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http://hdl.handle.net/11067/7380
https://doi.org/10.34628/XNZF-MQ59

Metadados

Data de Publicação 2023

Resumo Due to concerns about reducing CO2 emissions, the number of electric cars has increased in recent years, which promotes the need to increase the number of charging stations, especially in cities. This case study aims to identify the best point for the installation of a new electric charging station in the municipality of Viana do Castelo, Portugal. The methodology used is the centre of gravity method, using as data the number of charging stations available in the city. The aim is to find a centr...

Tipo bookPart

Editora Universidade Lusíada Editora

Centre of gravity method for locating an electric charging station – an initial approach for Viana do Castelo

DOI: https://doi.org/10.34628/XNZF-MQ59

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Abstract: Due to concerns about reducing CO_2 emissions, the number of electric cars has increased in recent years, which promotes the need to increase the number of charging stations, especially in cities. This case study aims to identify the best point for the installation of a new electric charging station in the municipality of Viana do Castelo, Portugal. The methodology used is the centre of gravity method, using as

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data the number of charging stations available in the city. The aim is to find a central location that minimises the distance between the new charging station and the existing ones. In this work, a first approach was made by analysing all existing charging stations, assuming the same weight in the network, disregarding the number of chargers in each station and the importance of the facilities available nearby. The results were promising and showed that the new location point was in the city centre, near a high school.

Keywords: Electric charging stations; Centre of gravity method; Location; Infrastructure; Viana do Castelo.

1. Introduction

The lifestyle and wealth that human beings have enjoyed in recent decades have evolved globally challenging the energy sector, especially in increasing environmental concerns as the author explains [1]. Almost every day we are instilled in the fact that global warming is a reality and that it is extremely necessary to act to reverse this situation, and one of the main causes for this event is the emission of gases from fossil fuels.

In this way, electric mobility emerges as a very promising substitute for reducing emissions. Electricity is a more economical source, thus enabling the introduction and use of electric vehicles in order to reduce costs and generate a better competitive advantage, which in turn will contribute to a more sustainable economy [2]. According to Nascimento [3], this states that in September of the year 2022 was the month in which more 100% electric vehicles were sold compared to the last three years, making a total of 3,831 vehicles sold of 3,831 both electric and plug-in hybrids.

However, with the use of electric vehicles it is necessary to analyse the number of charging stations, since these infrastructures also have an important role to play because, without these, electric vehicles cannot meet the needs that the customer wants.

In this way, sustainable mobility has been driven by the governments of several countries, resulting in a strong dynamic in the electric vehicle market. With the growth in the electric vehicle market, there is also a growing need to install charging infrastructure so much given the relationship of interdependence between the two [4].

Charging infrastructure could be considered as logistic infrastructure as it was a point of electricity supply, an electric energy warehouse. Logistics infrastructures are seen as a great enriching agent for the economic development of the country where its locations are decided in a broad and lasting way and with a certain impact on logistics operational decisions. The most effective infrastructures depend on the selection of the site, based on capital investments, labour and above all to minimize costs and time [5].

Siqueira and Calegario [6] points out, the decision of any location requires feasibility studies that allow a greater return, and these decisions should be based on the balance between profit and those inherent in the location of the facility with the service provided. The increase in more modern logistics demand has increased the demands. For example, we have increased quality, the type of infrastructure, the quality of logistics services and the restructuring of space that due to the present geographical dispersion of the supply chain leads to a greater distance between suppliers, distributors, manufacturers, and consumers. In this context, the reduction of logistics costs and improvement of the level of service provided by an exceptional geographical location are predominant for the survival of companies.

Viana do Castelo is a municipality of Alto Minho region, in the north of Portugal, where the local government has big concerns about sustainable technologies and better life for their citizens, promoting the acquisition of electric vehicles and guarantee the best conditions for their charging on the municipality. This study intends to answer to the RQ: Where is the best location for an additional electric charging station, in the Viana do Castelo municipality, considering the existing ones?

The objective of this work and based on the charging stations already existing in the city is to identify the best location for a charging station in the city of Viana do Castelo, minimizing the distances. This study will be elaborated applying the centre of gravity method to find the most viable location and a more competitive positioning.

2. Literature Review

2.1. Infrastructure

During recent years it has been possible to observe a transformation in logistics infrastructure. This notorious evolution, not only in terms of infrastructure, but also at the level of the supply chain, led to changes in the functions and locations of logistics facilities [7]. Although many studies analyse the various changes in the distribution of logistics facilities and indicate information on the factors that drive their migration, there are few studies that analyse the factors that influence the choice of the location of an infrastructure [8].

With the growth of the economic system, there is a new approach to location models, in which transport, logistics and infrastructure are considered very important in creating value for economic zones [9]. Organizations use logistics to gain competitiveness and build more sustainable relationships with their customers, as increasing competitiveness and performance are factors that drive the commitment to logistics and the supply chain itself.

In the last 20 years logistics infrastructures have been heavily studied due mainly to the growth of freight vehicle traffic attributed to the movement of logistics facilities from the interior to the outside of cities.

Infrastructure scans can be identified as specific buildings consisting of a set of production and non-production sectors that include logistics complexes, industrial, free economic zones and other forms of organization of economies [10]. In this way, the progress of logistics operations in conjunction with ICT has contributed to the growth of the supply chain oriented mainly to demand.

As the authors Musgrave & Peacock [11] claim, it is possible to relate infrastructure to economic development, and there are theories that capital accumulations, particularly in infrastructure investments, are subject to decreasing incomes. Therefore, regardless of whether infrastructure investment has a growth effect, it is an issue that will depend not only on the size of the investment but will also depend on a number of other factors that can foster or disrupt the literature between infrastructure and its economic development. It is important to show that location and infrastructure interact with each other and determine the direction and size of trade flows.

2.2. Charging stations location

The first studies addressing localization were done in the early 20th century, and the first location model was composed by Alfred Weber. Understanding where to best locate an installation involves a long-term strategic issue. Their economic investment can influence the decisions of the supply chain, which means that the decision becomes not only an economic issue, but also of its survival [12]. The choice of a location may involve several factors such as transportation cost, taxes and incentives, market potential, quality of life, space costs and expansion availability, as stated by [5]. Although site selection can be influenced by qualitative factors, a study based on quantitative methods such as costs and distances can give a more assertive and useful direction to reduce the probability of errors [5].

As the author [13] points out, the difficulties in meeting the strategic locations of the facilities no longer be used heuristic procedures and quantitative methods began to be used, and the primary objective is to obtain a solution that improves the relationship with customers through the quality and minimization of installation costs.

An electric vehicle charging station can be installed in a private space (house, work, condominium) or on a public road. However, the process of planning, installation and commissioning of charging stations in Portugal is a complex chain of procedures, which in itself does not help in the development of electric mobility [14]. The installation of a charging station is a very bureaucratic process where there can be two types of installations: a new DNO connection (Distribution Network Operator) or through an existing connection. Where there is a new connection, there will therefore be a new phase of the feasibility application, where the DNO assesses whether there is viability in the surrounding network. Next, the request for connection to the network appears, where the applicant requests how the extension and tracing should be done, where the applicant must start the construction of the connection point.

In parallel, the Charging Point Operator (CPO) can start installing the loader by waiting for the extension to be built, which may be the responsibility of the DNO or the customer. This operation may be even more time consuming if it must include applications for municipal permits, the roads of Portugal, the infrastructure of Portugal, interventions in the underground of the public road, among others.

That said, it will be necessary to check between the installation of the connection point and the charger, as well as the other certifications. After the approvals, registration is carried out in the DNO system, starting a registration phase with the EGME (Electric Mobility Management Entity) to which the documentation of the charging station is sent.

Thus, if the CPO's power contracts are recorded in collaboration with EGME will make the proper commissioning of the charging station, preparing all tests and tests to establish the communications and integration of the OPC in the infrastructure of public charging systems. Finally, the post will be fit for use.

2.3. Centre of Gravity Method

There are several methods used to determine the better location of infrastructures namely, centre of gravity method, linear programming, simulation, and heuristics [15, 16, 17]. The authors, Peinado and Graeml [18] expose that an alternative to looking for a better location is through the centre of gravity method. This method can be used when you want to study the location of a new facility, considering existing installations. The geographic point generated from the method application corresponds to the "centre of gravity" and represents the point where the costs are minimal. It should be noted that the centre of gravity method may be related to several variables such as weight, volume, rates and distance to select the lowest cost, as cited by Souza *et.al* [5].

Thus Hoover [19] showed that transportation charges decrease with increasing distances, that is, by seeking to minimize transportation fees a facility located between a source of raw materials and a market point will obtain a minimum cost of transportation at one of these two points.

The formula for minimizing the total cost is the sum of the flows, which can be quantity or cost, , multiplied by the distances (equation 1) and to calculate the distances the formula that is represented in equation 4 is used.

$$Min\ C = \sum_{j=1}^{n} W_j D_j \qquad (1)$$

According to Ballou [13], the process for finding the ideal location occurs in several stages, the first is designated by determining the initial solution of the centre of gravity method that consists of determining an initial location, thus determining the coordinates X^0 and Y^0 (equation 2 and equation 3). The second step consists of calculating the D_j (equation 4) from X^0 and Y^0 to all the other points (j). The third phase is to determine the total cost associated with this initial location (equation 1).

$$X^0 = \sum_{j=1}^{n} \frac{W_j\, X_j}{W_j} \qquad (2)$$

$$Y^0 = \sum_{j=1}^{n} \frac{W_j\, Y_j}{W_j} \qquad (3)$$

$$D_j = \sqrt{\left(X - X_j\right)^2 + \left(Y - Y_j\right)^2} \qquad (4)$$

The fourth step is to find the new points of location based on the distances calculated, D_j, (equations 5 and 6) X^i and Y^i.

$$X^i = \frac{\sum_{j=1}^{n} \frac{Wj\, Xj}{dj}}{\sum_{j=1}^{n} \frac{Wj}{dj}} \qquad (5)$$

$$Y^i = \frac{\sum_{j=1}^{n} \frac{Wj\, Yj}{dj}}{\sum_{j=1}^{n} \frac{Wj}{dj}} \qquad (6)$$

Then the and are replaced in the distance equation, and finally the total cost is determined again. This process is iterative and should stop with a stop criterion defined by the researcher. The goal is to minimize the final total cost for the solution to be optimized.

Intuitively, and like all existing methodologies, this method also presents fragile aspects. For the authors Peinado & Graeml [14] it is important to remember that for decision-making involving localization decisions it is advisable to use another evaluation method, allowing a more comprehensive and in-depth analysis of alternatives. Despite the importance of an economic analysis, increasingly the reduction of costs is not considered isolated to determine the location, being notorious that localization problems are solved using various quantitative and qualitative techniques of research in operations.

3. Methodology – Case study

This case study is an applied study that uses the centre of gravity method to solve the problem of locating an electric charging station in the municipality of Viana do Castelo.

As numerical data will be used, the method becomes quantitative, and the analysed data refer to the months of October and November 2022 and were collected through the ElectroMaps [20] application and Googleearth software. Through these applications it was possible to analyse the number of posts already existing in the municipality of Viana do Castelo, having concluded that there are in total 39 posts, located according to Figure 1.

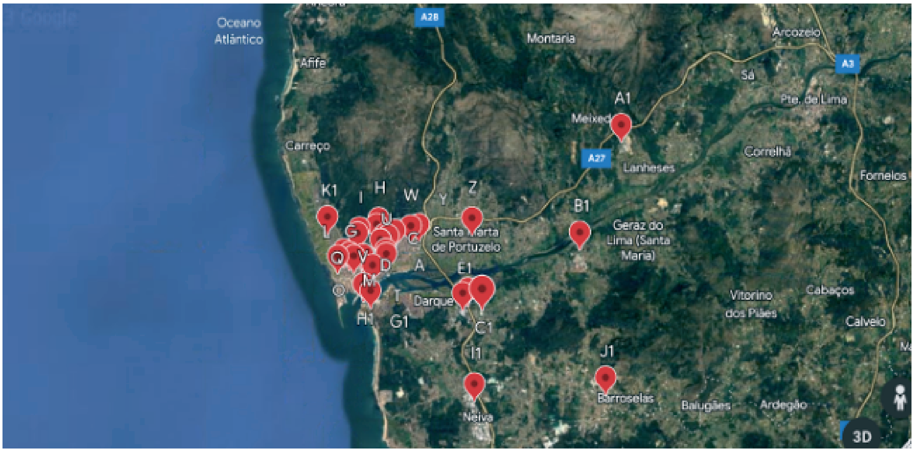

Figure 1: Identification of electric charging stations in Viana do Castelo (GoogleEarth)

With the help of Google Earth [21], the area (region) on which the study will be carried out, in this case the municipality of Viana do Castelo, then withdrew the data relating to each loading station, more specifically, the coordinates, power, what type of loading and the parish to which it is located. For this specific study, Table 2 shows only the coordinates related to the location of the 39 electric vehicle charging stations.

Table 2 - Coordinates referring to the locations of the existing charging stations in the municipality of Viana do Castelo

Posts	X	Y	Posts	X	Y	Posts	X	Y
P1	41,705517	-8,820177	**P14**	41,708814	-8,824271	**P27**	41,69711	-8,833432
P2	41,705199	-8,824123	**P15**	41,69376	-8,841589	**P28**	41,690347	-8,827646
P3	41,705133	-8,834503	**P16**	41,693446	-8,845992	**P29**	41,700053	-8,822737
P4	41,703205	-8,836116	**P17**	41,693749	-8,834071	**P30**	41,705675	-8,807487
P5	41,694807	-8,838027	**P18**	41,693267	-8,830758	**P31**	41,710756	-8,830178
P6	41,693039	-8,819355	**P19**	41,695166	-8,821614	**P32**	41,705756	-8,801528
P7	41,74583	-8,68879	**P20**	41,696675	-8,833905	**P33**	41,678206	-8,767299
P8	41,700941	-8,710983	**P21**	41,705884	-8,795827	**P34**	41,680819	-8,778324
P9	41,68153	-8,826224	**P22**	41,680064	-8,830697	**P35**	41,680161	-8,776789
P10	41,641377	-8,768788	**P23**	41,709943	-8,851421	**P36**	41,682093	-8,80888
P11	41,645566	-8,702329	**P24**	41,706155	-8,814934	**P37**	41.700642	-8.822117
P12	41,702125	-8,821545	**P25**	41,699182	-8,817819	**P38**	41.694807	-8.831416
P13	41.699381	-8.823410	**P26**	41,695386	-8,843901	**P39**	41,690018	-8,829326

4. Application of the method

After the identification of the loading stations and considering that all have the same importance/weight, that is, $Wj=1$, the centre of gravity method was applied to obtain the optimal point of location of the new charging station, considering as a stop criterion the variation between iterations of less than 0.5%. The result of iterations can be seen in Table 3. With only 4 iterations, the coordinates of the new loading station were obtained, with a variation of the total cost (distance) less than 0.5% of the previous iteration.

Table 3- Results of the application of the center of gravity method

	1st iteration	2nd iteration	3rd iteration	4th iteration
Coord. X	41,6952	41,6872	41,6977	41,698
Coord. Y	-8,8112	-8,8194	-8,8217	-8,8226
Objective Function	1,16808794	1,05144377	1,03540962	1,03279
Variation	**0%**	**10%**	**2%**	**0,30%**

The new charging station should be located at the point with the coordinates: (41.698; -8.8226). Figure 2 shows the concrete location of the optimal point (yellow point). It is in the town of Viana do Castelo near the Secondary School of Santa Maria Maior. This is a possible point to implement, with a potential for placement and serving a population area with services attached.

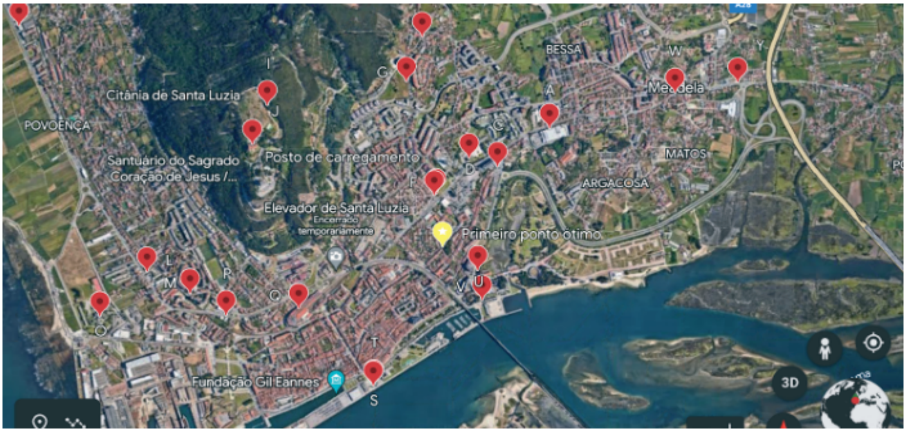

Figure 2: Location of the optimal location point at the new electric charging station in Viana do Castelo (GoogleEarth) (The first figure a generic view of Viana do Castelo; the second figure a more detailed view of the city).

5. Conclusions and limitations

In this study, we used as reference a set of 39 loading stations, duly identified with latitude and longitude, existing in the municipality of Viana do Castelo. Through the centre of gravity method, the best location for a new post was studied, which was the most central, considering the existing charging stations. The location found is deployable and appears near a school, with the coordinates (41,698; -8,8226). However, this study did not consider the number of charging stations that each station already has, nor its load capacity. Thus, as a future work, it is intended to use the centre of gravity method, using additional information from the loading stations (i.e., differentiating the value of W) to promote the inclusion of new charging stations in areas whose network coverage is more deficient.

Acknowledgements

This work is supported by The Center for Research and Development in Mathematics and Applications (CIDMA) through the Portuguese Foundation for Science and Technology (FCT - Fundação para a Ciência e a Tecnologia), references UIDB/04106/2020 and UIDP/04106/2020 (Rodrigues). This research is part of Catarina Gonçalves logistics master thesis.

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