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# Designing Sustainable Systems for Urban Freight Distribution through techniques of Multicriteria Decision Analysis

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## SUMMARY

This paper focuses on the analysis and selection of the parameters that have a major influence on the optimization of the urban freight distribution system by using sustainable means of transport, such as electric vehicles.

In addition, a procedure has been studied to identify the alternatives that may exist to establish the best system for urban freight distribution, which suits the stage that is considered using the most appropriate means of transportation available. To do this, it has been used the Analytic Hierarchy Process, one of the tools of multicriteria decision analysis.

In order to establish an adequate planning of an urban freight distribution system using electric vehicles three hypotheses are necessary: (i) it is necessary to establish the strategic planning of the distribution process by defining the relative importance of the strategic objectives of the process of distribution of goods in the urban environment, both economically and technically and in social and environmental terms; (ii) it must be established the operational planning that allows the achievement of the strategic objectives with the most optimized allocation of available resources; and (iii) to determine the optimal architecture of the vehicle that best suits the operating conditions in which it will work and ensures optimum energy efficiency in operation.

## 1. INTRODUCTION

Transportation is a key factor in the social and economic development of a country, as it not only influences the activity of the inhabitants in terms of mobility, but also influences the development of activities of all economic sectors. In turn, this sector is dependent on energy resources, being necessary a greater energy efficiency to ensure a sustainable development.

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On the other hand, at the present time, there is growing social awareness of the need for a more sustainable and environmental friendly mobility, especially in large cities where freight transport has an important impact on quality of life in urban areas, including emissions, safety, noise and visual intrusion (Dablanc, 2008; Yannis et al., 2006). In this regard, Public Administrations and some private entities are carrying out different initiatives seeking to advance in the concept of sustainable mobility. These initiatives include promoting the use of low emission vehicles, limiting polluting private vehicles circulation, implementation of fees and taxes on the most polluting vehicles and subsidies for purchasing environmentally friendly vehicles.

The growing importance of urban freight transport can be related to the increased population and sustained economic growth in urban areas (Cherrett et al., 2012). Because most people in Europe live in urban areas and the bulk of industrial production is sent to these areas, the result is an increase in demand for freight transport. Also, due the urban freight transport is mainly concerned with the distribution of products at the end of the supply chain (last mile logistics distribution), many deliveries are characterized for the small loads size and frequent trips, resulting in many kilometers per vehicle. On the other hand, it must be considered the great waste of energy that occurs in the use of the vehicles for the distribution of goods (combustion engine vehicles with low energy efficiency) because the vehicle is not adapted to the distribution features. In that regard, it is worth indicating that research on transport fleet evaluation has been rather limited and studies focusing on sustainable vehicle evaluation and selection are virtually non-existent (Bai et al., 2015).

From a technical point of view, even today continues skepticism regarding the need of using EVs and benefits derived. This may partially explained by the low supply of EVs and their acquisition costs, higher than combustion engine vehicles, mainly due to the components costs, especially the batteries (improved in recent years), and not optimized manufacturing processes because of current limited production volumes.

However, this skepticism turns into optimism if we analyze: (i) the benefits derived from the use of EVs such as high energy efficiency (Yuan et al., 2015), almost double that an internal-combustion vehicle; (ii) economic energy saving, considering the cost of recharging an EV is significantly cheaper than refueling an internal-combustion vehicle and (iii) derived environmental benefits (Yuan et al., 2015; Buekers et al., 2014). Therefore, the use of electric vehicles in urban freight transport would reduce the noise and air pollution in the urban center.

This paper shows a multicriteria procedure based on the Analytic Hierarchy Process (AHP) for the optimization of transport systems using EVs for freight distribution in urban environments. The alternatives studied are three: (i) Organized transport; (ii) Free access transport; and (iii) Mixed transport.

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## 2. OPTIMIZATION OF TRANSPORT SYSTEMS FOR FREIGHT DISTRIBUTION

This paper addresses the distribution of perishable products in urban environments through the use of EVs for a decrease in costs, emissions and an increase in organization in order to optimize the transport system. The optimization of transport systems in urban environments involves several difficulties. An overview of the main problems related to urban freight distribution is provided in Russo and Comi (2010).

In this paper, three alternatives of distribution are considered: (i) A1- Organized transport, few companies (2-3) are responsible for making transportation, which are subcontracted by the Logistics Center (electrical vehicles controlled fleet); (ii) A2- Free access transport, where the Logistics Center has no organized transport and every customer could use their own transportation service, and (iii) A3- Mixed transport, in which the customer selects between the two previous options.

The proposed model includes the main factors identified according to the methodology to be used: the Analytic Hierarchy Process. This methodology is presented in the following Section.

## 3. THE ANALYTIC HIERARCHY PROCESS (AHP)

### 3.1. A brief introduction to AHP

The Analytic Hierarchy Process (AHP) is a multicriteria procedure used in decision making which is based on the utility function. It structures the decision problem in levels, which correspond to one understanding of the situation: goal, criteria, sub-criteria, attributes and alternatives. Conventional AHP provides in an absolute scale the priorities of the elements being compared. Its methodology consists of four steps (Saaty, 1996):

- Modelling of the problem (hierarchy construction).
- Valuation or elicitation of judgments.
- Prioritisation or local and global priorities derivation.
- Synthesis or derivation of total or final priorities.

The most common procedures used for prioritization are the eigenvector method (EGV) and the row geometric mean method. One of the main characteristics of this methodology is that it measures the inconsistency of the actors when eliciting the judgments of the pairwise comparison matrices.

More and more, AHP is being used in the resolution of complex multi-actors problems due it can integrate the small with the large, the individual with the collective, the objective with the subjective and it incorporates the multi- actors visions into the model during the solution of the problem (Altuzarra et al., 2010).

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### 3.2 Decision model for urban freight distribution

The model has been structured according to a top- down perspective, where two criteria have been identified: the actors and the factors involved in an optimization process of transport systems for urban freight distribution. The hierarchy includes four levels (Figure 1): mission, criteria, sub-criteria and attributes. The actors considered are five:

A1. *Public Administrations*: responsible for carrying out the control, management and administrative regulation of the corresponding transport services. The attributes used to measure this sub-criterion are the existent regulation (Q1) and control (Q2).

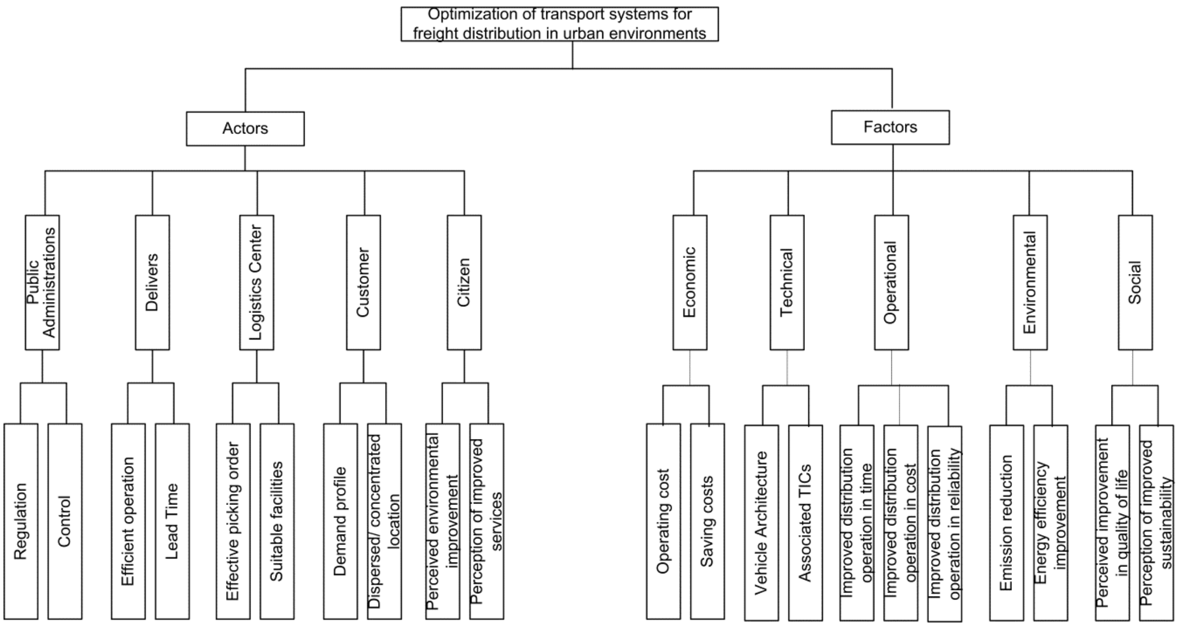


**Fig. 1 – Structure of the problem**

A2. *Delivers*: this actor is fundamental and necessary in any transportation operation. To optimize transport systems two attributes have to be considered: the existence of an efficient operation (Q3) and lead time (Q4) which is responsible for the service quality.

A3. *Logistics Center*: is a separate entity operating in a secured area, within which logistics activities i.e. transportation and forwarding, material handling, warehousing, inventory management, cross-docking, physical distribution of goods, are carried out on a commercial basis (Żak & Węgliński, 2014). The attributes taken into account are the existence of an effective picking order (Q5) and suitable facilities (Q6).

A4. *Customer*: this paper focuses on the distribution of perishable products in urban environments, in special fruits and vegetables, so customers are referred to greengrocers. The attributes chosen to measure this sub-criterion are: the demand profile (Q7) and location (Q8) which can be dispersed (neighborhoods markets) or concentrated (city markets).

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A5. *Citizen:* exercises the influential opinion on the services the customer offers, citizen perception motivates the customer to improve service. The attributes considered are the perceived environmental improvement (Q9) and the perception of improved services (Q10).

On the other hand, there are a number of factors to be taken into account when structuring a problem of transport systems optimization.

F1. *Economic*: in any optimization process, economic factors are essential. The following attributes are considered to be affected by an optimization process in the context of an optimization of transport systems for freight distribution: operating costs (Q11), and saving costs (Q12)

F2. *Technical:* are referred to the vehicle architecture (Q13), considering different EVs typologies, and the associated TICs (Q14) used in the distribution operation.

F3. *Operational*: the optimization of a transport system will directly influence the distribution operation. Thus, the attributes considered are improved distribution operation in terms of time (Q15), cost (Q16) and reliability (Q17).

F4. *Environmental:* This factor is selected due to the use of less pollutant vehicles and the optimization of routes and vehicles. The attributes taken into account are: the emission reduction (Q18) and the energy efficiency improvement (Q19).

F5. *Social:* this factor refers to the perceived improvement in quality life (Q20) and the perception of improved sustainability (Q21) derived from the mentioned optimization.

### 3.3 Evaluation of the model

The hierarchy (Figure 2) was assessed by means of a top- down perspective. Judgments were elicited by consensus in a direct manner, so there is no inconsistency in the judgments. By using the eigenvector method as the prioritization procedure, the local priorities of the nodes of the hierarchy were obtained. In addition, the global priorities of the 21 attributes were derived by means of the hierarchical composition procedure. The alternatives prioritization was obtained by using relative measures. From an operational standpoint, AHP uses (Saaty, 1980, 1994) relative measurements when the number of alternatives (n) is small ($n \leq 9$), and absolute measurements when the number is high ($n \geq 10$).

## 4. RESULTS

The application of the model to the alternatives above presented was carried out by using the Expert Choice (EC) Software. Results show (Figure 2) the ranking of alternatives

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(A1>A3>A2) where organized transport is the preferred for the optimization of transport systems for freight distribution in urban environments from a global perspective. One of the characteristic of EC is the possibility to support the study of the results stability with different sensibility graphic tools.

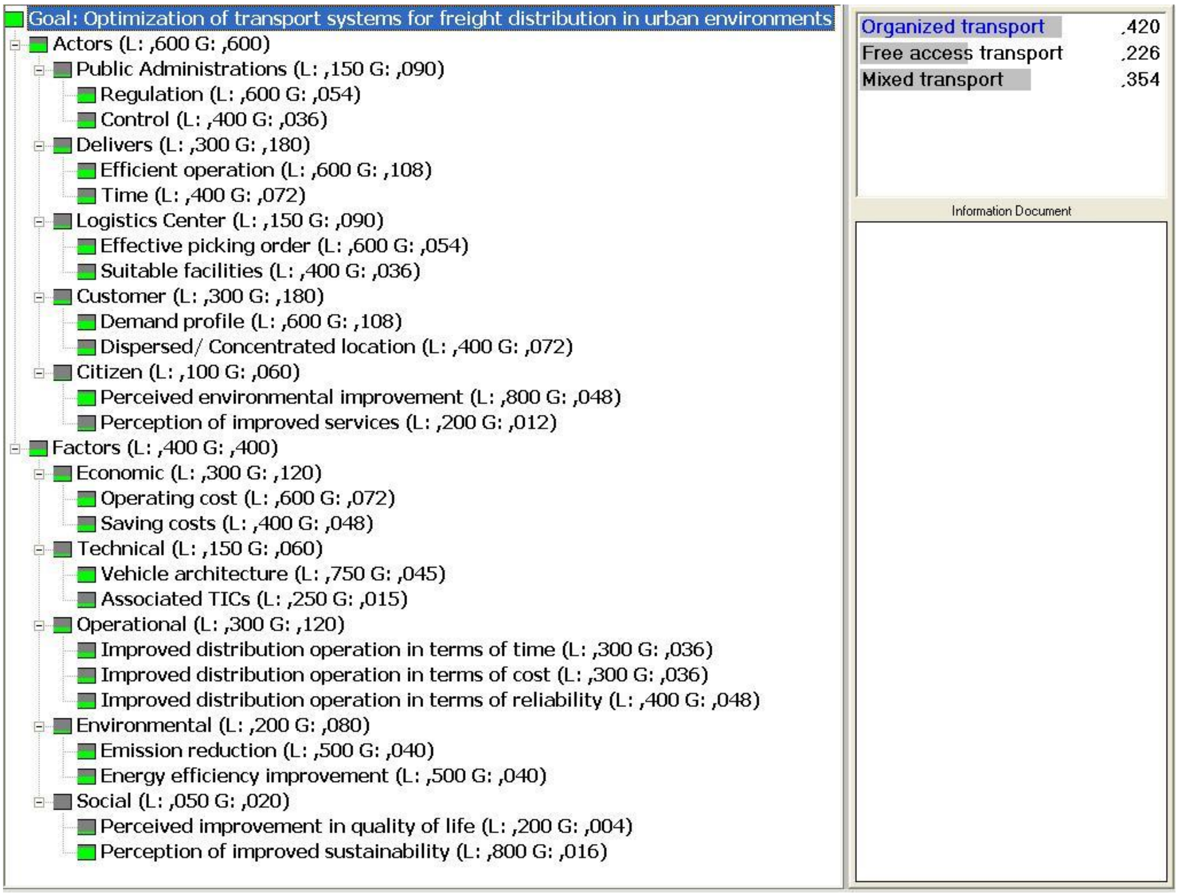
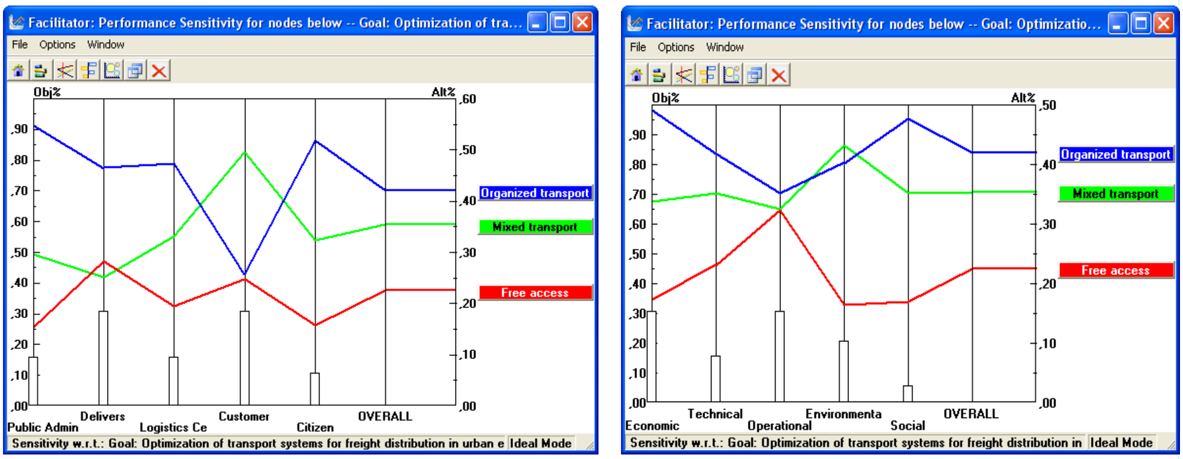



**Fig. 2 – Local, global and total priorities**




(a) (b)

**Fig. 3 – Sensibility analysis of the model: actors and factors**

The performance graphic (Figure 3) gives information on the total priorities of the alternatives and their global behavior with respect to the sub-criteria. From the point of

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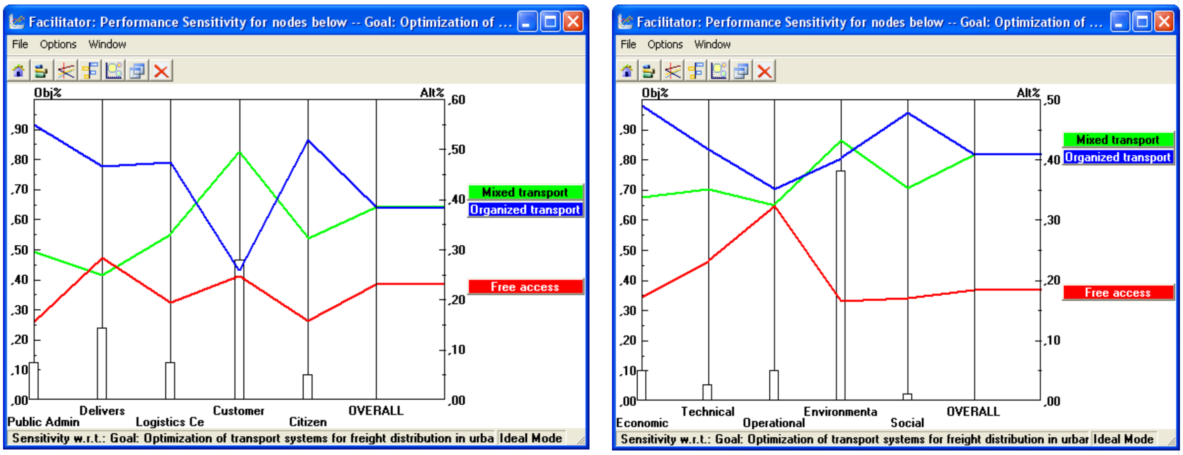
view of the actors, it can be seen A1 dominates the rest of alternatives in the Public Administration, Delivers, Logistics Centers and Citizen sub-criteria. At the same time, from the point of view of the factors, A1 dominates the rest of alternatives in the Economic, Technical, Operational and Social sub-criteria.

By introducing changes in the criteria weight, it can be provoked a rank reversal for the best alternative. For example, is it necessary to increase the weight of the Customer sub-criterion by 17%, for A2 to be the best alternative from the point of view of the actors (see Figure 4a), or the weight of the Environmental sub-criterion must be increased by 56%, for A2 to be the best alternative from the point of view of the actors (also see Figure 4b), although this change is pretty unlikely due to the radical changes to be produced with respect to the baseline values.




(a) (b)

**Fig. 4 – Sensibility analysis of the model: performance graphic simulation of the actors and factors**

The sensitivity analysis confirms that the ranking A1>A3>A2 is robust and “Organized transport” (A1) is the best alternative for the optimization of transport systems using EVs for freight distribution in urban environments.

## 5. CONCLUSIONS

The objective of this paper was the analysis and selection of the parameters that have a major influence on the optimization of the urban freight distribution system and how sustainable means of transport, such as electric vehicles, may strengthen the final decision.

It has been developed a multicriteria procedure based on AHP to prioritize and select the parameters that influence the decision making and it has been studied three distribution alternatives: (i) A1- Organized transport; (ii) A2- Free access transport; and (iii) A3- Mixed transport.

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Results show that A1 is the best alternative, being the proposed analysis very robust. Changes in the ranking of options can only occur from a sub-criteria level (increasing by 17% the Customer sub-criterion weight, or 56 % the Environmental sub-criterion), for A2 to be the best alternative from the point of view of the actors and the factors of the model.

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