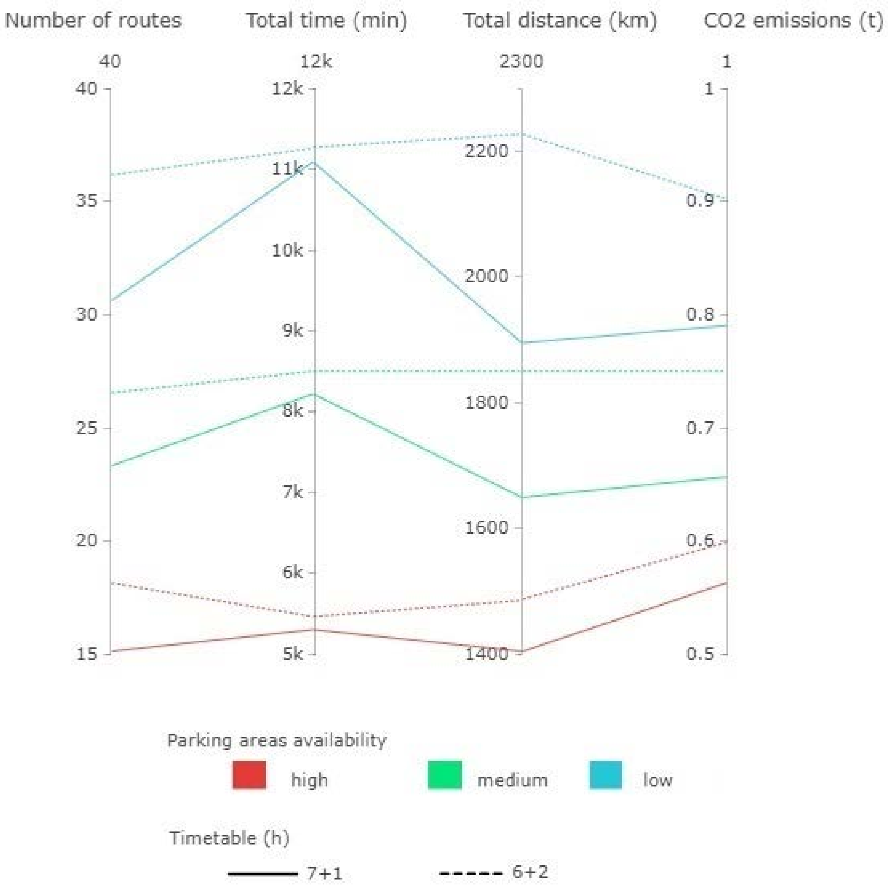

Fig. 3 – Parallel coordinates plot of the main performance indicators.

	Number of routes	Total time	Total distance	CO_2 emissions
Number of routes	1			
Total time	0.966	1		
Total distance	0.994	0.943	1	
CO_2 emissions	0.995	0.946	0.9996	1

Table 2 – Correlation matrix of performance indicators.

	Dependent variable		
	Time	Distance	CO_2 emissions
Intercept	11158.5 ***	2068.8 ***	0.845 ***
Availability - medium	-2834.3 ***	-309.1	-0.13
Availability - high	-5705.0 ***	-630.6 *	-0.26 *
$\bar{R}^2$	0.996	0.763	0.775

Table 3 – Linear regression models (codes for the significance tests: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1).**

37), the total time (from 5,399 minutes to 11,304), the total distance (from 1,400 to 2,213 kilometers), and the amount of CO_2 emissions (from 0.57 to 0.90). The effect of the maximum time per route is also relevant. From this figure, it is clear that there is a positive correlation between these performance indicators. The correlation matrix is displayed in

Table 2. A linear regression analysis is carried out to quantify the effect of the availability on the routing solutions. A summary of the results is displayed in Table 3. Three models have been estimated and, in all of them, the availability constitutes the independent variable (being 'low' the baseline). Each model has a different dependent variable: total time, total distance, and CO2emissions, respectively. The table includes the coefficient estimates, whether they are statistically significant, and the adjusted coefficient of determination. It can be concluded that the parking areas availability explains a high percentage of the variability of the dependent variable in the three models. Moreover, almost all the coefficients are statistically significant (for a standard significance level, i.e., α=0.05).

7. ANALYSIS OF RESULTS AND MANAGERIAL INSIGHTS

The analysis of this case study has revealed the important effect that the ordinances may have on the routing solutions and the performance indicators. Regarding parking areas, a medium or low availability level has a noticeable impact on the economic profitability of the companies (since they require the use of longer routes in terms of both time and distance), the environment (more pollution), and the social welfare (congestion, risk of accidents, etc.).

In addition, we have quantified the effect of varying the maximum time per route (that is, the maximum number of hours that a driver is allowed to drive). While reducing this maximum time may have a positive effect on the drivers' welfare, it also has a great impact on the sustainability of the routes. For that reason, a policy based on the reduction of the maximum time should be compensated with other measures. All in all, it has been shown that, when combined with optimization algorithms, visualization techniques and statistical analyses may be a powerful tool to assess/quantify the effects of changes in the ordinances.

8. CONCLUSIONS

Logistics and transportation operators are subject to an increasing pressure to design efficient delivery systems as a consequence of: *(i)* the growth of e-commerce (goods) and the on-demand economy (services) in urban, peri-urban, and metropolitan areas; and *(ii)* a global trend towards more sustainable transportation and mobility. In this context, we have analyzed the needs of logistics operators in the Barcelona metropolitan area by interviewing 16 key shareholders from different sectors. It is concluded that the next factors significantly affect the efficiency of deliveries: *(i)* current loading and unloading spaces; *(ii)* time windows restrictions for entering the city and for loading and unloading; *(iii)* restriction of the tonnage of goods delivery vehicles; and *(iv)* the lack of a unified criterion for the ordinances. Based on the insights, especially *(i)* and *(ii)*, we discuss the need for agile optimization algorithms. An illustrative case study is carried out, which allows us to quantitatively compare several scenarios with different configurations of working/resting times and parking areas availability. The results support, with numerical evidence, the capability of the proposed methodology to measure the impact of different logistics policies and strategies. Several lines of future research stem from this work. We have explored the problems emanating from the UFD, but an extension of this study could help to assess whether the needs and views differ between private companies and public administrations, or among different sectors (food distribution, construction, etc). It could also be possible to specify and prioritize policies that allow us to boost the efficiency of delivery systems. Regarding the illustrative case study, an enriched approach could consider not only economic and environmental dimensions, but also the social one with indicators such as traffic, accident risks, driving near schools, etc. Likewise, a richer approach could consider the incorporation of fleets of electric vehicles –which might generate additional constraints regarding driving ranges–, or autonomous vehicles, which might allow distribution during the night hours.

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REFERENCES

ALHO, A.R., SILVA, J.d.A., DE SOUSA, J.P., BLANCO, E. (2018). Improving mobility by optimizing the number, location and usage of loading/unloading bays for urban freight vehicles. Transportation Research Part D: Transport and Environment 61, pp. 3–18.

ANDERSON, S., ALLEN, J., BROWNE, M. (2005). Urban logistics—-how can it meet policy makers' sustainability objectives? Journal of transport geography 13, pp. 71–81.

ASPB (2020). Agència de Salut Pública de Barcelona. Aprenentatges en qualitat de l'aire. https://www.aspb.cat/documents/covid19-aprenentatges-qualitat-aire/

BENEICKE, J., JUAN, A.A., XHAFA, F., LOPEZ-LOPEZ, D., FREIXES, A. (2019). Empowering citizens' cognition and decision making in smart sustainable cities. IEEE Consumer Electronics Magazine 9, pp. 102–108.

BJERKAN, K.Y., SUND, A.B., NORDTOMME, M.E. (2014). Stakeholder responses to measures green and efficient urban freight. Research in Transportation Business & Management 11, pp. 32–42.

BJORGEN, A., BJERKAN, K.Y., HJELKREM, O.A. (2019). E-groceries: Sustainable last mile distribution in city planning. Research in Transportation Economics, pp. 100805.

BROWNE, M., ALLEN, J., NEMOTO, T., VISSER, J., WILD, D. (2008). City access restrictions and the implications for goods deliveries. Nova Science Publishers.

CHERRET, T., ALLEN, J., MCLEOD, F., MAYNARD, S., HICKFORD, A., BROWNE, M. (2012). Understanding urban freight activity–key issues for freight planning. Journal of Transport Geography 24, pp. 22–32.

ESTRADA-MORENO, A., SAVELSBERGH, M., JUAN, A.A., PANADERO, J. (2019). Biased-randomized iterated local search for a multiperiod vehicle routing problem with price discounts for delivery flexibility. International Transactions in Operational Research 26, pp. 1293–1314.

FAULIN, J., GILIBERT, M., JUAN, A.A., VILASOJANA, X., RUIZ, R. (2008). Sr-1: A simulation-based algorithm for the capacitated vehicle routing problem, in: 2008 Winter Simulation Conference, IEEE. pp. 2708–2716.

FERNANDEZ-BARCELO, I., CAMPOS-CACHEDA, J.M. (2012). Estimate of social and environmental costs for the urban distribution of goods. Practical case for the city of Barcelona. Procedia-Social and Behavioral Sciences 39, pp. 818–830.

FIGLIOZZI, M., TIPAGORNWONG, C. (2017). Impact of last mile parking availability on commercial vehicle costs and operations. Supply Chain Forum: An International Journal, pp. 60–68.

GATTA, V., MARCUCCI, E. (2016). Behavioural implications of non-linear effects on urban freight transport policies: The case of retailers and transport providers in Rome. Case Studies on Transport Policy 4, pp. 22–28.

GENERALITAT DE CATALUNYA (2020). Comerc¸ online i mobilitat. Evolució 2018-2020. Available at: http://ccam.gencat.cat/web/.content/05_arees_actuacio/comerc/estudis/Mobilitat-de-les-compres-online.-Anys-2018-2020.pdf

GONZALEZ-FELIU, J., PRONELLO, C., GRAU, J.M.S. (2018). Multi-stakeholder collaboration in urban transport: State-of-the-art and research opportunities. Transport 33, pp. 1079–1094.

HIERMANN, G., PUCHINGER, J., ROPKE, S., HARTL, R.F. (2016). The electric fleet size and mix vehicle routing problem with time windows and recharging stations. European Journal of Operational Research 252, pp. 995–1018.

JALLER, M., HOLGUÍN-VERAS, J., HODGE, S.D. (2013). Parking in the city: Challenges for freight traffic. Transportation research record 2379, pp. 46–56.

JUAN, A.A., FAULIN, J., RUIZ, R., BARRIOS, B., GILIBERT, M., VILASOJANA, X. (2009). Using oriented random search to provide a set of alternative solutions to the capacitated vehicle routing problem, in: Operations research and cyber-infrastructure. Springer, pp. 331–345.

JUAN, A.A., FREIXES, A., PANADERO, J., SERRAT, C., ESTRADA-MORENO, A. (2020). Routing drones in smart cities: A biased-randomized algorithm for solving the team orienteering problem in real time. Transportation Research Procedia 47, pp. 243–250.

JUAN, A.A., MENDEZ, C.A., FAULIN, J., De ARMAS, J., GRASMAN, S.E. (2016). Electric vehicles in logistics and transportation: A survey on emerging environmental, strategic, and operational challenges. Energies 9, 86.

KESKIN, M., C¸ATAY, B. (2016). Partial recharge strategies for the electric vehicle routing problem with time windows. Transportation Research Part C: Emerging Technologies 65, pp. 111–127.

KIBA-JANIAK, M. (2019). EU cities' potentials for formulation and implementation of sustainable urban freight transport strategic plans. Transportation Research Procedia 39, pp. 150–159.

KIM, R.Y. (2020). The impact of covid-19 on consumers: Preparing for digital sales. IEEE Engineering Management Review. doi:10.1109/emr.2020.2990115.

LIU, Z., LI, R., WANG, X.C., SHANG, P. (2018). Effects of vehicle restriction policies: Analysis using license plate recognition data in Langfang, China. Transportation Research Part A: Policy and Practice 118, 89–103.

LONDOÑO, J.C., TORDECILLA, R.D., MARTINS, L.d.C., JUAN, A.A. (2020). A biased-randomized iterated local search for the vehicle routing problem with optional backhauls. TOP, pp. 1–30.

MARTINS, L.d.C., DE LA TORRE, R., CORLU, C.G., JUAN, A.A., MASMOUDI, M.A. (2021a). Optimizing ride-sharing operations in smart sustainable cities: Challenges and the need for agile algorithms. Computers & Industrial Engineering 153, pp. 107080.

MARTINS, L.d.C., HIRSCH, P., JUAN, A.A. (2021b). Agile optimization of a two-echelon vehicle routing problem with pickup and delivery. International Transactions in Operational Research 28, pp. 201–221.

MCLEOD, F., CHERRETT, T. (2011). Loading bay booking and control for urban freight. International Journal of Logistics Research and Applications 14, pp. 385–397.

MUÑUZURI, J., CUBEROS, M., ABAURREA, F., ESCUDERO, A. (2017). Improving the design of urban loading zone systems. Journal of transport geography 59, pp. 1–13.

MUÑUZURI, J., LARRAÑETA, J., ONIEVA, L., CORTÉS, P. (2005). Solutions applicable by local administrations for urban logistics improvement. Cities 22, pp. 15–28.

MUÑUZURI, J., VAN DUIN, J. (2014). Time constraints: The cost of sustainability, in: Sustainable Urban Logistics: Concepts, Methods and Information Systems. Springer, pp. 165–185.

QUAK, H. (2008). Sustainability of urban freight transport: Retail distribution and local regulations in cities. EPS-2008-124-LIS.

QUAK, H., DE KOSTER, R. (2005). The effects of urban areas’ policies on distribution activities and the environment. Supply Chain Management: European Perspectives 285.

RAI, H.B., VAN LIER, T., MEERS, D., MACHARIS, C. (2017). Improving urban freight transport sustainability: Policy assessment framework and case study. Research in Transportation Economics 64, pp. 26–35.

REYES-RUBIANO, L., FERONE, D., JUAN, A.A., FAULIN, J. (2019). A simheuristic for routing electric vehicles with limited driving ranges and stochastic travel times. SORT 1, pp. 3–24.

ROCA-RIU, M., CAO, J., DAKIC, I., MENENDEZ, M. (2017). Designing dynamic delivery parking spots in urban areas to reduce traffic disruptions. Journal of Advanced Transportation. doi:10.1155/2017/6296720.

ROCA-RIU, M., FERNÁNDEZ, E., ESTRADA, M. (2015). Parking slot assignment for urban distribution: Models and formulations. Omega 57, pp. 157–175.

RUSHTON, A., CROUCHER, P., BAKER, P. (2014). The handbook of logistics and distribution management: Understanding the supply chain. Kogan Page Publishers.

SERRANO-HERNÁNDEZ, A., JUAN, A.A., FAULIN, J., PEREZ-BERNABEU, E. (2017). Horizontal collaboration in freight transport: concepts, benefits and environmental challenges. SORT 1, pp. 393–414.

TANIGUCHI, E., THOMPSON, R.G., YAMADA, T. (2010). Incorporating risks in city logistics. Procedia-social and behavioral sciences 2, pp. 5899–5910.

TORDECILLA, R., MARTINS, L., SAIZ, M., COPADO, P., PANADERO, J., JUAN, A. (2020). Agile computational intelligence for supporting hospital logistics during the COVID-19 crisis. Modeling and Optimization in Science and Technologies.

UNITED NATIONS (2019). World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420). Department of Economic and Social Affairs, Population Division. New York: United Nations.

VIDAL, T., LAPORTE, G., MATL, P. (2019). A concise guide to existing and emerging vehicle routing problem variants. European Journal of Operational Research.

VIU-ROIG, M., ALVAREZ-PALAU, E.J. (2020). The impact of e-commerce-related last-mile logistics on cities: A systematic literature review. Sustainability 12, pp. 6492.