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Modelling the problem of parcel distribution in urban environments and analysis of the determining factors

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Abstract

This research has the objective to develop a model for the location selection of Automated Parcel Delivery Terminals to optimize the overall service, increasing satisfaction and consumption of users and reducing costs. A combination of the Analytic Hierarchy Process (AHP) methodology with a geographic information system (GIS) has been applied to identify the influencing factors and perform the analysis of the alternatives. A case study focused on the city of Zaragoza, and specifically to a Spanish postal parcel delivery company, has been carried out to assess the model behavior. For this, a representative sampling of the postal districts and sections of Zaragoza has been performed, identifying the characteristics of the study areas. Next, sections and all possible locations have been identified and selected for study. Finally, the AHP methodology has been applied for the prioritization of alternatives. Results have shown that the operative criterion, accessibility (both pedestrian and with vehicle), time availability and safety are the most important elements to focus on, for solving the location selection problem. In addition, the use of GIS allows analyzing diverse urban areas in an agile and effective way.

Keywords: Automated Parcel Delivery Terminals; AHP; GIS

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1. Introduction

The introduction of the new communication and localization technologies in citizens' daily life, as well as the analysis capacity of the traceability control systems of the parcel distribution companies, have led to a revolution when addressing the last mile distribution problem.

The need to satisfy the increase in demand, and the desire to improve the current distribution system has made several companies in the sector e.g. Correos, DHL and Amazon, incorporate into their traditional distribution system the installation of Automated Parcel Delivery Terminals, where the client can collect or deposit parcels. The location of these terminals has a direct impact on mobility. In addition, the global automated parcel delivery terminals market is expected to reach USD 1.06 billion by 2025 (GVR, 2017). Furthermore, location decisions are a fundamental part of a company's strategic process. A suitable choice can influence the company's goals come true, while a bad decision can lead to adverse results.

The importance of the location decision is mainly due to: (i) the need to make an economic investment for the start-up and operation of the distribution system. Once the terminals are installed, the investment made is not recoverable without economic losses, in addition to the time and effort employed. Therefore, it is a rigid decision that commits the company during a period of time (Carro-Paz and González-Gómez, 2012); (ii) these decisions affect the competitive capacity of the company at different areas (e.g. Operations, commercial, human resources, financial). However, the competitive capacity of a parcel company not only depends on the influence of costs but also on other factors, e.g. proximity to customers, time and flexibility of delivery schedule, capillarity available in the national territory, the quality of the service offered by its employees, and the image and values.

This research presents a model for the selection of the influential factors in determining the best location for the installation of terminals destined for the collection and shipment of parcels. A combination of the Analytic Hierarchy Process (AHP) methodology with a geographic information system (GIS) has been developed. The model is applied thorough a case study focused on the city of Zaragoza.

The paper is structured in four sections. Next, Section 2 presents the proposed methodology; Section 3 focuses on the case study, and Section 4 presents the conclusions derived.

2. Background

The development of e-commerce has transformed the last mile delivery, increasing freight volumes, traffic and pollution (Schoeder et al., 2016). Several initiatives have been developed to ameliorate this problem. Thus, automated service delivery systems, e.g. Automated Parcel Delivery Terminals, have been introduced in recent years by many distribution companies as a strategy to expand their service offerings while lowering labor costs. Delivery service is one of the factors that influence the consumer decision to make a purchase (Morganti et al., 2014), and home delivery constitute a problem in terms of service costs and organization.

The use of consolidated deliveries to Automated Parcel Delivery Terminals benefits both transport operators and users. Transport operators are benefited by (Morganti et al., 2014): increasing the number of successful first-time deliveries, optimizing delivery rounds, and lowering operational costs. This supposes a positive impact in environment through the reduction of road congestion, demand for curb-side parking, emissions of greenhouse gases while improving urban livability (Chen et al., 2017). In turn, users are benefited by (Castro et al., 2010): faster service, more convenience, accessibility and ease of use. This characteristics along with 7×24 operation time, seamless and formalized assorting work, size options, authorized product check and consignee identification encourage its use to receive/collect parcels (White, 2015).

3. Method

3.1. The Analytic Hierarchy Process (AHP)

The AHP is a multicriteria approach commonly used in decision-making processes. It allows the resolution of highly complex problems characterized by the existence of multiple scenarios, actors and criteria. AHP seeks to make the difference between subjectivity and objectivity, when facing complex decisions. The general steps of the method are (Saaty, 1996):

- Modeling: construction of a hierarchy that best defines the problem, identification of the goal, the relevant criteria, the sub-criteria present in each criterion, the actors and alternatives. It must be complete, representative, non-redundant and minimalist.
- Valuation: Based on the judgments made by the decision maker, paired comparisons between the elements of the hierarchy are established by using the fundamental scale of Saaty (Saaty, 1980). In making the comparison, the element that shows the characteristic under study, is taken as a reference. In addition, a numerical value is given about the times the greater includes, contains, dominates or is more preferred than the least with regard to the studied attribute.
- Prioritization and synthesis: local and global priorities of the hierarchy elements are determined. Next, the principle of hierarchical composition is used to group the priorities with the aim to offer an overall assessment of the available alternatives.
- Sensitivity analysis: the system stability is analyzed regarding different changes in the criteria priorities.

According to Barba-Romero and Pomerol (1997) two main contributions are related to the AHP approach: (i) it detects and accepts the inconsistency of decision makers (within certain limits), and (ii) it allows employing a hierarchy of criteria, as a difference of other methods that require global comparisons of the alternatives. Nevertheless, some criticism has arisen around this methodology, mainly due to the laboriousness derived from the need to compare all possible pairs of elements (Takeda et al, 1987).

3.2. Model Construction

The construction of the hierarchy was carried out by a group of seven experts in different fields (transport and logistics, e-commerce, economy, multicriteria decision-making). Decisions were made in a consensus basis (Altuzarra et al., 2007; Altuzarra et al., 2010). Experts selected the elements of the model in a hierarchy of four levels (see Fig. 1): goal, criteria (C), sub-criteria (SC) and attributes (Q). Goal is referred as “to determine the best location of an Automated Parcel Delivery Terminal”.

3.2.1. Definition of the elements of the model

The model is composed by four criteria:

- C1. Economic. Integrates those characteristics that will negatively influence (costs) the cash flow when implementing the terminal system.
- C2. Operative. Combines those characteristics that the locations must meet to facilitate the user's use of the terminals.
- C3. Social. Intends to encompass some of the characteristics that terminals possess, giving value due to the influence on population and society.
- C4. Environmental. Gathers the characteristics that will positively or negatively influence the environment due to the implementation of the new parcel distribution system.

The third level of the hierarchy refers to the sub-criteria. Eight SC have been identified:

- SC1. Infrastructure. Includes the costs and investments to be made before the operation of the terminals.
- SC2. Operation. Includes the costs derived from the operation of the terminals.
- SC3. Accessibility. Groups the characteristics that the locations must meet so that users can use the terminals in the best conditions of safety and comfort (operational standpoint).

- SC4.Technical conditions. Groups the characteristics that the locations must meet for the installation of the terminals to be possible (operational standpoint).
- SC5. Closeness. Combines the characteristics related to the importance of bringing the new distribution system closer to the user compared to traditional systems.
- SC6. Time availability. Combines the characteristics related to the importance of reducing the user's waiting time for sending or collecting packages.
- SC7. Visual impact. It takes into account how the installation of the terminals affects the visualization, or how the appearance of a place changes.
- SC8. Emissions. It refers to the amount of air expelled due to the collection, transport and parcel delivery routes.

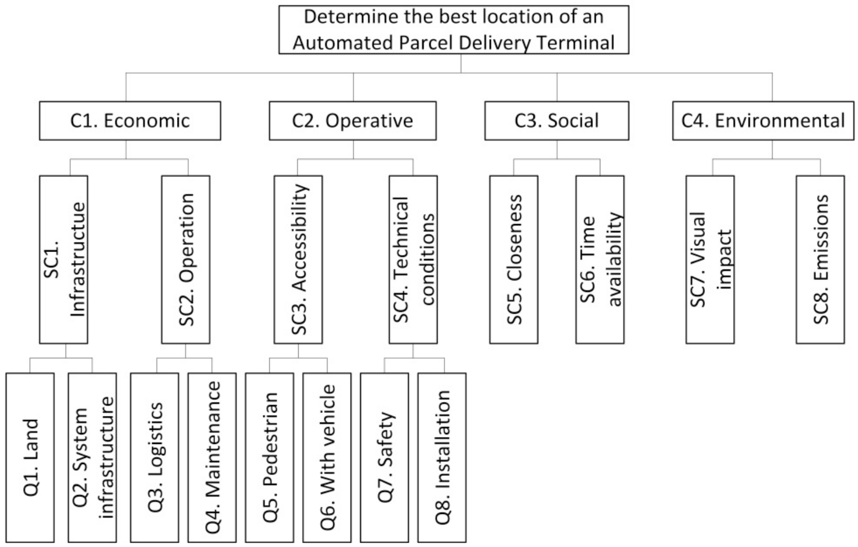

Fig. 1. Hierarchy elements.

Last but not least, eight attributes have been identified:

- Q1. Land. Necessary economic investment for the installation of these terminals due to the type of property of the land (i.e. public or private) on which they are installed.
- Q2. System infrastructure. Investment for the manufacture, storage, transport and installation of the terminals in their corresponding locations.
- Q3. Logistics. Cost involved in the implementation of the terminals due to the need to create new transport routes, treatment of a greater volume of parcels, recruitment of personnel and specific means of transport for collection and delivery of this new delivery system.
- Q4. Maintenance. Costs derived from the maintenance to be carried out in the terminals, specifically those due to its revision, repair and replacement.
- Q5. Pedestrian accessibility. It takes into account the characteristics of a location so that the user can access to the terminal either using public transport or on foot.
- Q6. Accessibility with vehicle. It takes into account the characteristics of a location so that the user can access to the terminal using their own means of transport.
- Q7. Safety. Characteristics of a location referring to the level of security for the sending and collection of packages, allowing differentiating between areas (public or private) with or without surveillance.
- Q8. Installation. Referred to the installation capacity of the terminal in a location, allowing distinguishing between the areas where its installation would be immediate, impossible or those in which adjustments would have to be made.

3.2.2. Assessment of the hierarchical model

The next step after the construction of the hierarchical model consisted of the establishment of the importance of the pair of elements. By consensus, the group of experts elicited 6 judgments for the pairwise comparison matrices of the criteria with regard to the goal, 4 judgements (1+1+1+1). For the pairwise comparison matrix which compares the sub-criteria with regard to the criteria, and 4 judgements (1+1+1+1) for the matrix which compares the attributes with regard to the sub-criteria. These assessments were made following the fundamental scale of Saaty (Saaty, 1980). All the matrices obtained acceptable inconsistencies (CR<0.1). Table 1 shows the local (L) and global (G) priorities of the model elements (with exception to the goal).

3.3. Proposed procedure for the selection of locations

The proposed procedure for the selection of locations consists of four stages:

- Stage 1: Study of the urban area through satellite location tools (Google Maps) and sociodemographic viewers (IDEZar- http://www.zaragoza.es/ciudad/idezar). Visualization of the areas with the highest population density, the largest number of inhabitants per household, the highest rate of youth or the aging of the population, etc.
- Stage 2: Selection of postal districts and sections to analyse.
- Stage 3: Analysis of the study section identifying possible locations according to the most relevant factors obtained in Section 2.2.
- Stage 4: Assignment of a weight to each of these locations following the AHP methodology.

Table 1. Global and local priorities of the model elements

Goal	Criteria	Sub-criteria	Attributes
Determine the best location of an Automated Parcel Delivery Terminal	C1. Economic (L: ,102 G: ,102)	SC1. Infrastructure (L: ,167 G: ,017)	Q1. Land (L: ,750 G: ,013)
			Q2. System infrastructure (L: ,250 G: ,004)
		SC2. Operation (L: ,833 G: ,085)	Q3. Logistics (L: ,833 G: ,071)
			Q4. Maintenance (L: ,167 G: ,014)
	C2. Operative (L: ,549 G: ,549)	SC3. Accessibility (L: ,833 G: ,457)	Q5. Pedestrian (L: ,750 G: ,343)
			Q6. With vehicle (L: ,250 G: ,114)
		SC4. Technical conditions (L: ,167 G: ,091)	Q7. Safety (L: ,833 G: ,076)
			Q8. Installation (L: ,167 G: ,015)
	C3. Social (L: ,297 G: ,297)	SC5. Closeness (L: ,167 G: ,049)	-
		SC6. Time availability (L: ,833 G: ,247)	-
	C4. Environmental (L: ,053 G: ,053)	SC7. Visual impact (L: ,500 G: ,027)	-
		SC8. Emissions (L: ,500 G: ,027)	-

4. Case Study

The case study is focused on the city of Zaragoza. The proposed procedure presented in Section 2.3 was applied. The city of Zaragoza is divided in 22 postal districts. Each of the 22 districts is in turn divided into sections of different sizes. The size of the districts grows in the suburbs. This is because the city center is more densely populated with a greater commercial activity. The case study is focused on one district of the city of Zaragoza (50005). This district (see Fig. 2) is composed of nine sections represented by different colors. From the nine sections, it was selected the one (section 2) with the highest daily demand of parcels according to the information provided by the company that performs the service.

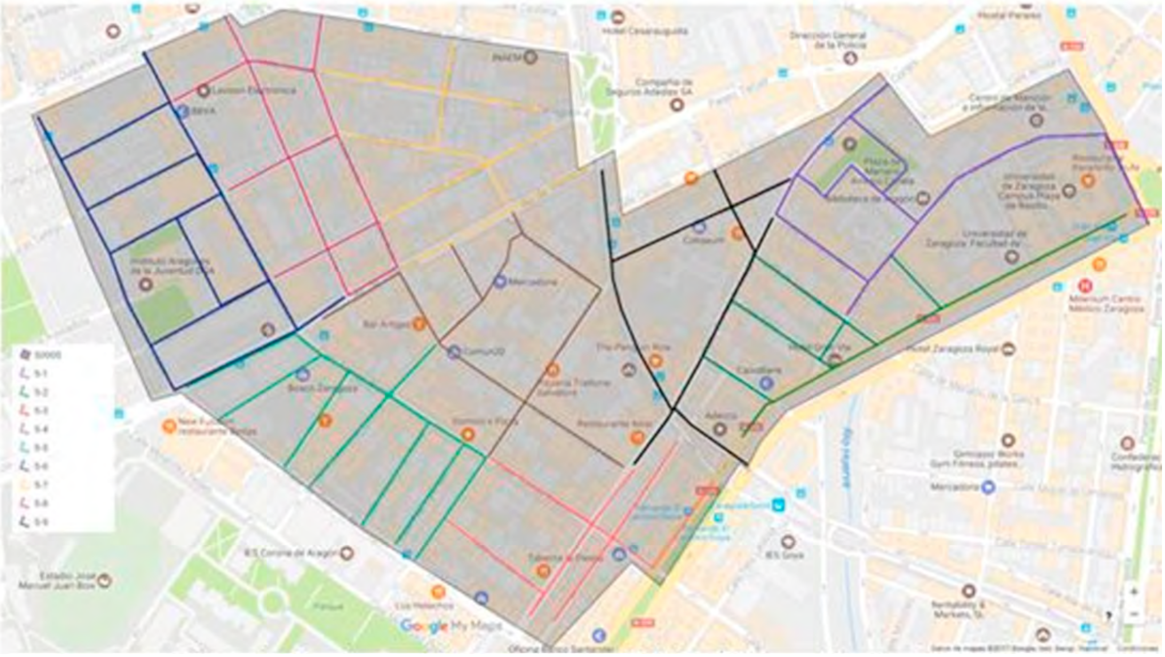

Fig. 2. Sections of the postal district 50005

The technical characteristics of the study are the following: Automated Parcel Delivery Terminal (six compartments), daily demand in the section (20 parcels/day), and the most unfavorable situation (up to three days without pick up of the parcels). The installation of up to 10 terminals will be necessary to cover the daily demand with guarantees. In addition, to avoid possible problems due to the appearance of peaks in the demand, it would be advisable to add a security coefficient (1.3) to the previous calculation. The number of terminals is obtained by applying Ec. (1). Thirteen terminals would be necessary in the section.

$$N_t = \frac{D * d}{N_c} * C_s \tag{1}$$

where N_t is the total number of terminals, D is the daily demand, d is the number of days without picking up, N_c is the number of compartments, and Cs is the security coefficient.

4.1. Location selection

Four possible locations with different characteristics have been selected by taking into account the local and global priorities of the proposed model and the characteristics of the locations (see Fig. 3). The assessment of the alternatives was carried out by applying Ec. (2).

$$w_l = \sum_{i=0}^{n} w_{globali} * s_j \tag{2}$$

where w_l is the weighting of the location, w_i is the global weighting of the attribute i, and s_j is the value of the attribute in a scale of five levels (1-Very high to 5- Very low). The group of experts, following the AHP procedure, has obtained the local priority vector of the five levels. Two scenarios have been considered: lineal and restrictive (see Table 2) and have been applied to the elements of the model (see Table 3).

Table 2. Priority vector of the five levels scale (ideal mode).

Type of scale	Very high	High	Medium	Low	Very Low
Lineal	1.000	0.706	0.501	0.218	0.072
Restrictive	1.000	0.560	0.278	0.146	0.076

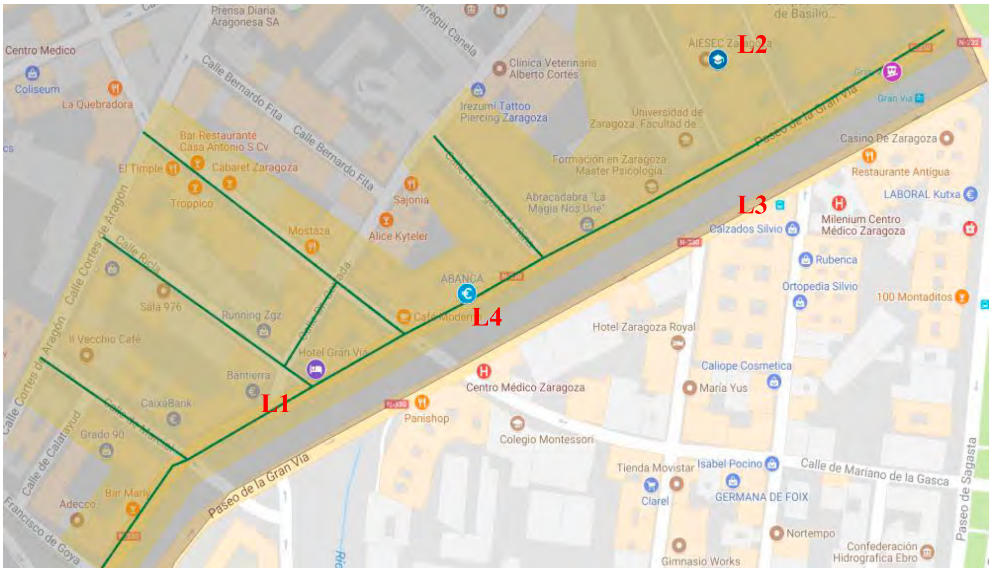

Fig. 3. Selected locations

The scores of the attributes for the calculation of s_j for the four possible locations (L) are shown in Table 3.

Table 3. Valuation of section 2, district 50005

Elements of the model	Type of scale	Hotel Gran Via (L1)	University Faculty (L2)	Tram Stop (L3)	Bank (L4)
Q1	Lineal	2	4	4	3
Q2	Restrictive	5	4	5	5
Q3	Lineal	5	5	4	3
Q4	Restrictive	5	5	3	5
Q5	Lineal	5	5	5	4
Q6	Lineal	5	5	1	2
Q7	Lineal	5	4	3	5
Q8	Restrictive	5	5	5	5
SC5	Lineal	4	3	3	4
SC6	Lineal	5	4	5	1
SC7	Restrictive	3	4	5	3
SC8	Restrictive	4	3	3	3

Table 4 shows the final or total priorities of the alternatives (locations): w(L1)=0.9504; w(L1)=0.9504; w(L2)=0.8436; w(L3)=0.7775; and w(L4)=0.4855. It can be seen that L1 is the best location for the implementation of an Automated Parcel Delivered Terminal (L1>L2>L3>L4).

Table 4. Preferred location

	L1	L2	L3	L4
Total priorities	0.9504	0.8436	0.7775	0.4855

5. Conclusions

The objective of this paper was to develop a model for the location selection of Automated Parcel Delivery Terminals to optimize the overall service, increasing satisfaction and consumption of users and reducing costs. A combination of the AHP methodology and a GIS has been applied to identify the influencing factors and perform the analysis of the alternatives (possible locations).

A case study focused on the city of Zaragoza, and specifically to a Spanish postal parcel delivery company, has been carried out to assess the model behavior. A group of seven experts in transport and logistics, e-commerce, economy, and multicriteria decision-making carried out the construction of the model and its assessment. For the selection and evaluation of locations the most influential criterion is the operative (54.9 % of the global weighting) followed by the social criterion (29.7 % of the global weighting). Regarding the sub-criteria and attributes of the model, it can be seen that accessibility (pedestrian- 34.3 % and with vehicle-11.4 % of the global weighting), time availability (24.7 % of the global weighting) and safety (7.6 % of the global weighting) are the most important elements to focus on, for solving the location selection problem. Last but not least, the use of GIS allows analyzing diverse urban areas in an agile and effective way.

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