Volume 2 | Issue 2 Article 2

Optimizing Locations and Sizes of Asphalt Concrete Plants in Karbala, Iraq

Ghayath Ali
Dept. of Civil Eng., University of Baghdad, Iraq

Sawsan R Mohammad
Dept. of Civil Eng., University of Baghdad, Iraq

Alaa M. Abdulhussein
University of Kerbala, Department of Physics, Kerbala, Iraq

Recommended Citation
Ali, Ghayath; Mohammad, Sawsan R; and Abdulhussein, Alaa M. (2023) "Optimizing Locations and Sizes of Asphalt Concrete Plants in Karbala, Iraq," *Al-Bahir Journal for Engineering and Pure Sciences*: Vol. 2: Iss. 2, Article 2.
Available at: https://doi.org/10.55810/2313-0083.1017

ORIGINAL STUDY

Optimizing Locations and Sizes of Asphalt Concrete Plants in Karbala, Iraq

Ghayath Ali [a,*], Sawsan R. Mohammad [a], Alaa M. Abdulhussein [b]

[a] Dept. of Civil Eng., University of Baghdad, Iraq
[b] University of Kerbala, Department of Physics, Kerbala, Iraq

Abstract

This study develops and presents a methodology for determining the optimal geographic distribution and size of asphalt concrete plants in Karbala, Iraq, in order to minimize the cost of asphalt concrete produced. The purpose of this study is to discuss these points. The methodology can identify potential locations for asphalt concrete plants within a study area, considering the plants' operation and capital costs and the costs of transporting raw materials to the plants and asphalt concrete to demand centers. Matrix Laboratory (MATLAB) software have been used to program the methodology.

This methodology has been applied to Karbala using actual data. The methodology's output identifies the optimal locations and sizes of asphalt concrete plants in Karbala. There are two optimal locations for asphalt concrete plants B and D; their total size is 80 tons per hour and 800 tons per hour, respectively. This is adequate to supply Karbala's asphalt concrete demand to 2032. The methodology effectively determines the optimal geographic locations and sizes of asphalt concrete plants in the study area.

Keywords: Optimization, Asphalt concrete, Location, Capital cost, Operating cost, Transportation cost

1. Introduction

For many decades, mathematical techniques, models, and methodologies have been critical for comprehending an infinite number of engineering processes and implementations. Numerous infrastructure problems can be solved using mathematical models in a variety of academic sorts of research, for example, finding facilities or infrastructure associated with a specific industry, such as asphalt concrete production.

Asphalt concrete is an important part of the construction process, particularly in road construction and maintenance projects. The fundamental purpose of the asphalt concrete plant site selection procedure is to guarantee that the plant is located in the most favorable location feasible, with the least negative influence on the environment or the community [1]. Asphalt concrete plants rely on cutting costs to maximize profits, and the plant's location has a significant impact on the project's success or failure due to the direct impact on costs. The factory with the best site options is the one that can obtain the various production elements at the lowest possible cost; this is important because the increase in construction costs was caused by increases in construction material costs as well as wage increases in the construction industry [2].

The facility's location refers to the site where the business will be established and continue to operate throughout the facility's service life. The business strategy defines the items or services offered and the market they will compete with. Following design decisions for the product and process, the next phase is location selection. The location decision affects the costs of obtaining inputs, manufacturing,

Received 27 December 2022; revised 20 January 2023; accepted 24 January 2023.
Available online 7 March 2023

* Corresponding author.
E-mail addresses: ghayathali70@gmail.com (G. Ali), Dr.sawsan.r@coeng.uobaghdad.iq (S.R. Mohammad), alaa.m.abdulhussein@uokerbala.edu.iq (A.M. Abdulhussein).

https://doi.org/10.55810/2313-0083.1017

and distribution, affecting productivity. In new establishments, but also in decisions to expand the facility, create new products, or add a new part to the plant, the establishment's location is critical [3].

Many studies comprise a variety of research and opinions that deal directly with and parallel the research. The authors Delivand and others (2015), created a solution based on (GIS-MCA) to handle biomass-to-electricity logistics in Southern Italy. They explored the regional distribution of olive and grape tree cuttings and durum wheat straw. Several locations were chosen based on a set of land suitability criteria [4]. Woo and others (2018) reported on a project that uses MCA and GIS to determine the optimal locations for future biomass power facilities. Utilizing MCA and a GIS model with supply chain cost analysis, optimal feasible locations within the biomass supply were identified and examined [5]. Jayarathna and others (2020) generated user-defined spatial biomass information by combining biomass availability and land use data. An algorithm that considered both transportation networks and regionally distributed biomass resources was then used to find the best locations for biomass energy facilities. Multiple scenarios for single and multi-biomass techniques were investigated to maximize plant size, biomass transport costs, and plant count in the region [6]. Holsbeeck and others (2020) identified the optimal places for forest biomass conversion based on availability, transportation distance, and cost. The method was A GIS-based study that pinpoints potential bioenergy plant locations in the first stage, stage two uses a transportation cost model based on stage one results to evaluate the most cost-effective places. The GIS investigation found 128 possible bioenergy conversion locations [7].

This study adopted and extended the methodology to provide a more powerful tool for swiftly determining the appropriate geographical distribution and size of asphalt concrete plants using data gathered from the previous literature. This methodology possesses the following attributes:

Asphalt concrete plant location. The methodology develops an algorithm for locating potential asphalt concrete plants in any location within the study area.

Transportation cost. Along with determining the optimal locations for asphalt concrete plants, the transportation cost was annualized by calculating the distances between those locations and the demand centers and raw materials used in the production of asphalt concrete, such as gravel and sand quarries and the oil refinery that supplies the plants with asphalt, as well as the location of the oil depot that supplies the plants with fuel, using GIS.

Operation costs. This methodology includes both fixed and variable O&M costs. This methodology adopted a fixed maintenance cost based on a fixed percentage of the capital cost.

Capital cost. The capital cost of the asphalt concrete plant has been determined using the manufacturer's price, assuming identical transportation and installation costs across all capacities, and has been represented as a single component in the production cost. A present worth model (PW) has been used in this study.

As a result, this work will explore how to determine the optimal geographic distribution and size of asphalt concrete plants in a study area to minimize the cost of asphalt concrete produced. The methodology can identify potential locations for asphalt concrete plants in any location within a study area while considering the asphalt concrete plants' operating and capital costs. Matrix Laboratory (MATLAB) software is used to program the methodology.

2. Modeling the optimal asphalt concrete plant size

This section shows how the size of an asphalt concrete plant is modeled and optimized to ensure adequate coverage of the study area. The total production cost of the asphalt concrete plant (C) is composed of the following components: capital cost (Cc), annual maintenance cost (Cm), raw material cost (Cr), labor cost (Cl), fuel cost (Cf), land equity cost (Ce) raw material transportation cost (Ctr), and final output transportation cost (Cto), as shown in equation (1):

$$C = Cc + Cm + Cr + Cl + Cf + Ce + Ct_r + Ct_o \quad (1)$$

(Res.)

The asphalt concrete plant has a 10-year service life [2]. As a result, the plant's service life study will begin in 2023. Capital cost (Cc) equals the sum of all plant prices allocated to demand centers. The sizes of the plants have been calculated based on the expected demand size in the tenth year of the study and the allocation method.

According to the manufacturer, the plant's initial cost includes maintenance costs for the first year. As a result, the annual maintenance cost has been calculated beginning with the second year of the plant's installation and continuing until the end of the plant's service life. The annual maintenance cost was estimated to be 6% of the plant capital cost [8]; several specialists with whom have been consulted approved this percentage. Maintenance costs have been viewed as future costs that have been converted to the present worth using the equation (2) [9]:

$$\mathrm{P}=\frac{F}{(1+t)^{n}} \tag{2}$$

[9] where:

P = present worth.

F = future value (annual maintenance cost),

t = interest rate, and

n = duration.

A 4% interest rate has been employed [10]. Therefore, the total maintenance cost (Cm) during the plant's service life has been expressed as in equation (3)

$$\mathrm{Cm}=\sum_{2}^{n}\frac{0.06Cc}{(1+t)^{n}} \qquad (3)(\mathrm{Res.})$$

The comparison is based on the total annual demand for asphalt concrete over the plant's service life, and the source and cost of supplying each raw material are the same. As a result, regardless of how demand centers were allocated to plants, the cost of raw materials was the same in each comparison; hence the cost of raw materials (Cr) was ignored and not considered in this model.

The same is true for the cost of labor (Cl) and fuel (Cf) required to operate the plant, as the cost of labor includes the plant manager, operation and maintenance (O&M) personnel, operators, workers, and administrative clerk; and the cost of fuel includes fuel required to operate the plant as well as equipment for moving and unloading materials within the plant, and both have been calculated as fixed costs in the production of each ton of asphalt concrete according to the manufacturer.

It was considered that there is no fundamental difference in land ownership costs between the potential locations [11]. Consequently, the land equity cost (Ce) was disregarded in the development of this model.

The cost of raw material transportation (Ctr) is the annual transportation cost of all raw materials required from the source to the asphalt concrete plant. The total annual cost of raw material transportation (Ctr) is composed of the annual cost of gravel transportation (Ctg), the annual cost of sand transportation (Cts), and the annual cost of asphalt transportation (Cta). Each ton of asphalt concrete contains 0.4 m3 gravel, 0.3 m3 sand, and 50 kg of asphalt [12].

The annual transportation cost of gravel (Ctg) has been calculated using personal interviews with owners of raw materials transport trucks. The cost of transporting 1 m3 of gravel and sand from the quarry to the asphalt concrete plant is 160 Iraqi dinar (IQD) per 1 km distance, while transporting 1 ton of asphalt from the oil refinery to the asphalt concrete plant is 390 IQD per 1 km distance.

Therefore, the cost of transporting gravel (Ctg) over the plant's service life has been expressed as in equation (4).

$$\mathrm{Ct_g}=\sum_{1}^{n}\frac{0.4*a_i*V_n*d_{jq}*160}{(1+t)^{n}} \qquad (4)(\mathrm{Res.})$$

After simplification

$$\mathrm{Ct_g}=\sum_{1}^{n}\frac{64a_iV_nd_{jq}}{(1+t)^{n}} \qquad (5)(\mathrm{Res.})$$

The cost of transporting sand (Cts) over the plant's service life has been expressed as in equation (6):

$$\mathrm{Ct_s}=\sum_{1}^{n}\frac{48a_iV_nd_{jq}}{(1+t)^{n}} \qquad (6)(\mathrm{Res.})$$

The cost of transporting asphalt (Cta) over the plant's service life has been expressed as in equation (7):

$$\mathrm{Ct_a}=\sum_{1}^{n}\frac{19.5a_iV_nd_{jr}}{(1+t)^{n}} \qquad (7)(\mathrm{Res.})$$

To calculate the annualized cost of transportation of final output (Cto), assume that the cost of transporting 1 ton of asphalt concrete from the plant to the demand centers is 85 IQD per 1 km distance, and the cost of transporting asphalt (Cto) over the plant's service life is expressed as in equation (8):

$$\mathrm{Ct_o}=\sum_{1}^{n}\frac{85a_iV_nd_{ij}}{(1+t)^{n}} \qquad (8)(\mathrm{Res.})$$

where:

a_i = Nonnegative weight of demand in demand center i.

V_n = total demand in year n

d_{jq} = the shortest distance from quarries area q to potential plant site j

d_{jr} = shortest distance from oil refinery area r to potential plant site j

d_{ij} = shortest distance from potential facility site j to demand centers i

t = interest rate

n = plant service life.

Given the requirement to serve each demand center, a constraint is that each demand center is allocated to a plant. When a demand center i assigns to a plant site j, then the assignment/allocation variable, x_{ij}, will equal 1 in value and equal 0 if not. This constraint has been structured as shown in equation (9) for demand center i:

$$\sum_{j=1}^{m} X_{ij} = 1 \qquad (9)(\text{Res.})$$

When allocating demand centers to plants, it is critical to guarantee that no allocation takes place except if a plant is located, this can be demonstrated mathematically for demand center i and plant j using the inequality equation (10):

$$X_{ij} \le Y_j \qquad (10)(\text{Res.})$$

If $Y_j = 0$, then X_{ij} must be zero because of the zero bound on the right-hand side of the inequality. Alternatively, if $Y_j = 1$, then X_{ij} can equal zero or one. That is, an allocation assignment is possible.

If it is assumed that a specific number of plants, p, will be located, this can be ensured mathematically using the following equation (11):

$$\sum_{j=1}^{m} Y_j = P \qquad (11)(\text{Res.})$$

Given the binary criteria for Yj, this condition assures that exactly the P of the Yj variables equals one.

Based on equations (1)−(11), equation (12) can be derived to minimize the total production cost of the asphalt concrete plants (C) during the calculated service life.

$$\text{Min C} = \sum_{i=1}^{k}\sum_{j=1}^{m}\left(Cc + \sum_{2}^{n}\frac{0.06Cc}{(1+t)^n} + \sum_{1}^{n}\frac{64*a_i*V_n*d_{jq}}{(1+t)^n} + \sum_{1}^{n}\frac{48*a_i*V_n*d_{jq}}{(1+t)^n} + \sum_{1}^{n}\frac{19.5*a_i*V_n*d_{jr}}{(1+t)^n} + \sum_{1}^{n}\frac{85*a_i*V_n*d_{ij}}{(1+t)^n}\right)X_{ij} \qquad 12(\text{Res.})$$

Subject to:

$$\sum_{j=1}^{m} X_{ij} = 1 \text{for each i} = 1,2,...,\text{n} \qquad (13)(\text{Res.})$$

$$X_{ij} \le Y_j \text{for each i} = 1,2,...,\text{n and j} = 1,2,...,\text{m} \qquad (14)(\text{Res.})$$

$$\sum_{j=1}^{m} Y_j = P \qquad (15)(\text{Res.})$$

$$Y_j = \{0,1\} \text{for each j} = 1,2,...,\text{m} \qquad (16)(\text{Res.})$$

$$X_{ij} = \{0,1\} \text{for each i} = 1,2,\ldots,\text{n and j} = 1,2,...,\text{m} \qquad (17)(\text{Res.})$$

By solving the model that has been represented in equation (12), the minimum asphalt concrete production cost can be determined by determining the optimal number and size of asphalt concrete plants by the optimal allocation of the plants around the study area. The overall production cost can be optimized if the asphalt concrete plant is sized per the optimum allocation. With allocation different than the optimal allocation, the additional distance to transport to and from the asphalt concrete plant will result in a higher overall operating cost, in addition to increasing the capital cost (Cc), as the different allocation may lead to an increase in the number of plants than the optimal number.

The minimum cost of asphalt concrete production has been computed with equation (12) with the optimal allocation. The optimal asphalt concrete plant size has been calculated by summing the demands of 10th year for all demand centers that have been allocated to each plant.

3. Methodology for optimizing the asphalt concrete plant size

The primary purpose of this methodology is to determine the optimal locations and sizes for asphalt concrete plants at the minimum capital and operating costs utilizing previously developed equations. The subject was approached as an optimization problem in this methodology to optimize the size of the asphalt concrete plant. The asphalt concrete plant's operating costs are minimized at the optimal point. Reduced operating costs enable the asphalt concrete plant to reduce the cost of producing asphalt concrete while maintaining financial viability.

A computer algorithm is developed using MATLAB R2015a software (version 8.5) from MathWorks Company. Fig. 1), the schematic diagram, represents the procedure of the algorithm. A new graphical

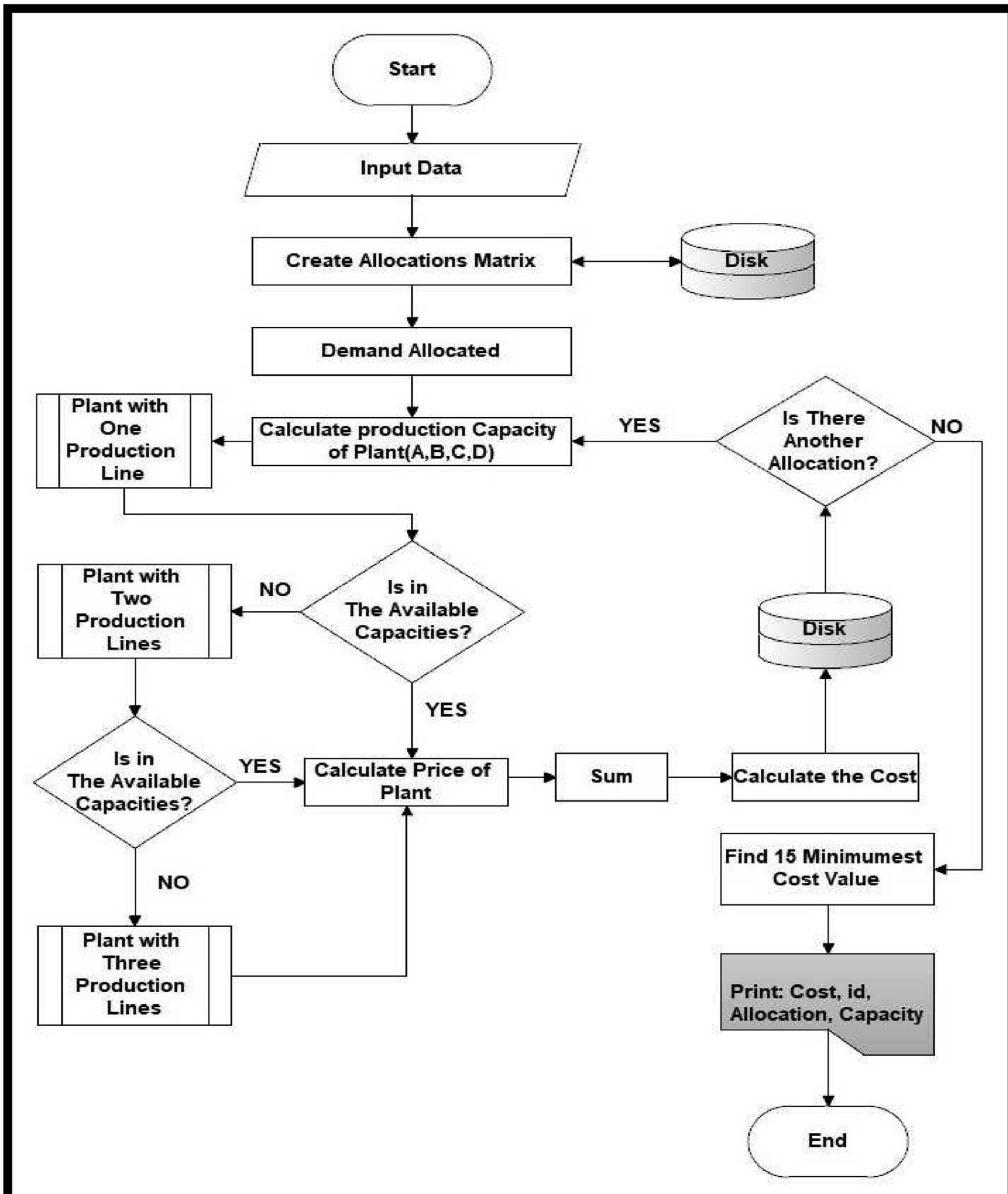

Fig. 1. Schematic diagram of the work.

user interface was programmed and designed using MATLAB software programming language, which had named Location Allocation Calculator. This Calculator can measure all necessary parameters for solving the model that have been represented in equation (11). The Location Allocation Calculator have been added to latest version of MATLAB software based on suggestion message sent to MathWorks Company, as shown at: https://www.mathworks.com/matlabcentral/fileexchange/109790-location-allocation-calculator.

3.1. Location allocation calculator

A graphical user interface for determining the lowest 15 values for the cost of erecting asphalt concrete plants sufficient to meet the future demands for asphalt concrete in the Karbala governorate over the next 10

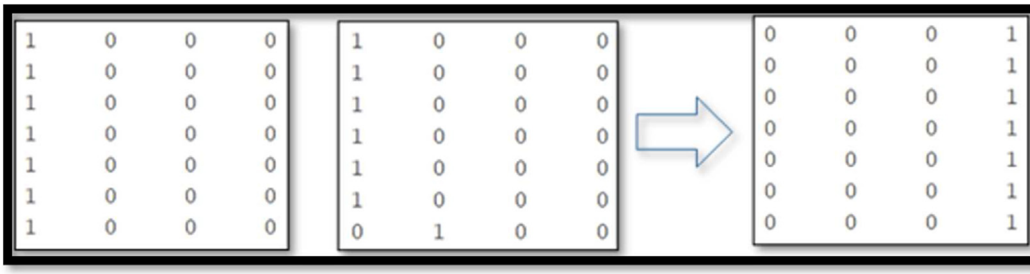

Fig. 2. Allocation probabilities.

years. The MATLAB R2015a software (version 8.5) was used to create this graphical user interface. The graphical user interface is often composed of a single window, including text boxes, processing buttons, and a table showing the final results. Additionally, the interface relied on several variables and fixed rates and inputs to calculate the required results.

The procedure is divided into three stages that will be completed sequentially to design a proposed Location Allocation Calculator as follows.

3.1.1. First stage: input

The input is divided into two types:

The first type of input is general, such as Divider, which represents the actual number of hours the plant operates in a given year; t, which represents the annual interest rate specified by the Iraqi Central Bank; and n, which represents the number of years, that can be changed them directly from the graphical user interface.

The second type was input in the form of tables obtained from the previous literature, or fixed data such as the price of plants according to a price model established through contact with one of the Chinese companies specializing in manufacturing asphalt concrete plants.

3.1.2. Second stage: operations

The operations were mostly based on programming, with the process of calculating the results being carried out in numerous sequential steps, as well as the process of saving the output components and calling them in the subsequent step, as illustrated in the following points.

1 The variables Divider, t, and n have been read from the graphical user interface and defined with the names Var_Devider, Var_t, and Var_n for the main algorithm.
2 As shown in Fig. 2 shows that the function Fn_1_Comb.m have been used to generate a three-dimensional matrix containing all possible probabilities for allocating seven demand centers to four plants (see Fig. 3).

Additionally, it have been taken into account that probabilities do not repeat and that each demand center is allocated to a single plant at a time. The result of this step is a binary matrix with 16,384 different allocations. These matrices were saved in a file named Table_ 1_Comb.mat, which was contained within a table named M_ones.

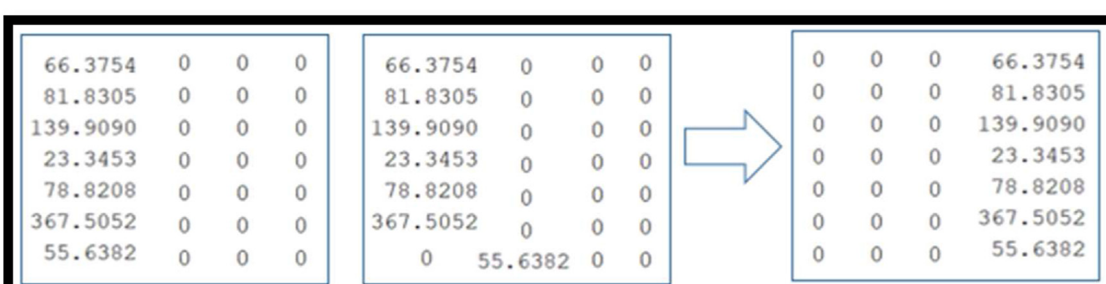

Fig. 3. New matrix to calculate P.

16384x4 double

	1	2	3	4
1	813.4246	0	0	0
2	757.7864	55.6382	0	0
3	757.7864	0	55.6382	0
4	757.7864	0	0	55.6382
5	445.9194	367.5052	0	0

16380	0	0	367.5052	445.9194
16381	55.6382	0	0	757.7864
16382	0	55.6382	0	757.7864
16383	0	0	55.6382	757.7864
16384	0	0	0	813.4246

Fig. 4. Single matrix containing four columns and 16,384 rows.

3 To calculate capital costs (Cc), which are equal to the sum of the prices of plants allocated to all demand centers, as previously discussed, equation (18) have been used to determine the maximum production capacity of each plant per hour (P) based on the weights of the demand centers, as well as the expected demand for the final year of the study period for each possible form of allocation.

$$P\,(A \text{ or } B \text{ or } C \text{ or } D) = a_i \times \frac{V_{10}}{Var\_Devider} \qquad (18)$$

Then, as illustrated in Fig.)3(, the program created a new matrix in the form of a table and named it M_comb in the previous file Table_1_Comb.mat.

4 To obtain the production capacity (P) of each plant based on its matrix positions, the process of summing the values of the four columns for all the matrices saved in the previous step was performed, resulting in a single matrix with four columns and 16,384 rows, as shown in Fig. 4. Then this matrix was saved in the form of a table named M_sum in the file Table_3_Sum.mat.

Each row of the matrix M sum represents a probable plant allocation form, and the value of each cell represents the plant's production capacity.

Table 1. Plants price according to the manufacturer.

No.	production capacity ton/hr.	Production line capacity ton/hr.	Price IQD
1	1–40	40	159,900,000
2	41–64	64	211,485,000
3	65–80	80	233,700,000
4	81–120	120	314,850,000
5	121–160	160	608,400,000
6	161–240	240	1,111,200,000
7	241–320	320	1,740,900,000
8	321–400	400	2,280,900,000

5 The capital cost (Cc) for each row has been calculated by summing the plant prices for each row based on the production capacity saved in Table M_sum after testing it using a function that determines the price based on Table 1, which represents the purchase prices of production lines according to the manufacturer.

If the calculated production capacity is between the values in Table (1), the program calculates the price of a plant with one production line to complete the task; for example, if the calculated production capacity is between (1–40) ton/hour, the program determines the size of the plant to be 40 ton/hour and calculates the corresponding price in Table 1.

If the value of production capacity between the highest value and less than the sum of two values from Table (1), then the lowest possible cost is calculated for a plant with two production lines to perform the task.

If the production capacity is greater than the sum of the two values in Table 1, a plant with three production lines will be identified to perform the task. Thus, until all costs have been determined and collected in all rows of the matrix.

The program selects the lowest possible cost from the previous three operations and divides the result into two parts:

The first section: It is a result that contains the names of the selected plants that are saved in an isolated table with the name M_ABC under the file Table_7_Select.mat to be used in the final results.

The second section: The cost result have been saved in the form of a matrix with one column and 16,384 rows, and they have been saved in the form of a table named M_Price in a new file called Table_5_Price.mat.

6 All saved variables and tables have been called and processed with equation (12) for each row in this step. After obtaining all of the results values, they are saved in the file Table_6 Min_cost.mat

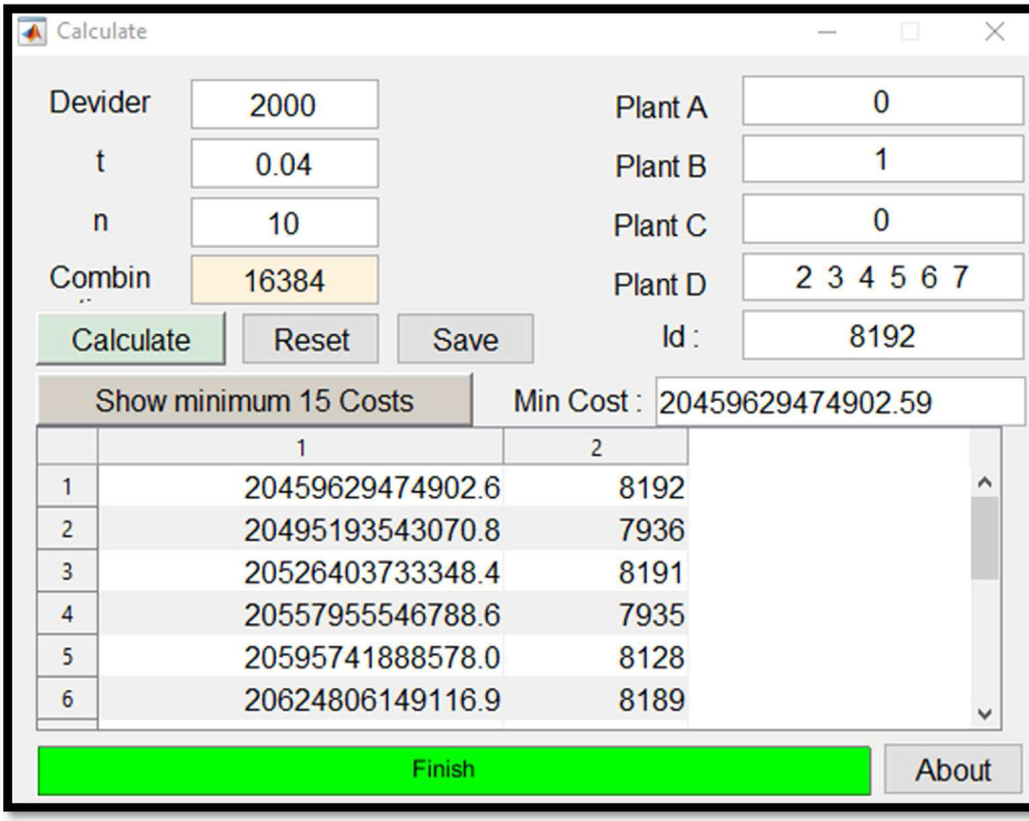

Fig. 5. Graphical user interface.

Table 2. Explanation of fields that have been included in an excel file.

No	Field	Explanation
1	Num.	The sequence in the excel table
2	Min Cost	The total cost results from solving equation (11).
3	Id	The allocation sequence is shown in Figure (4), chosen by the program.
4	A	The codes of the demand centers that have been allocated to location A.
5	B	The codes of the demand centers that have been allocated to location B.
6	C	The codes of the demand centers that have been allocated to location C.
7	D	The codes of the demand centers that have been allocated to location D.
8	Capacity A	The total demand that have been allocated to location A.
9	Price A	Total prices of production lines cover location A's demand as mentioned in Table 1.
10	select A	The sequence of production lines as mentioned in Table 1 that have been selected for site A.
11	Capacity B	The total demand that have been allocated to location B.
12	Price B	Total prices of production lines cover location B's demand as mentioned in Table 1.
13	select B	The sequence of production lines as mentioned in Table 1 that have been selected for site B.
14	Capacity C	The total demand that have been allocated to location C.
15	Price C	Total prices of production lines cover location C's demand as mentioned in Table 1.
16	select C	The sequence of production lines as mentioned in Table 1 that have been selected for site C.
17	Capacity D	The total demand that have been allocated to location D.
18	Price D	Total prices of production lines cover location D's demand as mentioned in Table 1.
19	select D	The sequence of production lines as mentioned in Table 1 that have been selected for site D.

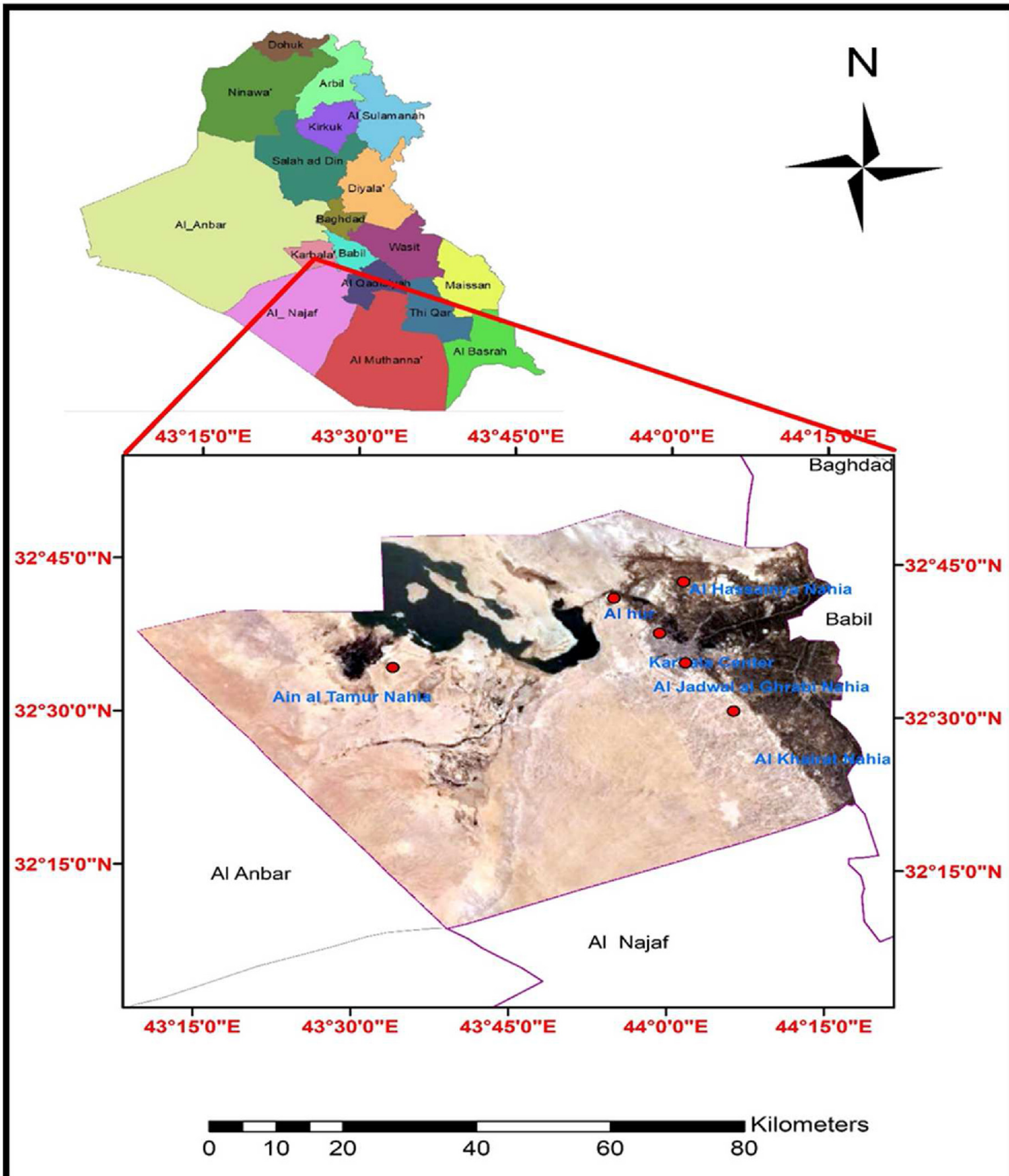

Fig. 6. Map of Karbala governorate.

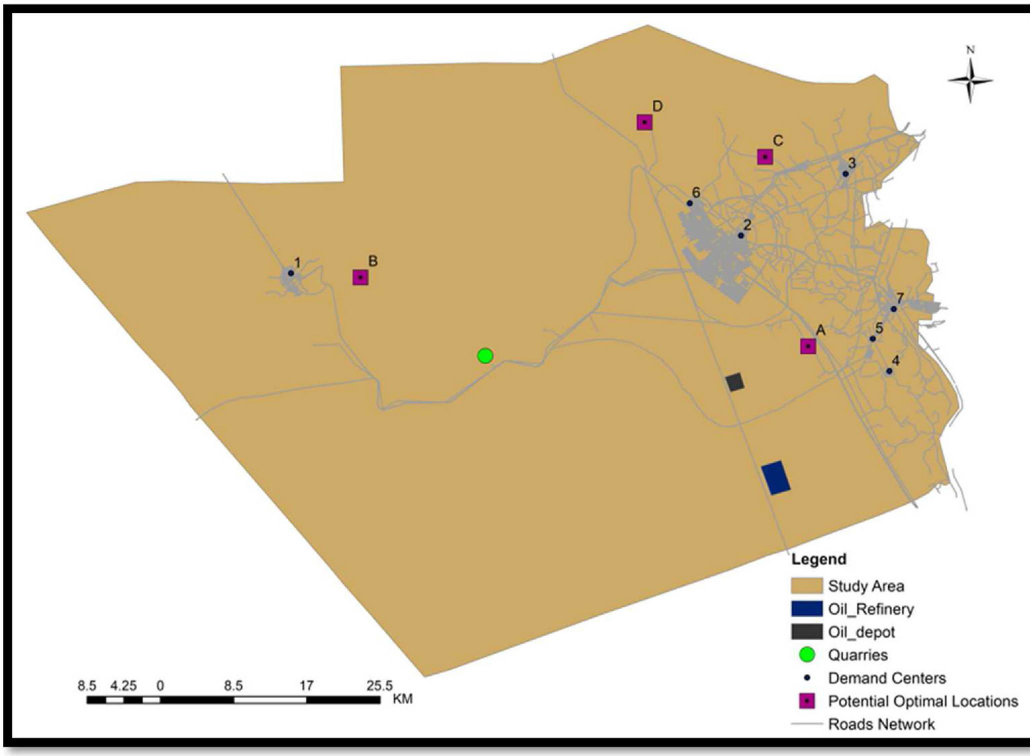

Fig. 7. The geographical information required to solve the algorithm [11].

in the form of a table have been named Min_cost.

7 In this step, the lowest 15 cost values calculated in the Min_cost table were identified and saved in a new table called Min_15 in the same file Table_6_Min_cost.mat.

3.1.3. Third stage: outputs

1. By clicking on the button (show minimum 15 prices), the values in table Min_15 will be presented on the table's grid on the graphic user interface, along with the sequence number for probable allocation of demand centers to plants.

2. In the final step, the (Save) button saves an excel file named Min_15.xlsx in the Results folder, which is placed next to the MATLAB project and contains the following items.

- The serial number starts from the lowest value to the highest cost value.
- The total cost of the assumed distribution pattern.
- Distributive pattern number.
- Four columns show the allocation of demand centers on plants.
- The capacity of each production line.

Table 3. Distances from optimal potential locations for asphalt concrete plants to demand centers in km.

Destinations	Plant A	Plant B	Plant C	Plant D
Center 1	85.629	7.326	87.857	76.265
Center 2	17.547	67.771	12.849	18.602
Center 3	32.628	82.927	12.120	32.983
Center 4	39.928	90.730	41.578	46.608
Center 5	34.633	85.435	36.278	41.313
Center 6	24.222	70.374	13.104	10.859
Center 7	41.395	92.197	39.805	46.871

3.2. Graphical user interface

The Calculator for calculating the minimum cost is shown in Fig. (5) Using the MATLAB software's graphical user interface development environment (GUIDE) and the suggested flowchart in Fig. (1).

When the Divider, t, and n values are entered in the input parameters section and the calculate

Table 4. Distances from raw materials to optimal potential locations for asphalt concrete plants in km.

Destinations	Plant A	Plant B	Plant C	Plant D
Quarries	65.764	30.854	54.436	39.080
Oil Refinery	46.604	84.700	48.832	42.865
Oil depot	34.552	72.648	36.780	30.814

Table 5. Annual forecasted demand for asphalt concrete in Karbala governorate [14].

No.	Year	Forecasted demand ton
1	2023	596,198
2	2024	676,164
3	2025	765,662
4	2026	865,325
5	2027	975,848
6	2028	1,097,950
7	2029	1,232,400
8	2030	1,380,018
9	2031	1,541,656
10	2032	1,718,227

button is pressed, the results are immediately displayed in the output parameters section. The save button is used to save the lowest 15 calculated results in an Excel file in a user-specified directory, in the form of a table that includes the fields described in Table 2. In addition, a reset button have been added to the graphical interface shown in Fig. 5 to delete data from all fields.

The required size of the asphalt concrete plant in each of the four locations was determined by summing the capacities of the production lines specified in Table (1) for that location.

4. Study area

The study was limited to Karbala governorate, which located approximately 110 km south of Baghdad's capital. It is at 32° 60' N, 44° 00' E. It is located approximately 36 m above sea level. As illustrated in Fig. 6, it is bounded on the south and southeast by Babil Governorate, 45 km to the south and southeast; on the north and northwest by Anbar Governorate, 112 km to the north and northwest; and on the south and southwest by Najaf Governorate, 74 km to the south and southwest [13].

Karbala governorate encompasses an area of roughly 5048.688 km2, accounting for 1.2 percent of Iraq's overall land area of 434,934 km^2 and 2.5 percent of the 96,808 km^2 of the Middle Euphrates governorates, which also includes the governorates of Babil, Najaf, Al-Qadisiyah, and Al-Muthanna. Karbala, Al-Hindiya, Ain Al-Tamr, Al-Hurr, Al-Hussainiya, Al-Jadwal Al-Gharbi, and Al-Khayrat are the governorate's seven districts [13].

Table 6. Annual asphalt concrete demand weights for each demand center.

No.	Sub-District	Code	weight %
1	Ain Al Tamur	1	8.16
2	Karbala Center	2	10.06
3	Al Hussainya	3	17.2
4	Al Khairat	4	2.87
5	Al Jadwal Al Gharbi	5	9.69
6	Al Hur	6	45.18
7	Al Haindiya	7	6.84

Table 7. Input parameters required for the program.

No.	Parameters	Symbol	Value
1	Plant operating hours per year	Divider	2000
2	Interest rate	t	0.04
3	Plant service life	n	10

5. Input data

The algorithm have been used to determine the optimal allocation of asphalt concrete plants in the Karbala governorate to achieve the minimum expenditure cost. Fig. (7) illustrates the geographical information, including the locations of demand centers, raw materials, the road network, and potential optimal locations for asphalt concrete plants in the Karbala governorate [11].

The transportation distance have been measured between the optimal potential locations for asphalt concrete plants and demand centers and between the optimal locations for asphalt concrete plants and raw materials using ArcGIS software, as shown in Tables 3 and 4, respectively.

The forecasted annual demand for asphalt concrete in Karbala governorate during the study period from 2023 to 2032 have been shown in Table 5 [14].

The annual asphalt concrete demand weights for each sub-district of Karbala governorate (demand center) have been determined using ArcGIS software as in Table 6. In ArcGIS, the district was selected using the Selection By Attribute tool, and then the road network for that district was selected using the Clip tool in the Tools Box. Finally, the area of the district's paved roads was calculated using the data in the Attribute Table.

Plant prices have been determined to their capacities based on prices obtained from the manufacturer, as shown in Table (1). The other input parameters required or the program have been summarized in Table 7.

6. Analysis of results

The optimal asphalt concrete plant size problem have been solved, and the results were analyzed using MATLAB. The optimal number, location, and size of asphalt concrete plants in the Karbala governorate have been summarized in Table 8 and

Table 8. The optimal number and size of asphalt concrete plants in the Karbala governorate.

No.	Location	Allocated demand center	Allocated capacity ton/hr	No of production lines	The capacity of production lines ton/hr	Plant size ton/hr
1	A	Non	Non	Non	Non	Non
2	B	1	70.1036616	1	80	80
3	C	Non	Non	Non	Non	Non
4	D	2,3,4,5,6,7	789.0098384	3	240 240 320	800

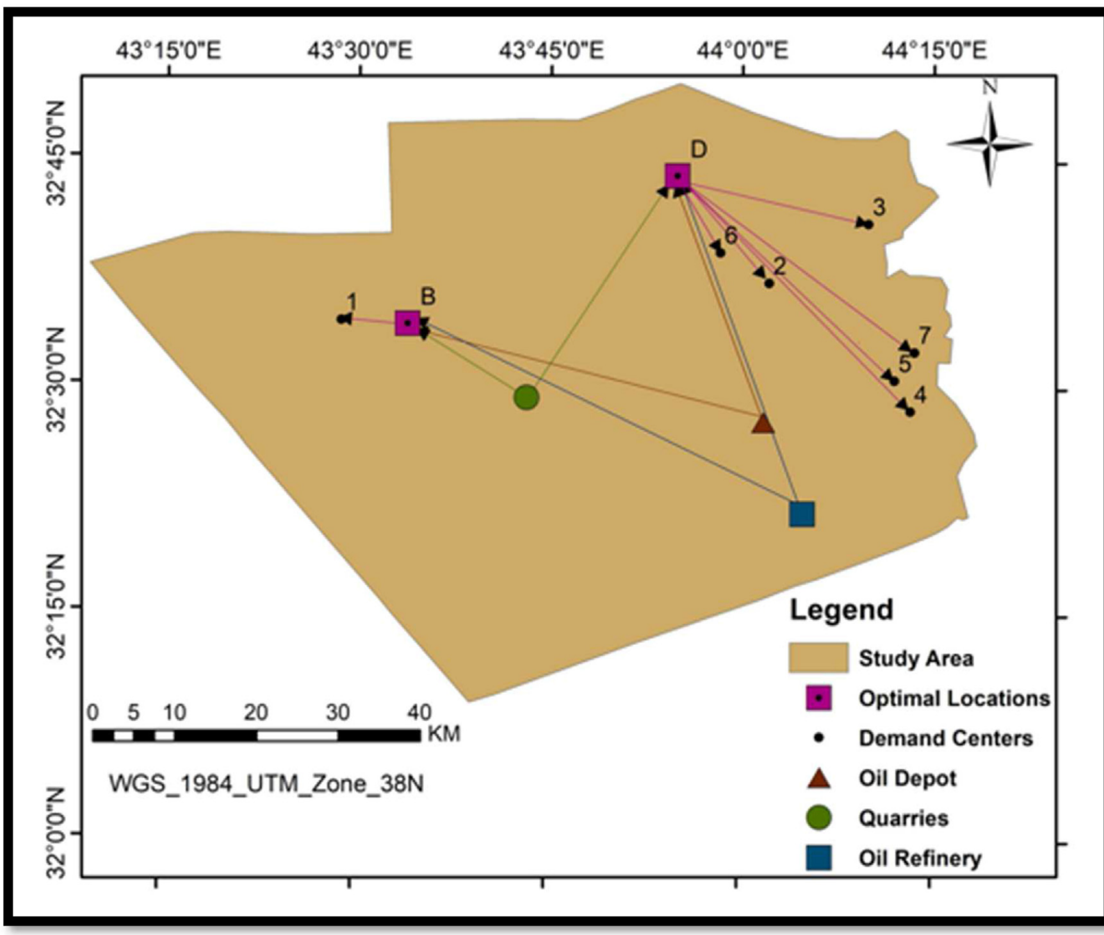

Fig. 8. The optimal number and location of asphalt concrete plants in Karbala governorate.

Table 9. The optimal number, locations, sizes and allocation of asphalt concrete plants in Karbala governorate.

No.	Location	Longitude	Latitude	Plant Size ton/hr	Allocation
1	B	43° 33′ 56.980″ E	32° 34′ 4.716″ N	80	Ain Al Tamur
2	D	43° 54′ 55.248″ E	32° 44′ 1.834″ N	800	Karbala Center Al Hussainya Al Khairat Al Jadwal Al Gharbi Al Hur Al Haindiya

Table 10. Sensitivity analysis of the interest rate change.

No.	Interest rate	Location	Allocated demand center	Allocated capacity ton/hr	No of production lines	The capacity of production lines ton/hr	Plant size ton/hr
1	2%	B	1	70.1036616	1	80	80
		D	2,3,4,5,6,7	789.0098384	3	240 240 320	800
2	4%	B	1	70.1036616	1	80	80
		D	2,3,4,5,6,7	789.0098384	3	240 240 320	800
3	6%	B	1	70.1036616	1	80	80
		D	2,3,4,5,6,7	789.0098384	3	240 240 320	800
4	8%	B	1	70.1036616	1	80	80
		D	2,3,4,5,6,7	789.0098384	3	240 240 320	800
5	10%	B	1	70.1036616	1	80	80
		D	2,3,4,5,6,7	789.0098384	3	240 240 320	800
6	12%	B	1	70.1036616	1	80	80
		D	2,3,4,5,6,7	789.0098384	3	240 240 320	800
7	14%	B	1	70.1036616	1	80	80
		D	2,3,4,5,6,7	789.0098384	3	240 240 320	800

illustrated in Fig. 8, as have been computed by the MATLAB R2015a software (version 8.5).

The geographical distribution of the optimal asphalt concrete plants locations is consistent with the location of existing demand centers and raw materials shown in Fig. (7).

Table 8 shows that the optimal number of asphalt concrete plants is two, plants B and D, with an optimal production size of 80 tons/hr and 800 tons/hr, respectively. The coordinates of the plants' optimal locations have been determined using the ArcGIS software's Calculate Geometry tool. The optimal number, location, and size of asphalt concrete plants in the Karbala governorate and the optimal allocation of Karbala districts to each of those locations are shown in Table 9.

7. Sensitivity analysis

Sensitivity analysis have been performed based on the results obtained for the optimal asphalt concrete plant size problem to analyze the changes in the number, locations, and size of asphalt concrete plants within the Karbala governorate when the problem constraint have been modified.

7.1. Sensitivity analysis of the interest rate change

The algorithm for determining the optimal size of an asphalt concrete plant has been solved in MATLAB by assuming a change in interest rates from 2% to 14%, with a 2% increase each time. Table 10 summarizes and analyzes the findings.

Based on analyses using various interest rate limits, it is concluded that the number, location, and size of asphalt concrete plants are not sensitive to changes in the interest rate's value, as illustrated in Table (9), where none of the values for the number, location, and size of asphalt concrete plants changed in response to changes in the interest rate's value.

7.2. Sensitivity analysis of the change in demand

The optimal size of the asphalt concrete plant algorithm have been solved using MATLAB, assuming a change in the forecasting demand for

Table 11. Sensitivity analysis of the change in demand.

No.	Change in demand	Location	Allocated demand center	Allocated capacity ton/hr	No of production lines	The capacity of production lines ton/hr	Plant size ton/hr
1	−10%	B	1	63.09329544	1	64	64
		D	2,3,4,5,6,7	710.1088546	3	240	720
						240	
						240	
2	−20%	B	1	56.08292928	1	64	64
		D	2,3,4,5,6,7	631.2078707	3	160	640
						240	
						240	
3	−30%	B	1	49.07256312	1	64	64
		D	2,3,4,5,6,7	552.3068869	3	160	560
						160	
						240	
4	−40%	B	1	42.06219696	1	64	64
		D	2,3,4,5,6,7	473.405903	3	120	480
						120	
						240	
5	−50%	B	1	35.0518308	1	40	40
		D	2,3,4,5,6,7	394.5049192	3	120	400
						120	
						160	
6	+10%	B	1	77.11402776	1	80	80
		D	2,3,4,5,6,7	867.9108222	3	240	880
						240	
						400	
7	+20%	B	1	84.12439392	1	120	120
		D	2,3,4,5,6,7	946.8118061	3	240	960
						320	
						400	
8	+30%	B	1	91.13476008	1	120	120
		D	2,3,4,5,6,7	1025.71279	3	240	1040
						400	
						400	
9	+40%	B	1	98.14512624	1	120	120
		D	2,3,4,5,6,7	1104.613774	3	320	1120
						400	
						400	
10	+50%	B	1	105.1554924	1	120	120
		D	2,3,4,5,6,7	1183.514758	3	400	1200
						400	
						400	

asphalt concrete in the Karbala governorate for the entire study period, with an increase or decrease of 10% each time, the forecasting demand for asphalt concrete for each year of the study period. Table 11 summarizes and analyzes the findings.

Based on the analyses performed with various demand limit values, it is concluded that the number and location of asphalt concrete plants are not sensitive to changes in the demand value, as shown in Table (10), as neither the number nor the location of asphalt concrete plants changed in response to the change in demand value. However, as illustrated in Table (10), the size of the asphalt concrete plant has changed in response to changes in the volume of demand for asphalt concrete in the Karbala governorate. The size of the asphalt concrete plant increased as demand increased and decreased as demand decreased. Fig. (9), shows the relationship between demand volume and the size of asphalt concrete plants in the study area's locations B and D.

As illustrated in Figure (9), the size of plant D is more sensitive to changes in the volume of demand for asphalt concrete than the size of plant B. This is because the volume of demand allocated to Plant D is greater than the volume of demand allocated to Plant B; the greater the volume of demand, the more sensitive the size of the plant to changes in the volume of demand.

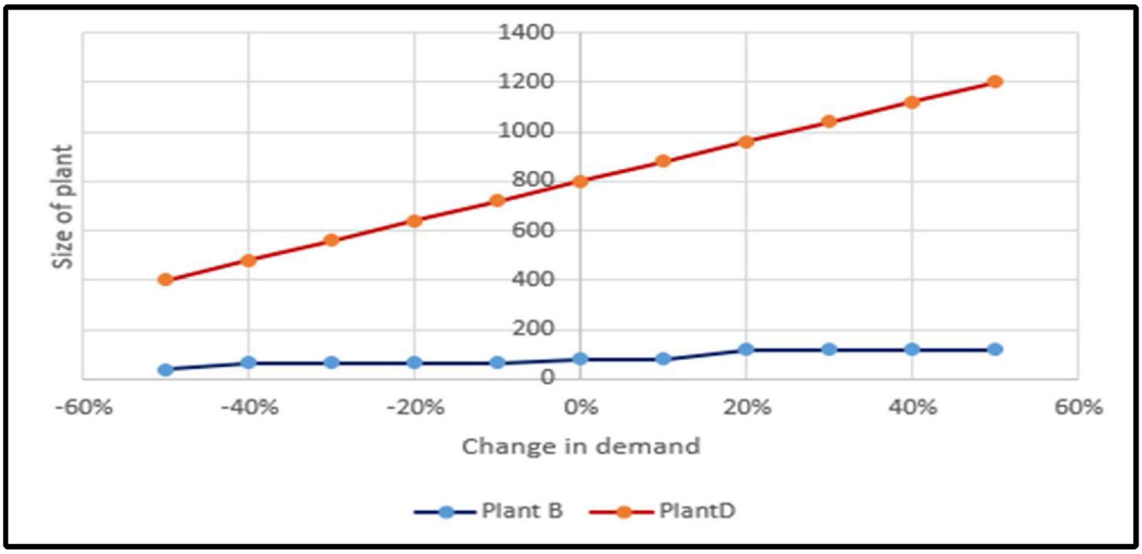

Fig. 9. Relationship between volume of demand and size of plants.

8. Conclusion

The plant location problem is a multi-objective problem. No location can satisfy all of the criteria. As a result, the multicriteria problem's solution is a compromise, not necessarily an optimal one.

Numerous infrastructure issues, such as the location of infrastructure, buildings, or even facilities, can be resolved through mathematical models and algorithms. For example, specific industries, such as asphalt concrete production, maybe seek a solution to help them choose the location and size of an asphalt concrete plant, which is one of the most typical concerns of entrepreneurs and consultants working with local or regional governments.

The location of an asphalt concrete plant was determined in this study utilizing a commonly used PW methodology that took into account several elements of capital costs, operating costs, and transportation costs, such as distances. In this case, a PW mathematical problem supported the development of the application model used in this study. As a result of the mathematical analysis presented in this paper, the locations of the asphalt concrete plants are proposed using spatial information.

Acknowledgment

This project is supported by the Directorate of Roads & Bridges Holy Karbala in supplying all data needed to achieve this work. The author gratefully acknowledges the support received from the Directorate of Roads & Bridges Holy Karbala. The authors appreciate the editor's and anonymous reviewers' suggestions for improving the quality of this work.

References

[1] Nas B, Cay T, Berktay A, Iscan F. Selection of MSW landfill site or Konya, Turkey using GIS and multicriteria evaluation. J Environ Eng 2010;160:491–500. https://doi.org/10.1007/s10661- 008-0713-8.

[2] Mohammed SR, Hamza G. Affordable housing and ways to achieve lower cost and less period of time. Journal of Kerbala University 2015;13(2):13–31. https://www.iasj.net/iasj/download/75a41a96f0b7f1e0.

[3] Mohammed SR. Forecasting of factors affecting thermiston work productivity estimation by using artificial neural network. J Construct Eng Technol Manag 2017;7(1):10–21. www.stmjournals.com.

[4] Delivand MK, Cammerino AR, Garofalo P, Monteleone M. Optimal locations of bioenergy facilities, biomass spatial availability, logistics costs and GHG (greenhouse gas) emissions: a case study on electricity productions in South Italy. J Clean Prod 2015;99:129–39. https://doi.org/10.1016/j.jclepro.2015.03.018.

[5] Woo H, Acuna M, Moroni M, Taskhiri MS, Turner P. Optimizing the location of biomass energy facilities by integrating multi- criteria analysis (MCA) and geographical information systems (GIS). Forests 2018;9(10):585. https://doi.org/10.3390/f9100585.

[6] Jayarathna L, Kent G, O'Hara I, Hobson P. A Geographical Information System based framework to identify optimal location and size of biomass energy plants using single or multiple biomass types. Appl Energy 2020;275:1–14. https://doi.org/10.1016/j.apenergy.2020.115398.

[7] Holsbeeck SV, Ezzati S, Röser D, Brown M. A two-stage DSS to evaluate optimal locations for bioenergy facilities. Forests 2020;11(9):968. https://doi.org/10.3390/f11090968.

[8] Construction Engineering/University of Toronto. Highway 401 expansion project. 2012. https://sites.google.com/site/hwy401exp/home. [Accessed 2 March 2022]. Accessed.

[9] Peurifoy RL, Schexnayder C, Schmitt R, Shapira A. Construction planning equipment and method. Seven Edition. McGraw-Hill Education; 2005.. https://www.abebooks.com.
[10] Central Bank of Iraq. Interest rate of commercial banks. 2022. https://www.cbiraq.org/SubCategoriesTable.aspx?SubCatID=114. [Accessed 7 March 2022]. Accessed.
[11] Mohammad SR, Ali G. Spatial analysis based method to determine the optimal locations for asphaltic concrete plants: case study in Karbala governorate of Iraq. IEEE, 2022 international symposium on multidisciplinary studies and innovative technologies (ISMSIT):105 - 110. 2022. https://doi.org/10.1109/ISMSIT56059.2022.9932745.
[12] Wu X, Gao L, Du S. Mix proportion design of asphalt concrete. Mater Sci Eng 2017;275:1–11. https://ui.adsabs.harvard.edu/link_gateway/2017MS&E..275a2019W/doi:10.1088/1757-899X/275/1/012019.
[13] Al-yasery H, Almuhanna R, Al-jawahery Z. Metro stations site selection in Karbala city using (GIS). IOP Conf Ser Mater Sci Eng 2018;433(1):1–11. https://doi.org/10.1088/1757-899X/433/1/012036.
[14] Ali G, Mohammad SR, Al-busaltan S. Forecasting the demand for asphalt concrete in Karbala governorate. AL-Bahir Journal for Engineering and Pure Sciences 2022;1:33–42. http://creativecommons.org/licenses/by-nc/4.0/.