Using Real-Time Spatial Delphi to locate Loading bays and Parcel Lockers

Yuri Calleo
Doctoral student, College of Engineering and Architecture, University College Dublin, Ireland

Nadia Giuffrida
Assistant Professor, Department of Civil, Environmental, Land, Construction and Chemistry, Polytechnic University of Bari, Italy

Francesco Pilla
Professor, College of Engineering and Architecture, University College Dublin, Ireland

ABSTRACT: Urban logistics has become part of the citizens' life, who often use e-commerce options to buy goods and groceries. The constant increase of this phenomenon which has been witnessed in recent years led to a consequent increase in the externalities associated with it, such as air pollution, traffic, land occupation and accidents generated by the vehicles carrying out the delivery of parcels in our cities. The decision on their correct location should respect high-quality technical standards but cannot disregard the objectives pursued by the different actors involved in the decision-making process related to logistics. Experts are called to identify common problems and answer different questions, where obtaining a univocal consensus may require much effort, due to their different ideas and visions. This paper proposes a participatory approach to identify suitable locations for automated parcel lockers and smart loading bays, involving the main actors in the decision-making process. The case study is the city of Dublin (Ireland), where an Urban Living Lab of the H2020 project SENATOR (Smart Network Operator Platform enabling Shared, Integrated and more Sustainable Urban Freight Logistics) is based. To overcome this challenge, we combine a multi-criteria analysis, involving a panel of experts partners of the project with a high expertise degree to identify suitable locations, and a revised Real-Time Spatial Delphi technique, useful to obtain a spatial convergence of opinion in a short time, enhancing the overall process.

1. INTRODUCTION

Urban logistics is an increasingly important aspect of the urban planning and mobility sectors (Lagorio et al. 2016). As cities become increasingly populated and congested, efficient urban logistics solutions are essential for maintaining sustainability and quality of life (Alho et al. 2014). Strategies for urban logistics must consider the unique challenges presented by dense and complex urban environments, such as limited space, competing demands for land use, and air quality concerns. In recent years, e-commerce has revolutionized the way we shop and conduct business, drastically reducing the physical distance between buyers and sellers (Laudon, 2013) and increasing its impact on the whole supply chain (Giuffrida et al. 2022). This comported significant impacts on urban logistics, as the need for efficient transport and delivery of goods has become increasingly important. E-commerce has also increased competition between retailers, as customers are able to compare prices and products quickly and easily. To successfully compete, retailers must optimize their operations, including adapting their supply chain networks, increasing the use of automation and robotics, and leveraging available data to optimize delivery and logistics. In this context, urban logistic facilities, e.g. parcel lockers and loading bays, are currently spreading in cities and constitute an important part of the supply chain. Parcel lockers provide a secure, convenient way for customers to pick up packages, reducing the problem of missed deliveries. Instead, loading bays are designated areas where goods are loaded onto and off delivery trucks. They help ensure efficient loading and unloading of goods and provide a safe and secure area for staff to work in. By using parcel lockers and loading bays, companies can reduce the risk of lost or stolen parcels and reduce the time it takes to get items from point *A* to point *B* (Vakulenko et al. 2018; Letnik et al. 2018). Nevertheless, this entails that, one of the main practical challenges is the identification of suitable locations which must respect high-level standards in order to avoid possible external effects of parcel delivery, including air pollution, traffic, land usage and automobile accidents; moreover, the choice of the location must be shared among the different actors of the process, including operators, planners, city administration and citizens.

To overcome this challenge, we propose a participatory approach in order to identify the best locations for automated parcel lockers and smart loading bays. To meet the research objectives, we adopt a modified Delphi approach, using multi-criteria analysis and Real-Time Spatial Delphi, engaging a panel of experts with the aim to develop strategies that effectively address future outcomes. We adopted our approach for the case of Dublin, Ireland, where an Urban Living Lab of the H2020 project SENATOR (Smart Network Operator Platform enabling Shared, Integrated and more Sustainable Urban Freight Logistics) is taking place. Overall, the main research objectives of this paper are listed below:

- Develop a method to identify suitable locations for parcel lockers and loading bays and apply it in the city of Dublin
- Perform a novel approach through the adoption of Real-Time Spatial Delphi as a tool for spatial convergence of opinions
- Assess the priority of the solutions identified by the experts for each decision

This paper is structured in the following sections: sec. 1 introduces the work. Sec. 2, illustrates the methodology used. Sec, 3, highlights the results and sec. 4, remarks on the conclusions.

2. METHODOLOGY

The following study proposes identifying suitable locations for parcel lockers and loading bays in Dublin city through multi-criteria analysis and Real-Time Spatial Delphi.

Real-time Spatial Delphi (Di Zio et al. 2017), is a modified version of the Delphi method, particularly suitable for complex spatial scenarios (Di Zio and Pacinelli, 2011). It is a method for gathering and aggregating expert judgments in real-time, considering the spatial components. It involves engaging a panel of experts, who are then asked to provide their opinions on a specific topic related to spatial data via a "roundless" process by placing multiple points on an interactive map. The responses are then aggregated in real-time, and used to create a spatial consensus, showing a geo-consensus radius on a map. In this case, RTSD is extremely useful because the outputs can be easily read and ready for decision-making or consultation. The method used for this preliminary case study involves 3 main steps, typical of the Delphi technique (Linstone and Turoff, 1975). 1) Desk research: in the first stage, the research team and the panel must have a clear framework of the research context and for this reason, we conducted a literature review, in order to understand more about the territorial framework, possible issues, and spatial data available, to provide the experts with a strong context of the study before starting the survey (Calleo and Di Zio, 2021). Subsequently, all the information acquired, including documents, maps and spatial data, is carefully evaluated before being uploaded to the platform. 2) Survey: the main innovation of this study is the use of the "Real-Time Geo-Spatial Consensus System" (RT-GSCS: www.rtgscs.com) a novel web-based open platform useful for complex scenarios to obtain a spatial convergence of opinion in less time and efficiently, without the need of further analysis. 3) Statistical analysis: the third step involves the use of Geographic Information System (GIS) processing analysis, in our case useful to depict the final radius of geo-consensus and a hotspot analysis in order to assess the priority of the solutions based on the experts' judgments.

2.1. Desk research

In the Delphi technique, one of the most important phases at the initial stages is desk research (Rowe and Wright, 1999), where efforts are made to scan the relevant literature and understand the territorial framework in order to provide the experts with relevant information to the context of the study. In this case, the literature review allowed us to select the most significant criteria to be used for the location of the two different facilities (loading bays and parcel lockers). These criteria have been extracted from a previous study with a panel of experts (Giuffrida et al. forthcoming) and are composed of:

- Topology and geometry of the location
- Demand and Accessibility
- Traffic and Operation

Once we obtain relevant information about possible criteria, experts have been called to assign importance weights to the criteria, permitting us to have a spatial ranking of locations according to the experts' judgments.

In this case, all the information has been uploaded on the platform, this is because the experts can consult all the documents before starting the survey and based on their expertise degree formulate decisions.

From what emerged we ask 2 main questions to the panel:

- RQ1: Please indicate proper locations for loading bays in Dublin
- RQ2: Please indicate proper locations for parcel lockers in Dublin

2.2. Panel of experts

In our study, we involved a panel of experts, to indicate possible locations for our facilities. In the scientific literature, there is no consensus on the optimal sample size for a Delphi survey (Hsu and Sandford, 2007). Nevertheless, we can state that in a condition of homogeneity, in RTSD, a panel of more than 3 experts can be considered valid for RTSD (Delbecq et al. 1975; Di Zio et al. 2017). To pursue the research objectives, we selected a panel of experts $N = 4$, adopting a snowball sampling, where participants were able to recommend one or more experts. The panel is composed of knowledgeable people with high competencies in the transport field, including academic experts and local stakeholders. In particular, 2 of the experts were researchers with strong expertise in the transport field, 1 with expertise in participatory planning and spatial planning, and 1 from the city administration. At this point, we allow the experts to register on the platform and start the survey.

2.3. Real-Time Spatial Delphi survey

Once the experts have been successfully registered to the platform, they can answer different questions by placing multiple points on the interactive map. Before uploading the point, we want to investigate the priority of the choice, we use a pop-up window, asking to choose on a scale from 1-5, where 1 is the minimum and 5 is the maximum. This is extremely useful to understand with post-processing analysis (such as hotspot analysis), the overall spatial distribution of the priority of the judgments compared to the final circle of convergence.

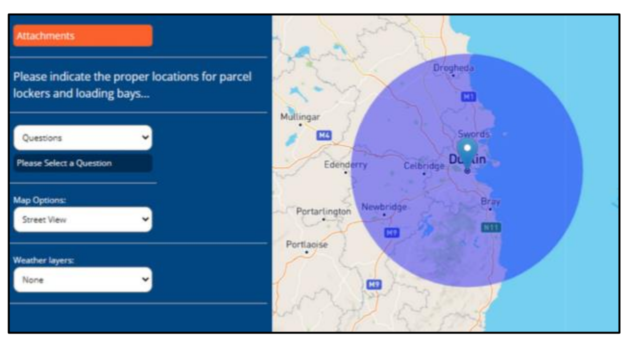

Figure 1: RT-GSCS Interface (v1.0)

From the first point (set a priori as 50 km^2) placed, a generated circle appears on the map, which is then modified in real-time based on the judgments of participants and a statistical algorithm proper of the Spatial Delphi.

The concept of the circle of convergence is developed using the reasoning outlined by Di Zio and Pacinelli in 2011. The spatial convergence is pursued by utilizing a geometric element represented by a circle C, which is the smallest among all possible circles and includes 50% of the opinions provided by panellists. This is equivalent to the interquartile range in the classical Delphi method. In this case, if we assume that $N = n_1, n_2, n_3, \dots, n_j$ is the number of experts judgments, we look for a minimum area A_i with a relative circle C equal or greater than half of the opinions $A_i >= (\frac{NN}{2})$. This is because if we take into account the distribution composed of N points, some of the points could be placed in some locations not suitable for the research objectives. In sum, we obtain for each question composed of $N = n_1, n_2, n_3, \dots, n_j$ judgments, a vector $A = A_1, A_2, A_3, \dots, A_N$ with a minimum area A_i, with N corresponding points. In this case, for each ordered vector A, the median is equal to the geo-consensus radius R_i containing the 50% of the N judgments with a centre N_j. The survey is designed to maintain anonymity among participants, allowing them to express their opinions freely without fear of being identified by others. Experts are able to contribute to the discussion at any point, helping to enhance the overall quality of the study. Upon completion, the survey yields two types of results: geographical and non-geographical. The geographical result is represented by a circle that encompasses half of the gathered opinions, which is readily understandable and can aid in decision-making. The remaining data, including numerical and textual information, as well as expert comments, are included as part of the non-geographical results.

In our study, spatial consensus is measured using three indicators proposed by Di Zio et al. (2017) called M_1, M_2, and M_3. The final area identified by the experts, is the indicator M_1, however, this is an absolute measure and does not consider the extension of the study area. To address this issue, we consider M_2, as second indicator, taking into account the ratio between the final area (FC) and the surface (S) of Dublin ($S = 117.8\ km^2$):

$$M_2 = 1 - \frac{FC}{S} \qquad (1)$$

In this case, we have as a result the degree of the geo-consensus, where the more measure is close to 1, the more circle is small compared to the surface area. Finally, with regards to the process of spatial convergence of opinions, we also consider the last indicator:

$$M_3 = \frac{FC}{IC} \cdot 100 \qquad (2)$$

where IC is the initial circle area. In our case, since it is not possible to calculate the radius from the first point, we set a priori $IC = 50\ km^2$. This indicator demonstrates the level of agreement among participants, and the higher the value (close to 100%), the lower the convergence of opinions among the panellists. The more the percentage is close to zero, the higher the spatial consensus is.

Before ending the session, the validation of the responses is evaluated in addition to the consensus criterion. A final email is sent to validate the scenarios and participants are asked to access the platform one last time to either select a new area within the circle or confirm the existing one (von der Gracht, 2012).

3. RESULTS

The results fully answered the research objectives, we obtain specific locations, with a substantial convergence of opinions. For RQ1: “Please indicate proper locations for loading bays in Dublin”, we obtained 42 judgments considered for suitable locations of loading bays and 11 comments. The area identified by the experts is in the city centre of Dublin, between the two banks of River Riffey. The main motivations depicted by the experts in the comments are safety improvement by separating commercial traffic from pedestrian and bicycle flows. Additionally, they mentioned that loading bays can help to reduce pollution and noise by keeping delivery trucks and other large vehicles out of residential areas. Finally, they stated that loading bays can also help to improve the efficiency of delivery operations by providing a convenient and accessible location for businesses to receive goods.

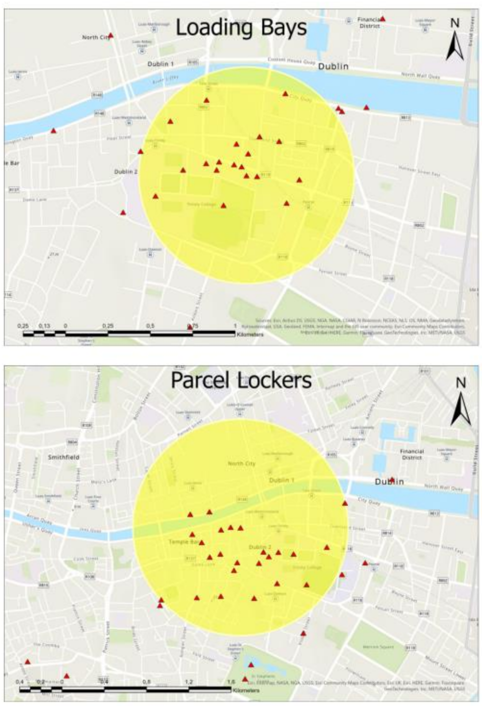

Figure 2: Geographical results.

With regards to the RQ2: "Please indicate proper locations for parcel lockers in Dublin", we obtain 49 geographic suitable locations with more than 13 comments. Interesting are the reasons expressed by the experts, such as the possibility to locate parcel lockers close to high schools or universities (e.g., Trinity College Dublin or University College Dublin). The area identified by the experts is as well in the city centre of Dublin (Fig. 2). The essential reason expressed by the experts is that they offer a convenient and secure way for residents and tourists to receive packages and deliveries. They can be placed in high-traffic areas such as train stations, shopping centres, and apartment buildings, making it easy for people to pick up their packages at their convenience. Finally, according to the experts, these locations for parcel lockers can also help to reduce the congestion and pollution caused by delivery trucks in the city centre.

3.1. Consensus and priority

Once the spatial data obtained have been illustrated, we proceed to Tab 1. with a clear definition of the non-geographical results. What emerged is a good level of convergence of opinions, the table is composed of different variables, including the IC, and the three indicators M_1, M_2, and M_3. In all the final decisions, we obtained a small area compared to the initial circle, with a reduction equal to 0.99 for both the research questions (see M_2 in Tab. 1). For RQ1, loading bays, we obtained a strong reduction of the initial circle ($IC = 3.98$), with a final circle of $M_1 = 0.61$, instead for RQ2, the initial circle was lower $IC = 3.98$, with a final circle of $M_1 = 0.38$. As said before M_2 is a valid indicator for the quantification of the efficacy of the solution compared to the area under investigation (in our case the Dublin surface area in km^2). Nevertheless, in the traditional version of the Delphi method, it is not possible to find a univocal rule to measure consensus, but one of the most important is the interquartile range (IQR). In the scientific literature, is considered reached the consensus when the IQR is less than 20% of the measurement scale used (von der Gracht, 2012).

Table 1: Non-geographical results.

	IC	M_1	M_2	M_3
RQ1	3.98	0.61	0.99	15%
RQ2	2.83	0.38	0.99	13%

In our case, we can consider valid the results obtained, since in both questions $M_3 \leq 20\%$. In particular for RQ1, the consensus result is $M_3 = 15\%$ and for RQ2 the consensus is $M_3 = 13\%$.

In conclusion, we take into account what is expressed by the experts for each judgment regarding the priority of the choice by performing a hotspot analysis. In this case, the hotspot analysis is extremely useful to understand if different clusters emerged, in fact, as it is depicted in Fig. 3, the high-priority strategies to be implemented are located in the geo-consensus radius. This is not to be underestimated, since different clusters of maximum priority are located outside of the radius.

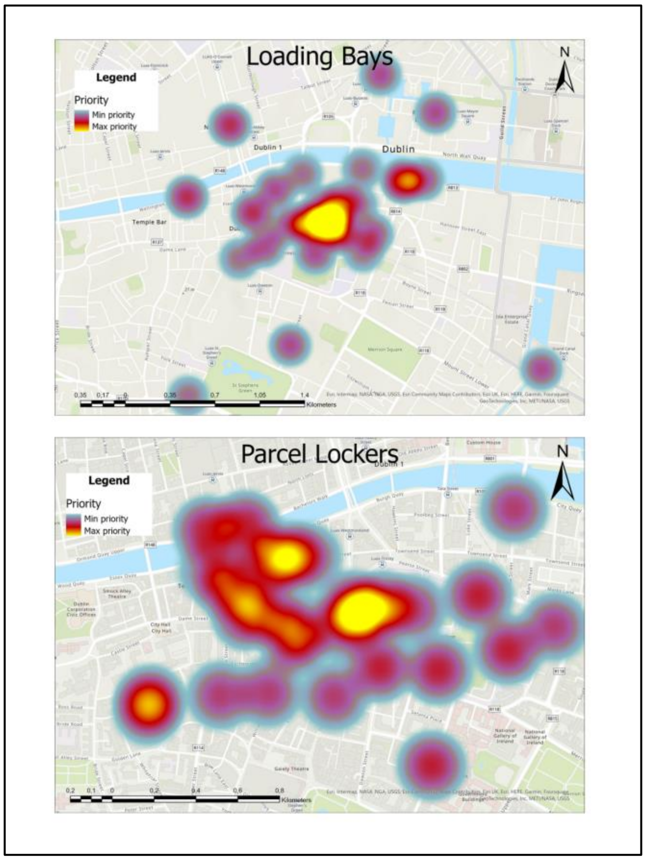

Figure 3: Hotspot Analysis of the priorities

For loading bays, in the distribution of the total judgments, the average in the scale of priority is equal to 3.76 while for parcel lockers, priority is high ($\mu = 4.28$).

4. CONCLUSIONS

This study presented a spatial participatory method to select suitable locations for loading bays and parcel lockers in urban areas, taking advantage of the Spatial Delphi technique. A test application has been performed for the case study of Dublin, involving 4 international experts in the fields of transport, city administration and urban planning. Results demonstrate that expert opinion converges towards locating both types of facilities in the central-southern area of the city, with some spots in the central-north for the case of loading bays, where a commercial street and two commercial malls are located. According to the experts, both facilities should therefore be positioned with priority in the beating heart of the city, where the main commercial activities and tourist attractions are located. The method proves to be robust for quickly reaching consensus among actors with different backgrounds, even without ever needing to bring them together. The success of this test experience paves the way for a real-life application within the SENATOR's project, inferring the opinions of the stakeholders involved in the urban living lab of Dublin.

5. REFERENCES

Alho, A., e Silva, J. D. A., & de Sousa, J. P. (2014). A state-of-the-art modeling framework to improve congestion by changing the configuration/enforcement of urban logistics loading/unloading bays. *Procedia-Social and Behavioral Sciences*, 111, 360-369.

Calleo, Y., & Di Zio, S. (2021, December). Unsupervised spatial data mining for the development of future scenarios: a Covid-19 application. In ASA 2021 Statistics and Information Systems for Policy Evaluation: BOOK OF SHORT PAPERS of the on-site conference (Vol. 132). Firenze University Press.

Delbecq, A. L., Van de Ven, A. H., & Gustafson, D. H. (1975). Group techniques for program planning: A guide to nominal group and Delphi processes. Scott, Foresman.

Di Zio, S., & Pacinelli, A. (2011). Opinion convergence in location: A spatial version of the

Delphi method. *Technological Forecasting and Social Change*, 78(9), 1565-1578.

Di Zio, S., Rosas, J. D. C., & Lamelza, L. (2017). Real Time Spatial Delphi: Fast convergence of experts' opinions on the territory. *Technological Forecasting and Social Change*, 115, 143-154.

Giuffrida, N., Fajardo-Calderin, J., Masegosa, A. D., Werner, F., Steudter, M., & Pilla, F. (2022). Optimization and machine learning applied to last-mile logistics: A review. *Sustainability*, 14(9), 5329.

Hsu, C. C., & Sandford, B. A. (2007). The Delphi technique: making sense of consensus. Practical assessment, research, and evaluation, 12(1), 10.

Linstone, H. A., & Turoff, M. (Eds.). (1975). The delphi method. 3-12. Reading, MA: Addison-Wesley.

Lagorio, A., Pinto, R., & Golini, R. (2016). Research in urban logistics: a systematic literature review. *International Journal of Physical Distribution & Logistics Management*.

Laudon, K. C., & Traver, C. G. (2013). 1-912. E-commerce. Boston, MA: Pearson.

Letnik, T., Farina, A., Mencinger, M., Lupi, M., & Božičnik, S. (2018). Dynamic management of loading bays for energy efficient urban freight deliveries. *Energy*, 159, pp. 916-928.

Rowe, G., & Wright, G. (1999). The Delphi technique as a forecasting tool: issues and analysis. *International journal of forecasting*, 15(4), 353-375.

Vakulenko, Y., Hellström, D., & Hjort, K. (2018). What's in the parcel locker? Exploring customer value in e-commerce last mile delivery. *Journal of Business Research*, 88, 421-427.