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Iterative methodology on locating a cement plant

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Abstract

In this study, a cement plant location was determined by considering essential parameters such as the locations of resources and their importance in the manufacturing process. A crucial mathematical problem, named Weber problem, reinforced the decision of the method of allocating the factory. Additionally, not only the limitations of the cement production but also the importance weights of goods used in the manufacturing were taken into account in the iterative methodology in order to answer the engineering question via the mathematical problem. As a result, by optimizing the case through the iterations introduced in the paper, the location of the cement plant was set. Hence several losses such as extra travel distances and time wasting in transportation were minimized.

Keywords: Cement plant; Iterative technique; Optimization; Transportation cost; Weber problem

1 Introduction

For many decades, mathematical techniques, models, and methodologies have been essential in order to provide the understanding of countless engineering processes and implementations. Using mathematical models in many academic researches, it was demonstrated that numerous infrastructure problems can be solved, for instance, locating facilities or infrastructure related to a specific industry such as cement production.

The location of a facility is the place where the business will be established and will continue to work throughout service life. In determining the business strategy, the company determines what goods or services will be offered and in which market it will compete. After making the product and process design decisions, the next step is the choice of location. Location decision affects costs of supplying inputs, production, and distribution, thus influencing productivity. The location of the establishment is in question not only in new establishments, but also in decisions expanding the facility, producing new products, or adding a new section to the plant.

Therefore, the scope of this work is to make right, healthy, and sustainable location determination for a selected specific industry, namely cement manufacturing facility by using a method mentioned later on, which can be applied to any kind of facility construction by taking the parameters affecting the cost into account. Cement production industry is vital for the economic development of a country and cannot be totally removed. Thus eliminating the damaging effects of such facilities can be a more preferable way in order to

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determine the most convenient location of these plants. This study will offer a route for determination of location for similar industrial activities rather than only cement production.

The remainder of this paper is organized as follows. In the next section (Sect. 2), a literature review is provided. Section 3 describes the methodology, including the models applied for the implementation of our proposed approach. In Sect. 4, we present a typical case study, followed by the main results in Sect. 5 with discussions. Finally, conclusions are delivered in Sect. 6.

2 Literature review

Using mathematical techniques and models in many academic researches for many decades, it was shown that several infrastructure and transportation problems can be solved when locating facilities related to a particular industry. For instance, research on the problems of optimizing transportation costs, network analysis, and regulating the road capacities on a transportation network can be described via inequalities [1–3]. After employing an optimization technique, solutions with an adequate performance of traffic, location analysis, including transportation, can be found. Another specific area could be determining a transportation activity location such as that of a cement plant, which is one of the most common concerns of local or regional authorities. For such a purpose, many researches have been conducted in the literature. Researchers [4] studied the problem of locating undesirable facilities such as landfills, creating potential effects of soil anomalies. They utilized different maps such as those of land use, soil, rivers, road networks, etc., in order to overlay them in a geographical information system (GIS). There are musts and needs in order to locate facilities. For example, a facility could be located a few kilometers away from cultivable lands and within a specific distance from an asphalt road. In addition, specific facilities such as cement plants, which may cause undesirable effects to the environment, must keep a certain distance to special places such as residential areas. Therefore, due to the negative impact of cement plants on the environment, alternative materials instead of cement have been sought by some investigators in their research [5, 6]. Alternative areas can be revealed using the tools of computer software including mathematical models.

Another study [7], in order to situate an alumina–cement plant, suggested a multicriteria estimation method that was to compare a couple of alternative sites analyzing the important factors of accessibility to raw materials in terms of distance, water, and power supply, as well as land concerns. The model proposed a location of a plant by integrating typical inputs of a facility such as transport, water, power, fuel consumption, and land.

The authors of [8] proposed an approach of type-2 fuzzy sets and compared their method with a few other fuzzy approaches in order to solve a single-facility location problem. Additionally, several criteria of fixed and variable costs such as the costs of land, transportation, raw material, energy, environment, and insurance were considered in their study.

A couple of recent studies [9, 10] utilized analytical hierarchy processes and GIS techniques to develop decision making processes. An example can be for a site selection of an industry such as cement production. While the candidate areas were weighted by the criteria related to the industry, the characteristics of the areas were evaluated according to their sustainability concerns.

Recently, some other studies [11–14] proposed methodologies of optimization models including decision making goals, as well as multi-objective decision making problems having conflicting objectives. While a couple of them looked for the optimization of properties of materials through models, the rest sought for the set of Pareto solutions rather than optimal solutions to determine a facility location.

3 Methodology

This study focuses on finding and determining the most suitable location for an intervention of a facility. Hence, an approach of locating a single point facility location is constructed; thus, a couple of techniques and methodologies completed in the related literature can be implemented to solve the case in this study. For example, an approach to solve the central median location problem known in the literature can be applied for determining the location [15, 16]. However, when placing a cement plant, we must consider more parameters. Therefore, scientifically a more advanced technique should be constructed for competent results.

3.1 The technique of Weber problem

When solving the central median location problem, the location of the plant or institution can be easily calculated because the sum of the geometric planar costs (i.e., distances) to the final location from the demand points (i.e., places needing a kind of service) is a minimum. Even though this method seems applicable, unfortunately, it does not take the weights of demand points (i.e., service required points) into account. Apart from that, another technique regards the weights of demand points with the help of minimization of the weighted Euclidean distances in a two-dimensional space to a single facility location. This mathematical technique was presented by Alfred Weber [17], and the method was named the Weber Problem (WP). The optimization of location is the main purpose in this operation research problem. WP is essentially solved by minimizing the weighted Euclidean distances for finding the best location in terms of the service to the demand locations [15, 16, 18–21]. WP can be briefly described as follows:

$$\min \sum_{j=1}^{n} w_j |\bar{x} - \bar{x}_j|. \tag{1}$$

The description in (1) uses $\bar{x} = (x, y)$, that is, the optimum location coordinate which is wanted and preferred, and $\bar{x}_j = (x_j, y_j)$ which represents the particular demand point location of j where $j = 1, \dots, n$. Therefore, by subtracting $\bar{x}$ from the location information of $\bar{x}_j$, the optimization process can detect the distance measure between two locations. Further, the weight of a specific demand point is presented by w_j in the description of (1). Put it differently, w_j symbolizes the significance or rank of the particular location point of $\bar{x}_j$ in comparison to the other location points. In addition, all of the location points (i.e., $\bar{x}$ and $\bar{x}_j$) in (1) are the points at the surface of E^2, that is, the Euclidean plane. It is the two-dimensional space of real numbers (i.e., commonly denoted by $\mathbb{R}^2$). Lastly, the minimization of the products of the certain distances and the related weights is finished. Consequently, by optimizing (1) we select the most appropriate position or location of $\bar{x}$.

3.2 The application of Weber problem to Weiszfeld algorithm

Because the weights of demand points will be considered in this study, the most proper approach to answer our location question is to solve a particular WP. Weiszfeld has proven in his investigation that an iterative procedure can be implemented in order to solve WP [22–24]. This iterative technique, called Weiszfeld method or algorithm (WM), is accepted as a very powerful process in practice to identify the optimal facility location of WP [15, 25]. On the market, there are computer programs or software which are used for running the methodology of WM and achieving solutions through WM. Because the computer program LINGO can achieve the solution of WP by applying WM [25, 26], it is used as a tool for analyzing the location, and thus optimizing the location. The reason of solving the optimization problem in this study by using the computer software LINGO is that it is able to analyze and detect the optimum location of a solution point using the weighted Euclidean distances of demand points in a predetermined surface of a topography [27]. The program continues the iterations until all the demands in the analysis are satisfied in terms of their weights [28]. As soon as the location of solution does not change when running further iterations, the iterations are stopped and the final decision of the optimization is reported by the program.

The location allocation problem, which is a mathematical problem discussed above, will be solved by WM. Since the location of a facility and the weighted importance (i.e., including the capacity of the facility, production rate, accessibility to the resources, etc.) are the inputs, the methodology discussed in this section can be adapted to the problem of this research. Related formulation can be stated as follows:

$$\min\Big[a_1\sqrt{(X_f - x_1)^2 + (Y_f - y_1)^2} + \cdots + a_n\sqrt{(X_f - x_n)^2 + (Y_f - y_n)^2}\Big]. \tag{2}$$

The formulation in (2) uses some variables which are described as follows: (X_f, Y_f) denotes the most suitable location of the facility; n is the number of demand points; $i = 1, 2, \ldots, n$ indexes the demand points from 1 to n; (x_i, y_i) are the spatial coordinates of a demand point i, which runs from 1 to n; a_i is the total demand of point i, again from 1 to n; D_i is the Euclidean distance to (X_f, Y_f):

$$D_i = \sqrt{(X_f - x_i)^2 + (Y_f - y_i)^2}; \tag{3}$$

a_iD_i is the weighted Euclidean distance to (X_f, Y_f):

$$a_iD_i = a_i\sqrt{(X_f - x_i)^2 + (Y_f - y_i)^2}. \tag{4}$$

The objective function (2) is optimized in the following:

$$\min \sum_{i=1}^{n} a_iD_i \tag{5}$$

such that a_iD_i is the weighted Euclidean distance to the location of facility (X_f, Y_f) where n is the number of resources around the facility. Also the position of the location must be subject to the inequality $(X_f, Y_f) \geq 0$. Basically, as can be seen in (5), the goal is to minimize the cost which is the distance for all resource points within the scope of the research [15].

The following section describes the scope of the input data, as well as the use of data including the conversions and the processes required.

4 A case study

The data are derived synthetically and include a couple of resources to be used in the cement production industry. In total there are 5 resources that the cement factory needs to receive as materials and goods. For the resources, every location of a particular resource has a specific weight. The weights show the importance of the particular good or the amount needed from that particular good in the resource. In the data, while *good*-1 has a total of 63 resources at different locations with their individual weights (Fig. 1), *good*-2 has 58 resources at various locations with their distinguishing weights. Moreover, *good*-3 and *good*-4 are to be collected from 20 and 14 resource points, respectively, having particular weights as well. At last, *good*-5 is another must-have ingredient for the production at the factory, which is found at 7 locations with their peculiar weights.

In order to elaborate on the distinctive values of the weights, we refer to Table 1 in the following. As mentioned, every good has a specific weight of importance in order to be involved in the cement production process. For example, while *good*-1 has the weight of 0.090 for the manufacturing process, *good*-2 and *good*-3 keep the weights of 0.200 and 0.310, respectively. Additionally, *good*-4 is required to have a weight of 0.165, while *good*-5 holds the weight of 0.235.

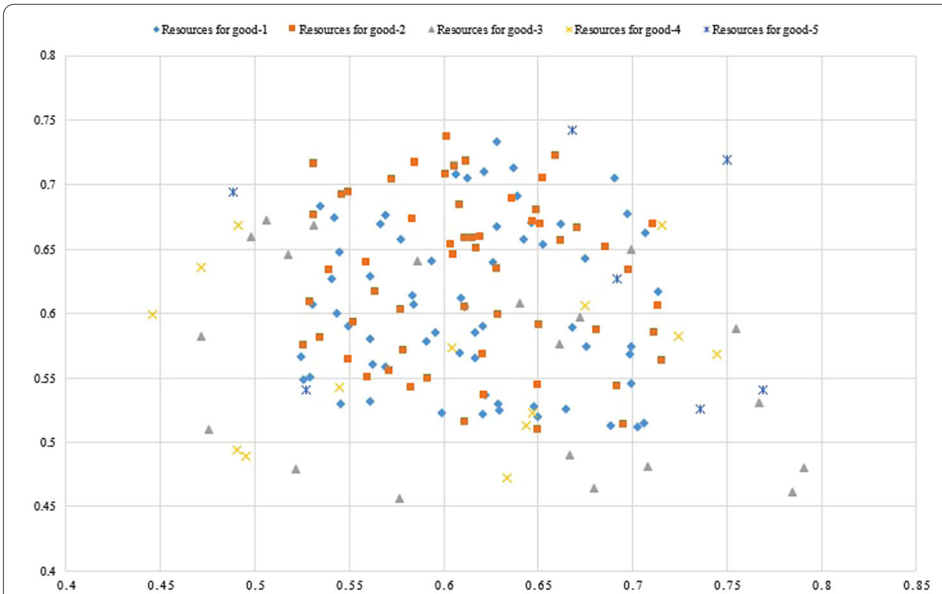

Figure 1 All of the resources and their locations for all five goods

Table 1 The weights of all five goods

Data	Number of resources	Weight
good-1	63	0.090
good-2	58	0.200
good-3	20	0.310
good-4	14	0.165
good-5	7	0.235

As the location information provides a very important parameter of cost which can be described as the distance in this research, positional data of all resources are taken into account in order to determine the location of the facility. For discovering the cost, the Euclidean distances between the resources are computed by a Mercator projection conversion, because of the geoid shape of the Earth. Therefore, the coordinates of a location can be used as they are on a rectangular (x, y) projection [15, 29]. The coordinates of the locations can be entered to Eqs. (6) and (7) in the following, in order to convert the positional data and prepare for using on a rectangular projection:

$$x = \pi R(\lambda^\circ - \lambda_0^\circ)/180^\circ, \tag{6}$$

$$y = R \ln \tan(45^\circ + \phi^\circ/2). \tag{7}$$

For this computation, x (the rectangular coordinate on the x-axis), y (the rectangular coordinate on the y-axis) can be found by using R (the radius of the sphere), λ° (the latitude in degrees), λ_0° (the central latitude in degrees), and ϕ° (the longitude in degrees). With the help of the conversion, WM can be applied for the location analysis on a rectangular projection.

5 Main results and discussion

For assessing the results of the optimization, the data were processed in LINGO 16.0 x64 [26]. The data as input and the objective function (2) were entered into the software. Then, the solver was run by a computer with an Intel®Core^{TM} i7-2640M CPU @ 2.80 GHz.

When the program was run with the inputs of *good*-1 and the inequality $(X_f, Y_f) \geq 0$, the coordinates of (X_{f_1}, Y_{f_1}), which was the optimum solution for *good*-1 resources, were determined as (0.6144099, 0.5994187). For the Mercator projection, the spatial result for the resources of good-1 corresponds to 35°12′11.1″ N and 32°27′17.7″ E, respectively. Likewise, the coordinates of (X_{f_2}, Y_{f_2}), (X_{f_3}, Y_{f_3}), (X_{f_4}, Y_{f_4}), and (X_{f_5}, Y_{f_5}) also satisfy the inequality $(X_f, Y_f) \geq 0$ (Table 2). These were the solutions of the optimal locations for *good*-2, *good*-3, *good*-4, and *good*-5 resources, respectively, which were assessed by the solver. As can be seen in Table 2, they were found on a rectangular projection. Corresponding coordinates were also computed with the help of the Mercator projection. Additionally, each of them was the local optimal solution of each cluster, and no infeasibility was reported by the solver. Because each cluster was formed by a convex problem, the local minimum was actually the global minimum in our case. Thus, the results were verified.

The optimal locations of every resource were computed by the iterative methodology of WM (Table 2). An output of location represents the best location of the facility for a particular resource by considering the resource points. For example, the resource of good-2 has a total of 58 resource points, and the optimal location for placing a facility

Table 2 The optimal locations of five goods

Data	Number of resources	Location	Latitude	Longitude
good-1	63	(X_{f_1}, Y_{f_1})	35°12′11.1″ N	32°27′17.7″ E
good-2	58	(X_{f_2}, Y_{f_2})	35°11′49.8″ N	34°27′07.0″ E
good-3	20	(X_{f_3}, Y_{f_3})	36°14′30.5″ N	31°05′18.4″ E
good-4	14	(X_{f_4}, Y_{f_4})	35°47′13.7″ N	30°10′26.0″ E
good-5	7	(X_{f_5}, Y_{f_5})	38°10′31.3″ N	36°54′10.3″ E

for this particular one is at 35°11′49.8″ N and 34°27′07.0″ E. Also, the best location of placing a facility for good-5 is determined at 39°10′31.3″ N and 36°54′10.3″ E among those particular 7 points of resources. Consequently, as can be seen in Table 2, all the location outputs differ from each other. The main reason of possessing several optimal locations at the beginning is that every good has a particular optimal location because the resources of all of the goods are at different spatial positions (Fig. 1). Likewise, many researchers [8, 25, 30] demonstrate similar approaches for many other facility placement problems, rather than for a cement production plant, related to the resources as in our study. Therefore, the location outputs in Table 2 do vary.

Furthermore, as mentioned previously, every good has a specific weight of importance to be included in the cement production process. Therefore, the optimal location of all goods is required for locating the cement production facility. When the program was run using the inputs of the weights of goods (Table 1) and the location information recently acquired (Table 2), the coordinates of (X_f, Y_f), which was the final optimal solution for all goods, were determined as (0.6287260, 0.5890077). Related to Mercator projection, the spatial result of (X_f, Y_f) for all goods corresponded to 36°01′24.1″ N and 31°57′00.6″ E, meeting the inequality $(X_f, Y_f) \geq 0$. As discussed before, the result was verified, because the data cluster created a convex problem, delivering a local minimum which was actually a global minimum in a convex problem. Thus, the convexity in our study simplifies the search for a global optimum location, as also indicated by other researchers [25, 31, 32].

6 Conclusions

Several infrastructure problems, including the locations of infrastructure, buildings, or even facilities, can be solved by using mathematical models and algorithms. Using mathematical techniques and models in several academic studies completed thus far, researchers demonstrated that many infrastructure problems could be solved by applying mathematical techniques. For instance, particular industries such as that of cement production can be looking for a solution in order to select a cement plant location, which is one of the most common concerns of entrepreneurs or consultants at the level of local or regional authorities. In this study, a cement production facility location was determined using a common iterative methodology of WM by considering some parameters of the weights and the transportation costs, such as distances. For this case, a mathematical problem of WP supported the model of the application in this investigation. Therefore, according to the mathematical evaluation in this paper, the location of the cement production facility is proposed with the help of the spatial results. This study can contribute to not only regional planning, but also to state planning, which is vital for the economic development of a country. As an outcome, important losses for many industries such as time wasting, extra travel distances, and unnecessary expenditures due to distances traveled can be minimized by applying the technique used in this study.

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Competing interests
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Authors' contributions
Both authors participated in every stage of the research, and both authors read and approved the final manuscript.

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