OPTIMIZATION MODELS FOR ELECTROMOBILITY IN FREIGHT TRANSPORT

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Abstract

Our contribution is focused on the problem of the use of electric vehicles in freight transport. The area of potential use of electric cars is affected by a high level of uncertainty in terms of efficiency and operating costs. The analysed problems are related to the limited charging station infrastructure and the planning of driving performance with respect to the capacity of the batteries and the total time spent on the route. Current charging stations for passengercture cars cannot be used in case of freight transport, so there is a need to create an overall infrastructure for such type of electric vehicles. The subject of the article is the application of a multi-criteria analysis method ANP and PROMETHEE method for the purpose of locating charging stations, in terms of availability of energy network sources and efficiency of use during charging. Our paper presents some optimization mathematical methods in connection with the application for the purpose of charging station definition, charging station location, etc. The main effect of the application of mathematical models is the efficient use of resources and the mitigation of environmental impacts in the field of construction of new charging stations and their location within existing logistic and production parks.

Keywords: Multiple attribute decision making, charging stations, electric vehicle, freight transport, analytic network process, PROMETHEE

1. INTRODUCTION

Increasing numbers of inhabitants in urban agglomerations bring about increased requirements in terms of provision of supplies which is associated also with negative impacts caused by freight transport. We often include among the main negative influences increased noise, CO_2 and nitrogen oxides emissions and an increased number of means of transport on major traffic arteries. In order to be able to comprehensively address the concept of procurement in urban agglomerations, we often refer to so-called "CITY LOGISTICS". In the area of sustainable road transport, the use of electric trucks as an alternative to conventional vehicles has been discussed in recent years [3,4]. The area of potential use of the vehicles is limited both by an insufficient or completely missing infrastructure of charging stations for electric trucks and by the time needed to charge the batteries. By contrast, the main reason for the introduction of electromobility is its minimal impact on the environment [1]. A study on the use of the energy network shows the vehicles' benefits in the area of charging at night when mainly charging of electric vehicles takes place [7]. Night charging helps balance voltage in the energy network by consuming surplus production. Along with the development of electric vehicles, we should be developing the idea of a smart energy network that will provide energy for these vehicles in the future [6]. Improving the efficiency of charging is related to increasing the efficiency of the energy network, thereby, it is possible to achieve a significant reduction in energy consumption and reduce carbon emissions from energy production. Recently, autonomous charging stations have been emerging as an alternative to stations connected to the central energy network. These stations are dependent on the energy network only if electricity cannot be obtained from renewable sources. Autonomous stations use mainly solar energy [10]. Electromobility also has its limitations, the main one of which being the vehicle's driving range. For vehicles with the total weight of up to 18 t, manufacturers state a range of about 120 km [5]. This range may change depending on the vehicle's load, weather and transport conditions on the route. Based on long-term Mercedes-Benz tests, the range is sufficient only within urban logistics [5]. But what if a vehicle is to be supplied outside this radius? In general, we may say that the network of charging stations for trucks is insufficient and therefore, there is scope for systemic analysis of the charging station definition and for optimization of locations of these charging stations. The quantity of charging station criteria highlights the complexity of the issue ensuing from the possible charging station sites for which multi-criteria decision-making methods can be used when choosing a compromise solution. The multi-criteria decision-making issue of a charging station definition may, for example, be based on the analysis using the Analytic Network Process (ANP) method [8, 9]. From a methodological point of view, the ANP based approach to the assessment of electrical charging stations is a significant innovation. It is very complicated to make a decision about the correct definition of a charging station without using such a method (because the criteria and sub-criteria are not mutually independent) that will be suitable in terms of the availability of energy network sources and charging efficiency. In the ANP method, what is determined is the importance of all relevant circumstances and location parameters as well as the determination of the criteria by which we will judge the ideal location. One of the evaluation criteria is a location near logistics parks or a location at places with a high concentration of freight traffic (parking areas, motorways, express roads). The essence of using the ANP model is the efficient use of resources and the mitigation of environmental impacts in the area of construction of new charging stations. In the application section, the ANP method is complemented by the PROMETHEE method. The PROMETHEE method is based on a pair comparison of options, gradually in terms of all criteria. The result of this comparison is the expression of the intensity of preference between pairs of options in the evaluation in terms of all criteria. The main objective of this contribution is to use these two methods to find and assess suitable criteria for the construction of charging stations for electric trucks.

2. METHODS

2.1. The ANP as a tool for evaluating the criteria of charging stations

Multi-criteria decision-making models are used in many areas for quantification, comparison and evaluation today. The Analytic Network Process method is a method proposed by T. L. Saaty in 1996. The method was primarily derived from the Analytic Hierarchy Process, however, it is, in fact, a more universal method. The Analytic Network Process (ANP) is one of the most efficient tools where interactions between qualitative and quantitative factors create a network structure [9]. It breaks the decision-making issue down to a network of partial issues which are then analysed and evaluated. The network structuring of the decision-making issue helps express situations whereby the decision-making criteria put partial sub-criteria into groups and model their interaction. Groups of criteria may be also represented by individual clusters, such as partial criteria for a decision-making issue. The main benefit of the method is that it allows modeling and evaluation of interdependencies between options, criteria and sub-criteria, or rather between individual sub-criteria. The general ANP model thus has a four-stage hierarchical structure:

- the objective of the analysis, or rather, of the decision;
- a group of criteria;
- a group of sub-criteria. Sub-criteria usually include barriers to achieving goals;
- a group of alternatives.

Essential for defining the charging station definition is feedback of clusters that are connected one by one to form a comprehensive network model. We assume that the individual criteria interact and mutually affect each other. This means that the hierarchical structure could be transformed into a network structure, and the ANP model appears to be a very good tool for solving this issue.

2.2. PROMETHEE Method

Another option for determining the weights of individual criteria is to apply the PROMETHEE method. The first step of this method is to determine the coefficients $P_i(a_r, a_s)$ from the interval that express the intensity of the

preference for option a_r in relation to option a_s according to criterion j. This intensity depends on the difference of the criteria values $d_j = y_{rj} - y_{sj}$. For the maximization criterion it holds that the greater this difference is, the higher is the intensity of the preference. The intensity of preferences in the evaluation of two options in terms of all criteria is expressed by $Q(d_j)$.
Preference intensity values are based on the following relations:

$$P_j(a_r, a_s) = Q(d_j), \text{ if } d_j \text{ is non-negative}$$
$$P_j(a_s, a_r) = Q(d_j), \text{ if } d_j \text{ is non-positive.}$$

The PROMETHEE method offers 6 basic types of preferential *Q* functions to the user [2]. The basic parameters of these functions include the preference threshold, the indifference threshold and the standard deviation of normal distribution while the application of any particular parameter depends on the structure of each particular preference function. For the given model, the *Q*6 preference function has been selected. This is a special type of a preference function that transforms the difference in evaluation of options according to the criteria using the Gaussian function. In this case, it is necessary to specify a standard deviation of the normal distribution. The value of this function is approaching one with the increasing difference but it never achieves it; it thus means that, according to this function, no difference between the options is classified by the absolute preference relationship.

The decision-maker must take into account the following information when choosing a preference function:

- If decision-makers have a good idea of the importance of the differences in the criteria values, they are able to choose both the preference function type and the threshold values.
- If they do not have an idea of the importance of these differences, they use the *Q*6 function which requires a parameter that can be derived based on values in the decision-making matrix. The sigma parameter is calculated as the standard deviation from the criteria values.
- If users do not dare to enter the parameter values, they still have available preference function Q1. However, this function is used in criteria in which options would have only a few specific values (a typical example is the "yes" - "no" evaluation). Therefore, this function cannot be generally recommended.

3. A CASE STUDY

3.1. The ANP Model for Charging Station Definition

The Superdecision software model was used as a tool for building a dependency network between criteria evaluation attributes. The first level of the hierarchical network under the Goal node represents the level of criteria as unique clusters (between which there are no interdependencies). The unique clusters weights were set identically to 0.167.

Another level is represented by individual criteria (clusters) with sub-criteria which are a key part of the process of evaluating the importance of each sub-criterion within the ANP process. Relationships within clusters are most topical in terms of economic and technical factors and locations. Achieving some sub-criteria excludes the achievement of others or, vice versa, achieving some sub-criteria accelerates the achievement of others. Similar relations have been observed within other clusters and between them. Respecting these current weights based on expert judgment and they are calculated using Saaty's matrix which is an integral part of the Superdecision software.

3.2. Charging Station Criteria

Level of criteria in the ANP process is designed by SMART principle. The aim is a general declaration of the desired outcome with one or more sub targets that define exactly what the resulting charging station should look like. Criteria and sub-criteria that are taken into account to select the location of the charging stations have been derived from Wu et al [11] and customized for freight transport in Czech conditions. Thus some criteria were refined and expanded (Geographical location) and some of them were modified and enhanced (original Wu text was designed for Chinese conditions). Among most modified ones Energy saving (stability) can be named. Here the possibility of creating an autonomous station independent of the energy network was taken into account. All the criteria are complex and are composed as a mix of demand based (e.g. Convenience of transportation, Location) supply based (e.g. Rechargeable Capability, Capacity expansion) and general ones (Environmental impacts, Support from local government)

Table 1 Criteria and sub-criteria

Evaluation Atributes	Criteria	Destription	Measurable
Economic factors	Construction costs	costs associated with the purchase of land, project documentation, construction of the charging station	EUR
	Operating costs	costs including all operating charges related to daily operation. Operating costs are important in terms of financial gain	EUR
	Return on investment (ROI)	relevant in terms of cost and operating income assessment. The most important economic criterion in the commercial sphere	EUR
Technical factors	Distance from the distribution station	location near the distribution station affects loss of power transmission	Km
	Impact on the energy network	relevant for the safe operation of the energy network	MWh
Service availability	Rechargeable Capability	Maximum number of charging stations in a single moment. This sub-criterion is related to the number of vehicles that can be charged	number of charging stations
	Availability (Convenience of transportation)	criterion important from the point of view of the available road network by a lorry	number of accessible roads
Social factors	Capacity expansion	a necessary requirement in terms of further increases of freight electric vehicles	volume of newly build charging stations
	Local position	relevant requirement of impact on the potential health problems of the population (electromagnetic fields, traffic growth)	number of issues released for construction
	Support from local government	this attribute may include possible grant titles for construction (National Action Plan for Clean Mobility)	number of issues released for construction
	Increasing employment	relevant for new labor market opportunities and job creation	number of newly created jobs
Environmental impacts	Environmental impact	the necessary environmental impact assessment (EIA process)	carbon footprint CO_2
	Energy saving (stability)	the possibility of creating an autonomous station independent of the energy network or creating a hybrid model that could respond to excess of energy in the network and thus compensate for fluctuations	MWh
	Impact on the energy network	an immediate demand for performance (charging) can destabilize the energy network	MWh
Location (geographic location)	Logistic Parks	relevant from the point of view of logistics chains engagement accepting places with a high concentration of vehicles used for products (goods) transportation	number of available logistic parks
	Logistic objects	places with concentration of production plants	number of production plants and parking areas with logistic services
	Parking Places	transport terminals (ports, railway stations) places with a high concentration of freight traffic	number of parking places

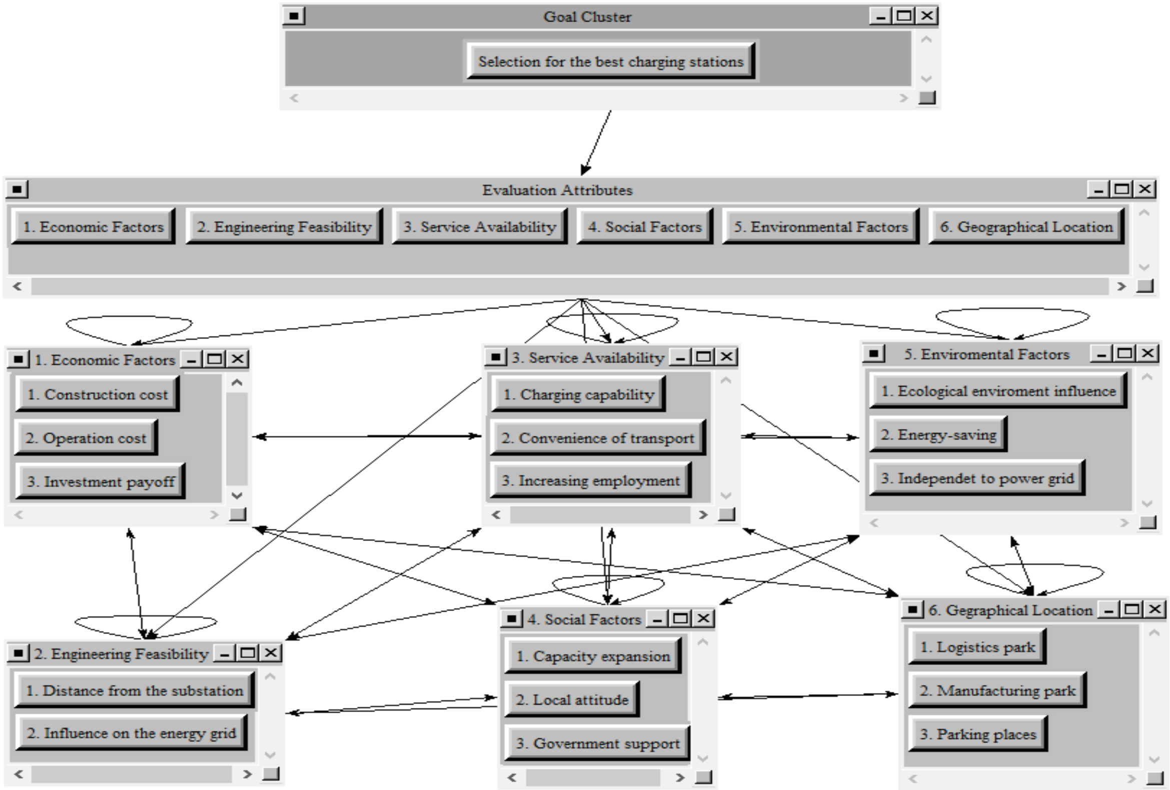

Figure 1 Network model of Charging Station Definition (software Superdecision)

3.3. The PROMETHEE Method Application

Two independent logistics experts have been approached to provide a more precise definition of the criteria. Based on the specified score scale, they determined the relevant number of points associated with the specified criteria. Each expert expressed the importance of the criteria using a scale of 0 - 100 points. Subsequently, the PROMETHEE method with *Q6* preference curve was applied. The calculation itself was carried out by the software with the help of the programmed Excel add-in tool.

4. RESULTS

The aim of the paper was to analyze the quality and quantity of the various criteria which are essential to define the charging station for electric vehicles. The problems of freight electro-vehicles charging stations unlike the charging stations for passenger cars have not yet been analyzed in detail and thus ANP analysis with a SMART approach to evaluating the criteria, here can be beneficial.

The first results of the ANP method indicate a significant influence of the "number of charging stations" criterion with weight of 0.166. This is thus the main criterion that will affect all the other criteria, in particular, the economic criteria associated with the investment, operating costs and return on investment. The second criterion is the "Distance from the substation" with a weight of 0.113.

On the contrary, the PROMETHEE method, based on the judgment of experts, defines as the main criterion "construction costs" with a weight of 0.2839. The second criterion is the "number of charging stations" with a weight of 0.2809. Due to the minimal distance between these criteria, this criterion can be marked as highly important in terms of further evaluation of the selected sites.

The resulting ranking of the two methods shows the economic focus of the experts who set, as the third criterion, the "return on investment". This criterion is important in terms of commercial construction. It cannot be assumed that the construction of charging stations will be covered from public budgets and will, therefore, be one of the main indicators for investors

5. FUTURE RESEARCH

Another procedure within the addressing of the issue is the application of localization issue algorithms in order to optimize the distribution of charging stations to ensure that they will adequately cover the needs associated with the charging of trucks and that the solution is rational in economic terms. The solution will make it possible to assess the effectiveness of the location of an existing infrastructure element (logistics parks, resting stations and analogous elements) or rather locations of the charging station into its premises if its calculated optimal location is in its integral proximity. In the case of its calculated location being completely outside this structure, the solution analyses the costs and the viability of its potential establishment in view of the planned completion of the motorway network and the network of 1st class roads in the Czech Republic.

After defining the issue (constructing the graph) and solving the optimal location of the absolute depot/absolute depots, we get the theoretical location of the charging stations. Ideally, this means building the charging station exactly at the specified point. It can be estimated that, if the requirement for an optimal location of absolute depots is met, it would be necessary to spend a lot of funds to build completely new charging stations. This solution is not financially acceptable as it would mean a complete construction of mostly new infrastructure.

The proposed solution, as mentioned above, is in the predetermined radius near the identified point of an absolute depot to search for some already existing infrastructure suitable for completing a charging station. The result is a proposal of suitable points within the existing infrastructure combined with completely new identified sites, with the assessment of the viability of their being constructed

6. CONCLUSION

Choosing the location for a charging station is an important item in terms of sustainable freight transport development. In order to define a suitable place, we need to analyse a number of different criteria that are necessary to define a charging station. The issues surrounding charging stations of electric trucks, as opposed to charging stations for passenger cars, have not yet been analysed in detail. The methods used seem to be appropriate from the point of view of different criteria. The comparative analysis of both methods showed the stability of the decision-making process.

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