MULTI-CRITERIA STRUCTURE TO LOCATE URBAN DISTRIBUTION CENTRES

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ABSTRACT
This paper aims to propose a framework to locate urban distribution centres (UDC), considering the opinion of the main stakeholders involved in the urban distribution of goods and a set of criteria. Based on a survey carried out with carriers, traffic wardens and retailers, a decision hierarchy structure, consisting of criteria evaluated by statistical techniques for the ranking will be used to select the best location for UDC. The methodology was applied to a case study in the historical centre of Ouro Preto, which contains common characteristics of other cities that are included in the World Heritage List. However, the methodology can be adopted in different cities using appropriate criteria and alternatives according to the characteristics of the cities. As the main results, 'traffic congestion', 'noise nuisance level', 'insecurity', 'visual pollution' and 'professional qualification' were considered the most important variables by all stakeholders involved in urban logistics.

RESUMO
O objetivo deste artigo é propor uma estrutura para a localização de centros de distribuição urbana (CDU), considerando a opinião dos principais atores envolvidos na distribuição urbana de carga, e um conjunto de critérios. Com base em uma pesquisa com transportadoras, guardas de trânsito e varejistas, uma estrutura hierárquica de decisão, consistindo de critérios avaliados por técnicas estatísticas para a classificação, é usada para selecionar a melhor localização de um CDU. A estrutura foi aplicada a um estudo na cidade de Ouro Preto, a qual contém características comuns a outras cidades históricas que estão incluídas na lista de patrimônio histórico mundial. No entanto, a metodologia pode ser adotada em diferentes cidades utilizando critérios e alternativas adequadas de acordo com as características locais. Como principais resultados, 'congestionamento de tráfego', 'nível de poluição sonora', 'insegurança', 'poluição visual' e 'qualificação profissional' foram considerados as variáveis mais importantes pelos agentes envolvidos na logística urbana.

1. INTRODUCTION

The relevant stakeholders in the urban distribution of goods include transport operators; local authorities; residents who live in the urban area and retailers. The different interests of these stakeholders contribute to the complexity of the distribution of goods (Awash, Chauhan & Goyal, 2011). One example would be the interest of transport operators having more flexibility with deliveries (Marcucci, Gatta & Scaccia, 2015) and with the possibility of off-hour deliveries, because it would facilitate the loading and unloading operations without any traffic congestion. On the other hand, retailers would prefer to receive goods during regular opening hours, with citizens agreeing that they would prefer not to experience noise during the night and have their goods available in grocery stores when shopping (Marcucci, Gatta & Scaccia, 2015). The focus of regulations is to ensure equality between social well-being, costs and benefits for most of the stakeholders involved.

Since this study considers the distribution of goods in historical city centres, substantially occupied with residents and tourists, and with no empty space available for building facilities, some requirements should be listed. The main problem in this case is that historical cities usually contain narrow streets which were not originally designed considering cars, trucks and people. Thus, the delivery of goods is very special, particularly during peak-hours since there are no parking spots available for transport operations (Marcucci, Gatta & Scaccia, 2015). For each delivery, the freight costs can differ according to the vehicles that were used (in size and weight) and the capacity that was used (in a full truck load or not) (Awash, Chauhan & Goyal, 2011). Not to mention that these constraints should respect regulations, such as prohibiting construction works that do not comply with the architecture of historical cities; the restrictions of load and size of trucks driving into the urban area; the geography of the city and the land; among other aspects will influence the number of vehicles allowed and the quantity of goods delivered (Allen, Browne, & Cherrett, 2012).

A viable solution would be to establish urban distribution centers (UDC) close to the customers' location, although at the same time it challenges governmental regulations incurring high costs. There are many details to be addressed: (a) what are the interests of the main stakeholders involved; (b) where should a UDC be set up; (c) which criteria should be considered.

The decision of where to locate UDCs is also not simple to make because there are multiple criteria to be considered, such as: minimizing distribution costs; optimizing customer coverage; as well as minimising social, economic and environmental impacts. Mainly, the process of locating UDCs can be compared with facility location problems. Due to their similarities we can consider that the problem has a set of locations or alternatives which can be evaluated against a set of weighed criteria (Chakraborty, Ray, & Dan, 2013). A general facility location problem involves a set of spatially distributed customers and a set of facilities to meet these customers' demands (Drezner, Hamacher, 2004; Nickel and Puerto, 2005), considering distances, times and costs between customers and facilities (ReVelle and Eiselt, 2005). Thus, the best alternative which considers all the criteria can be chosen. The only difference is that in the problem of locating UDCs, the interests of all stakeholders will be considered.

The objective of the research is to propose a framework to locate a distribution centre, considering the opinion of carriers, traffic wardens and retailers. A multi-attribute decision approach will be used for selecting the best location for a UDC in historical cities. A survey was carried out with these stakeholders to build a decision hierarchy structure, comprising criteria evaluated by statistical techniques for ranking criteria. In addition, a case study in the historical centre of Ouro Preto, which contains common characteristics of other cities that are included in the World Heritage List, was carried out.

2. LITERATURE REVIEW

2.1. Problem of selecting the location of urban distribution centres

A UDC is a facility which is responsible for the transshipment of goods directed to urban areas to consolidate deliveries and provide greater efficiency in the distribution process (Chakraborty, Ray, & Dan, 2013; Wang, Xiong & Jiang, 2014). However, the main problem is to decide how to select one from a potential set of locations of a UDC while considering and satisfying a set of criteria such as investment costs, proximity to suppliers, legal and tax implications (Chou, Chang & Shen, 2008). Furthermore, it is up to a certain number of decision makers to determine the quantity of distribution centres desired and then to decide where to locate them (Chakraborty, Ray, & Dan, 2013). The decision makers can, in some cases, choose one or more distribution centres among the potential locations according to several different criteria.

Most local authorities agree that UDCs should become self-sustaining in the medium to long term, so that they do not need to provide financial support after the first years of operation (Panero, Shin & Lopez, 2011). Due to this, the public involvement in financing UDCs is usually explained by the benefits it can generate for citizens and in giving a solution to urban traffic.

Two major difficulties regarding implementing the UDC are the allocation of costs and benefits and the willingness of transportation companies to cooperate. Both consignees and transportation companies can benefit financially from using the UDC. Its operation, however, incurs costs. The municipality should play a role in bringing the costs and benefits together. A solution could be to run the UDC as a cooperative including several different transportation companies (Van Duin, Quak, Muñuzuric, 2010).

2.2. Criteria for selecting a location for a UDC

The criteria that can be used for selecting a UDC can be classified into five aspects (Carvalho et al., 2019): a) *the economic aspect* covers local prosperity via job opportunities (e.g., for drivers, as well as operational and administrative employees of a UDC), more efficient freight distribution systems, currency value, business climate and many others (Marcucci, Gatta & Scaccia, 2015; Macharis & Milan, 2015); b) *the environmental aspect* considers the emission of pollutants, noise pollution and traffic jams (Quak, 2008; Rao et al., 2015); c) *the social aspect* includes the accessibility of platforms and their settlement areas, the ability to reduce insecurity and the number of accidents with loading and unloading operations (Anderson et al., 2005; Gonzalez-Feliu and Morana, 2010; Awasthi and Chauhan, 2012). Local prosperity also has a social aspect, as well as the ability to reduce insecurity (the number of accidents caused by the uncontrolled acts of loading and unloading prohibited in the city centre, large vehicle traffic and recklessness of the drivers) (Agrebi, Abed & Omri, 2015; Kin et al., 2016). The last, (d) *the operational aspect* includes facilitation of freeing parking spots (Awasthi and Chauhan, 2012, p.579), a reduction in the congestion caused by trucks blocking a street (Gonzalez-Feliu, 2008; Gonzalez-Feliu and Morana, 2010); e) *the cultural aspect* that considers urban traffic, mechanical damage to historical heritage caused by vehicles (Browne et al., 2005). These criteria are essential for making the right decision, especially in the case of historical cities such as the one studied in this paper. Several criteria can be used for selecting the location of a UD, as shown for this research.

The prevalence of some criteria in relation to others usually comes with trade-offs. For example, although the use of vehicles with alternative energies can reduce environmental impacts, such as air pollution, noise, traffic congestion (Estrada & Roca-Riu, 2017) and less damage to the infrastructure of cities, it may cause several conflicts with pedestrians. Moreover, the transshipment of high value products in small vehicles such as bicycles is prohibited by insurance companies (Browne, Sweet, Woodburn & Allen, 2005). Another trade-off found is related to location. When UDCs are designed to serve a whole city, the facilities are always located in the city's perimeters and close to major communication lanes, which can reduce costs. However, in cases where the UDCs were designed to supply a central area within the city, they can be located either inside or outside of it. Likewise, the efficiency of the distribution can be a trade-off. In some cases, a higher rate of occupation of the load capacity is better because fewer vehicles must enter the main city centre. It can also be more efficient to enter the main centre with many smaller vehicles. On the other hand, regarding the environmental aspect, a location of UDC can reduce atmospheric/air pollution, visual intrusion and noise nuisance levels (Rao et al., 2015). The agreement regarding efficiency is that no matter the situation chosen, the efficiency of the supply chain can become greater by improving information flows and increasing transparency, by using the right vehicles and most suitable load carriers (Van Duin, Quak, Muñuzuric, 2010).

3. METHODOLOGY

The methodology used in this research is based on a descriptive survey (Forza, 2002) distributed to the three city logistics agents: traffic wardens, retailers and carriers. To aid the decision of where to locate the UDC, this study was conducted as follows: a) the main criteria that had significant influence on the decision of where to locate the UDC were defined; b) the surveys were applied to the decision makers, such as carriers, traffic wardens and retailers; c) the results were then observed in a descriptive statistics analysis (mean, standard deviation) and in a factorial analysis, to then be used for the development of a multiple hierarchical decision structure. This research was conducted in Ouro Preto, one of the most famous historical cities in Brazil. The reasons why this city was chosen is because it has a lack of parking spaces and it has specific transport regulations, since it was the first Brazilian city included in the World Heritage List by UNESCO (Oliveira, 2016).

The population of retailers was obtained from the Municipality’s database and only companies focused on commerce/retail were considered, except for those that work with services of high added value, such as retailing jewellery. This refinement generated a population of 196 retailers. The population of carriers is unknown, and then they were select according to convenience. For retailers, the sample was calculated based on a finite and known population as presented by Cochran (1985). We considered a statistical confidence level equal to 95% and a standard deviation of 0.5 for the sample. We surveyed a sample of 122 retailers from different sectors (foodstuffs, textiles and clothing, pharmacies, etc.). Most of the retailers interviewed (67%) stand in strategic positions (partner owners, managers or directors) and have 13 years of experience on average. In relation to carriers, 46 questionnaires were collected from drivers with an average 10 years of experience in the profession. From the total number of drivers, 63% were employed by carriers, and 37% were autonomous.

Furthermore, the data for this research was obtained from interviews conducted with Brazilian local authorities, such as the mayor’s secretary, traffic warden commander and the coordinator of the Commercial and Business Association in 2017. These stakeholders were questioned about problems with the current urban logistics in the historical city of Ouro Preto, regarding the possible alternatives of location for the UDC and their opinion on the implementation.

A decision hierarchy structure, consisting of criteria evaluated by statistical techniques (descriptive analysis, analysis of variance and T-tests and factorial analysis) for the ranking of criteria were used for building the framework.

4. DEVELOPING THE STRUCTURE OF THE MULTIPLE HIERARCHICAL DECISION

To develop the structure of the multiple hierarchical decision, the criteria needed to be established for the UDC. This generic structure (see Fig. 1) can be applied to any location (i.e., further alternatives), considering different criteria according to the specificities of a city. Fig. I shows, from the hierarchical decision structure, the goal of the problem’s decision which is where to locate a UDC, with several criteria (*Cx*, *Cv*,*Cz*) assembled into their indexes.

The steps for developing a decision hierarchy structure to address the problem are:

Step 1 – Calculating the factors and respective indexes

As a long list of criteria can be made to represent the problem, it is appropriate to group the criteria. Then, factorial analysis was used to reduce the problem into main factors, which establish similar criteria into the same factor. To compare the different criteria according to the hierarchical decision structure, indexes which summarise the information of each factor extracted were calculated through the weighted average of factorial loads for each criterion, as follows (equation 1):

$$\frac{\sum_{i=1}^{n} bij\ Xij}{\sum_{i=1}^{n} bij} \qquad (1)$$

Where *i:* the number of criteria;
J: the number of factors;
b the factorial load; and
X the variable for each factor.

Therefore, each I_j represents a group of similar criteria and *W* represents the weights. The criteria are represented by Cx_j, Cv_j, Cz_j; where j = *1* to *n*, and *x*, *v*, *z* refer to different groups of criteria (Figure 1).

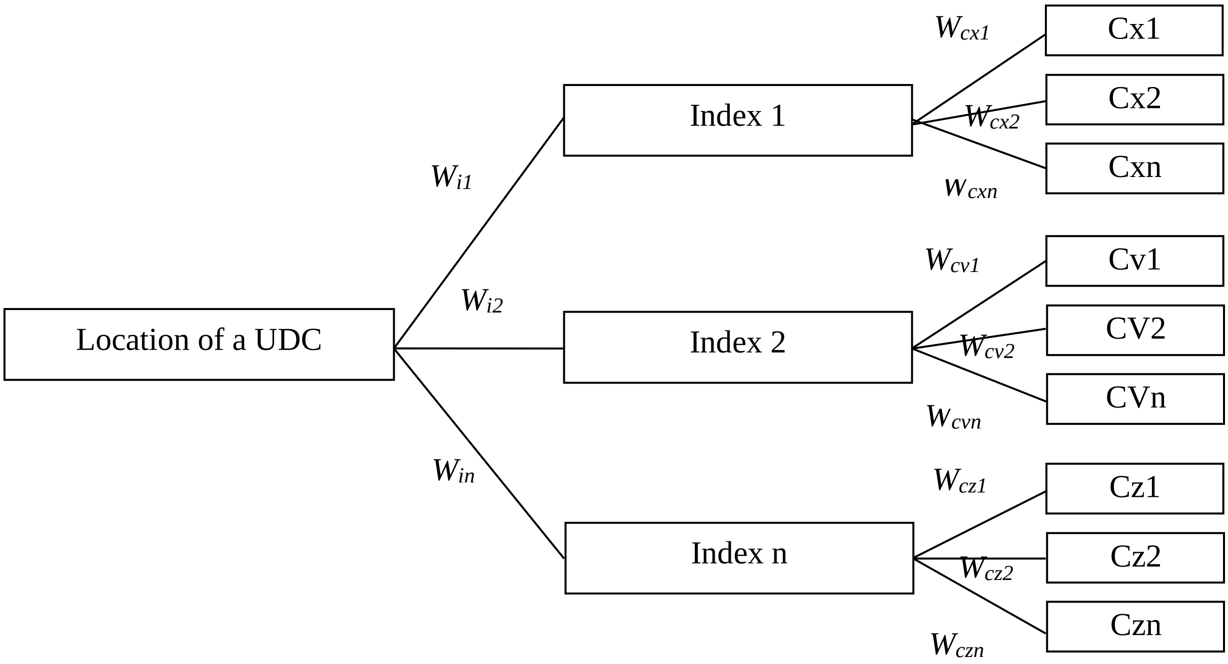

Figure 1: Multiple hierarchical decision model.

Step 2 – Comparing the indexes/criteria and assignment of weights

The weights were obtained by the ranking of indexes/criteria (from more important to less important, in their level). To do this, first we compared the averages of pairs of indexes or criteria. To compare whether a criterion or an index (in their level) has a greater average than the other, the t-test for paired samples was carried out. The Kolmogorov-Smirnov test for normality must show that the indexes/criteria are normal, in their classes, at 1 percent statistical significance, which makes the paired t-test useful. The null hypothesis: "The average of two indices/criteria is equal". If H_0 is rejected, it can be said that an index/criterion has a greater or smaller average than the other. If there were no statistical significance in the average between the indexes/criteria (in pairs), the One-Sample T-test was applied to compare each criterion/index to a fix value, and then to determine the great average for each index and criterion. It may be relevant to verify the intensity and also to validate, with statistical significance, the measures (averages) among variables. This relevance may bring up nuances regarding the criteria to be considered in the decision hierarchy structure.

It is important to mention that each criterion and index will be given a specific weight, (*Wc* and *Wi*) according to the level of importance assigned by the general evaluation of all stakeholders. Any alternative can be added to be evaluated by this structure.

5. CASE STUDY

The case study chosen to apply the proposed hierarchical decision structure is represented by the city of Ouro Preto, which has a relatively small number of trucks, combinations of high demand for the delivery of goods and limited parking spaces increase logistics and social costs. As a result, transport operators have to search for the nearest parking spots for the supply destination or park illegally (most common). In both cases, there is a high delay in delivery, additional fuel consumption, and parking fine costs resulting in heightened levels of stress (Marcucci, Gatta & Scaccia, 2015). From a social perspective, there are also issues concerning the damage to the infrastructure of the historical heritage, increase in greenhouse gas emissions by vehicles and other sorts of pollution (air, visual, noise). Therefore, to find an efficient and effective solution for the distribution system, interviews with local authorities, such as the mayor's secretary, the traffic warden commander and the coordinator of the Commercial and Business Association, were conducted. According to these stakeholders, the city has been facing these issues since 2008, and the idea of implementing UDCs is still being considered.

5.1. Building the structure based on stakeholders' opinion

This section follows the steps described in Section 4.

The variables that were considered most important by all stakeholders involved, based on their original scores, were: increase in 'traffic congestion', 'noise nuisance level', 'insecurity', 'visual pollution' and 'professional qualifications'. In other words, these five variables can be considered as important criteria for implementing a UDC in historical centres. It is interesting to note the inclusion of 'visual pollution' in this list. We can infer that the stakeholders recognize the importance of reducing the number of trucks or large vehicles coming in and out of a historical city.

Additionally, regarding the 'professional qualifications', most of the stakeholders believe that it is crucial to use qualified personnel able to use all sorts of communication devices such as tablets, mobile phones or even radios to improve the information flow between retailers and carriers, mostly. They mention that with better communication, more accurate delivery deadlines and customer satisfaction can be achieved in general.

On the other hand, the variables that were of minor importance were: 'vehicle size', 'use of technology', 'service level' and 'investments and costs', according to most carriers and retailers. It can be assumed that urban mobility solutions are still unknown or undervalued by the general population in Brazil. The need for education programs provided by governmental or non-governmental organisations is urgent so that traffic in cites can be minimised, occupation rates of the vehicles can be optimised, the municipality can help bring costs and benefits together, and city planning can be better organised, mostly heritage ones, among others.

However, to deal with the sample of 19 variables separately, and considering 181 answers, factorial analysis was used to reduce the number of variables and help understand the phenomenon. Analysing all these variables separately also increased the error type II. Then, factorial analysis is appropriate because it reduces the variability of the sample.

5.1.1. Calculating the indexes based on the factorial loads

To analyse data adequacy for the technique, the Bartlett's sphericity test was significant at 1 percent, rejecting the null hypothesis that the correlation matrix is an identity matrix. The Kaiser-Meyer-Olkin (KMO) test presented a value of 0.803. It is important to notice that the variables with factorial loads less than 0.5 were eliminated from the data.

Based on the remaining 16 variables, the main component method was adopted to extract the common factors and obtain the number of factors. We used the varimax rotation method to determine the original variable distribution in their factors (called Factor_1, Factor_2, Factor_3, Factor_4, Factor_5), as shown in Table 1. The factorial loads, communalities and Cronbach's Alpha are also represented.

The factors could be joined to measure the importance of each factor for the location problem. Then, the allocation of variables into factors was done when the highest factor loads for each variable was observed. It can be observed that factor 1 has the highest percentage of the total variance explanation, followed by factor 2, which means that they produce the biggest contribution to explaining the total variance of the variables. Therefore, these factors are the most important to represent the best location. The five factors represent about 58.755% of the variance of the 16 original variables. Due to the lowest Cronbach's Alpha value, Factor_5 was eliminated from the analysis. Even removing Factor_5, the results are still statistically significant.

Table 1: Extraction of common factors

Factors extracted	Original variables	Factorial loads					Communalities	Cronbach's Alpha values (0-1)
		1	2	3	4	5		
Factor_1 – Economic (ECON)	R8	**.823**	.123	-,098	.015	-.023	.703	**.798**
	R7	**.791**	.265	-,016	.096	-.088	.713,	
	R10	**.653**	.337	.096	-.014	.121	.564	
	R12	**.591**	.050	.220	.171	.366	.564	
	R11	**.586**	.367	-.059	.107	-.095	.502	
Factor_2 – Environmental (ENVI)	R6	.219	**.698**	.077	-.069	.119	.561	**.659**
	R13,	.138	**.633**	-.174	.222	-.083	.506	
	R2	.360	**.590**	.031	-,096	.042	.490	
	R3	.245	**.574**	.208	,288	.120	.530	
Factor_3 – Social (SOCI)	R15	-.052	-.027	**.807**	.059	.002	.659	**.537**
	R5	.084	.060	**.780**	.069	.054	.627	
Factor_4 – Operational (OPERA)	R14	.095	-.057	-.077	**.722**	.183	.573	**.427**
	R1	-.221	.289	.301	**.629**	.017	.618	
	R4	.376	.044	.134	**.582**	-.085	.508	
Factor_5 – Cultural (CULTUR)	R16	-.056	-.060	.002	.206	**.800**	.690	**.313**
	R9	0.086	.436	.062	-.158	**.606**	.593	
% of variance explained		18.122	13.681	9.558	9.552	7.842		
% of cumulative variance		18.122	31.803	41.362	50.914	58.755		

Factor F1 (ECON) contains the variables 'R8-damage to historical heritage', 'R7-architectural impacts', 'R10-visual pollution', 'R12-use of alternative propulsion vehicle' and 'R11-noise nuisance level'. Given that, we can assume that as 'architectural impacts' shows how buildings can be mechanically affected with collisions by vehicles (generating fissures, cracks and increase in damage to walls of historical buildings) (Marcucci, et.al 2015**)**; and 'noise nuisance level' indicates the level of vibrations acting in communities and buildings (Gonzalez-Feliu and Morana, 2010; Rao et al., 2015); these variables together represent the consequences of urban transportation vehicles (mostly) to historical buildings. According to Marcucci et.al (2015), the variables 'architectural impacts' and 'damage to historical heritage' are highly related to the conservancy of historical sites. Therefore, if fewer vehicles enter the city's historical centre, there will be lower impacts on 'visual pollution' and 'insecurity', which indicates that this factor represents the effects of the urban distribution of goods for the conservation of historical buildings and for road safety.

Additionally, the variables 'use of alternative propulsion vehicles' and 'noise nuisance level' can bring positive aspects such as noise reduction with the use of quieter vehicles (such as electric and hybrid vehicles or even bicycles). It suggests that F1 represents environmental improvements (Gonzalez-Feliu and Morana, 2010). As a result, we can say that these variables are related to sustainability aspects, since the 'use of alternative propulsion vehicle' (Browne et al., 2011; Marcucci, et.al, 2015) can be used by many transportation companies as an environmentally friendly strategy to achieve more clients; 'visual pollution' (Quak, 2008; Rao et al., 2015) can also encompass the importance given by the rest of the community to the delivery zones (which should be respected so that pedestrian and cyclists can coexist).

Factor F2 (ENVI) contains the variables: 'R6-insecurity', 'R13-compliance with legal regulation', 'R2-traffic congestion' and 'R3-professional qualifications'. According to some authors (Quak, 2008; Van Rooijen and Quak, 2010; Fauret et al., 2016; Kin et al. 2016), 'insecurity' and 'traffic congestion' are considered as negative impacts related to the urban distribution of goods and may be attenuated using the UDC. In this case, the understanding of certain aspects of historical cities such as their formation in narrow streets (without parking lots or alleys) is crucial for the mitigation of traffic congestion and insecurity as some cities were not originally designed for the coming and going of cars, people and trucks (Marcucci, Gatta & Scaccia, 2015). For instance, the variable 'professional qualifications' can increase productivity and efficiency in urban distribution systems and reduce 'traffic congestion'; therefore, it can also minimise traffic congestion. Given that, we can assume that F2 also represents drivers' behaviour and decision making. Although 'traffic congestion' had a low communality (0.490), we kept this item in our analyses due to its strong contribution to the content validity of this factor. Traffic congestion causes negative aspects to the city's residents and the environment (Estrada & Roca-Riu, 2017).

Factor F3 (SOCI) considers 'R15-service level' and 'R5-local gain'. These variables may indicate local prosperity through job creation and improvement of fulfilment to residents and retailers in the micro-region (Marcucci, et.al, 2015).

Factor F4 (OPERA) contains the variables 'R1-parking spots', 'R4-vehicles size' and 'R14-use of technology'. Considering the variables 'parking spots' and 'vehicles size', it can be assumed that using ways to reduce the number of vehicles entering a city centre (a UDC or consolidation centre, for example) prevents urban traffic and increases the efficiency of deliveries (Estrada & Roca-Riu, 2017), and it also increases the availability of parking spots during the loading and unloading of cargo. In the same way, more efficiency and productivity for urban distribution systems can be achieved in relation to the 'use of technology' (Marcucci, et.al 2015). Therefore, factor F4 can be considered an efficiency factor.

After extracting the factors, indexes were calculated for each factor from the weighted mean of factorial loads of the rotated component matrix. These indexes were used to measure the alternatives of location among the stakeholders. Therefore, the first index was calculated from the factorial load results of the first factor extracted. For instance, Index_1 essentially comprises items related to the economic/local prosperity and was called ECON. Similarly, Index_2 (environmental) was called ENVI, Index_3 (social) SOCI and Index_4 (operational) OPERA.

5.1.2. Assignment of criteria weights

To compare whether an index has a greater average than another, a *t-test* was conducted in pairs of indexes. Moreover, the same procedure was used for the variable sample. Although the Kolmogorov-Smirnov test for normality discards the null hypothesis that the samples/indexes follow normal distribution, it was assumed that the distribution can be approximated by a normal distribution applying the central limit theorem ($n > 30$) (Hair et al. 2005), thus the paired *t-test* can be used.

The results for the paired samples *t-test* showed that for the indexes with significance levels higher than sig. = 0.000 cannot be statistically stated that one index is different from another. Then, we applied one sample test with a certain fix value for the pair of indexes in order to find each one is greater than the other. Table 2 shows the descriptive statistics and *t-test* for the indexes. The (positive/negative) signal of the t-test indicates that the average of index (i) (line) is greater/smaller than the average of the second index (j) (column). The results in Table 2 show that the difference of the averages of all pairs are different from zero. That is, the null hypothesis is rejected.

Table 2: Averages of the paired indexes

Index	**I_SOCI**	**I_OPERA**	**I_ENVI**
I_OPERA	**NS**		
	(0.060)		
I_ENVI	**14.814** *	**19.223** *	
	(1.053)	(1.114)	
I_ECON	**11.682** *	**15.153** *	**-3.681** *
	(0.914)	(0.974)	(-0.139)

Note: Values in bold and between brackets represent the differences between the pair averages. H_0: $\mu_i - \mu_j = 0$. IC = 95 percent. *Indicates significance at 1 percent and * *at 5 percent. NS = no significance.

The analysis of the I_ECON x I_SOCI and I_ECON x I_OPERA relations indicates that I_ECON (economic) has a greater average than the I_SOCI (social) and I_OPERA (operational), respectively. That is, stakeholders care more about the economic aspects to implement a UDC than social or operational aspects.

When comparing I_ECON (economic) and I_ENVI (environmental), I_ECON has a smaller average than I_ENVI. Furthermore, the analysis of the I_ENVI x I_SOCI and I_ENVI x I_OPERA relations indicates that I_ENVI has a greater average than the I_SOCI and I_OPERA, respectively. Therefore, the stakeholders believe that environmental aspects are the most important to locate a UDC in a historical city. This result is similar to the descriptive statistical analysis when traffic congestion' and 'insecurity' are the main aspects to be considered to locate a UDC.

The last, the analysis of I_OPERA x I_SOCI relation indicates we cannot make sure that the averages are statistically significant due to the differences between them to be too small and the present high standard deviation. However, when we compare the average of I_OPERA (1.643) and the average of I_SOCI (1.702) to a fix value (1.600) by using one sample *t-test*, the results reveal that only I_SOCI has a greater average than this fix value, in this case at a 5 percent statistical significance. Therefore, we may infer that I_SOCI is more important than I_OPERA to locate a UDC according to the stakeholders. This means having a good level of service or local gain is more important than having parking spaces or using smaller vehicles or using technology to operate a UDC.

The same methodology was applied to ranking the criteria. Figure 2 shows a decision hierarchy structure with normalized weights for the indexes and respective weights of variables.

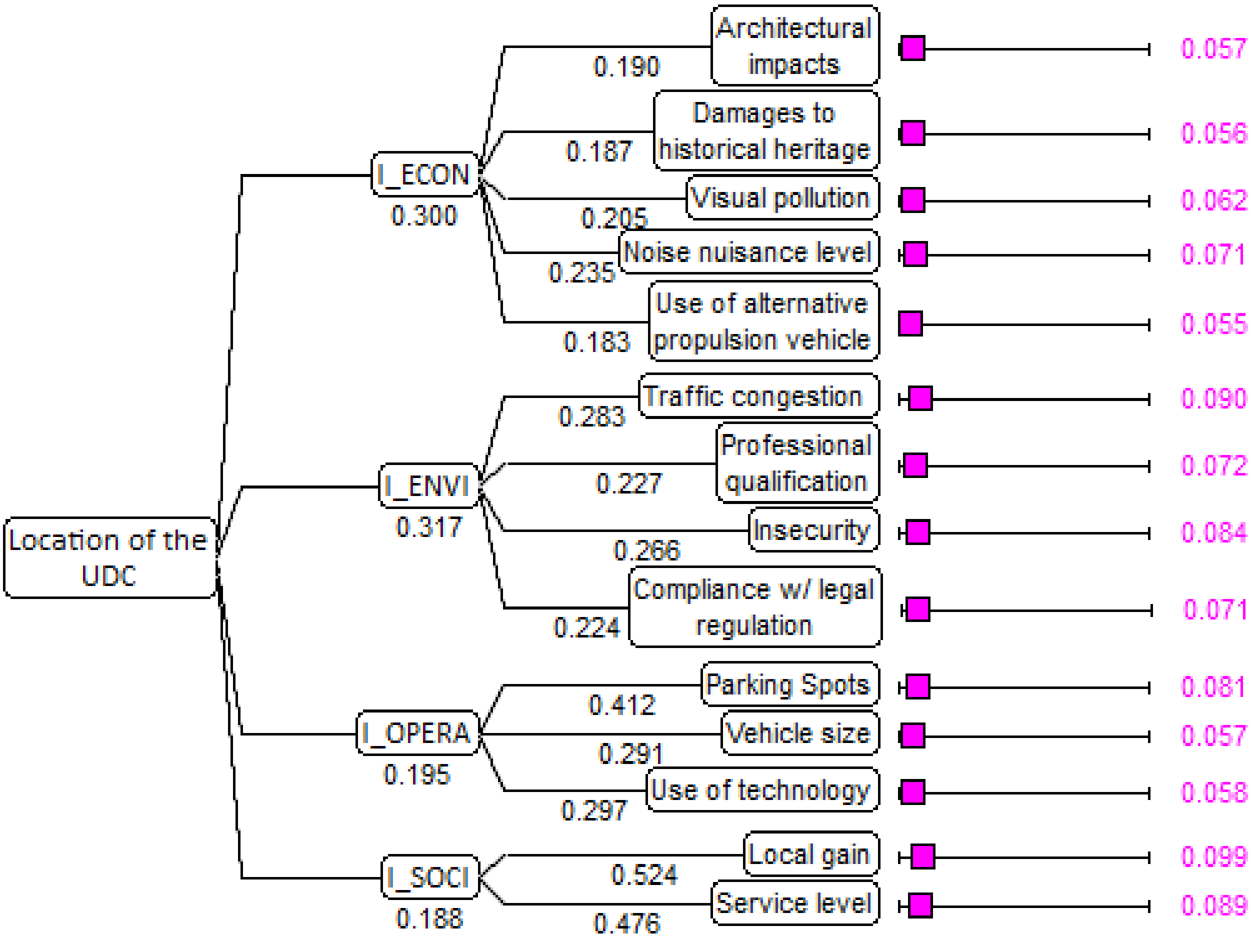

Figure 2: Hierarchical decision structure for locating UDC in historical city.

The results show the relevance of the economical and environmental aspects to location of UDC. For example, the reduction of atmospheric/air pollution, visual intrusion and noise nuisance levels were also considered by Rao et al. (2015) to locate a UDC. The results also confirm the importance of the local prosperity compared to service level, as described by Agrebi, Abed & Omri (2015) and Kin et al. (2016) in related to the reduction of local insecurity, provided by the uncontrolled acts of loading and unloading prohibited in the city centre, large vehicle traffic and recklessness of the drivers.

It is also important to highlight that the results shows the most important criteria (regarding economic and environmental aspects) (Carvalho et al, 2019) meet the opinion of retailers (most part of the sample – 122 responses) and the population of traffic wardens (33 responses). Also, carriers and retailers perceived, with minor importance, the criteria associated to operational and social aspects (vehicle size, use of technology, service level and investments and costs).

This structure can be **applied to alternatives for implementing UDC.**

6. CONCLUSION AND FUTURE STUDIES

Based on carriers, traffic wardens and retailers' opinions, this research proposes a multi-criteria decision framework for selecting the best location for urban distribution centres (UDC), and it was applied to the historical city of Ouro Preto. The study was conducted in three stages. First, based on the literature review, the criteria for the evaluation of potential locations for the UDC were identified. Second, the criteria were summarized in four factors which were transformed in respective indexes, representing the hierarchical decision structure. Third, the decision makers rated the criteria/indexes by using statistical techniques (*T-tests* and one sample test) in order to compare pairs of criterion/index, and ranking them by the averages. These averages represent the weights for the ranking of criteria/indexes in the structure.

From the statistical techniques, the variables that were considered most important by all stakeholders involved were determined: an increase in 'traffic congestion', 'noise nuisance level', 'insecurity', 'visual pollution' and 'professional qualifications'. These five variables can be considered as important criteria for implementing a UDC in historical centres. It suggests that one of the greatest goals of the UDC's applicability is well-known by the stakeholders, since they recognize the importance of reducing the number of large vehicles coming in and out of a historical city (in this case). Additionally, regarding the 'professional qualifications', most of the stakeholders believe that it is crucial to use qualified personnel able to use all sorts of communication devices to improve the information flow between retailers and carriers and achieve more accurate delivery deadlines and customer satisfaction in general.

Moreover, the variables of minor importance were identified: 'vehicle size', 'use of technology', 'service level' and 'investments and costs', according to most carriers and retailers. Accordingly, it could be assumed that urban mobility solutions are still unknown or undervalued by the general population in Brazil. The need for education programs provided by governmental or non-governmental organisations is urgent so traffic in cites can be minimised, occupation rates of the vehicles can be optimised, the municipality can help bring costs and benefits together and the preservation of cities, mostly those with historical heritage, can be initiated, among others.

Concerning future research, it would be interesting to conduct other interviews with local citizens, retailers and carriers to evaluate the preference for each alternative for each factor; evaluating other variables that may also help measure the best alternative and extending the research to another Brazilian historical city, provided that this proposed structure can also be applied to evaluate an additional alternative. We also suggest using the idea of this study in similar implementations of UDCs in other cities (not only historical cities), provided that other groups of criteria will be selected according to the similar economic, cultural and political reality. Thus, this framework can be used by logistics operators and local authorities for implementing UDCs to address urban distribution issues.

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