Republic of Iraq
Ministry of Higher Education & Scientific Research
University of Kerbala
College of Engineering
Civil Engineering Department

Developing a System for the Selection of Optimum Locations for Asphalt Concrete Units Plants for Roads Projects in Iraq

A Thesis Submitted to the Council of the Faculty of the College of the Engineering/University of Kerbala in Partial Fulfillment of the Requirements for the Master Degree in Infrastructure Engineering

By:
Ammar Diame Salih

Supervised By:
Asst. Prof. Dr. Hussein Ali Mohammed

October 2022 Rabi` Al-Awal 1444

Republic of Iraq
Ministry of Higher Education & Scientific Research
University of Kerbala
College of Engineering
Civil Engineering Department

Developing a System for the Selection of Optimum Locations for Asphalt Concrete Units Plants for Roads Projects in Iraq

A Thesis Submitted to the Council of the Faculty of the College of the
Engineering/University of Kerbala in Partial Fulfillment of the
Requirements for the Master Degree in Infrastructure Engineering

By:
Ammar Diame Salih

Supervised By:
Asst. Prof. Dr. Hussein Ali Mohammed

October 2022 Rabi` Al-Awal 1444

بسم الله الرحمن الرحيم

يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ

صدق الله العلي العظيم

(المجادلة: من الآية 11)

Examination committee certification

We certify that we have read the thesis entitled "**Developing a System for the Selection of Optimum Locations for Asphalt Concrete Units Plants for Roads Projects in Iraq**" and as an examining committee, we examined the student "**Ammar Diame Salih**" in its content and in what is connected with it and that in our opinion it is adequate as a thesis for the degree of Master of Science in Civil Engineering.

Supervisor

Signature:
Name :. Asst. Prof. Dr. Hussein Ali Mohammed
Date: / / 2022

Member

Signature:
Name :. Asst. Prof. Dr.
Raid R. A. Almuhanna
Date: 10/11/ 2022

Member

Signature:
Name :. Asst. Prof. Dr.
Mohammed Neamah Ahmed
Date: / / 2022

Chairman

Signature:
Name :. Prof. Dr. Hatem Khaleefah Breesam
Date: / / 2022

Signature: sadjad AH
Name : Prof. Dr. Sadjad Amir Hemzah
Head of the Department of Civil Engineering
Date: / / 2022

Signature: L. Sh. Rashd
Name : Prof. Dr. Laith Sh. Rasheed
Dean of the Engineering College
Date: 15/11/ 2022

Supervisor certificate

I certify that the thesis entitled **"Developing a System for the Selection of Optimum Locations for Asphalt Concrete Units Plants for Roads Projects in Iraq"** was prepared by **Ammar Diame Salih** under my supervision at the Department of Civil Engineering, Engineering college, University of Kerbala as a partial of fulfilment of the requirements for the Degree of Master of Science in Civil Engineering.

Signature:

Asst. Prof. Dr. Hussein Ali Mohammed

Date: / / 2022

Linguistic certificate

I certify that the thesis entitled **"Developing a System for the Selection of Optimum Locations for Asphalt Concrete Units Plants for Roads Projects in Iraq"** is submitted by **Ammar Diame Salih** has been proofread and its language has been amended to meet the English style.

Signature:
Hayder Hussein Alwan Algretawee
Date: / /2022
25 9

Abstract

Plants of producing asphalt concrete units for road projects purposes are considered to have a progressive influence on enhancing the construction process generally and paving projects in particular. The selection of the optimum location for these plants has a great directional long-term effects from an environmental, economic, and social point of view.

This study aims to prepare and define quantitative and qualitative factors (Traditional and sustainable) affecting directly or indirectly, on the process of the selection of optimum location for asphalt concrete units plants for paving projects and developing a system for solving the problem of selecting the optimum location of asphalt concrete unit plants based on the mentioned factors.

The methodology consisted of two stages: the first stage, a survey of related literature was made, the second stage, a field study was carried out,which involved data collection on the statues of the selection of location for constructed asphalt concrete plants in Iraq. Personal interviews were achieved, and introductory and Delphi technique questionnaires were set up and submitted to experts in the roads and asphalt industry field to determine the relative importance of almost each qualitative and quantitative factors affecting on the process of selection optimum location for asphalt concrete units plants.

Then, a system was suggested involving the quantitative and qualitative factors by its relative importances from Delphi questionnaires results, using POM-QM software to simplify its use, which selects the optimum location for asphalt concrete units plants. The proposed system consists of three cases:

achieving the highest socio-environmental benefits, achieving the highest economic benefits, and achieving the two cases.

the most suitable location out of four locations for the construction of asphalt concrete unit plant for paving projects and maintenance of roads in the Al-Hur district / Karbala Province was selected as an example for applying the system. These locations are: Industrial Zone of Razzaza, Industrial Zone of Al-Sharia, Industrial Zone of Khan Al-Rubue, and Industrial Zone of Husseiniya. Where, when applying this system to the four industrial zones, it was found that the optimal location in terms of the of three cases would be in the Industrial Zone of Razzaza. The conclusions of applying the proposed system have indicated its economic feasibility, and guides decision-makers in the asphalt industry to select the optimum and sustainable location for asphalt concrete units plants in Iraq.

Undertaking

I certify that research work titled “**Developing a System for the Selection of Optimum Locations for Asphalt Concrete Units Plants for Roads Projects in Iraq**” is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

Signature:
Ammar Diame Salih
Date: /   / 2022

Dedication

I dedicate this work to my parents, my father and my mother, for their efforts in supporting me during my studies.

I also dedicate this work to General Directorate of Municipalities, where I work, to be more creative in the work of this institution.

Signature:
Ammar Diame Salih
Date: / / 2022

Acknowledgements

In the name of Allah, the most compassionate the most merciful. Praise be to Allah and pray, and peace be upon his prophet Mohammed his relatives and companions, and upon all those who follow him. First and foremost, I have to thank and praise to Allah, who gave me health and necessary strength to perform this work. I am extremely grateful to my supervisor "**Dr. Hussein Ali Al-Hamami**" for his help, encouragement, and patience throughout all stages of the work. Under his supervision and teachings, I have improved my skills as a researcher and gained new insights. I have been extremely fortunate to have a supervisor who, without his enormous knowledge, would not have made this work possible.

I'd also like to thank the faculty staff of the Construction Management branch/ civil engineering department/ University of Baghdad, represented by **Assist. Prof. Dr. Meervat Altaie** for her scientific support during the research phase.

I sincerely thank the Department of Civil Engineering / University of Kerbala for providing me with information and sources, especially.**Prof. Dr. Shaker Al-Bo Sultan**, and **Assist.Prof. Gafel Aswed.**

I extend my sincere thanks to the Dean of the College of Engineering and the Head of the Civil Engineering Department for providing the possible administrative assistance and facilities during the study period.

Also, many thanks and gratitude to **Dr. Hassan Faisal Shalabh** / Office of the Scientific Assistant, and **Mr. Ehsan Al-Tamimi /** Office of postgraduate, for their efforts in helping postgraduate students.

I extend my thanks and praise to the University of Warith Al-Anbiya for providing me with programs and scientific resources, especially: **Prof. Dr.**

Awad Al-Khalidi, **Assist. Prof. Dr. Anmar Diekn**, **Ass. Lect. Abdulrasool Th. Abdulrasool.**

I express my gratitude to the Ministry of Construction, represented by the following engineers and directorates, for their assistance in providing the necessary information to complete the field study requirements.

Eng. Ali Yahya / Directorate Of Roads & Bridges Holy Karbala

Eng. Irfan Talib / Directorate Of Roads & Bridges Holy Karbala

Eng. Baligh Al-Hasnawi/ Hamorabi State Construction Contracts Company

Eng. Sundus Rahman Meekhan/ Ashour State Construction Contracts Company

Eng. Samir Abdullah Salman/ Ashour State Construction Contracts Company

I express my thanks and gratitude to the Iraqi Geological Survey for providing me with information of aggregate quarries site in the country, especially: **Dr. Younus I. Al-Saady, Dr. Safaa Al-Shawi, Geologist. Sinan Talib Ahmed.**

I give my thanks to General Directorate for Industrial Development (GDID), represented by the lady: **Amal Hassan Mutheeb**, for her efforts in providing me with information on the asphalt plants belonging to the private sector.

I sincerely thank Holy Kerbala Province/ Direct Implementation Dept., in particular: **Eng. Muhannad Abdul-Jabbar, Eng. Hazem Hassan Shati**, for their efforts in supporting this research work.

I also thank **Insha Al-Khalij Company for General Contracting and Asphalt Industry** for their help and cooperation with me in feeding this research with full information on preparing asphalt mixtures in plants.

I also extend my thanks to all the engineers who contributed to answering the questionnaire forms, as well as the experts who contributed in the Delphi method questionnaire.

Signature:
Ammar Diame Salih
Date: / / 2022

Contents

List of Tables

List of Figures

List of Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
AMS	American Mathematical Society
ASTM	American society for testing materials
CEOs	Chief Executive Officers
FR	Factor Rating
GDID	General Directorate for Industrial Development
GSRP	General Specifications for Roads and Bridges
HMAs	Hot-Mixes Asphalt
ID	Iraqi Dinar
LP	Linear Programming
OR	Operations Research
PMB	Polymer Modified Bitumen
RAP	Reclaimed Asphalt Pavement
SCM	Supply Chain Management

Chapter One: Introduction

1.1 Preface

Pavements made of asphalt concrete are among the largest and most critical infrastructures in the world today (Kim, 2009). There has been a recent focus on the appropriate location of asphalt concrete unit plants due to the high demand for Iraq's pavement network and a limited supply. In light of today's constantly shifting demands for urban, environmental and central locations, even the most ideal location might turn into a costly investment mistake (Owen & Daskin, 1998). As a result, corporations throughout the globe are obliged to rethink the placement of a specific factory, even if it worked well in the past (Mohsen & Al-Najjar, 2012).

1.2 Study justifications

The problem of paving in Iraq is one of the important problems facing the country, due to the expansion of the master plans of cities, and thus the expansion of the road network. Because of the importance of this problem and the complexity of its causes, the state has attached great importance to it in terms of study and follow-up of implementation while providing the available resources.

One of the studies that shed a light on project delays in Karbala, Iraq, covering the period between (2012 and 2013) mentioned that among the six types of delay projects, the largest percentage was road projects with a ratio of 45%, and it is the most common type of project (Muhammad & Ibrahim, 2017) with delays return to lack of readiness of the contracting asphalt companies with these projects (Yahia, 2020).

Two different expressway projects are being planned in our country, Expressway No. (2), when constructs, it will be the main route linking both

Iraqi's southern and northern regions on the one hand, and also linking between Europe and the Arabian Gulf on the other hand, and maintenance the Expressway No. (1) connects the country's southern parts with Baghdad and further west to the Syrian and Jordanian borders (Janaby, 2017)(Qanber, 2020).

Since the country, represented by the authorities that carry out the paving work, lacks the existence of integrated studies according to which the optimum locations are selected for establishing of new asphalt concrete units plants or redistribution of existing plants, and that selecting the optimal location for these plants has significant effects from the construction, economic, social, and environmental aspects on a continuous and long-term basis. Therefore, the researcher prepared this study to contribute to overcoming the existing deficit in the supply of asphalt concrete for the purposes of paving works in Iraq.

1.3 Problem statement

In Iraq, the asphalt concrete industry policymakers have a good knowledge of quantitative (economic) and qualitative (social and environmental) essential factors for selecting the asphalt concrete unit plants. However, they lack the system or technique that achieves potential location alternatives' suitability according to these factors. This study work proposes a new understanding of asphalt concrete unit plant location. It helps decision-makers in the asphalt industry to select the optimum alternative location.

1.4 The study hypothesis

This study was designed on a fundamental hypothesis:

There is the fact that existing of two locations to establish an asphalt concrete unit plant, which both of them are similar in terms of return on investment is not correct. Each location has the characteristics are distinguished it from the other location as a result of the existence of differences in natural, economic, and social resources, and there is a need for an integrated and efficient system to choose the optimal location by determining the impact of all quantitative and qualitative factors affecting the location selection process.

1.5 The objectives of the study

The most important objectives that we seek to achieve in this study are as follows:

1. Identify the quantitative and qualitative factors affecting selecting the optimal location for the establishment of the asphalt concrete unit plant.
2. Identify the relative importance degree for each selected factor.

1.6 The aim of the study

Based on the objectives of the study, the aim of the study will be to develop a system based on the selected factors and the relative importance for each one to select the optimal location for establishing the asphalt concrete unit plant.

1.7 The limits of the study

The duration of the study (time limits) was determined from 1/10/2019 to 20/8/2022, while the spatial limits for the study include all Iraq except for the Kurdistan region, noting that the data which was applied to the system belongs to the Karbala Province.

1.8 The methodology of the Study

For achieving the objectives of this study, the conducted methodology throughout the study was based on the following sections:

1.8.1 Theoretical study

The theoretical study reviewed the literature, studies, and research related to the industrial location issue in Arab and foreign periodicals.

1.8.2 Field study

The field study included the following:

1.8.2.1 Field survey

The researcher executed a field survey on some asphalt concrete unit plants during the private and public sectors to obtain information on the plants' capacities, raw materials and its sources, and the costs of its transportation through a particular information form designed for this purpose.

1.8.2.2 Open questionnaire (personal interviews)

To achieve the first study’s objective, which is to determine the qualitative and quantitative factors affecting the selection of asphalt concrete unit plant location, the researcher executed several personal interviews with engineers and experts working in asphalt concrete units plants of the Ministry of Construction and Housing, Mayority of Baghdad, and several private asphalt concrete units plants.

1.8.2.3 Closed Questionnaire

Depending on the theoretical study, field study, and personal interviews, an introductory questionnaire form was designed that includes general and technical information about the costs of making asphalt and the factors affecting the selection of a plant location, the aim of which is to identify the most prominent quantitative (economic) and qualitative factors (including social and environmental factors), affecting the selection of asphalt concrete unit plant location. Depending on the results of the introductory questionnaire, the researcher executed a special questionnaire for experts according to the Delphi technique to determine the degree of the relative importance of the quantitative and qualitative factors affecting the selection of plant location and to know the level of importance for each factor compared to other factors and then use it to build the proposed system.

1.8.2.4 System Dveloping

A mathematical model was developed based on the linear programming technique, and the researcher used this model to establish the proposed system.

1.9 Previous studies about strategic decision-making for industrial location

A study has shown that experts employ heuristics (or "rules of thumb") and cognitive frameworks (schemas) to integrate information into a single option in making decisions (Schwenk, 1984). To be more specific, senior managers make use of preexisting cognitive schemas and heuristics to streamline the decision-making process and organize data (Miller, 1991). Therefore, decision-makers do not have to go through all the available data to make a good idea of what is going on. The use of past experiences, cognitive schemas, and heuristics may speed up the processing of information, but they can introduce systemic biases and lead to mistakes in decision-making (Tversky & Kahneman, 1974). Cognitive schemas may also foster stereotyping, fill in data gaps with usual but false information, lead to the omission of potentially crucial discrepancies, discourage doubting the current structure of knowledge, and impede innovative problem resolution (Walsh, 1995). Decision-makers often depend on tried-and-true approaches in even the most complicated scenarios (Cyert & March, 1963). In this sense, strategic choices are affected by biases when old experiences are utilized to diagnose and frame new strategic issues (Bolo et al., 2011). Table 1-1 presents the summary of global and local contemporary studies in the domain of industrial location and provides background about how previous researchers have quantified diverse decision techniques.

In general, from note Table 1-1, the previous studies mainly focused on the influence of Quantitative and qualitative factors without using a suitable tool for these factors in addition to Neglecting the impact of sustainability and recycling factors in selecting the optimal industrial location. for example, we find the researchers Hassan and Mohsen neglect the effect of qualitative factors in selection process, In contrast, Naji introduces the effect of quantitative and qualitative factors combined using the Analytic Hierarchy Process AHP, which is known for its bias toward qualitative factors. The most important thing that differentiates this study from what the researcher Al-Jumaili has done is to include the impact of sustainability and recycling in the process of selecting the optimal location for the plant, this make the selection process of asphalt concrete unit plant more sustainable.

Table 1-1: Summary of previous studies

No.	**Author Name, Case Study, and country**	**Industry Type**	**Technique(s) Used**	**Factors/ Criteria**
1.	(Al-Jumaili, 2002) Iraq	Precast concrete	Developing a new system upon linear programming & a weighted approach	Quantitative and qualitative factors
2.	(Li, 2007) USA & China	General	1. theoretical analysis 2. empirical analyses, which include: *a. statistical and econometric analysis* *b. case studies* c. *comparative analysis*	1. Modern logistics, including various inventory-control techniques 2. Supply Chain Management SCM
3.	(Hafeth I. Naji, 2009) Diyala City Iraq	Asphalt concrete	Analytical Hierarchy Process AHP	Quantitative and qualitative factors
4.	(Hassan & Mohsen, 2011) Diwaniyah city Iraq	Concrete mixtures	Linear programming	Quantitative factors
5.	(Rikalovic et al., 2014) Vojvodina region Serbia	General	GIS-based MCDA approach The family of Multi-Criteria Decision Analysis (MCDA) used are: • *Weighted Linear Combination (WLC)* • *Analytic Hierarchy Process (AHP)*	Experts in the field and/or decision-makers would determine the criteria for industrial locations based on the sort of business they serve, and these criteria may include: political, technical, geographical, physical, and environmental criteria

			• *Multiple-Objective Land Allocation (MOLA*) • *Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE)* • *Ordered Weighted Averaging (OWA)*	
6.	(Delgado et al., 2014) USA	General	clustering algorithm generates and assesses sets of industry clusters definitions	Two thousand nine data for US industries at North American Industry Classification System (NAICS). 3-digit & 6-digit
7.	. (Boutkhoum et al., 2015) Casablanca Morocco	General	hybrid multi-criteria/ multidimensional model based on OLAP analysis and fuzzy multi-criteria analysis.	1. Geo-environmental criteria (GE): • *Land* • *Situation and nearness of green areas.* 2. Economic criteria (EC): • *Cost.* • *Competition and provision.* 3. Social criteria (SC): • *Manpower and information exchange* • *Proximity to the customer base and traffic movement*
8.	(Taibi & Atmani, 2017) Constantine Algeria	General	An approach combines Fuzzy Analytic Hierarchy Process (FAHP), (GIS) and Decision rules (Ranking model based on GIS-FAHP integration).	1. Natural risk criteria: • *Risk groundwater pollution.* • *Fauna and flora problem.* • *Citizens noises.* 2. Socio-economic criteria:

				• *Seismicity.* • *Flood.* 3. Environmental impact criteria • *Temperature.* • *Rainfall.* • *Bioclimatic Floor.* 4. Climate characteristics criteria: • *Cost management.* • *Equipment and development potentiality.* • *Transport Infrastructure.*
9.	(Sami et al., 2020) Constantine Algeria	General	Weighted linear combination (WLC) with (GIS) & Remote Sensing	1. Exclusion factors: • *Urban areas and a zone of 500 m in their proximity.* • *Wadis and a zone of 500 m in their proximity.* • *The road network and a zone of 50 m in their proximity.* • *Areas with a slope greater than 15%.* • *Protected areas (forests, agricultural land and water areas*). 2. Appreciation factors: • *Road distance [km].* • *Slope less than 15%.*
10.	(Aliverdilou et al., 2021) Markazi Provinces Iran	General	Adaptive Neuro-Fuzzy Inference System (ANFIS) & Fuzzy Inference System (FIS) methods	Quantitative and qualitative criteria

1.10 Thesis structure

The following is the structure of the thesis:

Chapter 1 An introductory chapter defines the importance statement, objectives, methodology, and an overview of this study.

Chapter 2 presents an overview of the most prominent theories in the domain of industrial location selection. It presents various opinions and provides background for how previous researchers approached the concepts of industrial localization and location.

Chapter 3 provides information regarding the factors influencing plant location and various models that help identify the ideal location.

Chapter 4 presents a brief description of the essential aspects of asphalt mixtures plants, asphalt paving platform, and various properties that can be required of asphalt, followed by brief descriptions of the locations for asphalt concrete units plants in Iraq at present.

Chapter 5 illustrates, in detail, how implementing the methodology of an introductory questionnaire and the Delphi technique questionnaire, respectively, and the methodology of determining the quantitative and qualitative factors affecting the selection of the asphalt concrete unit plant location according to the results of the questionnaires.

Chapter 6 is dedicated to indicating the approach in which the proposed system was developed for the selection.

Chapter 7 summarizes this research work's conclusions with recommendations and proposed future studies about industrial location.

Chapter Two: Theoretical Framework

2.1 Introduction

The requirements for the success of any industry are related to the technical aspect of the production process, they are also linked, from the beginning to the spatial space in which this industry is established, in particular the selection of the location for its production activity, Economic rationality necessitates choosing that location to achieve the lowest possible cost with the greatest economic return in its social, material and environmental dimensions because this choice has an impact on the cost of the product, especially the cost of transporting the inputs and outputs of the production process. In contrast, the inappropriate choice will casue an increase in the cost of the product for the consumer and affects the volume of production and consumption together, and the resulting economic effects with social repercussions on the individual and society. Therefore, several studies tried to reach the so-called optimal industrial location, which will be explained in this chapter.

2.2 Concept of industrial location

The concept of industrial location includes relationships and spatial interdependence that crystallize in patterns and models for these relationships between economic activities within a specific spatial space (Al-Kenany, 2009). Thus, it's interested in studying these patterns and spatial relationships, and the factors that control selecting locations for industrial facilities. Given that the areas of concentration of production factors (supply), and the areas of market distribution (demand) vary from one region to another, the industrial location plays a major role in determining the size of production costs and thus affecting the volume of profits achieved by industrial facilities (Al-

Kenany, 2008). Selecting the best location for the industrial project and its spatial effects occupied the interest of many thinkers and scientists to understand the factors affecting, which determining the best location for industrial projects; this interest began to crystallize since the attempt of von Thünen (1826) & Launhardt (1885) explained the phenomenon of industrial settlement (Garcia Pires & Pontes, 2021). This was followed by after the attempt of the German scientist Alfred Weber (1909), where he put his famous book: *Theory of the location of industries,* Weber's theory followed the main ideas and models that addressed the problems of this choice by group of scientists, such as Christaller (1933), Hoover (1937), Lösch (1940), Isard (1949), Koopmans (1951a, b), Koopmans and Beckmann (1957), Moses (1958), Cooper (1963), Hakimi (1964, 1965), Balinski (1965), and Beckmann (1968) (Eiselt & Marianov, 2019).

The concept of industrial location is often within one of the following two concepts or both together (Al-Jumaili, 2002):

The first concept represents the narrow meaning of the industrial location, which means the optimal location of the industrial project to engage in a specific activity within certain assumptions.

Second concept: This concept means trying to determine the reasons that cause settling a certain type of industry in one place and not happened in another.

A close looking at each of the two previous concepts confirms the close link between them, because determining the optimal location for a particular industrial project cannot be acheived without preparing a careful analytical study of the factors that govern the nature of the activity. The study and analysis of the main factors that governed the localization of the industry actually are meaningless unless it helps to derive some technical methods or practical rules that help for determiming the optimal location for the project. Nevertheless, the essence of the problem remains to selecting the optimal location for the industrial project.

2.3 Industrial location theories

The understanding and interpreting of the factors that influence on the selection of the optimal location for industrial project by the scientists, that mentioned above and others led to the crystallization of major models and theories that addressed the problems of this choice. Because of the diversity of factors affecting the location, these theories varied in the likelihood of these factors and their relative importance, this study will attempt to shed a light on four main theories that deal with the problem of selecting the industrial location (Al-Kenany, 2009).

2.3.1 Least Cost Location Theory

The concept of the industrial project location is summarized in this theory as the location in which the project can be established to achieve the minimum production cost compared to other locations. The analysis in this theory is based on the assumption that conditions of free competition are provided with the presence of demand for products in a single market (Al-Sammak, 2012). The beginnings of the realization of this theory were made by von Thünen (1826) (Eiselt & Marianov, 2019), who studies the optimal location for crops of the city, and this study relied on determining the optimal location of farming crops on the following two factors (Walker, 2021):

1. Transportation cost: It increases by an increasing distance between crop locations and the city.

2. The land cost: It is characterized by its rise near the city and decreases as we move away from it.

Thünen's idea of finding the optimum location for crops was the basis on which later theories were based in finding the optimum industrial location based on these two factors.

After that, the German researcher Launhardt (1885) presented the idea that the plant's location would be at the lowest cost point by clarifying the differences in the locations of industrial projects through cost variables and Demand factors in the available alternatives to the location. He also explained that the cost of transportation has a significant impact on determining The industrial location. Launhardt came up with the idea of the Locational Triangle to settle the industrial project, where two points represent the primary sources, and the third point represents the market, these were the foundations of the theory of industrial location developed by Alfred Weber (Laporte, 2019).

Alfred Weber (1909) is considered the first researcher to develop a comprehensive theory of optimal industrial location based on the following hypotheses (Smith, 1981):

a. Heterogeneous distribution of raw materials sources (supply)
b. Market volume stability (demand)
c. Spatial variation in the distribution of labor

According to these three hypotheses, Weber tried to determine the industrial location based on three basic variables that he considered as the main factors for establishing the industry in a region:

A. Transportation Cost

Weber emphasized that the optimal location is represented by the point at which transportation costs are the least possible. In the other words, the sum of the costs of transporting raw materials (Inputs), and the costs of distributing final products (Outputs) are the least possible. He concluded that the industry uses raw materials and loses from Its weight during production is preferably settled near the sources of raw materials. In the opposite case, it is preferable to settle near the market and find the Material Index. If the materials index is higher than (1.0), the industry is approaching the sources of raw materials, and if it is less than (1.0), it is approaching the market (Smith, 1981). The Material Index (MI) was created by Weber can be represented by the expression (2-1) (Webber, 2020):

$$\mathrm{MI} = \frac{\text{weight of row materials use up}}{\text{weight of product}} \qquad (2-1)$$

In the case of more than one raw material, Weber relied on what was called *Locational Triangle*, as shown in Figure 2-1, where the optimal location (T) represents the balance between the costs of transportation for raw materials (Inputs) and the costs of distributing the final products (Outputs) (Chao, 2018).

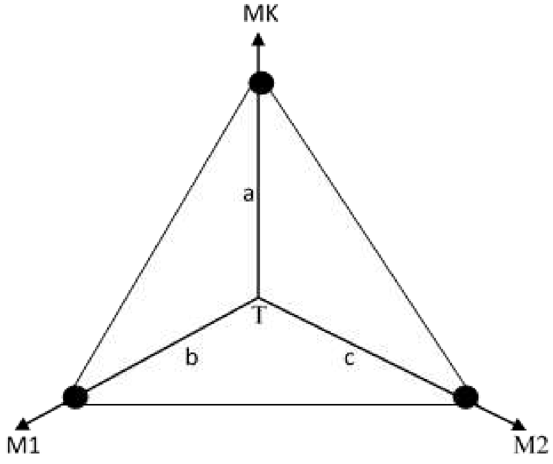


Figure 2-1: Alfred Weber's triangle of industrial locations (Chao, 2018).

Where:
T: optimal location.
M1&M2: Row materials resources.
a,b,c: The distance between location, row materials, and market.
MK: Market

B. Labor Cost

The location where the cost of transportation is the least possible is not necessarily that the cost of labor is also the lowest possible; accordingly, when there is a large discrepancy between the two costs in the same location, it is preferable that the industrial project be settled in another place where cheap labor costs are available (Webber, 2020). In his method of analysis, Weber tried to link the costs of labor and transportation, where he called it Total Costs, summarizing his idea that changes in settlement of industrial projects compared to the minimum cost of transportation and under the influence of the labor cost factor cannot affect the settlement of the industrial project unless the resulting savings are the cost of labor exceeds the cost of transportation (Eiselt & Marianov, 2019).

C. Concentration and dispersion factor

The factor of concentration and dispersion was adopted by Weber for determining the industrial location, which has a significant impact on reducing production costs by taking advantage of the availability of Economies of Scale and Scope element, which represented in the gains obtained by the industrial project as a result of selecting its location near an industrial complex, where the base structures that contribute in services for the industrial project easily and at a lower cost. There is also a wide market for the discharge of the product in such areas, in addition to the integration of the project as a result of industrial concentration, which encourages the demand for such locations and also creates intense competition for them to the extent that it may negatively affect the cost of establishing the project as a result of the high land prices, labor wages and transportation costs, in addition to the pollution of the area, and this negative effect may press the industry to move away from these areas (Capello, 2015).

It is more important respective to Weber acknowledges that there could be more than two raw materials, and even more than one market as Alfred Weber's triangle; Weber defines this pure location problem under the expression (2-2) (Eiselt & Marianov, 2019):

$$Min\, Z = A \sum_{i=1}^{m} wrm_i\, t_i + \sum_{j=1}^{n} wfp\, a_i d_j \qquad (2-2)$$

Where:

I: an index has been used to refer the different localized raw materials, i = 1, 2, …, m.

J: an index has been used to refer the different locations of product consumption (markets), j = 1, 2, ..., n.

wrm_i: the weight of raw material i needed per unit of the finished product.

wfp: the weight of the finished product.

a_i: the amount of finished product required at market j.

$$A = \sum_{j=1} a_j$$

t_i: the Euclidean distance between the production facility and raw material i, where: $t_i = [(x-x_i)^2 + (y-y_i)^2]^{1/2}$

d_i: the Euclidean distance between the production facility and market location j, where: $d_i = [(x-x_j)^2 + (y-y_j)^2]^{1/2}$

(x, y): the location of a production plant.

(x_i, y_i): the location of raw material i.

(x_j, y_j): the location of market j.

Formally, expression (2-2) defines as Weber Model: The Classic Location Model with Multiple Source Materials and Multiple Markets (Eiselt & Marianov, 2019).

Weber's theory has been subjected to several criticisms, according to which there is a discrepancy between the cost of transporting one ton of raw materials and one ton of the final product (Al-Nasiri, 2019). In addition, freight costs are not always directly proportional to distance and freight costs are unequal for different goods. However, despite these criticisms, the basic principle of Weber's theory is still the cost of the transportation component, which plays the main role in selecting the location of the industrial project (Ahmed Habib Rasoul, 1999). Weber's theory has also been subjected to a number of analysis and development attempts, including the aspect of reducing the possibility of exceeding the cost limit (T. Drezner & Drezner, 2011), Including what tried to praise several modern and emerging concepts on the factor of transportation cost in this theory, including the concepts of sustainability and noise (T. Drezner et al., 2018), and the number of demand points reached a stage (infinity) (Z. Drezner, 1979).

2.3.2 Market Location Process Theory

The second trend is the industrial location theory went through the interest in the market when selecting the industrial location, as the interest in the market factor for selecting the industrial location is due to the recognition of the writer of this theory, that there is no equal distribution between the population and natural resources in the regions, in addition to the lack of competitive conditions in the shopping process (Laporte, 2019). One of the main weaknesses of the Least Cost Location Theory is the heavy emphasis on the input's aspect to reduce costs, neglecting final products or market demand based on the assumption that a plant can sell its products anywhere it is established. However, the demand intensity for products varies from one location to another and the consumers spread over a wide area, as the plants will search for the market with the most demand. Thus, the main determining in the process of location selecting will be the market (Glasson & Marshall, 2007). Hotelling was one of those which emphasized the link of the industrial location to the market, he proposed the so-called "proximity rule" that every customer in the market deals with the facility with the lowest total cost (which including the costs of service and transportation) with the stability of product prices and transportation cost per distance unit. The attraction factor will be the lowest service price, and therefore the lowest total cost (Eiselt & Marianov, 2019). Hotelling has based his rule on the following assumptions (Miller, 1977):

1. The consumers are distributed along with the market.
2. The price is the same for all producers.
3. The cost of transportation is fixed for the same distance.
4. The plant can supply the entire market.

5. The consumer bears the cost of transportation.
6. The complete freedom of the laboratory to change its location without any cost.
7. Production costs are fixed.

The concept of Hotelling (Figure 2-2) is summed up in the presence of two companies: A & B, which manufacture the same products at the same price and compete with each other in a particular market. The only difference is the transportation cost which added to the price of the product per unit distance, where P_1 represents the production price of firm A, P2 represents the production price of firm B, firm A's market area is a−x and firm B's market is b−y (Miller, 1977).

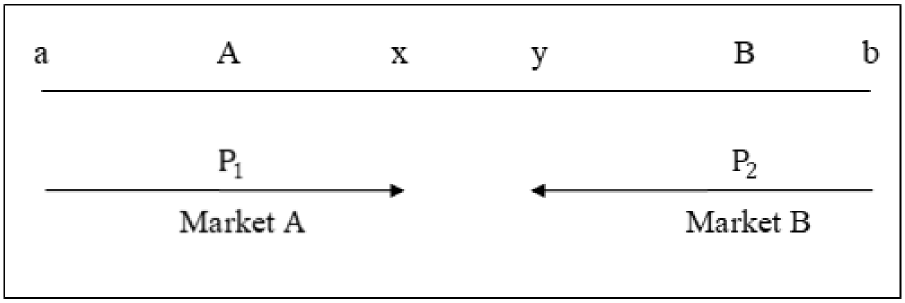


Figure 2-2: Spatial distribution of markets according to the concept of Hotelling (Miller, 1977).

The main focus of Hotelling is the presence or absence of a stable solution, i.e. equilibrium, he points out that this equilibrium can exist with both companies being next to each other and in the same market; this is called the "principle of minimum differentiation", likening this as the existence of two political candidates are quite similar to each other, although the state of equilibrium will not last long in a highly competitive situation, this exactly is what happens when two companies are very close to each other, which is what Hotelling called the concept "Industrial Agglomeration" (Laporte, 2019).

2.3.3 Profit Maximization Theory

The content of this theory lies in reconciling the factors of costs and returns at the same time, and searching for the location in which the profits of the industrial facilities are maximized. The German scientist Augest Lösch (1939) was considered the first to formulate a theory of profit maximization, setting some general conditions that he believes determine the industrial location; these conditions are (Smith, 1981):

1. The industrial location should achieve the highest profits for the producer, and the maximum benefits for the consumer.
2. The production locations must be many and varied so that they occupy the entire space, and there are no other sources that allow the entry of new competitors.
3. The existing industrial facility does not achieve extraordinary profits, so that there are no attractive factors for other facilities.
4. The production, processing, and sale areas should be as small as possible to keep the producers who can achieve the greatest benefit for them.
5. Consumers on the market frontier are not interested by buying from a particular location.

Lösch (1944) affirmed for the first time that the difference between total sales income and total costs determines the industrial location. Thus, his theory links location theory and market theory (Walker, 2021). He assumed in 1954 a homogeneous distribution of raw materials and uniform transportation rates in all directions.Additionally, the distribution of the population is equal in all regions based on the central place theory[1]

Another contributor to the development of this theory is the economist Greenhart (1956), who put the below specific factors for the selection of the industrial location (E. W. Miller, 1977):

1. Locations cost factors include transportation costs, labor costs, and production costs.
2. Cost-reducing factors.
3. Revenue-increasing factors.
4. Factors of demand on the location or the locational interference of the plants.
5. Personal factors to increase returns and decrease costs.

2.3.4 Low-Cost Consumer Theory

This theory emphasizes selecting the location that achieves the least cost to the consumer and depends on replacing the production elements with each other "Substitution Principle "in alternative locations. It also depends on paying attention to the volume of production and disposing of the largest amount of it, where this theory considers the various economic factors that affect the costs of production, distribution, and the delivery of the commodity to the consumer at the lowest possible cost (Al-Rawi, n.d.).

The economist Walter Isard (1956) is considered the first to contribute to the development of this theory and adopted in his theory to select the optimal location in the analysis of the market area and its impact on the settling of industrial projects and took the Substitution Principle (that is, the substitution of one material for another that gives the same product to reduce costs.)

---

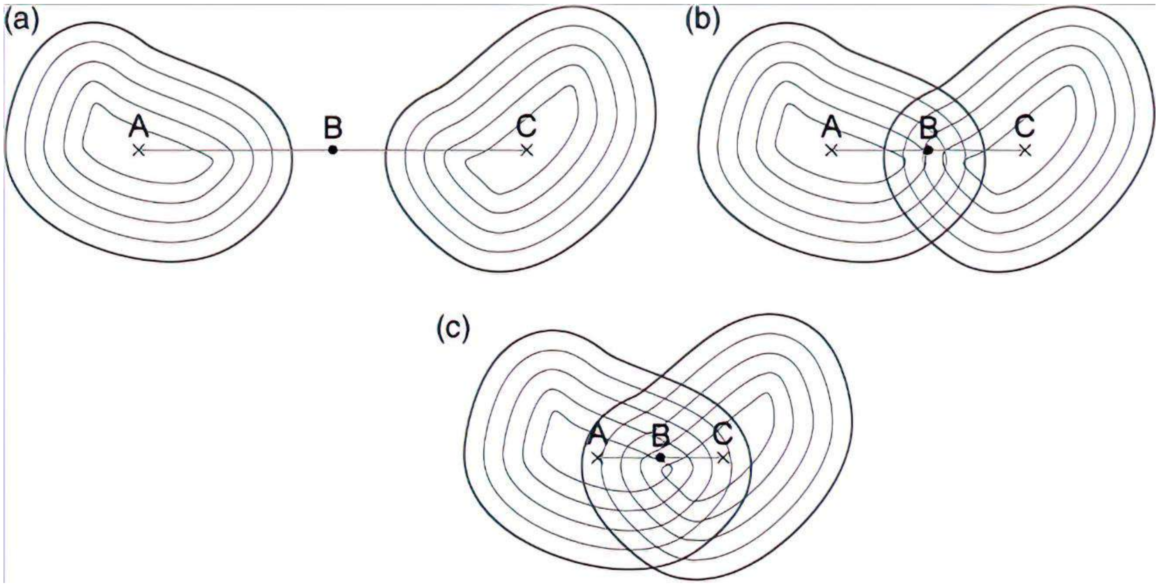
[1] Central Place Theory is a spatial theory in urban geography that attempts to explain the spatial reasons behind the distribution and size patterns in several cities and towns in the world (Hurter & Martinich, 2012).

extensively in his analysis; he classified the location factors into three groups (Hanink & Cromley, 2008):

1. Transportation cost.
2. Production costs include labor costs, energy, taxes, insurance, water sources, and others.
3. Concentration and dispersion economics.

As shown in Figure 2-3, Izard assumed the so-called isodapanes, which are contour maps whose centers represent the production costs and their contour lines the transportation costs, and that the least expensive production site for producer X is located in location A and that the least cost production site for producer Y is located in location C, Critical isodapane: It is the limit at which production costs are equal to the savings from industrial agglomeration. Therefore, industrial agglomeration will occur wherever the critical isodapane of one product intersects the critical isodapane of another product and is in location B; this point will represent the single-plant least-cost location (Eiselt & Marianov, 2019)(Hanink & Cromley, 2008).

Isard has taken the factors of concentration and dispersion based on Weber's idea into consideration, as he considered that moving from the least transportation cost location to a location within an area that has factors of industrial concentration represents a substitution of transportation costs with production costs (Al-Jumaili, 2002), He was supported in his approach by scholar Smith (1967) (Hanink & Cromley, 2008).



(a): *Nonintersecting critical isodapanes.*
(b): *Intersecting critical isodapanes with original locations lying outside the intersection.*
(c): *Intersecting critical isodapanes with original locations lying inside the intersection*

Figure 2-3: The Intersecting Critical Isodapanes (Hanink & Cromley, 2008).

2.4 Summary

These four theories differed in the likelihood of the factors affecting determining the best location for industrial projects and their relative importance; this likelihood depends on the structure of the national economy and the nature of the socio-economic relations prevailing in that economic system. Whoever focuses on the first and second theories will find that each of them does not consider all the factors affecting the selection of the industrial location, as the Least Cost Location Theory focuses on Inputs Factors only. In contrast, the Market Location Process Theory focuses on Demand Factors and production discharge, assuming the constants of the production factors. While the Profit Maximization Theory considers both production and demand factors, we find that selecting the industrial location in the Low-Cost Consumer Theory depends on statistics related to transportation and distribution costs for the consumer. This theory is based on modern methods and analytical techniques in location selection, such as Linear programming models and others.

Likewise, this discrepancy has occurred in the opinions of the scholars and thinkers of these theories who were mentioned above. From the beginning, the thinkers were convinced that industrial settlement is the result of the interaction of a group of factors to be chosen the best location for the industrial project. This interaction oscillates gives an importance to this factor or that from others in deciding to be selected. Therefore, the discrepancy between these ideas was in the preponderance of an analysis of a particular factor over another. On the other hand, the period in which this thinker lives is certainly reflected in his trends through the analysis focusing on a particular factor or group of factors.

Chapter Three: Conceptual and Strategical Framework

3.1 Introduction and meaning

The basic objective of industrial facility location problems is to locate the facilities among several alternatives. However, before proceeding to the depth of the various concepts related to the location problem of asphalt concrete unit plants, the factors affecting industrial facility location problem and various models (methods) that help identify the ideal location need to be discussed first. In this chapter, the most important influencing factors and the methods used in selecting the optimal locations for industrial projects are reviewed.

3.2 Review of factors for the selection of industrial location

Economists initially viewed the locational problem as a transportation cost-minimization problem. They described the best location as the point where the combined cost of transporting raw materials to the plant, and transporting the products to the markets was the least. By 1970s period, labor, raw materials, access to markets, and transportation were the dominant locational factors. It has now been shown that these conventional variables are still important. However, their dominance has waned due to other factors, such as taxation and the public's attitude toward industrial enterprises (Blair & Premus, 1987). The most current criteria for determining a suitable location (factors & constraints) expanded the scope of programs to enhance the industry's economic competitiveness. These factors depend on whether the problem is a public or private sector, national or international, state or community problem (Bandyopadhyay, 2020). The selection of industrial locations, in the view of some researchers, is influenced by two categories of factors (Al-Ghariri, 2013)(Gupta & Starr, 2014)(KRAJEWSKI et al., 2019):

a. Quantitative factors: These factors can be measured by financial units, such as (transportation cost, location cost, taxes), or measured by another quantitative units, such as (distance traveled, driving time, labor).
b. Qualitative factors: These factors cannot be evaluated, measured, or expressed directly in a progressive or quantitative form like (community attitudes to the industrial project, neighborhood with competitors' locations, government motivations).

Analysis of the quantitative and qualitative factors of a given location and its relative superiority to others is used to determine how much weight to give that location in comparison to others. If the analyses yield conflicting results, preference is typically given to the location that is more appropriate in quantitative factors (Al-Ghariri, 2013).

Production processes (inputs, outputs, and needs), State policy, location and plant availabilities, human variables, and the location of competitors are all categories that have been proposed by other researchers to explain its influence as a factors on location selection (Starr, 2008)(Gupta & Starr, 2014)(Al-Tamimi, 2016):

A. *Factors related to the inputs of the production process*

Of these, raw materials are extremely significant when the manufacturing process is highly reliant on them; this is especially true if the resources are fragile, need expensive transportation, or have a large weight (Kumar & N.Suresh, 2008)(KRAJEWSKI et al., 2019). Therefore, we notice businesses that prioritize raw materials as key inputs to the production process try to locate as close as possible to their sources of raw materials in order to cut down on transportation costs. This includes both the costs of transporting raw materials to the plant and the costs of transporting final outputs to distribution centers (Al-Tamimi, 2016), as putting up cement plants next to stone quarries, paper mills at the edges of woods, and canneries close to farmland (KRAJEWSKI et al., 2019), unlike industrial businesses, which mostly use manufactured materials rather than raw resources (i.e. Those that have been manufacturing process to a certain degree) (Al-Tamimi, 2016). Another benefit of being close to raw materials is that it may be possible to eliminate storage, which lowers the cost of production (Heizer et al., 2017), in addition to the timely and accurate delivery of products with no hiccups due to transportation problems (Jayraman, 2013). Consequently, lean systems can be optimized for use in supply chains (KRAJEWSKI et al., 2019).

Raw materials are important, but labor is also a consideration. Wage rates, training requirements, worker attitudes, worker productivity, and union power all contribute to the employment climate, which in turn affects the cost of production and is especially relevant for businesses that need a significant number of workers. The excellent work environmental is reflected in the labor already existing on the location, and in the good employees who are recruited to, or transferred to, the desired job location. Many CEOs see weak unions or low union efforts as a distinct advantage (KRAJEWSKI et al., 2019). Therefore, businesses look to cut costs by paying workers less or relocating to locations where labor costs are lower. However, low wages are not a deciding factor in favoring one place over another, and industrial enterprises cannot prioritize the reduction of pay rates while ignoring production. For example, if a firm pays a worker $6 per hour to produce 12 units per hour, and the replacement worker costs the firm $5 per hour to produce 8 units, the firm would be better off keeping the first worker, since the cost of work in the first case is less than the cost of work in the second case (Heizer et al., 2017):

$$\frac{\text{Labor cost per day}}{\text{Production (units per day)}} = \text{Labor cost per unit} \qquad (3-1)$$

Case 1: $\frac{6}{12} = \$0.5$
Case 2: $\frac{5}{8} = \$0.625$

When workers are inexperienced, poorly trained, poorly educated, and lack the ideals and habits of organized work, low wage rates become less of a factor in picking an industrial location. The importance of low wage rates in location selection has diminished because of other factors including automation, robotics, artificial intelligence, and the internet of things that increase the ability to carry out industrial processes. Challenges related to foreign exchange (exchange rates), the high cost of raw materials, and the high compensation rates... etc. accompany the issue of the pay gap across countries (Al-Tamimi, 2016).

B. Factors related to the outputs of production process

Companies in the service industry, for instance, need to be in close proximity to their target customers in order to maximize their profits. This is because the volume of outputs (production) is determined based on the needs of these markets. The same holds true for industrial firms, who, when selecting location, must prioritize accessibility to consumer markets for their products (Al-Tamimi, 2016). Similar to how items that are either too big, too heavy, or too easily broken during shipment, prioritize proximity to the markets, the world's largest foreign-owned car companies like Mercedes, Toyota, Honda, and Hyundai have established their plants in the USA to bring it closer to the world's largest car market, the United States (Heizer et al., 2017). Being adjacent to high-demand locations has several benefits, including the speed with which you can serve customers, give after-sale support, and fulfill replacement orders (Jayraman, 2013).

C. Factors related to the requirements of production process

Proximity to water resources is one of the important factors for choosing the location of an industrial project that manufactures a product for which a great deal of water is required during the manufacturing process, just as the proximity to energy sources is important when producing a product for which a great deal of energy is required. One of the differentiating considerations in choosing a place for a new industrial start is the accessibility of transportation and contemporary means of communication, both of which are necessities in the manufacturing process. Furthermore, the location of certain plants might have an effect on the environment due to the nature of their manufacturing processes, which can lead to corruption and pollution. Different cities, regions, and countries may have different regulations on carbon emissions and pollution management, therefore it's important for businesses to consider how close they are to urban areas. The nature of the manufacturing processes of certain industrial companies—such as those dealing with chemical substances, steel, and radioactive materials—leads to waste and enormous debris, which must be avoided upsetting inhabitants even if there is no rule or regulation requiring them to do it. Most nations have laws dictating how these businesses must handle their waste products, including construction debris and byproducts of manufacturing. Therefore, this is an important consideration when selecting a location for these types of firms. Some plants have very specific requirements for the environmental conditions under which they can produce at maximum efficiency, and these constraints must be taken into account when selecting location for an industrial project. Although the problem of maintaining a comfortable environment inside the plants has been resolved, the local climate is still a deciding factor when selecting location for an industrial project. Although the impact of climate on the workforce varies from place to another, and industry to industry, it is generally best for an industrial company to avoid locating in an area where the climate is the root cause of many employees' illnesses. This is especially true if the employees in question possess a high level of expertise, and it would be difficult to find a suitable replacement at a moment's notice (Al-Tamimi, 2016).

D. Factors related to the State policy

Considerations like these reveal how the government views private property and the equitable distribution of plants among areas. There are two types of laws that reflect the state's policy: tax laws and investment laws. The former give preference to the location that enjoys tax exemptions over others, while the latter encourage investors and businessmen to establish industrial projects in certain regions over others by providing them with favorable terms, such as providing them with land without cost or at a nominal price or lowering the interest rate on loaning (Al-Tamimi, 2016).

E. Land and plant availability factors

There are variety of options available to a manufacturing firm when it comes time to construct a new facility. Does it build part or all of the necessary structures, does the location already contain structures meeting the necessary criteria, and does the firm have the option to purchase or lease them if and when they become available? When an industrial firm opens a new facility, it must decide whether to locate it close to headquarters so that it can take advantage of the onsite talent pool, or to locate it elsewhere, requiring the business to relocate its workforce and transfer its technicians and know-how to the location,and that the primary industrial enterprise would choose to locate in areas where employees already have access to services like schools, amenities, entertainment, healthcare, religious institutions like mosques, affordable housing… etc. (Al-Tamimi, 2016). The location selection choice is strengthened by the interdependence of the plant with the parent firm on the one hand, and with the nearby facilities and services on the other (Gupta & Starr, 2014). The major industrial firm should not overlook the importance of land area, which must be large enough to accommodate the plant, stores, spare tools, the normal parking spots for cars, wheels, and trucks used in the course of work, and the efficient absorption of the labor force. In the case that ther is no such land available, the industrial firm would likely select the location that offers the most land (Starr, 2008).

F. Personal factors

There is a role for personal factors in the selection of the industrial location, whether in response to the desires of the owners or the shareholders (investors). Sometimes, the logical discussion of other locations is not executed because the personal desire comes first; and the industrial company may need to relocate its current main location or move a plant affiliated with it from its location to the other location in order to satisfy the employees in its affected by personal fac (incentive bonuses or an increase in wages and salaries) (Al-Tamimi, 2016).

G. Factor of Competitors' locations

Administration should not only worry about the locations of existing rivals, but also strive to know their emotions towards the new location, since competition impact is connected to sales estimate in many possible locations. Avoiding niches where rivals excel has been fruitful in the past. At other times, however, an industrial firm may benefit from setting up shop in close proximity to its rivals. This tactic aims to establish a critical mass, the idea being that a concentration of rival businesses in one area will attract more customers more than would be attracted to the same number of stores in different locations. Also, some businesses choose to "follow the leader" when deciding where to set up shop (KRAJEWSKI et al., 2019).

In sum, Figure 3-1 is a compilation of the main considerations that go into industrial location selection.

The third group of researchers classified the factors of decision-making of the location as "specific locational factors" and "general locational factors" (Kumar & N.Suresh, 2008)(Heizer et al., 2017)(Bandyopadhyay, 2020), The economic stability of the nation, the diversity of its people in terms of culture and language, and the potential of collaboration with local businesses are not prerequisites for the implementation of general factors, but they are important for the development of specific factors (Heizer et al., 2017). The general locational factors can be categorized into controllable and uncontrollable factors. Material availability is a key component that falls under the category of controllable factors. If the needed material can not be found locally, it can be bought and transported from other zones. Yet another crucial aspect whose expenses may be managed by the implementation of a good transport strategy is transportation. Labor may be employed at lower rates, while workers from other areas can be brought in at higher rates. In this way, the availability of labors is likewise a factor that may be controlled. Similarly, the company may also choose to sell its products in any market it like. The company may also choose the level of investment needed. However, the necessary infrastructure will rely on its accessibility and the scope of the expenditure. Environmental conditions, governmental laws, ancillary industries (which may already exist), and public opinion on industrial projects are uncontrol. The specific factors can be applied for manufacturing and a service business togather.

Factors, such as nearness to suppliers, markets, resources, labor, quality of life, taxes, other utilities (such as energy sources), cost of constructing any facility, availability of various modes of transportation, expansion potential, and competition from other firms are relevant to manufacturing. Customer and market proximity, transportation costs, competitor locations, population density (which affects local sales), retail availability (which affects the number of potential local retail customers), traffic intensity (which affects both transportation costs and the quality of service provided to customers), and weather are all relevant factors for any service-oriented business (Kumar & N.Suresh, 2008)(Bandyopadhyay, 2020). Therefore, we learn that the Specific factors may also be used to choose an industrial and service locations too. This is most evident in the location preferences of major industrial and service corporations, particularly multinational companies (Heizer et al., 2017). In this study, only the factors of industrial location selection factors will be concentrated on. Figure 3-2 summarizes the general and specific factors that influence industrial location decisions.

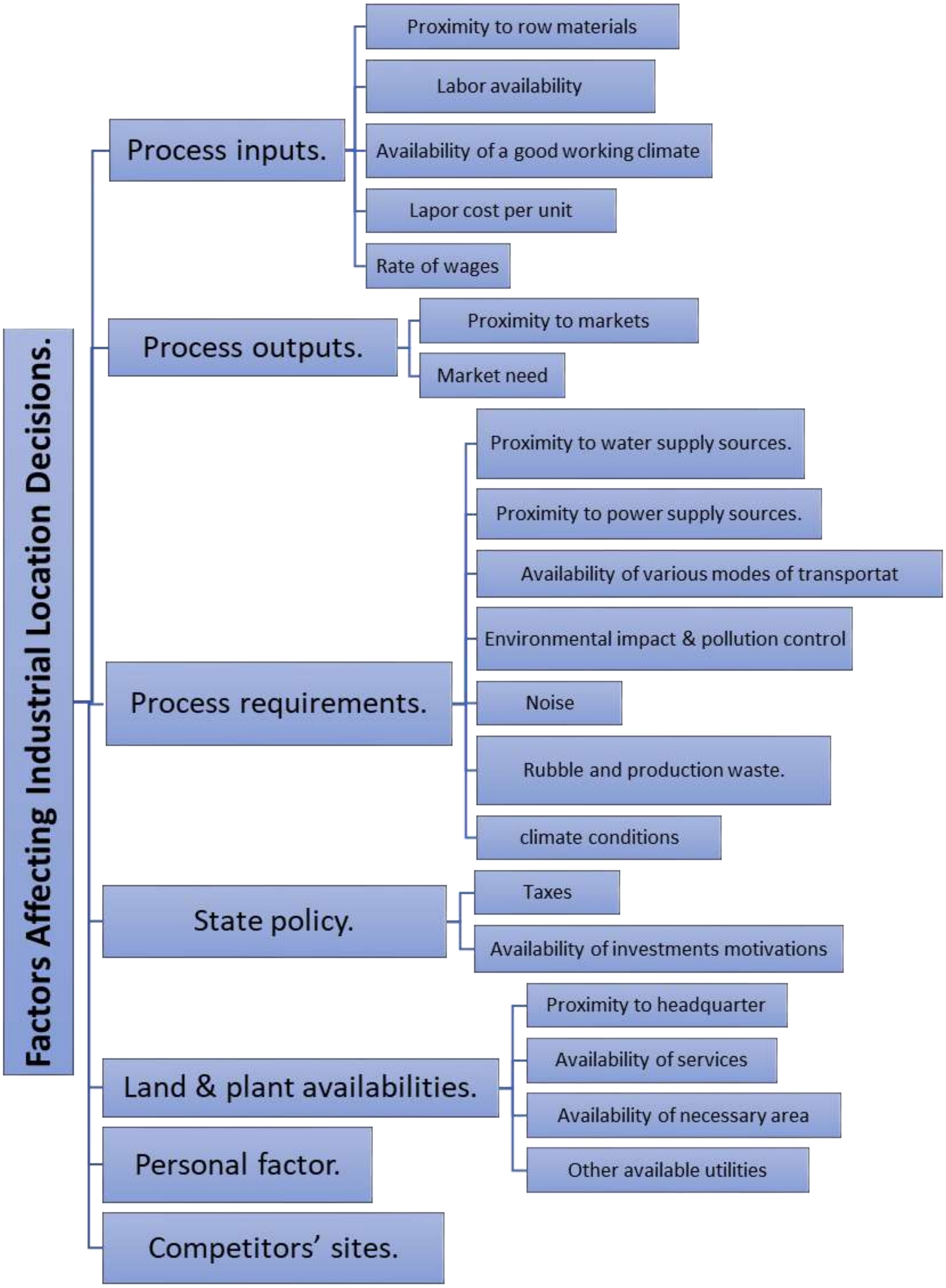


Figure 3-1: Factors influencing industrial location decisions (the researcher).

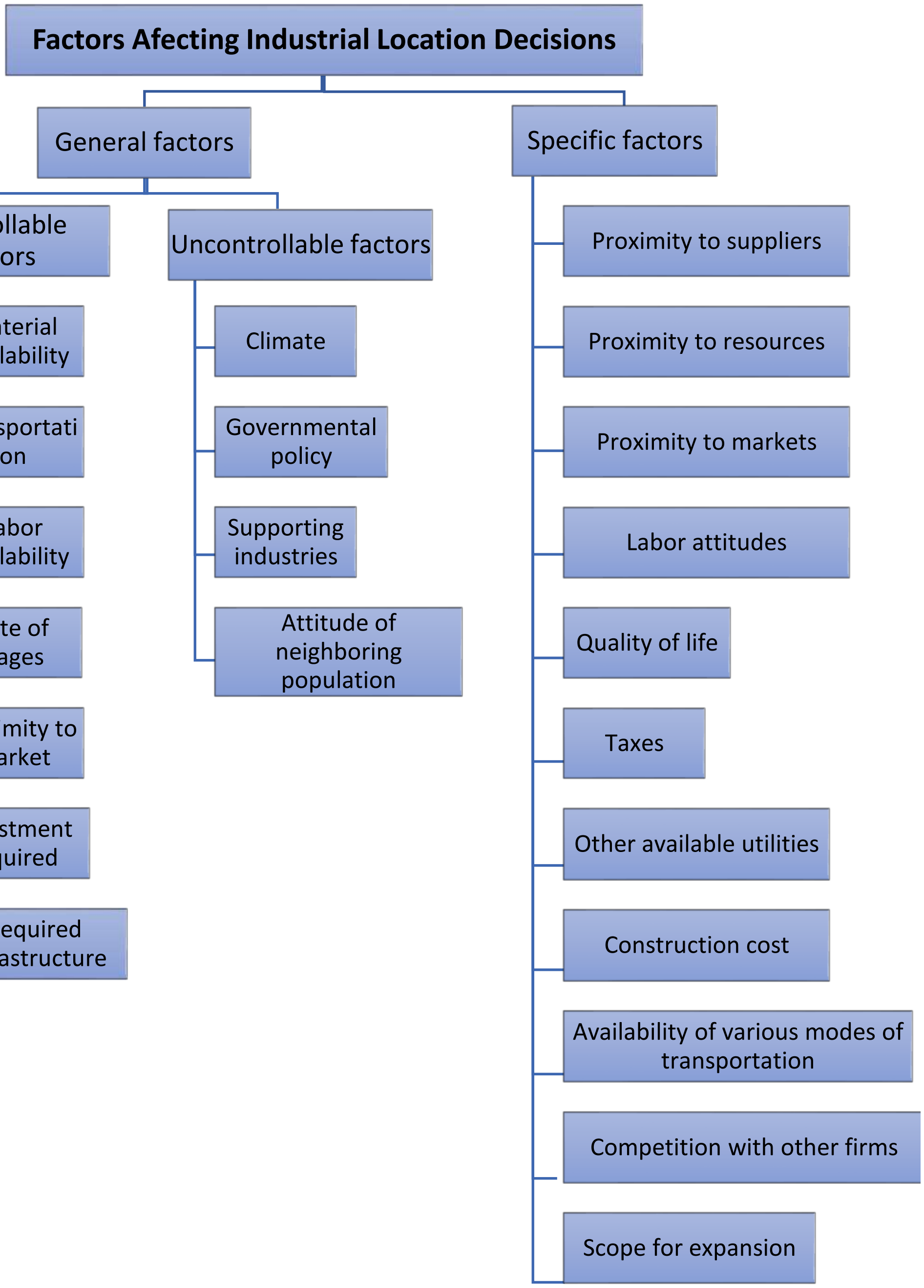


Figure 3-2: General & Specific locational factors influencing industrial location decision (the researcher).

3.3 Location models

Facilities locations have been a well-established research subject within Operations Research (OR). For the importance of this subject, the American Mathematical Society (AMS) created special codes for location problems (90B80 for a single facility location and 90B85 for Multi facility location). Nevertheless, the subject of the applicability of location models has always been under discussion (Melo et al., 2009). The sort of company is typically a deciding factor in choosing a location. Research, development, and innovation centers have no different when it comes to deciding where to locate their facilities. Maximizing profits is typically the goal when it comes to retail and professional service establishments. While the Warehouse's locations strategy is a combination of cost and speed of delivery (Heizer et al., 2017). Therefore, the three types of locations can be selected by location models. In paragraph 3.3, only the selection of industrial location by these models will be clarified. Focus on the factor rating and linear programming methods because of their importance in building the proposed model for selecting the optimal locations of asphalt concrete units plants.

3.3.1 Linear Programming method (LP)

In many business management situations, resources are limited and demand for them is considerable. For example, a limited number of vehicles may have to be scheduled to make multiple trips to customers. The best location for the facility must be selected to minimize costs or maximize profits, or a staffing plan may have to be developed to cover expected variables demand with the fewest employees. Here, we need a helpful technique for allocating scarce resources among competing demands. This technique is called linear programming. There may be limits in terms of time, money, or materials, and these are known as constraints. Managers and policymakers may use linear programming to determine the optimum allocation option and obtain insight into the value of extra resources (Heizer et al., 2017)(KRAJEWSKI et al., 2019).

Characteristics of linear programming models are objective function, decision variables, constraints, feasible region, parameters, linearity, and nonnegativity(KRAJEWSKI et al., 2019):

Objective Function. Mathematically, an expression states what is being minimized (e.g., cost or scrap) or maximized (e.g., profit or present value) and provides the scorecard on which the ordinal of different solutions is judged.

Decision Variables. The choices that the decision-maker can be controled. The linear programming methodology delivers these as the best possible values. Inventory units or product units to create next month are two possible decision variables that may be used in a scenario like this. Assuming decision variables are continuous, linear programming does not need them to be integers. This assumption is often accurate when the choice variable is stated in dollars, hours, or any other continuous measure. It is possible to find a decent answer even if the decision variables reflect nondivisible units, such as employees, trips, or trucks, by rounding the linear programming solution up or down or using an advanced approach known as *integer programming*.

Constraints. The limitations restrict the permissible choices for the decision variables (or the factors that limit the system's performance and constrain its outputs). Each limitation can be expressed mathematically in; a less than or equal to (≤), a greater than or equal to (≥), or an equal to (=) constraint. A (≤) constraint puts an upper limit on some function of decision variables and most often is used with maximization problems like the maximum number of customers who can be served. A (≥) constraint puts a lower limit on some function of decision variables like the production of a specific product must exceed or equal demand. An = constraint means that the function must equal a specific value. For example, a product must be produced in quantities of 100 (not 99 or 101). Some necessary connections, such as ending inventory always equaling starting inventory plus production minus sales, are commonly described using a = constraint.

Feasible Region. A region represents all allowable combinations of the decision variables in an (LP) model. In some exceptional situations, the problem is so strictly constrained that there is only one possible solution—or possibly none. However, the feasibility region contains infinitely many possible solutions, assuming that the feasible compounds of the decision variables can be partial values. Here, the aim of the decision-maker is to find the best possible solution.

Parameters. A constant or coefficient value that the decision-maker cannot change or control when the solution is applied. Each parameter is made-up to be known with certainty. For example, a programmer knows that running the software will take 20 minutes—neither more nor less.

Linearity. A characteristic of (LP) models that imply proportionality and additivity. That is, there can be no multiplying (e.g., 10 X_1X_2) or power (e.g., X_1^3) of decision variables.

Nonnegativity. A postulation that the decision variables must be positive or zero. For example, a cement plant cannot produce a negative number of tons. A linear programming formulation should show X ≥ 0 constraint for each decision variable to be formally correct.

Although the norms of linearity, certainty, and restriction of decision variables, LP can help managers & decision makers study many complex resource allocation problems. The sensitivity analysis can help the managers deal with parameters under uncertainty and answer "what-if" questions.

3.3.1.1 Formulation of a mathematical model for linear programming

The formula is used to mean the process of converting oral description into mathematical expressions. Here represent the relevant relationships among objectives, decision variables (factors), and constraints on resource use (Dubey et al., 2017a). Stated formally, the linear programming model entails an optimizing process in which nonnegative values for a set of decision variables $X_1, X_2, \ldots, X_n$ are selected to maximize (or minimize) an objective function in the form (JACOBS & CHASE, 2020):

$$\text{Maximize (or minimize) } Z = C_1X_1 + C_2X_2 + \cdots + C_nX_n \qquad (3-2)$$

subject into resource constraints in the form:

$$\begin{gathered} A_{11}X_1 + A_{12}X_2 + \cdots + A_{1n}X_n (\le, =, \ge) B_1 \\ A_{21}X_1 + A_{22}X_2 + \cdots + A_{2n}X_n (\le, =, \ge) B_2 \\ \vdots \\ A_{m1}X_1 + A_{m2}X_2 + \cdots + A_{mn}X_n (\le, =, \ge) B_m \qquad (3-3) \end{gathered}$$

Where: $C_n, A_{mn}, and\ B_m$ are given constants (parameters).

In sum, we can write the Final Formula of the linear programming model in the form:

$$\text{Maximize (minimize) } Z = \sum_{n=1}^{N} C_n X_n \qquad (3-4)$$

Sub. To

$$\sum_{m=1}^{M} \sum_{n=1}^{N} A_{mn} X_n \ (\leq, =, \geq)\ B_m \qquad (3-5)$$

Possible objectives that suggested for optimization are as follows (Williams, 2013):

Minimize cost;

Maximize profit;

Maximize return on investment;

Maximize utility;

Minimize number of employees;

Maximize turnover;

Maximize net present value;

Minimize redundancy;

Maximize customer satisfaction;

Maximize strength of operating plan.

Maximize probability of survival;

3.3.1.2 Sensitivity Analysis

The linear programming method aims to reach the optimal and acceptable solution to the linear programming model representing the problem under discussion. The optimal solution is obtained in the light of the values of a set of parameters (constants) for the decision variables in the objective function and the parameters of those variables in the constraints as well as the constants of the right side of the constraints (RHS). These parameters are not known for sure and be subjected to change over time, which calls for knowing the effects of different factors on the optimal solutionhas been reached and whether the optimal solution remains an optimal solution or not in light of changing those parameters. This process is called sensitivity or post optimality analysis, which includes the analysis of the following changes:

1. Change in the values of the constants on the right side of the constraints (RHS).
2. Change in the parameters of the objective function.
3. Change in constraint parameters.
4. Effect of adding a new variable or variables to the model.
5. Effect of adding a new constraint or constraints to the model.

3.3.1.3 Methods for solving linear programming models

A. Graph analysis

A graph-based approach to tackling linear programming issues Model constraints are plotted at a set of coordinates, and a feasible area on the graph is identified; the point on the border of this region that maximizes (or minimizes) the objective function is the solution in this technique (ROBERTA S. RUSSELL & TAYLOR, 2019).

Although it is not a practical technique for solving problems with more than two decision variables, it is useful as an introduction to understanding linear programming problems (KRAJEWSKI et al., 2019).

B. Computer analysis

In order to solve most linear programming problems, an algebraic solution approach must be used since they are too complex to be solved graphically. For solving linear programming problems, the simplex method is the most often used algebraic strategy. Linear programming problems with hundreds of variables and constraints are commonly solved by computer systems based on this strategy (David R. Anderson et al., 2019). Simplex method A mathematical procedure for solving a linear programming problem by putting the model as a tabular; several mathematical steps are performed on this tabular. Whenever the equations of constraint meet or cross, we have found our solution to the linear programming issue. Rather than inequalities (≥ or ≤), all model constraints must be equations (=). Inequality constraints are converted to equations by adding a new variable called a *slack variable* to each constraint. A minimization problem with ≥ constraints requires modifying by subtracting a *surplus variable* instead of adding a slack variable (ROBERTA S. RUSSELL & TAYLOR, 2019).

The solution procedure in computer programs basically depends on Simplex Algorithm for solving LP problems; among these programs: WinQSB, TORA, MPSX, LINGO, CPLEX, OSL, QSOM, MATLAB (Martinich, 2008).

3.3.1.4 Applications of linear programming in Industrial locating

Industrial Siting. The optimal location of a new plant can be found through linear programming by comparing the cost of purchasing raw materials and transportation costs between different locations and different sources of supply and demand (JACOBS & CHASE, 2020) or plants that may supply either warehouses or exporters (Dubey et al., 2017b).

3.3.2 Factors Rating method (FR)

Some scholars call it the weighted approach (Al-Tamimi, 2016), and others call it the preference matrix (Faihan, 2018). It is a practical method used to make decisions about a particular product, location, or activity under situations with multiple qualitative factors that cannot be expressed quantitatively ;for the decision to be more objective, we use this method as it sets preferential standard weights for these factors(Al-Tamimi, 2016)(Faihan, 2018)(Reid & Sanders, 2020).

This method has the following features in evaluating alternatives (Jayraman, 2013):

A. Enables bringing various locational considerations into the evaluation process.
B. The simple understanding of why one location is better than another.
C. Stand-in consistency of judgment about location alternatives.

The process of selecting a new industrial location according to the Factor-rating method involves a series of following steps (Kumar & N.Suresh, 2008)(Heizer et al., 2017)(Reid & Sanders, 2020):

1. Identifying Dominant Factors in Manufacturing in general and the industry to be established in particular.
2. Rating each factor according to its importance (Factor Weight) at the decision-maker.
3. Evaluation of each location relative to each factor (for example, 1 to 10 or 1 to 100 points) based on the quality of each factor for this location (Factor Score for Each Location).
4. Determine the Weighted Score for Each Location by multiplying Factor Weight in step 2 by Factor Score for Each Location in step 3.

5. Selection best location, which is the alternative with the highest score.

3.3.3 Multicriteria Decision Analysis (MCDA) techniques.

It's a set of qualitative techniques that describe decision locations depending on several criteria along with several alternatives as depicted below (Bandyopadhyay, 2020):

1. Identify the factors and the locations.
2. Allocate weightage to each factor and score between 1 and 100 for each location against each factor.
3. Multiply the weight of each factor to their respective scores of the location to get the weighted score.
4. Summarize the weighted scores for each location and select the location with the highest score as the best location.

Some powerful MCDA techniques are enlisted below (Bandyopadhyay, 2020):

A. Aggregated Indices Randomization Method (AIRM)
B. Analytic Hierarchy Process (AHP)
C. Analytic Network Process (ANP)
D. Data Envelop Analysis (DEA)
E. Dominance-based Rough Set Approach (DRSA)
F. Elimination and Choice Translating Reality (ELECTRE)
G. Evidence Reasoning (ER) approach
H. Grey Relational Analysis (GRA)
I. Inner Product of Vectors (IPV)
J. Measuring Attractiveness by a Categorical Based Evolution Technique

K. (MACBETH)
L. Multi-attribute Global Inference of Quality (MAGIQ)
M. Multi-attribute Utility Theory (MAUT)
N. Multi-attribute Value Theory (MAVT)
O. Potentially All Pairwise Rankings of all possible Alternatives (PAPRIKA)
P. PROMETHEE
Q. Superiority and Inferiority Ranking (SIR) method
R. SMART (Simple Multi-attribute Rating Technique)
S. Superiority and Inferiority Ranking (SIR) method
T. Technique for Ordering of Prioritization by Similarity to Ideal Solutions (TOPSIS)
U. Weighted Product Model (WPM)
V. Weighted Sum Model (WSM)

3.3.4 Weighted Linear Combination (WLC) method

This technique also is called a “scoring method.” (Jafari et al., 2015), and sometimes known as a “multiparametric decision.” (Sami et al., 2020). It's a combination procedure that associates factors weights (or relative importance of factors) with the decision alternatives. The analyzer or decision-maker is based on the “relative importance” weighted directly to the scales; a final measure can be obtained by multiplying the relative weight by the factor rank; After deciding on the final value for each choice, the best options will be those with higher values that meet the goal (Malczewski, 2006). The Weighted Linear Combination (WLC) method can be represented by the expression (3-16) (Ghosh & Lepcha, 2019):

$$WLC = \sum_{j=1}^{n} a_{ij} \times w_j \qquad (3-6)$$

Where: a_{ij} is the ith rank of jth factor; w_j; Weightage of jth factor.

3.3.5 Center-of-Gravity Method (or Centroid method)

It is a quantitative approach for locating a facility at the center of the movement in a certain area based on weight and distance since the center of the activity in a certain geographic area depends on transport weight and distance, and transportation costs are a function of distance,time , and weight (ROBERTA S. RUSSELL & TAYLOR, 2019). This technique starts by plotting the current locations on a grid system using coordinates, assuming that all transportation expenses are the same, both incoming and outward. Due to the rapid use of GPS devices for mapping places, most coordinates are based on longitude and latitude measurements. We utilize random X & Y coordinates to make things easy; the centroid is discovered by calculating the X and Y positions that have the lowest transportation cost; the two coordinates for the new location are computed using the expressions (3-10) & (3-11) (JACOBS & CHASE, 2020):

$$C_x = \frac{\sum d_{ix} V_i}{V_i} \qquad (3-7)$$

$$C_y = \frac{\sum d_{iy} V_i}{V_i} \qquad (3-8)$$

Where:

C_x, C_y: Coordinates of the new location at the center of gravity

d_{ix}, d_{iy}: Coordinates of the *i*th location

V_i: Volume of the amount shipped from/to the *i*th location

3.3.6 Break-Even Analysis method

The break-even point of a product or service may be used to estimate a new service or product concept or analyze the performance of an existing one. Therefore, the break-even volume is the volume at which revenues and expenses are equal. It is called a break-even analysis when used in this way. Comparing two processes with the same total costs may also be done using break-even analysis. Break-even analysis can help Decision Makers compare location alternatives based on quantitative factors expressed in terms of the total cost given a set of potential locations for a facility (KRAJEWSKI et al., 2019). This method is based on the following assumptions (Mohsen & Al-Najjar, 2012):

- The income generated from selling one unit is equal regardless of where it will be produced.
- The costs and volume of the production are constant and do not change over time.

The basic break-even expressions (Reid & Sanders, 2020):

$$Total\ cost = F + cQ \qquad (3-9)$$

$$Total\ revenue = pQ \qquad (3-10)$$

Where:

F: fixed cost.

c: variable cost per unit.

Q: number of units sold.

p: price per unit.

The basic steps for solutions (graphic and algebraic) are as follows (Reid & Sanders, 2020):

1. For each location, determine fixed & variable costs.
2. Draw the total costs for each location in one graph.
3. Identify all ranges of the products for which each location has the lowest total cost.
4. Solve for the Break-Even Points algebraically over the identified ranges.

Chapter Four: Production Technology

4.1 Introduction

This chapter discusses materials, equipment, and procedures involved in constructing hot mix asphalt concrete. Materials consist of bitumen, aggregate, and filler. production specifications and procedures will also be discussed, along with the most common methods of re-utilzing Reclaiming Asphalt Pavements (RAP).

4.2 Materials

In order to create Hot-Mixes Asphalt (HMAs), bitumen typically heated beforehand to reduce viscosity and aggregates also heated beforehand to eliminate moisture. Then, filler is added to fill air voids in the mixture. Therefore, the asphalt mixture has three main components: bitumen, aggregate, and filler.

4.2.1 Bitumen

The term ‘bitumen’ describes refined bitumen, a hydrocarbon product produced by removing the lighter parts (such as liquid petroleum gas, petrol, and diesel) from crude oil during the refining process. In other words, it dose not undergo any more processing after the vacuum distillation step. Bitumen has often been referred to as asphalt or asphalt binder. Conventional bitumen is referred by a number of terminology, including paving grade and penetration grade (sometimes known as "pen grade"). The name "pen grade," which is short for "penetrating grade," refers to the fact that this product is most often categorised utilising the penetration testing (in areas of Europe and Asia).

Bitumens with a penetration grade are defined by the softening point and penetrating testing. Just the penetrating range is utilized in the designation procedure. For instance, 40/60 pens bituminous seems to have a penetrating range of 40 to 60, inclusive. The deci-millimeters (0.01 cm), which is the unit evaluated in the penetrating test, is the penetration unit. Nevertheless, it is commonplace to speak to penetration grade bitumens without mentioning units.

There are several grades of bitumen. These grades typically defined by specifications that take into account end uses, loading conditions, climate, and applications. Typically, they were depending on a set of accepted test procedures that specify the characteristics of each grade, including viscosity, hardness, solubility, and durability.

During the last three decades, Polymer Modified Bitumen (PMB) has become increasingly popular as a replacement for deviation of penetration grade bitumen in the upper layers of asphalt pavements. The outstanding characteristics of PMB influence policymakers in the asphalt sector most often. They were identified by their large penetrating range and low softening point even if they are sophisticated technology binders (Hunter et al., 2015).

Essentially, good performance of traditional (or neat) bitumen on the road can be ensured if four main properties are controlled: rheology, cohesion, adhesion, and durability. However, by increasing demand on the roads, the Required limits of performance of traditional bitumen should be increased due to (Mallick & El-Korchi, 2018):

1. Increase in rainfall and temperature variation.
2. An increase in tire pressure, axle weight, and freight moving causes an increasing in the cost and greater maintenance requirements.
3. A preference is to use thinner layers in pavements.

4. Maximize cost savings and financial efficacy by decreasing the maintenance frequency needed, minimizing traffic flow disable and ensuring high service life.

For the modifier (polymer, additives) to be effective and for its use to be both practicable and economic, it must (Hunter et al., 2015):

- Mix in bitumen.
- Not degrade at temps utilized for blending asphalt.
- Boost bitumen's flow resistance at hot highway temps without having it excessively viscous while mixing and laying it or just too brittle or stiff when this is cold.
- Boost the adhesion or cohesiveness characteristics of bitumen.
- The modification must also be able to be processed utilizing conventional equipment if mixed with bitumen.
- Keep its top qualities when being stored, transported, laid, and utilized.
- Maintain its chemical and physical stability while being stored, transported, laid, and utilized.
- The ability to coat or spray at application temps typical of that process.

4.2.2 Aggregate

Pavements typically employ aggregates that is occurs naturally. To create materials with a certain size range, soil or rock are treated to create aggregates (and other characteristics). In general, soil particles of a size higher than 0.0075 cm are referred to as aggregates. To assess their appropriateness, these particles are described and examined for their mechanical characteristics. The aggregates utilised as bound layers is produced by combining various proportions of various sized grains as part of the mixture design processes, which differs from the existing soil in the subgrade or subbase. Every aggregates grain and the mixture of particles of various sizes must thus be of a desired quality. Additionally, such aggregates should be of such (physically as well as chemically) condition once utilised in conjunction with bitumen that it resists all kinds of flaws and maintains the covering of asphalt binders (bitumen) under impact of traffic and severe climate changes. crushed stone, gravel, sand, or any mix of these in manufactured or natural forms are considered aggregates. Although produced aggregates were collected from quarries, natural aggregates were found in riverbeds or pits. Dredging or blasting are the methods utilized to get aggregates. For the majority of asphalt mixtures, large particles have been crushed to produce working sizes that vary from 5 cm to lower than 0.0075 cm. As a byproduct of various industrial operations, artificial aggregates are produced (including slag from steel manufacturing) (Mallick & El-Korchi, 2018).

The size of HMA's aggregate has often been divided into fine and coarse aggregates. Based on ASTM, coarse aggregates is defined as material that cannot pass through a No. 4 (0.475 cm) screening, whereas fine aggregates is defined as material that can (Brown et al., 2009). As a consequence, which unlike subgrade's existing soil, the aggregates utilised in binding layers are created by mixing various ratios of various particles-sized. This mixture is done as a component of the mixture design processing. As a result, every aggregates particle and the resulting mixture of particles of various sizes should be of a desired quality (Mallick & El-Korchi, 2018). In addition, these aggregates should also be of a condition (morphological and mechanical) that will prevent cracking and maintain the bitumen coating while exposed to traffic and severe environmental factors (Wang, 2011).

4.2.3 Mineral filler

Fillers are particulate materials added to the asphalt concrete to fill its air voids and therefore enhance its properties and performance.

Mineral filler shall consist of finely divided mineral matter such as crusher fines, Limestone, Portland cement, fly ash, hydrated lime, or other non-plastic material. And therefore, filler shall have a plasticity index[2] (PI) not greater than four (AASHTO, 2016).

At the time of use, the filler should be: sufficiently dry to flow freely and essentially free from agglomerations, free from organic impurities, and unsettling or readily dispersible.

ASTM classifies mineral filler as materials with at least 70 percent passing the No. 200 (75 microns) sieve. A certain part of the mineral filler (the small particles) is embedded with the resin[3] without touching the components of the fine aggregate; this mixture forms a bonding material for the parts of the fine aggregate, as for the larger mineral filler parts, they will be part of the fine aggregate and serve as contact points between its unworkability particles (AASHTO, 2016).

4.2.4 Composition of asphalt for roads projects in Iraq

Based on the Iraqi (GSRP-R9) standards, HMAs for the base course (Type I), binder course (Type II) and surface course (Type IIIA & IIIB) must

---

[2] Plasticity index is the difference between liquid and plastic limits of the material passing the No. 40 (0.42 mm) sieve.

[3] It is a dark semi-solid substance, but it liquefies upon heating and becomes brittle upon cooling.

consist mainly of coarse & fine aggregate, filler, and bitumen. The multiple components shall be in size, uniformly graded, and grouped in proportions such that the resulting mixture meets the classification requirements for the type course. Bitumen shall be added to this composite mixed aggregate (considered 100% by weight) within the specified type's percentage limits specified in the specifications (S. Highway & Bridges, 2007). The requirements for HMAs shall comply with the classification shown in Table 4-1. The grading of aggregate materials should not differ from the low limit in one sieve to the high limit in the adjacent sieve.

Table 4-1: Asphalt mixtures gradings (S. Highway & Bridges, 2007)

Sieve size		**Sort I**	**Sort II**	**Sort IIIA**	**Sort IIIB**
		Base course	**Binder course**	**Surface course 1**	**Surface course 2**
in.	mm.	% passing by weight of total aggregate & filler			
$1\,{}^{1}/_{2}$	37.5	100			
1	25.0	90-100	100		
${}^{3}/_{4}$	19.0	76-90	90-100	100	
${}^{1}/_{2}$	12.5	56-80	70-90	90-100	100
${}^{3}/_{8}$	9.5	48-74	56-80	76-90	90-100
No. 4	4.75	29-59	35-65	44-74	55-85
No. 8	2.36	19-45	23-49	28-58	32-67
No. 50	300 μm	5-17	5-19	5-21	7-23
No. 200	75 μm	2-8	3-9	4-10	4-10
Bitumen (% total mixture weight)		3-5.5	4-6	4-6	4-6

4.2.5 Sieve analyses of HMAs

From Table 4-2, We determine the mid-percentage weights of coarse aggregate (gravel), fine aggregate (sand), mineral filler, and bitumen for the base course will be as below:

37.5 mm	0.0 %	56 % (Gravel)
25.0 mm	12 %	
19.0 mm	15 %	
12.5 mm	7.0 %	
9.50 mm	17 %	
4.75 mm	12 %	39 % (Sand)
2.36 mm	21 %	
0.30 mm	6.0 %	
75 µm	5.0 %	5 % (Filler)

Due to the addition of bitumen should be within the percentage limits set in the specifications for the specific course (S. Highway & Bridges, 2007), and the composite blended aggregate and filler (considered as 100% by weight).Therefore, the mid percentage weights of gravel and sand will be minimized by the amount of bitumen which added to all mixtures. Therefore, the mid percentage weights of gravel, sand, and filler for the base course will be 53.62%, 37.34%, and 4.79%, respectively as well as 4.25% of bitumen, and for the laboratory densities of gravel and sand are 1.7 ton/m^3 & 1.6 ton/m^3 respectively, the optimal amounts of one ton of asphalt concrete components are illustrated in Table 4-2.

Table 4-2: Optimal amounts of Asphalt mixtures components [the researcher]

Components	**Base course**	**Binder course**	**Surface course 1**	**Surface course 2**
Gravel (m^3)	0.315	0.28	0.23	0.17
Sand (m^3)	0.23	0.26	0.31	0.375
Filler (ton)	0.048	0.057	0.066	0.066
Bitumen (ton)	0.0425	0.05	0.05	0.05

4.3 Asphalt concrete plant

The primary purpose of the Hot Mix Asphalt (HMA) plant is heating aggregates, then adequately mixing and blending it with bitumen and filler to produce a mix of asphalt at a temperature between 150 °C and 180 °C, which are good temperatures to meet the requirements (Yonar, 2007). Environmentally, the asphalt concrete unit plant's designated location should be away from the limits of the urban fabric at a distance not less than 15 km in the direction of the prevailing wind and at least 10 km in the other direction (AL-Jorani, 2017), while Increased emissions mean substantial usage fuel throughout the manufacturing process, which economically affects the factor of plants' distance from sources of fuel supply

There are two essential types of HMAs plants: batch and continuous (drum mix) plants. Drum mix plants can also be of parallel flow if the burner of the dryer drum is in the same direction as the entrance of the aggregates and counter-flow in the opposite direction (Brown et al., 2009)(dos Santos et al., 2020). A schematic diagram of the components in a typical asphalt concrete unite plant is shown in Figure 4-1.

Figure 4-1: Schematic shows major components of a typical asphalt concrete unit plant (modified after (Brock & Richmond, 2007)).

4.3.1 Production process

Batch plant kind concurrently creates one asphalt concretes batch (ASTM D995-95b, 2010). A conveyor belting process moves the aggregates that is kept in feeders in the direction of the dryer. In the dryer, aggregates was heated and dried before being placed into the elevator. The elevators transports aggregates to the screen unit on the manufacturing tower. This tower is made up of many components. The screening unit typically has 3 to 4 vibrating screens of various sizes. Reorganized aggregates has been gathered in the hot aggregates bin. Prior to being introduced to the combination, held aggregates in the hot aggregates bin was cumulatively weighed at weighing units. The aggregate is then released into the mixer in the proper quantity. Bitumen was weighted in another buckets and sprayed over the material in the mixers in an acceptable proportion. Bituminous extrusion nozzles and parallel twin shafts in a mixers combine bitumen and aggregates (Brown et al., 2009). Typically, the quantity of asphalt concrete depends on the mixer's capacity. Today, one batch's plants are about 1.8 tons to 2.7 tons (Perko et al., 2000).

Asphalt concretes would be generated in the drier drum of continuous kind plants. This is how asphalt concretes of this kind is often produced. Similar to the mixers in batch kind plants, the dryer is employed in continuous kind plants. Nevertheless, in batch processing, aggregates is indeed heated and dried in the blender, but in continuous processing, the combination is also created in the drier drum. There are no continuous versions of the screen unit, hot aggregates bins, weighing units, or mixers, of course. The grade and quantity of aggregates are under control via the cold aggregates feeders system. In the first section of the drier, aggregates was heated and dried. Asphalt concretes is created by spraying filler and bitumen in the second section (Brown et al., 2009). Due to continuous manufacturing, large storage (single) silos have been required for continuous kinds.

4.3.2 Asphalt recycling

Vividly rising bitumen costs, decreasing budgets, increasing traffic load, and the wish to find more sustainable paving observes are forcing scholars and engineering to find methods for maximizing the use of Reclaimed Asphalt Pavement (RAP) (Zaumanis et al., 2016). Bitumen became costly due to depleting supplies and fluctuating oil prices, making recycling crucial. Bitumen prices have grown since 1990. (Figure 4-2). The major contributor to the added carbon for asphalt ingredients is the manufacturing of aggregates and bitumen (Liu et al., 2017).

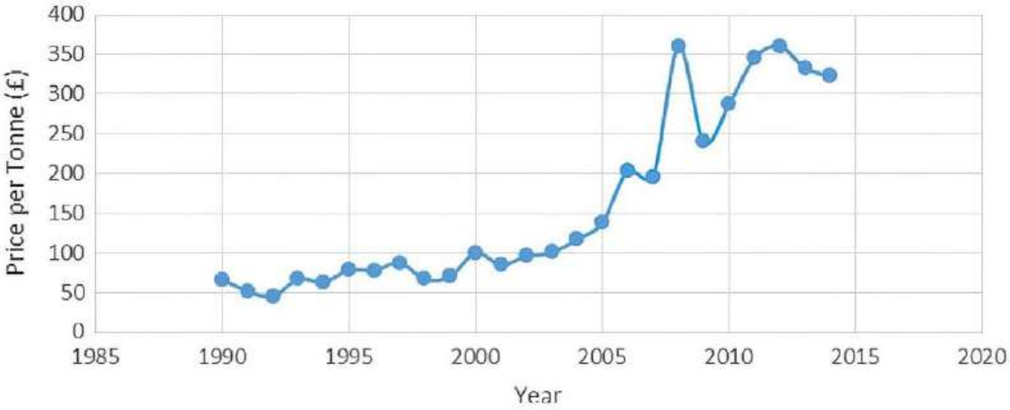


Figure 4-2: Historical price of bitumen (Liu et al., 2017)

The most common uses of RAP are in the lower courses of pavement, where it has been confirmed as a good replacement for virgin materials. Rather, the use of RAP in asphalt surface courses is narrower, with significant anxiety being that the high RAP mixtures may not qualify as traditional asphalt mixtures. RAP use is generally controlled by specifications that define the allowed quantity of recycled material in the mixtures to reduce the risks of low asphalt performance. However, environmental savings and low costs can be achieved if more RAP is contained in the asphalt surface course while maintaining good performance (Meroni et al., 2020). The blending and rejuvenation processes are two essential factors that can raise RAP content in the asphalt mixtures. While a rejuvenator is an additive that acts as a motivation and enhances the properties of aged RAP bitumen, the blending between the virgin materials and RAP is very important In terms of the durability and performance of RAP mixtures (Devulapalli et al., 2019). The practice of re-use of Reclaimed Asphalt Pavement (RAP) has become widely utilized in pavement construction worldwide. This practice must be implemented in Iraq towards optimal recycling and waste management, especially since millions of tons of asphalt concrete waste are generated each year from reconstruction roads in Iraq.

4.3.2.1 Inclusion of RAP in asphalt mixtures

Modern plants of HMA could be modified to incorporate RAP as a fresh materials for new asphalt (Figure 4-3); this modification Depends on the type of plant (batch or continuous). In the case of the batch type, adding RAP will be either to weighing units or to the mixer (cold feed), while utilizing a mixture dryers for heating the RAP in the case of continuous type.

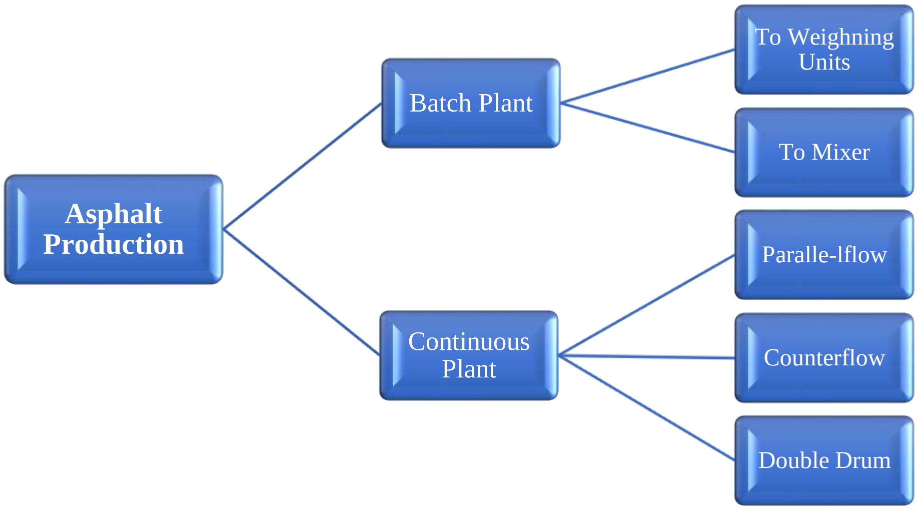


Figure 4-3 options for HMAs plant to include RAP (the researcher)

4.3.2.1.1 Cold feed RAP recycling

The cold feeding or cold technique is the addition of RAP at ambient temp and heated by orginal aggregates. The orginal aggregate is heated to a firm temp which depends on the plant's capacity, the amount of RAP to be added, the moisture amount of the virgin aggregate & RAP, and the temp of the final mix (Liu et al., 2017). The usual temps required for mixing virgin aggregates with 10 percent RAP to reach the preferred temp are given below (Table 4-3).

Table 4-3: Superheating temperature for cold feed (10% RAP & 90% aggregate (Liu et al., 2017).

Moisture content (%)	**Recycled mix discharge temperature (°C)**			
	104 °C	**115 °C**	**127 °C**	**138 °C**
0	121	138	152	163
1	127	143	154	168
2	132	146	157	171
3	138	149	163	174
4	141	152	166	177
5	143	157	168	182

In a batch plants of RAP could be feding in two techniques: weighing units and mixer.

RAP fed to weighing units. As shown in Figure 4-4, once the aggregates from the hot bins are deposited into the weighing units and weighed, the RAP could be feding to the weighing units as other aggregates. Utilzing a max of 25 percent of the RAP amount is suggested through this technique. The major beenfit of this technique is that orginal aggregate coud be sifted, which allows for greater control and accurate sizing of RAP weight, resulting in improved quality of asphalt (Kandhal & Mallick, 1998).

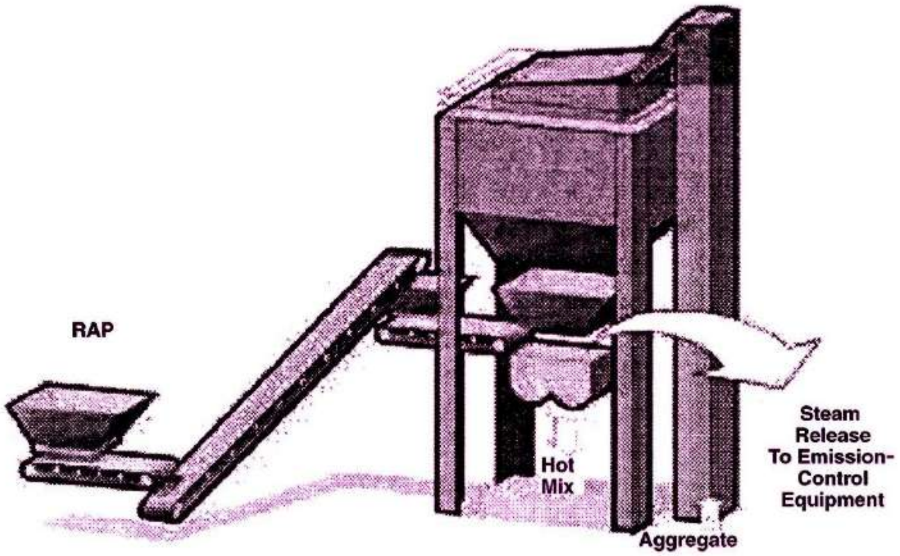


Figure 4-4: Cold RAP fed to weighing units (Kandhal & Mallick, 1998)

feed to the mixer. By adding an additional weighing unit to the batch tower, the RAP could be weighed and transported in the additional weighing unit while weighting the bitumen and virgin aggregate into the original weighing unit. This procedure allows 30-35 percent of RAP use within the asphalt combinations. This technique is more popular since (Liu et al., 2017):

1. Increased hourly production rate with shorter batch cycle time.
2. Weighting can be achieved more accurately.
3. Requires less maintenance due to less starting and stopping.

4.3.2.1.2 Using a combination dryer (continuous plants)

Combination dryers can be integrated into both continuous and batch plants but generally utilized in continuous plants. The Hot RAP and orginal aggregates are kept in one drum in these dryer drums before being fed to the product silo. RAP and orginal aggregates are interred in similar drum, but in two various locations depending on the technology (Liu et al., 2017). Combination dryers are mostly in three formats (shown in Figure 4-5): dual dryer drum, counter-flow drum, and parallel-flow drum (Brock, 2016)(Brock & Richmond, 2007). The most important aspect of successful mixture production is that the aggregates are dried and superheated before mixing with RAP. The hot gases in the drum cause considerable convective heating transfer inside the RAP, thus the virgin aggregates should be heated as effectively as feasible.

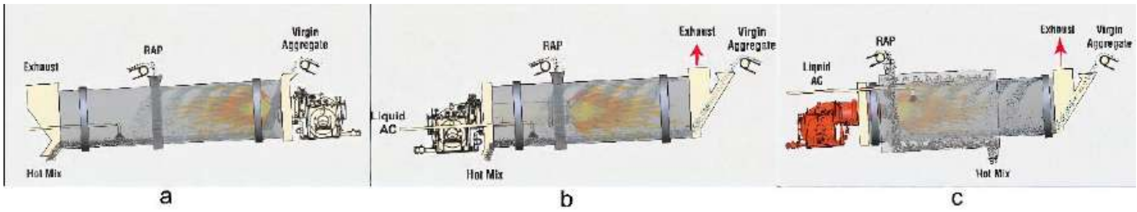


Figure 4-5: Schematic illustrations of Using a combination dryer heating the RAP and virgin aggregate together: (a) Parallel–Flow Drum; (b) Counter–Flow Drum; (c) Dual Drum (modified after) (Brock, 2016)(Brock & Richmond, 2007).*)*

Drum of a parallel-flow dryer. The virgin aggregates and emission gases both flow through the same directions in a parallel flow systems. The burner essentially sits where the virgin aggregates enter the dryer at the front (Brock, 2016). The aggregates are warmed up as it passes through, eliminating any moisture. RAP tries to enter the blending drum in the middle in so as to avoid being subjected to the burner's extreme heating (Fig. 4-5.a). Bitumen has been injected into the drum once the aggregates and RAP have reached the rear of the drum. In order to move the asphalt to the HMA storage silo, the components are combined and discharged from the rear of the mixing drum onto a conveyor.

Drum of a counter current flow dryer. Conventional parallel-flow drums and counter-flow drums are different in that the entrance of the aggregates and the flow of heated burner gases happen in opposing directions (Fig. 4-5.b). Whereas the burner gases go in the oppositing direction, the virgin aggregates separates from one side. RAP tries to enter the path in the centre. In order to ensure RAP fully warmed behind the flames prior entering the combining area, the burning nozzle is sufficiently expanded into the drum.and bitumen are thus kept away from fires and hot gases. Technically speaking, the counter flow concept lowers the temp of the hot gases, which enhances environmental performance by causing recycled asphalt to heating up less (Liu et al., 2017).

Drums for two dryers. A Double Barrel Dryers Drum Mixers combines a dryer's and a continuous mixer's capabilities into one small device. It consists mainly of an exterior drum surrounding a counter-flow drier drum, where RAP and new bitumen are mixed (Figure 4-5.c). The initial phase in this procedure, drying the natural aggregates, taking place within the inner drum. It comes after the outer drum's blending of the aggregates and other ingredients (Brock, 2016).

The superheating temps differ for the technology type, moisture content of RAP, and the final mix temperature; The researcher summarized the superheating temps gained thru the previous studies (Liu et al., 2017) in Table 4-4, the fuel required will be calculated based on superheating temperatures gained for utilized RAP technology.

Table 4-4: Superheating temperatures according to the type of technology, including RAP (the researcher).

Technology type	RAP content (%)	RAP moisture (%)	Superheating temp. (°C)	Final mix temp. (°C)
Cold Feed	30	5	274	**138**
Parallel-flow	50	5	305	**150**
Counterflow	50	5	404	**150**
Double Drum	50	5	316	**149**

4.4 Asphalt transportation

Trucks must be insulated for long-distance haulage. A tarpaulin (canvas) must retain heating, shield the HMA from light rain, and keep dust at bay. However, the tarp needs to be tied down properly - otherwise, it will tend to flap in the air and cool down the mix by fanning as the truck moves down the road. To prevent segregation, truck beds ought to be spotless and loads should be secure. Trucks must usually be loaded from the front, therefore the rear, and lastly from the centre. Trucks can be of different types—end dump, bottom or belly dump (high capacity), and live bottom (flow-boy) (delivers HMA by a conveyor). The first is suitable for paving on crowded streets. It has better manoeuvrability because of its size and no trailer; the second is suitable for paving on rural roads, while the third can be utilized for mixes with segregation potential. The bed in the end dump truck generally extends past the rear wheels such that the mix could be dumped into the paver hopper, or else an apron is attached to the bed. The bed should fit the hopper without having to press down on the paver, and the truck should not make contact with the paver during delivery of the mix to avoid forcing the screed back into the mat and causing a bump on the pavement. (Mallick & El-Korchi, 2018).

Chapter Five: Field and Statistical Framework

5.1 Introduction

To identify the status of the asphalt concrete unit plants in Iraq and indicate the most important positive and negative points, an investigation was carried out on the status of these plants; this investigation included a field survey in addition to conducting the introductory questionnaire (both open and closed types) and a Delphi questionnaire. The steps adopted in the implementation of the field study were as follows:

1. Determining the required and necessary sources of information and through what is documented in the field survey process.
2. Take advantage of the information collected during the field survey and use it in open, closed, and Delphi questionnaires.
3. Carrying out the open questionnaire process to benefit from it in creating and designing the questionnaire form.
4. Distribute the questionnaire in its final form to the individuals of the selected research samples, which are within the closed questionnaire stage.
5. Analyzing the answers contained in the regular questionnaire form using the approved statistical methods and reviewing the results reached and using it in organizing the questionnaire with Delphi technique.
6. Analyzing the answers contained in the Delphi questionnaire and reviewing the results that were reached and using them in selecting the optimal locations for asphalt concrete units plants in Iraq.

To know the results of the closed introductory and Delphi questionnaires, it was necessary to analyze the answers of the respondents and experts statistically. The analysis was done by IBM SPSS Statistics 26. The first stage includes Descriptive Statistics [Frequencies and Percentile, The mean

(Measure of central tendency), Standard deviation (Measurement of dispersion based on the mean] for the closed questionnaire. The second stage includes the Relative Important Index (RII) for the factors affecting selecting the asphalt concrete unit plant location According to the Delphi technique.

5.2 Field survey

At this stage, it relied on collecting the necessary information and data from the concerned departments and authorities that implemented the paving projects and ran the asphalt concrete unit plants, according to the documents provided by these authorities that enriched the study subject. To give a clear picture and information extrapolation that is the basis for the process of selecting the optimal locations for asphalt concrete unit plants in Iraq, a field survey form was designed (Appendix A) to collect information about these plants in terms of their locations about the sources of raw materials, the locations of implementation of paving, the costs of transporting raw materials from their sources, the costs of transporting the asphalt product, as well as identifying on the output capacity (design & effective capacity)[4] and the number of workers needed to work the plant.

5.2.1 Asphalt concrete units plants in Iraq

In view of the great increase in the number of cars in Iraq during the past two decades and the lack and obsolescence of roads available within the master plan of cities and highways outside them, as well as the planning of two mega projects; Construction of the Expressway No. (2), and maintenance

---

[4] The design capacity is the maximum output rate that a plant can achieve under ideal conditions, while effective capacity: is the maximum output rate that can be sustained under normal conditions (Reid & Sanders, 2020).

the Expressway No. (1) Therefore, the state has given paving projects special importance.

The asphalt industry in Iraq dates back to the first quarter of the twentieth century when the first plant was established in Basra, known as (Al-Farhan Asphalt Plant) (Ismael & Rashid, 2021).

Today, the most prominent paving works in Iraq are carried out by the General Directorate of Municipalities and Road and Bridges Directorate. Accordingly, 73 plants belonging to the General Directorate of Municipalities, 23 & 20 plants belonging to Hamorabi and Ashur companies, respectively, which carry out the Road and Bridges Directorate contracts, were established. In addition, five plants were established for the Mayoralty of Baghdad and one plant for Karbala Province. As for the private sector, there are 32 plants in the country. Tables (5-1), (5-2), (5-3), (5-4), (5-5), and (5-6) show information about the asphalt concrete units plants operated by each of the entities mentioned above in terms of location and capacity until 2022, (except for the Kurdistan region), where: Table 5-1 shown plants belonging to General Directorate of Municipalities, Table 5-2 illustrated plants belonging to Mayoralty of Baghdad, Table 5-3 offered plants belonging to Hamorabi State Construction Contracts company, Table 5-4 shown plants belonging to Ashur State Construction Contracts company, Table 5-5 illustrated plant belonging to Karbala Province/Direct Implementation Dept., Table 5-6 explained plants belonging in the private sector. Below are the results of the survey study for each of these plants:

Table 5-1: Plants managed by the General Directorate of Municipalities.

No.	Plant name	Plant location	Capacity (T/H)	
			Design	Effective
1.	Hamdaniya Municipality Asphalt Plant	Tal Afar-Nineveh Province	100	70
2.	Tal Afar Municipality Asphalt Plant	Hamdaniya-Nineveh Province	50	stopped
3.	Mosul Municipality Asphalt Plant	Mosul-Nineveh Province	250	stopped
4.	Hawija Municipality Asphalt Plant	Hawija-Kirkuk Province	50	40
5.	Kirkuk Municipality Asphalt Plant	Kirkuk-Kirkuk Province	90	60
6.	Khalis Municipality Asphalt Plant	Khalis-Diyala Province	100	stopped
7.	Muqdadiya Municipality Asphalt Plant	Muqdadiya-Diyala Province	50	stopped
8.	Baladrooz Municipality Asphalt Plant	Baladrooz-Diyala Province	50	stopped
9.	Baquba Municipality Asphalt Plant (1)	Baquba-Diyala Province	100	70
10.	Baquba Municipality Asphalt Plant (2)	Baquba-Diyala Province	100	70
11.	Haditha Municipality Asphalt Plant (1)	Haditha-Anbar Province	80	60
12.	Haditha Municipality Asphalt Plant (2)	Haditha-Anbar Province	50	stopped
13.	Anaa Municipality Asphalt Plant	Anaa-Anbar Province	100	stopped
14.	Rutba Municipality Asphalt Plant	Rutba-Anbar Province	50	stopped
15.	Al Qaim Municipality Asphalt Plant	Al Qaim-Anbar Province	50	stopped
16.	Fallujah Municipality Asphalt Plant (1)	Fallujah-Anbar Province	100	stopped
17.	Fallujah Municipality Asphalt Plant (2)	Fallujah-Anbar Province	80	60
18.	Fallujah Municipality Asphalt Plant (3)	Fallujah-Anbar Province	120	90
19.	Heat Municipality Asphalt Plant	Heat-Anbar Province	100	70
20.	Amriya Municipality Asphalt Plant	Amriya-Anbar Province	100	stopped

No.	Plant name	Plant location	Capacity (T/H)	
			Design	Effective
21.	Habbaniyah Municipality Asphalt Plant	Habbaniyah-Anbar Province	100	stopped
22.	Ramadi Municipality Asphalt Plant	Ramadi-Anbar Province	90	70
23.	Mahmoudiyah Municipality Asphalt Plant	Mahmoudiyah-Baghdad Province	50	stopped
24.	Saouira Municipality Asphalt Plant	Saouira-Wasit Province	80	60
25.	Hayi Municipality Asphalt Plant (1)	Hayi-Wasit Province	50	stopped
26.	Hayi Municipality Asphalt Plant (2)	Hayi-Wasit Province	50	stopped
27.	Zubaidiah Municipality Asphalt Plant	Zubaidiah -Wasit Province	50	stopped
28.	Numaniyah Municipality Asphalt Plant	Numaniyah-Wasit Province	80	stopped
29.	Kut Municipality Asphalt Plant (1)	Kut -Wasit Province	80	60
30.	Kut Municipality Asphalt Plant (2)	Kut-Wasit Province	80	60
31.	Kut Municipality Asphalt Plant (3)	Kut-Wasit Province	160	stopped
32.	Hashemia Municipality Asphalt Plant	Hashemia-Babylon Province	50	stopped
33.	Hila Municipality Asphalt Plant (1)	Hila -Babylon Province	100	70
34.	Hila Municipality Asphalt Plant (2)	Hila -Babylon Province	50	stopped
35.	Hindia Municipality Asphalt Plant	Hindia-Karbala Province	50	stopped
36.	Karbala Municipality Asphalt Plant	Karbala-Karbala Province	100	80
37.	Kufa Municipality Asphalt Plant	Kufa-Najaf Province	50	stopped
38.	Najaf Municipality Asphalt Plant (1)	Najaf-Najaf Province	80	50
39.	Najaf Municipality Asphalt Plant (2)	Najaf-Najaf Province	100	80

No.	Plant name	Plant location	Capacity (T/H)	
			Design	Effective
40.	Afak Municipality Asphalt Plant (1)	Afak-Diwaniyah Province	50	stopped
41.	Afak Municipality Asphalt Plant (2)	Afak-Diwaniyah Province	50	40
42.	Diwaniyah Municipality Asphalt Plant (1)	Diwaniyah-Diwaniyah Province	100	70
43.	Diwaniyah Municipality Asphalt Plant (2)	Diwaniyah-Diwaniyah Province	50	stopped
44.	Rumaitha Municipality Asphalt Plant	Rumaitha-Al-Muthanna Province	50	stopped
45.	Khadar Municipality Asphalt Plant	Khadar-Al-Muthanna Province	100	stopped
46.	Samawa Municipality Asphalt Plant (1)	Samawa-Al-Muthanna Province	80	60
47.	Samawa Municipality Asphalt Plant (2)	Samawa-Al-Muthanna Province	50	40
48.	Shatrah Municipality Asphalt Plant	Shatrah-Dhi Qar Province	50	stopped
49.	Suq Shuyukh Municipality Asphalt Plant	Suq Shuyukh-Dhi Qar Province	100	stopped
50.	Al Rifai Municipality Asphalt Plant	Al Rifai-Dhi Qar Province	90	stopped
51.	Nasiriyah Municipality Asphalt Plant (1)	Nasiriyah-Dhi Qar Province	100	70
52.	Nasiriyah Municipality Asphalt Plant (2)	Nasiriyah-Dhi Qar Province	50	40
53.	Nasiriyah Municipality Asphalt Plant (3)	Nasiriyah-Dhi Qar Province	120	90
54.	Amara Municipality Asphalt Plant (1)	Amara-Maysan Province	100	70
55.	Amara Municipality Asphalt Plant (2)	Amara-Maysan Province	50	40
56.	Amara Municipality Asphalt Plant (3)	Amara-Maysan Province	80	stopped
57.	Amara Municipality Asphalt Plant (4)	Amara-Maysan Province	100	stopped
58.	Amara Municipality Asphalt Plant (5)	Amara-Maysan Province	120	stopped

No.	**Plant name**	**Plant location**	**Capacity (T/H)**	
			Design	**Effective**
59.	Zubair Municipality Asphalt Plant (1)	Zubair-Basra Province	130	100
60.	Zubair Municipality Asphalt Plant (2)	Zubair-Basra Province	130	100
61.	Zubair Municipality Asphalt Plant (3)	Zubair-Basra Province	130	100
62.	Zubair Municipality Asphalt Plant (4)	Zubair-Basra Province	130	100
63.	Zubair Municipality Asphalt Plant (5)	Zubair-Basra Province	90	stopped
64.	Abu al-Khasib Municipality Asphalt Plant	Abu al-Khasib-Basra Province	130	100
65.	Basra Municipality Asphalt Plant (1)	Basra-Basra Province	100	70
66.	Basra Municipality Asphalt Plant (2)	Basra-Basra Province	80	50
67.	Qurna Municipality Asphalt Plant	Qurna-Basra Province	200	160
68.	Samarra Municipality Asphalt Plant (1)	Samarra-SalahAldin Province	50	stopped
69.	Samarra Municipality Asphalt Plant (2)	Samarra-SalahAldin Province	50	stopped
70.	Baiji Municipality Asphalt Plant	Baiji-SalahAldin Province	80	60
71.	Tuz Municipality Asphalt Plant	Tuz-SalahAldin Province	80	50
72.	Sharqat Municipality Asphalt Plant	Sharqat-SalahAldin Province	50	stopped
73.	Tikrit Municipality Asphalt Plant (1)	Tikrit-SalahAldin Province	50	40
74.	Tikrit Municipality Asphalt Plant (2)	Tikrit-SalahAldin Province	50	40

Table 5-2: plants managed by Mayoralty of Baghdad.

No.	Plant name	Plant location	Capacity (T/H)	
			Design	Effective
1.	Al-Obaidi Asphalt Plant (1)	Al-Obaidi-Baghdad Province	400	300
2.	Al-Obaidi Asphalt Plant (2)	Al-Obaidi-Baghdad Province	400	300
3.	Taji Asphalt Plant (1)	Taji-Baghdad Province	400	300
4.	Taji Asphalt Plant (2)	Taji-Baghdad Province	400	300
5.	Karrada municipality asphalt plant	the intersection of Muhammad Al-Qasim-Al-Dora highways-Baghdad Province	120	80

Table 5-3: Plants managed by Hamorabi State Construction Contracts company.

No.	Plant location	Capacity (T/H)	
		Design	Effective
1.	Salman Pak-Baghdad Province	250	150
2.	Salman Pak-Baghdad Province	400	stopped
3.	Tarmiyah-Baghdad Province	100	160
4.	Expressway No.1-Section (R6)	200	160
5.	Expressway No.1-Section (R6)	200	180
6.	Al Hifaar-Diwaniyah Province	200	180
7.	Al Hifaar-Diwaniyah Province	60	stopped
8.	Al Hifaar-Diwaniyah Province	60	stopped
9.	Abi Sakhir-Najaf Province	160	120
10.	Abi Sakhir-Najaf Province	60	stopped
11.	Abi Sakhir-Najaf Province	95	60
12.	Samarra-SalahAldin Province	250	150
13.	Baiji-SalahAldin Province	95	stopped
14.	Kut -Wasit Province	60	stopped
15.	Badra -Wasit Province	200	100
16.	Taza-Kirkuk Province	95	stopped
17.	Daquq-Kirkuk Province	160	120
18.	Hawija-Kirkuk Province	95	stopped
19.	Kilo 18-Ramadi-Anbar Province	100	60
20.	Kilo 70-Ramadi-Anbar Province	95	stopped
21.	Anaa-Anbar Province	100	stopped
22.	Arar-Ramadi-Anbar Province	250	120
23.	Al-Jarayshi-Ramadi-Anbar Province	250	stopped

Table 5-4: Plants managed by Ashur State Construction Contracts Company.

No.	Plant name	Plant location	Capacity (T/H)	
			Design	Effective
1.	AS 28	Al-Jarayshi-Ramadi-Anbar Province	100	50
2.	AS 17	Haswa-Babylon Province	100	50
3.	AS 29	Rumaila-Basra Province	160	120
4.	AS 20	Abu al-Khasib-Basra Province	95	60
5.	AS 5	Expressway No.1-Section (R6)	200	150
6.	AS 18	Expressway No.1-Section (R6)	200	200
7.	AS 6	Expressway No.1-Section (R6)	200	180
8.	AS 4	Expressway No.1-Section (R6)	380	250
9.	AS 16	Babel-Diwaniyah Road	120	60
10.	AS 7	Hila -Babylon Province	80	50
11.	AS 11	Abu Ghraib-Baghdad Province	180	100
12.	AS 15	Muqdadiya-Diyala Province	200	130
13.	AS 13	Wajihiya-Diyala Province	80	50
14.	AS 14	Khanaqin-Diyala Province	80	50
15.	AS 21	Al-Razzaza-Karbala Province	200	150
16.	AS 24	Komate-Maysan Province	200	100
17.	AS 22	Amara-Maysan Province	180	100
18.	AS 23	Kaleat Salih-Maysan Province	80	60
19.	AS 25	Salamiyah-Nineveh Province	250	150
20.	AS27	Kukjli-Nineveh Province	95	60

Table 5-5: Plants managed by Karbala Province/Direct Implementation Dept.

No.	Plant name	Plant location	Capacity (T/H)	
			Design	Effective
1.	Karbala Asphalt Plant	Industrial zone of Rizaza Karbala Province	100	80

Table 5-6 Asphaltconcrete unit plants in the private sector[5].

No.	Plant name	Plant location	Design Capacity (T/H)
1	Raheem plant for the production of asphalt	Al-Jabal-Anbar Province	120
2	Zaki plant for the production of asphalt	Karma-Anbar Province	120
3	Ardth Al-Samoud plant for the production of asphalt	Karma-Anbar Province	120
4	Al-Tur plant for the production of asphalt	Al Jazeera-Karbala Road-Najaf Province	120
5	Wadi Al Ghari Asphalt Plant	Al Kifl-Babylon Province	120
6	Asphalt plant Raheem Jabbar Mansi	Al Kifl-Babylon Province	120
7	Ihsan Al Janabi Asphalt Plant	Al Kifl- Babylon Province	120
8	Al Wefaq Asphalt Plant	Hamzawiya-Babylon Province	120
9	Al Jahra Asphalt Plant	Al Kifl- Babylon Province	120
10	Iyad Jabbar & Partners Asphalt plant	Radwaniyah-Baghdad Province	120
11	Naim Al-Nahrain Asphalt plant	Baquba-Diyala Province	120
12	Hamrin Asphalt Plant	Muqdadiya-Diyala Province	160
13	Saqr Khanaqin Asphalt plant	Karataba-Diyala Province	320
14	Al-Abed plant for the manufacture of asphalt paving	Habhib--Diyala Province	120
15	Riyadh Al-Foratain Asphalt plant	Khalis-Diyala Province	120
16	Future Road Asphalt plant	Shatrah-Dhi Qar Province	120
17	Gulf plant for the production of concrete asphalt	Tikrit-SalahAldin Province	120
18	Fayadh Asphalt plant	Al-Musaihili-SalahAldin Province	120
19	Muhammad Fahd Mutlak Asphalt Plant	Alhajaaj-Tikrit-SalahAldin Province	120
20	Al Shiffar plant for Asphalt Production	Alhajaaj-Tikrit-SalahAldin Province	120
21	Zweya Asphalt plant	Makhoul Mount-SalahAldin Province	120

---

[5] According to the information of the General Directorate for Industrial Development (GDID)

No.	Plant name	Plant location	Design Capacity (T/H)
22	Sorouh Al-Maher plant for the production of asphalt paving	Abu Al-Hil-SalahAldin Province	120
23	Jannat Maysan Asphalt Plant	Almaymuna-Maysan Province	120
24	Muhammed Aliwi Maigo & Partners Asphalt Plant	Almaymuna-Maysan Province	120
25	Arab Company for Roads Ltd.	Aldawaasa-Nineveh Province	800
26	Shamil Abdul Razzaq Factory for the production of asphalt	Telcaif-Nineveh Province	120
27	The Arab Black Gold Company for the production of asphalt	Telcaif-Nineveh Province	120
28	Al-Jawary plant for the production of asphalt paving	Telcaif-Nineveh Province	120
29	Noor Al-Mosul Asphalt Plant	Hamdaniya-Nineveh Province	120
30	Al Ula Asphalt Plant	Bashiqa-Nineveh Province	120
31	Saouira plant for the production of asphalt	Saouira-Wasit Province	120
32	Insha Al-Khalij Company for General Contracting and Asphalt Industry	Industrial zone of Karbala	160

Regarding the distribution of asphalt concrete units plants in the Kurdistan region, one of the geographical studies concerned with the spatial distribution of the asphalt industry (Table 5-7) displayed the geographical distribution of asphalt concrete units plants in the provinces of the region (the Halabja Province does not include any asphalt concrete unit plant).

Table 5-7: Geographical distribution of asphalt concrete units plants in Kurdistan (Ismael & Rashid, 2021).

Province	Districts	number of plants
Erbil	City center	28
	Khabat	2
	Kuayh	1
Sulaymaniyah	City center	7
	Rania	3
	Sayid Sadiq	3
	Clar	3
	Dokan	2
	Darbandikhan	2
	badger	1
Dohuk	Simil	8
	Zakho	2
	Bardarash	1
Total		63

5.2.2 Row material sources

Raw materials are the main food for the plant, and the production process cannot continue without the availability of raw materials. Raw materials play a crucial role in selecting the plant's location, as the plant's proximity to the sources of raw materials necessarily leads to reducing production costs and occupying a better competitive position for the plant (Al-Jumaili, 2002). In fact, settling the asphalt concrete unit plant near the sources of raw materials to save transportation costs is difficult to achieve.

Through the field survey form (Appendix A), the locations of the sources of raw materials needed for production in the asphalt concrete units plants were obtained as follows:

5.2.2.1 Bitumen

The bitumen content depends on the aggregate and the expected traffic (Robinson & Thagesen, 2018). Normally, it lies between 4% and 7% by mass of total asphalt mix and the exact “design bitumen content” is determined by course type (S. Highway & Bridges, 2007).

Due to Bitumen being a Hydrocarbon product produced from refining crude oil, it relies on the Ministry of Oil's refineries, scattered throughout the country, to prepare the asphalt concrete units plants. The number of these refineries in the country reaches (20) filters distributed over the country's Province, as shown in Table 5-8.

Table 5-8: Oil Refineries in Iraq.

No.	Refinery	Location	Notes
1	Baiji Salahedden Refinery 1	Salahaldin Province	
2	Baiji Salahedden Refinery 2	Salahaldin Province	
3	Baiji North Refinery	Salahaldin Province	
4	Kirkuk Refinery	Kirkuk Province	
5	Gaiyarah Refinery	Nineveh Province	
6	Jazeera Refinery	Nineveh Province	
7	Kusk Refinery	Nineveh Province	
8	Erbil Refinery	Erbil Province	
9	Khanaqin/Alwand Refinery	Diyala Province	
10	Signia Refinery	Anbar Province	
11	Haditha Refinery	Anbar Province	Under Construction
12	Daurah Refinery	Baghdad Province	
13	Kut Refinery	Wasit Province	Under Construction
14	Karbala Refinery	Karbala Province	Under Construction
15	Najaf Refinery	Najaf Province	
16	Samawah Refinery	Al-Muthanna Province	
17	Maysan Refinery	Maysan Province	
18	Nasiriyah Refinery	Dhi Qar Province	
19	Muftiah Refinery	Basra Province	
20	Shuaiba Refinery	Basra Province	
21	Faw Refinery	Basra Province	Under Construction

Previously, the processing of Bitumen within the geographical area of refineries and asphalt concrete units plants. At present, through the field survey process, except for the Mayoralty of Baghdad plants, all asphalt concrete units plants obtain bitumen from Nasiriyah Refinery, and Mayoralty of Baghdad plants to be obtained bitumen from Al- Daurah Refinery.

5.2.2.2 Aggregate

Aggregate is the largest constituent in HMA, typically 92–96% by mass (Hunter et al., 2015). In Iraq, Natural aggregates are either obtained from rock (or gravel) quarries or dredged from river beds. The largest spread of quarries in Iraq is in the Al-Nabai zone (which is an overlapping area between Baghdad and Salah al-Din Provinces) and the Dhiraa Dijla zone (which is an area overlapping between the Salah al-Din (Baiji) and Nineveh (Sharqat) Provinces). Quarries are also spread in Kirkuk, Anbar, Karbala, Najaf, Diyala, Wasit, Muthanna, Maysan, and Basra Provinces. The Hawija quarries are located in Kirkuk, and the Habbaniyah quarries are located in Anbar. Karbala has quarries of Al-Akhaidir, al-Ebiedth valley, and Al-Fahud and quarries of the Karbala-Najaf plateau. In Najaf, there are quarries of Abu Khamsat and Hassab valley. The Sonia quarry in Wasit is the largest quarry, and there are other quarries in Hashima, Zorbatiyah, Badra, and Jissan. In Muthanna, there are Bissyah quarries. In Maysan, there are many quarries in the Al-Taeb zone. In Basra, quarries are spread in particular in the Al-Zubair district (in the Shuaib Al-Batin and Jabal Sanam). Al-Luhais is an overlapping zone between the Provinces of Basra, Dhi Qar, and Muthanna, in which aggregate quarries are spread in particular. To the north, there are quarries of Bai Hassan in Sulaymaniyah Province. The production of quarries above is coarse and fine aggregate. However, fine aggregates can be produced from aggregates treated by crushers. Fine aggregates are also obtained from rivers beds but are not used to produce asphalt concrete in Iraq (only in ordinary concrete). Coarse aggregate is also obtained from rivers beds like the bed of Shatt Al Arab, but Not used yet. This study received this information from the Iraqi Geological Survey and field survey form (Appendix A). through the field survey form, some aggregate quarries that equip asphalt concrete units plants were identified. Including the Hawija quarries supply asphalt concrete units plants in Kirkuk Province, Al-Ukhaidir quarries supply asphalt concrete units plants in the Provinces of Karbala and Babil, Al-Mansuriyah quarries in the Al-Nabai zone, Asaliya and Muhammadiyat quarries in Al-Habbaniyah, supply aggregates for plants managed by Mayoralty of Baghdad, and Khazir quarries in the Dhiraa Dijla zone that supply asphalt concrete units plants in Nineveh Province, in addition to the quarries Located in Salah Al-Din Province, which is shared between the Dhiraa Dijla and Al-Nabai quarries, as well as the Al-Tayeb quarries, it supplies aggregates for the asphalt concrete units plants located in the Maysan Province and many other quarries scattered throughout the country.

5.2.2.3 Mineral filler

The field survey form concluded that cement is the main material be used as a filler (Table 5-9) illustrates cement plants in Iraq. In some cases, Lime plants are relied upon to produce filler. However, Iraq plants to produce the filler material like AS 52 plant / Al-Jarayshi-Ramadi-Anbar Province & AS 51 plant/ Samawa-Muthanna Province, managed by Ashur State

Construction Contracts company and Ramadi plant / Ramadi-Anbar Province, which is managed by the private sector.

Table 5-9: Cement plants in Iraq (*Iraqi Cement State Company*, 2022).

No.	Plant	Province
1	Falluja Cement Plant	Anbar
2	Al-Qaim Cement Plant	Anbar
3	Kubaisa Cement Plant	Anbar
4	Kirkuk Cement Plant	Kirkuk
5	Al Kufa Cement Plant	Najaf
6	Al Najaf Cement Plant	Najaf
7	Karbala Cement Plant	Karbala
8	Karbala Cement & lime Plant	Karbala
9	Al Muthanna Cement Plant	Muthanna
10	Al Samawah Cement Plant	Muthanna
11	Babil Cement Plant	Babil
12	Al Basra Cement Plant	Basra
13	Al Rafidain Cement Plant	Nineveh
14	New Badoush Cement Plant	Nineveh
15	Expansion Badoush Cement Plant	Nineveh
16	Al Hadbaa Cement Plant	Nineveh
17	New Hammam Al Aleel Cement Plant	Nineveh
18	Sinjar Cement Plant	Nineveh

5.2.3 Discussing the results of the field survey

Through what was presented in the previous paragraphs of this chapter and according to the information and data obtained during the field survey process, it was possible to conclude and discuss the following results preliminarily:

1. Weak level of programming and planning in the asphalt industry in the public sector, especially the complexity that occurs in production, transportation and pricing programming, and the priority in paving projects.

2. The aggregates in the public sector plants are processed by the tenders method, while the filler and Bitumen are supplied by the direct purchase method.
3. Raw materials are supplied by the direct purchase method in private sector plants.
4. The number of suspended plants in the General Directorate of Municipalities Hamorabi company. is 36, 11 respectively, while all plants of Mayoralty of Baghdad and Ashur co. are workable.
5. The selection of asphalt concrete unit plant location managed by the General Directorate of Municipalities and Mayoralty of Baghdad was based mainly on the Land Ownership and availability of necessary areas for equipment and raw materials. While Hamorabi company. relies on a factor of proximity to demand area for asphalt concrete (paving projects).
6. Ashur company depends on the factors of availability of land, proximity to paving projects, and proximity to sources of raw materials (transportation methods) as key factors in selecting the locations of the asphalt concrete units plants it manages.
7. There is no application for sustainability in any of the asphalt concrete units plants in the country.

5.3 Open questionnaire stage (personal interviews)

The open questionnaire means the flexible open personal interviews for deliberation and dialogue about the creation and design of the closed questionnaire form in terms of format and style and supporting it with questions arising from the experience of the stakeholders and decision-makers. At this stage, it has relied on personal interviews with some engineers and decision-makers involved in the management and implementation of paving projects and the asphalt industry (as Table 5-10). These interviews were used to:

1. Creating and designing the closed questionnaire form and ensuring the comprehensiveness of the information requested.
2. Finding new additional information that cannot be obtained without interviews, including information on the sources of raw materials used in the asphalt industry and the factors that helped to select the locations of the current asphalt concrete units plants in Iraq.
3. Ensure the success of formulating and presenting the questions and the extent to which the sample members understand the formula of the question posed.
4. Determining the type of sample that will be interrogated.

Table 5-10: The personal interviews

No.	Responder Description	Institution
1	Head of plants section	General Directorate of Municipalities
2	Manager of production units office	Mayoralty of Baghdad
3	Managers of Al-Obaidi Asphalt Plant (1)&(2)	Mayoralty of Baghdad
4	Manager of Karrada municipality asphalt plant	Mayoralty of Baghdad
5	Head of machinery and Production units Department	Ashur State Construction Contracts company
6	Manager of mixers & crushers Section	Ashur State Construction Contracts company
7	Head of machinery and Production plants Department	Hamorabi State Construction Contracts company

No.	Responder Description	Institution
8	Manager of Production plants Section	Hamorabi State Construction Contracts company
9	Head of projects Department	Hamorabi State Construction Contracts company
10	Headmaster of highways Directorate	Road and Bridges office
11	Manager of Mineral Investigation Division	Iraq Geological Survey
12	Manager of Hindia Municipality Asphalt Plant	Hindia Municipality
13	Manager of Karbala Municipality Asphalt Plant	Karbala Municipality
14	Manager of Karbala Asphalt Plant	Direct Implementation Dept./Karbala Province
15	Manager of Insha Al-Khalij Company for General Contracting and Asphalt Industry	Public sector
16	Manager of Al Wefaq Asphalt Plant	
17	Manager of Al Jahra Asphalt Plant	
18	Manager of Ihsan Al Janabi Asphalt Plant	

5.4 Closed questionnaire stage

The closed introductory questionnaire is intended to answer the questions in the regular questionnaire form in all its sections, prepared by the researcher and distributed to the selected research individuals after completing the open questionnaire. The closed questionnaire was conducted according to the following steps:

1. Designing the regular questionnaire form and determining the axes of the questions.
2. Choosing the research sample to be questioned.
3. Determine the sample size.
4. Distribute the questionnaire form to the sample members to answer the questions contained therein.

Here are the details of these procedures:

5.4.1 Designing the questionnaire form

The design and preparation of the questionnaire form (Appendix B) were based on each of the three theoretical chapters of the study (first, second, and third), the field study of the asphalt concrete units plants, and the exploratory personal interviews conducted by the researcher in a clear manner that allows all members of the research sample to answer them without difficulty.

The form (Appendix B) included in its introduction on the personal identification information page of the sample members aimed at collecting information and data about them representing company or office name, Academic achievement, job class, job title, number of years experience as an engineer and experience in the implementation of paving projects. As for the rest of the questionnaire, it included two main sections of the questions in all their details, and the following is a detail of the final sections of the questionnaire:

5.4.1.1 The first section\ information on asphalt plants returning to Iraq's public and private sectors.

This section included seven questions revolving around:

1. Whether the asphalt concrete plants in Iraq were selected as the optimal locations that give greater economic returns.
2. The impact of the location of the asphalt concrete plant on the final cost of production.
3. How important is the preparation of a long-term on-locational distribution program for establishing an asphalt plant.
4. The most important factors helped localize the asphalt concrete plants for road projects in Iraq.
5. The most important reasons that lead to the high costs of the asphalt industry.
6. The most important reports to be prepared in asphalt concrete plants.
7. Have you ever seen a managerial system, a mathematical model, or a specific framework for selecting the optimal location for the asphalt concrete plant.

5.4.1.2 The second section/factors affecting the selection of asphalt concrete plant location

It includes twenty-eight questions about the decision-making factors in selecting the optimal location for the asphalt concrete plant for road projects. It was presented in two parts, as follows:

5.4.1.2.1 Part 1. Quantitative factors

The objective of the analysis of locations is to achieve the largest possible amount of profits because careful selection leads to reducing costs to the maximum extent possible, as quantitative factors have a direct impact on production costs, and they have been classified into the following:

First. Factors related to the inputs of production process:

1. Availability of labor of skilled and unskilled technicians and workers.
2. Proximity to sand and gravel quarries.
3. Proximity to filler sources.
4. Proximity to the sources of the bonding material (Bitumen).
5. Sustainability or ability to recycle asphalt materials when doing maintenance work.
6. Availability of transportation network to transport the raw materials to the plant.
7. Availability of spare parts and spare tools for production machinery.

Second. Factors related to the outputs of production process:

1. Proximity to road projects and maintenance
2. Market needs or size of the roads to be implemented or maintained.
3. Availability of transportation network to transport asphalt products to implementation projects or maintenance.

Third. Factors related to the requirements of production process:

1. Proximity to water supply sources.
2. Proximity to electricity supply sources.
3. Proximity to sewer networks.
4. Proximity to the sources of fuels and oils.

5. Availability of necessary areas for warehouses of raw materials, spare materials, and parking.

5.4.1.2.2 Part 2. Qualitative factors

They are not directly related to the cost and have emerged in the last period and indirectly affect selecting the optimal location for the plant. These factors included the following:

1. Environmental impact.
2. Noise.
3. Transportation availability.
4. Rubble and production waste.
5. Climatic conditions.
6. Availability of services.
7. Factors related to general opinion.
8. Local laws and regulations.
9. Personal factors.
10. Proximity to the main office or company.
11. The geological nature of the land on which the plant will be built.
12. Availability of housing in the area.
13. Availability of the road and transportation network to transport the raw materials to the plant and transport the asphalt products to the implementation sites.

5.4.2 Choosing the research sample

The most important characteristic of the closed questionnaire process and its success is the success of choosing the research sample. The sample is a part of the whole chosen for considerations estimated by the researcher (Al-Jumaili, 2002). The choice is neutral so that the part carries all or most of the characteristics, appearances and features of the research population from which the sample was chosen. The samples are classified into random, stratified, cluster, snowball, and purposive samples.

The choosing of a research sample as a model consisting of a group of engineers with experience in the field of roads and asphalt concrete units plants must be accompanied by a focus on the accuracy required from the results of the questionnaire, with an economy in the cost necessary to complete the process and the time required to implement the questionnaire. The purposive and snowball sampling methods were used. The first depends on the researcher's opinion and ability to choose a sample representing the population of the case under research. The second relies on the Nomination of others by the respondents.

5.4.3 Determine the sample size

Based on the Central Limit Theorem, which states that “when taking a sample size (n) from a statistical population distributing its mean (μ) and variance (δ^2), the arithmetic mean distribution of the samples (X) is subject to a normal distribution, its mean (μ), and its variance (δ^2/μ) provided that the sample size is relatively large (n>30)” (Emara & Tawfik, 1989) ;the sample whose size is greater than (30), its distribution is close to the normal even if it was not originally distributed normally. Thus, the sample size required (according to **ASTM-E122-79**) depends on the type of distribution and confidence level (Table 5-11).

Table 5-11: Sample size at the desired confidence level[6].

Confidence Level	**Confidence Factor**	**Sample Size (n)**	
		Normal Distribution	**Triangular Distribution**
95%	**1.96**	**11**	**16**
99%	**2.58**	**19**	**28**
99.7%	**3.00**	**25**	**38**

To achieve a high level of confidence, the researcher chose the upper limit of the confidence level (99.7), that is, with a sample size (n=38), and to increase accuracy, the sample size was increased to (108) respondents.

5.4.4 Distribution of questionnaire forms among the sample members

This study follow the following steps in distributing the questionnaire forms:

1. Conducting personal interviews (in presence & online) with the respondents and explaining any ambiguity in the questions contained in the form.
2. Allow enough time for each person to answer the questionnaire questions.
3. Checking each form before submitting it, ensuring the answers included all the questions, and discussing any fuzziness with the concerned respondent.

5.4.5 Description of questionnaire sample

After completing the open questionnaire, the closed introductory questionnaire was prepared (Appendix B). According to Table 5.10, The confidence interval equal to (99.7%) was chosen, and thus the sample size

---

[6] Standard Recommended Practice for choice of sample size to estimate the average Quality of a lot or process (ASTM-E122-79)

should be equal to (38) respondents. To increase confidence, the sample size was increased to (108) respondents from the engineers. These engineers belong to 31 institutions, 24 public sector institutions, and seven private sector companies (Table 5-12). Figures: 5-1, 5-2, 5-3, and 5-4 represent the respondent academic achievement, the respondent job title, the number of years of his experience, and the frequencies distributions percentages of respondents' participation in pavement projects as below respectively.

Table 5-12: Contributors to the Closed introductory questionnaire.

No.	Company or office name	Frequency
1	General Directorate of Municipalities	21
2	Ministry of Planning/ Government Contracts Directorate	10
3	Road and Bridges Directorate	9
4	Ashur State Construction Contracts company	9
5	Holy Kerbala Province/ Direct Implementation Dept./Road Sec.	7
6	Holy Kerbala Province/ Direct Implementation Dept./ Muncicpalities Sec.	6
7	Hamorabi State Construction Contracts company	5
8	Privet Sector	5
9	Mayoralty of Baghdad/ project office	4
10	University of Kerbala/ College of Engineering	4
11	Holy Kerbala Province/ Direct Implementation Dept./ Karbala Asphalt plant	3
12	Holy Kerbala Province/ Administration Affairs	3
13	Ministry of Education	2
14	Mustansiriya University/ College of Engineering	2
15	General Directorate of Sewerage	2
16	Ministry of Oil	1
17	Ministry of Transportation	1
18	Ministry of Water Resources	1
19	Ministry of Construction, Housing, and Municipalities	1
20	Ministry of Planning/ Government Contracts Directorate	1
21	Imam Hussein Holy Shirne	1
22	Thi Qar Oil Company	1
23	University of Garmian	1
24	Wasit Province Court	1
25	Private Sector Companies	7
Total		108

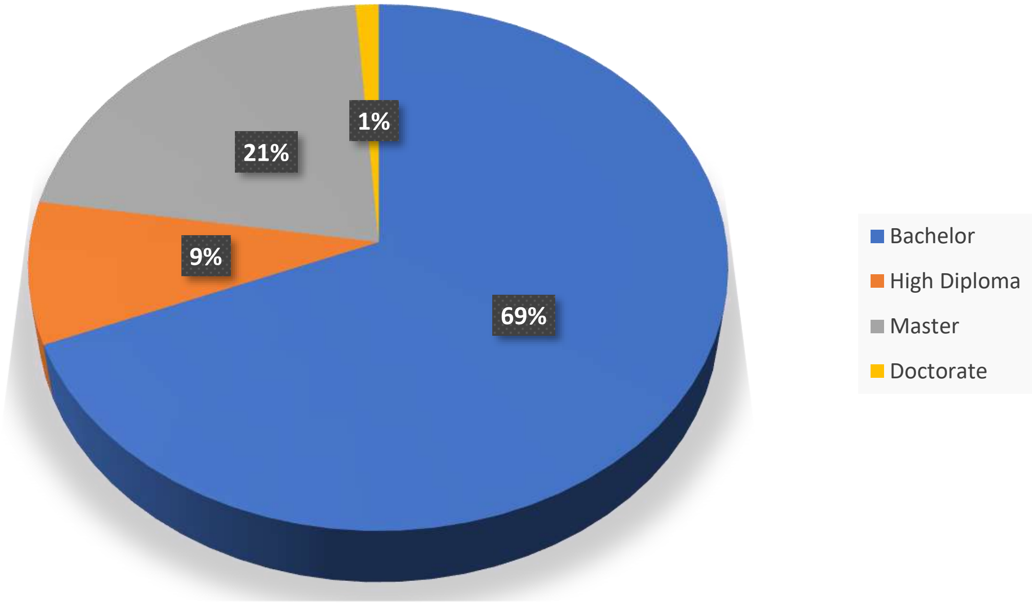


Figure 5-1: Frequency distribution for academic achievement.

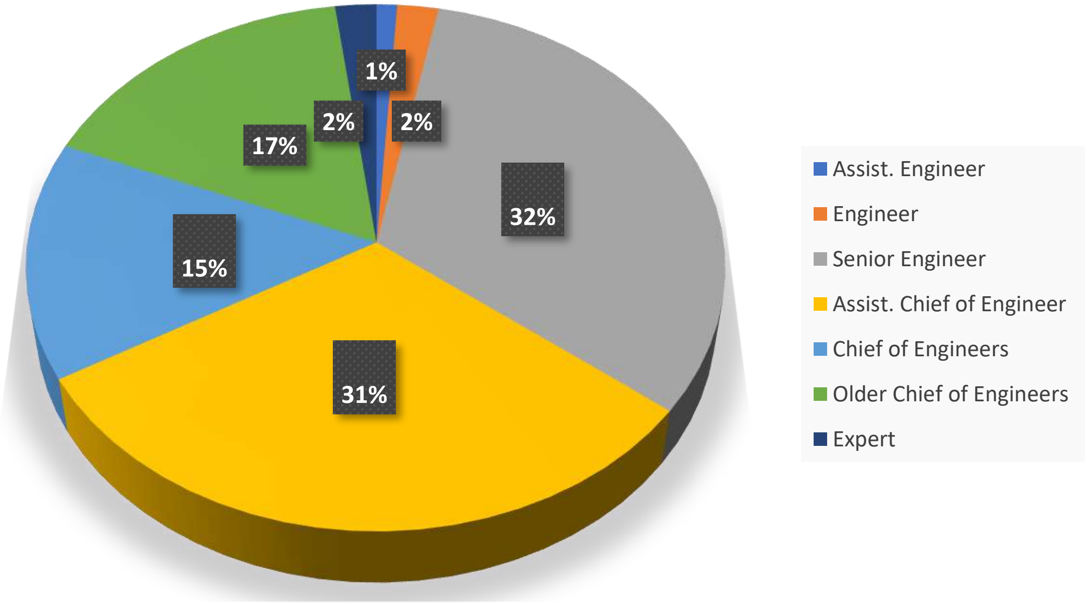


Figure 5-2: Frequency distribution for job title.

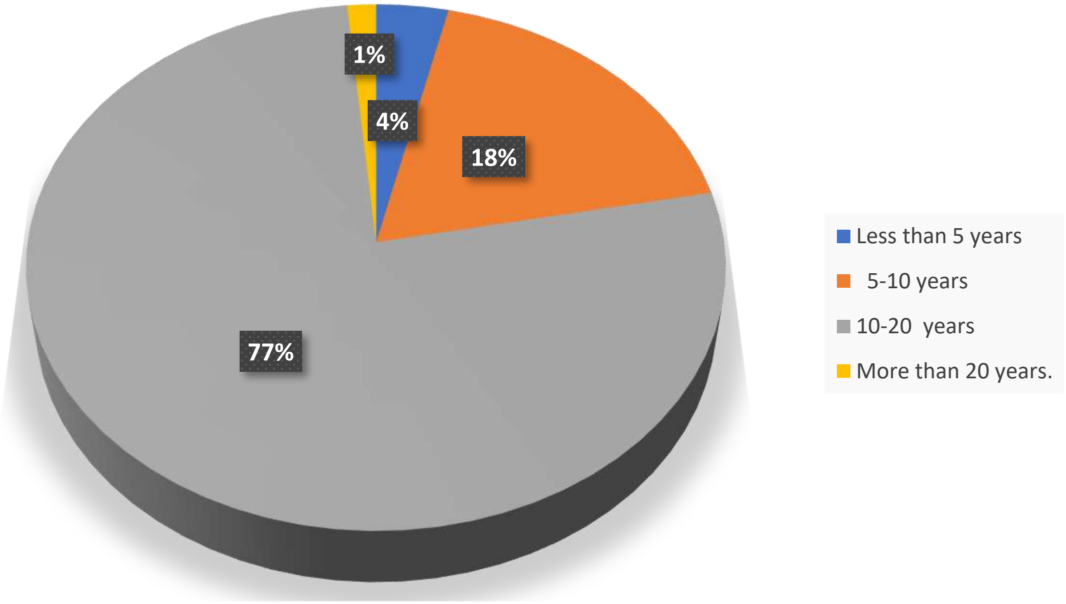


Figure 5-3: Frequency distribution for years of experience.

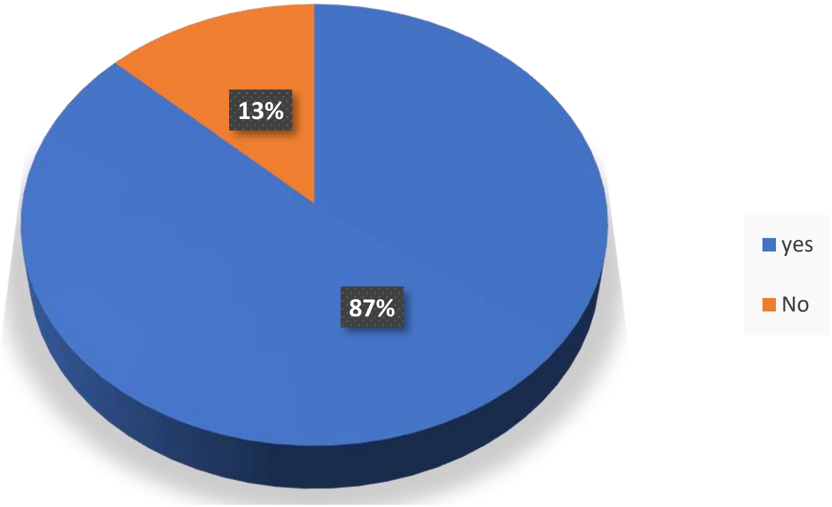


Figure 5-4: Frequency distribution according to participation in paving work.

5.4.6 Questionnaire answers analysis

A five-point Likert scale was used to compute the frequencies of the answers and their means to know the majority opinion according to the respondents' views. The scale provides an ordinal type as rank orders are in the form of:

Always	Often	Sometimes	Rarely	Never
Very high importance	High importance	Medium importance	Low importance	Unimportant

Moral weight values (1-5) are given with a five-point Likert scale, represnts the ranks of the answers (Table 5-13), to analyze respondents' answers (George & Mallery, 2020)(Al-Jassar, 2017).

Table 5-13: weighted values of the answers.

Answer type	Answer Rank
Never	1
Unimportant	
Rarely	2
Low importance	
Sometimes	3
Medium importance	
Often	4
High importance	
Always	5
Very high importance	

Then, the researcher extracting the mean and standard deviation for each factor based on the answers of the respondents, where the mean is a score to represent the impact of each factor through respondents' answers and can be determined by equation (5-1) (Jumaah, 2020):

$$M = \frac{\sum R \times F}{N} \qquad (5-1)$$

Where:
F = Answers frequencies
R = Answers ranks
N = Sample size

For factors screening, the factors whose mean value was less than 3.0 were eliminated to keep the most important ones (Al-Jassar, 2017).

5.4.6.1 Answers to the questions of the first section

During the field survey conducted by the researcher, did not obtain any firm or clear information explaining the reasons or factors that helped to select the locations of the current asphalt concrete units plants. Therefore, it was necessary to mine about these factors, and the scope of the impact of location of the plant on the final cost of paving. The answers in Table D-1 (Appendix D).

5.4.6.1.1 Discussion

1. Regarding the locations of asphalt concrete units plants in Iraq, and these locations considered optimal to give a greater economic return, the opinions of (44.4%) of the questionnaire sample within a period (sometimes), and (24%) within a period (often).

The respondents’ answers were identical to what the researcher touched during field visits to several plants and personal interviews. This aspect needs more attention from the state, which calls for conducting the necessary studies before selecting the locations of the asphalt concrete units plants.

2. On the extent to which the final cost of asphalt concrete production is affected by the plant location, the opinions of (57%) of the questionnaire sample were within the period (always) and mean within the period (always). The respondents' answers were identical to what was stated in the theoretical study and what was discussed during personal interviews with the stakeholders, as the plant's location has a direct impact on the final cost of producing asphalt concrete.
3. Concerning the preparation of a long-term on-locational distribution program before establishing plants for asphalt concrete as a condition, the opinions of (62%) of the questionnaire sample were within the period (always) and the mean within the period (always) too. The respondents' answer was identical to what is applied in the field in Iraq, as such laboratories were established according to a specific factor, not an ideal set of factors.
4. The most important reasons or factors that helped to localize the asphalt concrete units plants in Iraq, for which the means of answers were arranged in descending order from (always) & (often) according to their importance through the opinions of the questionnaire sample are:
    a. Availability of the necessary land for building the plant and enough area for stores.
    b. Availability of necessary services for running the plant as water, electric power,... Etc.

c. Near the plant from raw materials sources.
d. Near the plant from the transportation network.
e. Near the plant from projects of road paving and maintenance.
f. Availability of technicians, skilled, and unskilled workers near the plant location.

The factor of land availability had the highest mean, which came within the (often) period, as the respondents considered it one of the most important reasons that led to the settlement of these plants, and this is what the researcher touched during the field survey and personal interviews, especially with the plant belonging to the public sector. A kind of underestimation for the answer of factor c. Given that these reasons were not achieved to the extent that they should have been taken into account when selecting the locations of these plants.

5. As for the most important reasons that lead to the cost of the asphalt industry, the means of the answers varied within the periods (often) and were ranked in descending order according to their importance through the opinions of the sample of the questionnaire:

a. Distance the plant from aggregate quarries.
b. Distance the plant from projects of road paving and maintenance.
c. The distance the plant from bitumen sources.
d. Unavailability of asphalt concrete transportation to the project's sites.
e. Distance of plant from the services needed to operate it as water, and electric power, ... Etc.
f. Unavailability of raw materials transportation to the plant location.
g. Unavailability of transportation network near the location of the asphalt industrial plant.
h. Unavailability of spare parts for production machinery.

i. The distance of the plant from filer sources.
j. High wages of labor near the asphalt plant.
k. Unavailability of necessary labor near the location of the asphalt industrial plant.
l. Disability of recycling the old asphalt waste.

Although not enough importance is given to the factor of recycling the old asphalt (reclaimed asphalt), these answers are considered felicitous; the above reasons should take greater care when selecting the location of the asphalt concrete unit plant to achieve the objectives envisaged in reducing the cost of production, taking into account the development of culture (recycling) For workers in the paving sector.

6. Concerning the most important reports to be prepared in the asphalt concrete units plants, all their means were within a period (always) except for the reports related to sustainability and the possibility of recycling; the mean was within a period (often). Arranged in descending order of importance according to the questionnaire sample opinions:

a. Productivity.
b. Market needs or size of the road projects to be implemented or maintained.
c. Information about the case of equipment and production machinery.
d. Information about the cost of transporting raw materials.
e. Information about the asphalt product's transportation cost to the implementation sites.
f. Information about the sustainability or possibly recycling previous asphalt waste in the implementation zone.

The respondents' answers came expressing what reports should be prepared in such plants, and given the lack of preparation of such reports at present, and this is what the researcher touched during the field research, and this is due to the lack of interest in the economic aspect, which requires the competent authorities to pay more attention to this aspect To ensure the sustainability of these plants and to preserve the economic returns from them.

7. Most of the opinions of the questionnaire sample, with a percentage of (97.22%), were unanimous in the absence of an administrative system, a mathematical model, or a specific framework for selecting the optimal location for the asphalt concrete unit plant. In comparison, only (2.78%) confirmed that they were informed.

5.4.6.2 Answers to the questions of the second part

The following is a presentation, analysis and discussion of the answers to the questionnaire for the second section, which was divided as follows:

5.4.6.2.1 Part 1. Quantitative factors

They are the factors that directly affect the cost of producing asphalt concrete and transporting it to the pavement sites when choosing the optimal location for the plant. The candidate locations' comparison is based on achieving the lowest possible asphalt production cost. The quantitative factors can be summed up as follows, as indicated in the questionnaire answers in Tables: D-2, D-3, & D-4 (Appendix D).

First. Factors related to the production process inputs:

<u>Discussion</u>

Respective to the importance of the factors related to the inputs of production process in the asphalt concrete units plants, the respondents' opinions were unanimous on their importance, as the means for them ranged within the period (high importance), except for the factor of proximity to the aggregate quarries, which obtained (very great importance). The factors were arranged in descending order through the respondents' opinions:

1. Proximity to sand and gravel quarries.
2. Availability of labor of skilled and unskilled technicians and workers.
3. Availability of a transportation network to transport raw materials to the plant.
4. Proximity to the bitumen sources.
5. Availability of spare parts for production machinery.
6. Proximity to filler sources.
7. Sustainability or ability to recycle asphalt materials when doing the maintenance work.

The respondents' answers came expressing what the locations of asphalt concrete units plants should be in terms of their proximity to the aggregate (gravel and sand) locations, where the aggregate constitutes more than 90% of the components of asphalt mixtures and the need to provide it with the required gradation. The low importance of factors of proximity to sources of filler and bitumen (i.e., factors 3 & 4) is due to the country's optimal distribution of cement plants and oil refineries, and thus the availability of fillers and bitumen easily and the cost of transporting them is cheap.

The interest in the importance of factors of proximity to sources of raw materials represents an interest in the economic aspect of the asphalt industry, and most of the plants that have been implemented lack the presence of these factors because most of these plants in Iraq are not investment, in addition to the absence of plans by the state in their development.

Second. Factors related to the production process outputs:

Discussion

The production process outputs are of great importance in selecting the optimal location for the asphalt concrete unit plant according to the respondents' opinions, as the means for them ranged within the period (very high importance), Arranged in descending order of importance:

1. Market needs or size of the roads to be implemented or maintained.
2. Proximity to road projects and maintenance.
3. Availability of transportation network to transport asphalt products to implementation projects or maintenance.

The respondents’ answers matched what was expected and discussed during the personal interviews with the stakeholders, especially the factor (market need), which is superior to the factor (proximity to project sites).

Third. Factors related to the production process requirements:

Discussion

Concerning the factors related to the requirements of the production process, opinions were unanimously agreed on their importance in the process of selecting the optimal location for the asphalt concrete unit plant, which received a mean frequency of answers within the periods (high importance) and (very high importance about the factor of land availability) and ranked in descending order of importance:

1. Availability of necessary areas for warehouses of raw materials, spare materials, and parking.
2. Proximity to electricity supply sources.
3. Proximity to water supply sources.

4. Proximity to the sources of fuels and oils.
5. Proximity to sewer networks.

The first factor in terms of mean frequencies (the fifth in the questionnaire list) is more important than other production process requirements due to the lack of sufficient area to construct the plant means the impossibility of establishing it in that zone. Usually, 10 acres are allocated as an area for an asphalt concrete unit plant. As for the supply of electric power in Iraq, the national electricity network has been delivered to all industrial cities in the country.

5.4.6.2.2 Part 2. Qualitative factors

In addition to the aforementioned quantitative factors, several other social and environmental considerations can be considered when selecting the location of the asphalt concrete unit plant, as they indirectly affect the production costs in the plant, which cannot be quantified. Table D-5 (Appendix D) shows Questionnaire answers on qualitative factors.

Discussion

These answers are considered proper, and we must pay attention to them when selecting the optimal location for the asphalt concrete unit plant to achieve the social and environmental goals envisaged by the establishment of the plant. Here we note the superiority of the environmental factors (environmental impact and noise factors) according to the opinions of the respondents, as the means frequency of answers within the periods was (very high importance), as well as the exit of the personal factor from the qualitative factors, where the mean of answers frequency for it within the period (low importance), below is the descending order of the qualitative factors:

1. Environmental impact.
2. Availability of the road and transportation network to transport raw materials to the plant and transport the asphalt products to the implementation sites.
3. Noise
4. Local laws and regulations.
5. Available transportation.
6. Availability of services.
7. The geological nature of the land on which the plant will be built.
8. Rubble and production waste.
9. Factors related to general opinion.

5.5 Delphi questionnaire stage

Depending on the result of closed questionnaire, to rank the relative importance of various quantitative and qualitative factors in selection the location of asphalt concrete unit plant, the researcher prepared a special questionnaire for specialists (experts) in accordance with the Delphi technique. This technique is a kind of forecasting that uses the combined knowledge of a group of specialists to make a prediction about a specific case. With the use of these compiled expert views, we can pinpoint every parameter at play in a given case. The supposed parameters are aggregated, rated, and revised over the course of numerous rounds using the Delphi approach. In order to improve the reliability of the questionnaire, experts are subsequently polled for their thoughts and given many opportunities to enhance the quality questionnaire; these rounds restart until a consensus is acquired (Hsu & Sandford, 2007). The Delphi approach has been widely used in the academic community as a research tool for over two decades, and its widespread applicability across a wide variety of study disciplines suggests that its popularity among scientists and policymakers will grow in the years to come (Flostrand et al., 2020). In this study, as shown in Figure 5-5, there have been three main rounds to the Delphi method: the aggregating round, during which all possible quantitative and qualitative factors are compiled; the rating round, during which these factors are evaluated and ranked; and the revising round, during which these factors are reviewed and adjusted. Thus, the experts have reached an agreement, and these factors were the top-ranked factors based on their valuation.

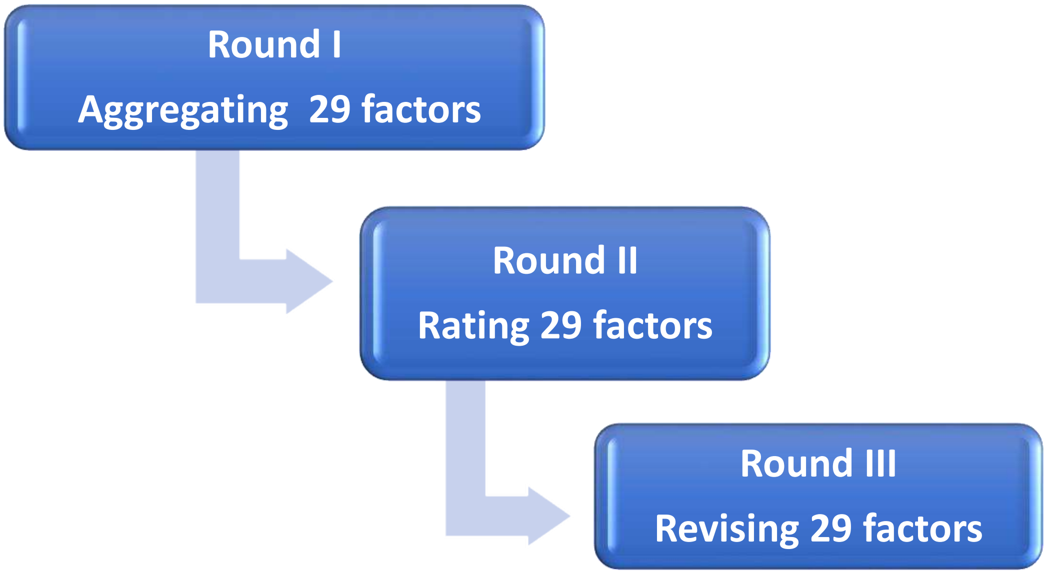


Figure 5-5: The rounds of Delphi questionnaire.

5.5.1 Background and general information of experts

Since the study's primary goal is to identify the best possible location for the asphalt concrete unit plant, Delphi questionnaire participants included all major stakeholders in paving projects and the asphalt concrete industry. Experts' backgrounds are: engineering staff of asphalt concrete units plants, teaching staff of transportation engineering, and teaching staff of industrial engineering. Specializations of the experts and their workplace are illustrated in Figures 5-6 & 5-7, respectively, the summary of expert's demographic information in Table 5-14.

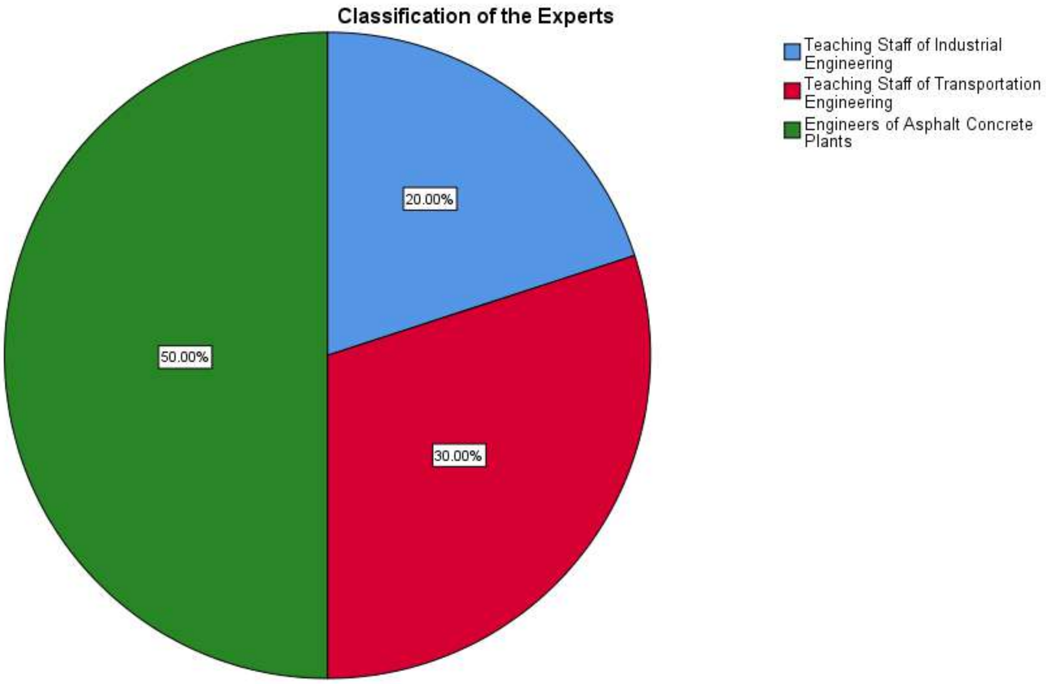


Figure 5-6: Classification of the experts.

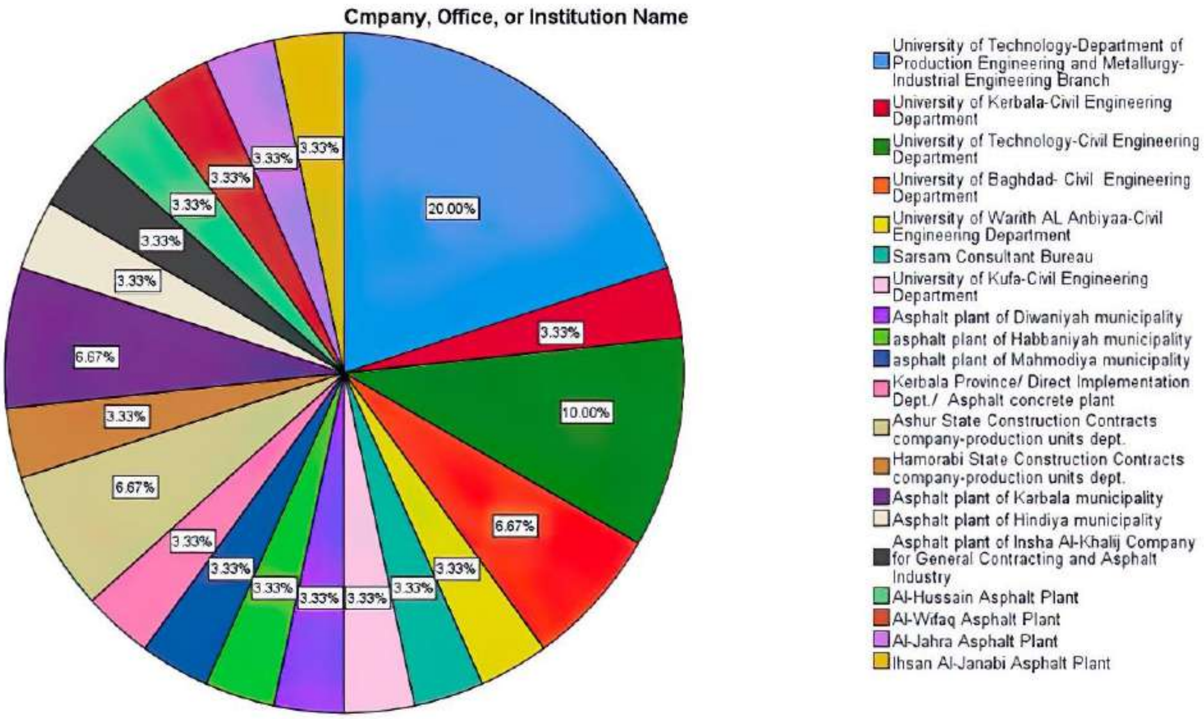


Figure 5-7: Workplace of the experts.

Table 5-14: Expert's contextual information.

S. No.	Variables	**Frequency**	**Percent %**
A	*Job title*		
	Faculty staff	15	50
	Asphalt plant staff	15	50
B	*Experience*		
	10-20 years	10	33.3
	> 20 years	20	66.7
C	*Level of education*		
	Bachelor	12	40.0
	High Diploma	1	3.33
	Master	4	13.33
	Doctorate	13	43.33
D	*Specialization*		
	Industrial Engineering	6	20.0
	Civil Engineering	13	43.33
	Survey Engineering	1	3.33
	Mechanical Engineering	9	30.0

	Architectural Engineering	1	3.33
E	*Exact Specialization*		
	Operations Research	2	6.7
	Industrial Management	1	3.3
	Process Researches	1	3.3
	CAD/CAM	1	3.3
	Artificial Intelligence	1	3.3
	Highways & Airports Engineering	3	10.0
	Transportation Engineering	6	20.0
	Municipalities management	1	3.3
	Mechanical Engineering	8	26.7
	applied	1	3.3
	Civil Engineering	4	13.3
	Architecture theory	1	3.3

5.5.2 Ranking analysis for factors

Experts' opinions on various quantitative and qualitative factors in determining the optimal location of the asphalt concrete unit plant were gathered through a series of Delphi rounds using the Five-point Likert scale. Appendix C summarizes the results of the three Delphi rounds in which the factors were aggregated, rated, and revised. The five-point Likert scale was assumed as: Unimportant = 1, low importance = 2, Medium importance = 3, High importance = 4, and Very high importance = 5. Using the parametric methods is unworkable for evaluating the respondents' preferences (Siegel & Castellan, 1988). Therefore, the researcher used the relative importance index technique to determine the relative importance of the factors, a non-parametric technique usually be used by construction and facilities management scholars to assess questionnaire responses that represent an ordinal measurement (Kometa et al., 1994). Expression (5-2) shows a using formula to determine the relative importance indices (Rooshdi et al., 2018):

$$RII = \frac{\sum W}{A \times N} = \frac{5n_5 + 4n_4 + 3n_3 + 2n_2 + 1n_1}{5 \times N} \qquad (5-2)$$

Where:

W: weighting assigned to each variable (factor) by the respondent (expert).

A: the highest weight (here = 5).

N: total number of respondents.

The range of RII value is zero to one (zero is not within); whenever the higher the value of RII, the more important the factor, and vice versa, the proposed matrix by Chen et al. for derived importance levels from RII is (Chen et al., 2010):

High (H)	$0.8 \le RII < 1.0$
High-Medium (H-M)	$0.6 \le RII < 0.8$
Medium (M)	$0.4 \le RII < 0.6$
Medium-Low (M-L)	$0.2 \le RII < 0.4$
Low (L)	$0.0 \le RII < 0.2$

The SPSS was first used to determine the frequencies of the factors rated by experts, which were then fed into Expression 5-2 to calculate the factors' respective ranks, relative importance indices, and levels. Tables 5-15 & 5-16 show the Relative Importance Index (RII) of the quantitative (economic) and qualitative (socio-environmental) factors, respectively, along with their corresponding ranking and importance level.

Table 5-15: Ranking quantitative factors for selecting the optimal location for the asphalt concrete unit plant.

Factor	**RII**	**Ranking by category**	**Overall ranking**	**Importance level**
Production Process Inputs				
Proximity to sand and gravel quarries.	0.89	1	4	H
Proximity to the sources of the bonding material (bitumen).	0.83	2	7	H
Availability of transportation to transport the raw materials to the plant.	0.68	3	12	H-M
Availability of labor of technicians & skilled & unskilled workers.	0.67	4	13	H-M
Proximity to filler sources.	0.57	5	14	M
Sustainability and ability to recycle asphalt waste.	0.55	6	15	M
Production Process Outputs				
Providing modern means of transport dedicated to transporting the asphalt concrete product.	0.90	1	3	H
Need of the Market or the amount of asphalt concrete required.	0.83	2	5	H
Proximity to zones of demand for asphalt concrete product.	0.81	3	9	H
Production Process Requirements				
Environmental impact and pollution control.	0.96	1	1	H
Proximity to electricity supply sources.	0.91	2	2	H
Proximity to the sources of fuels and oils.	0.83	3	6	H
Proximity to water supply sources.	0.82	4	8	H
Availability of transportation network.	0.7	5	10	H-M
Noise.	0.69	6	11	H-M
The Rubble and production waste.	0.51	7	16	M
Proximity to sewer networks.	0.43	8	17	M

Table 5-16: Ranking qualitative factors for Selecting the optimal Location for the asphalt concrete unit Plant.

Factor	RII	Ranking	Importance level
Governmental motivations like; tax exemptions, facilities for investors, and industrial loans.	0.81	1	H
Availability of necessary areas for warehouses of raw materials, spare materials, and parking.	0.81	2	H
Availability of spare parts and spare tools for production machinery.	0.79	3	H-M
Local laws and regulations.	0.77	4	H-M
Impact of climate conditions on the plant locations.	0.73	5	H-M
The geological nature of the land on which the plant will be built.	0.72	6	H-M
Availability of a good working climate and avoidance of the risks of labour or popular strikes or political, security, and economic strikes.	0.61	7	H-M
Factors related to general opinion (Community opinion towards the project).	0.49	8	M
Availability of the housing in the zone.	0.45	9	M
Proximity to the main office, foundation, or institution.	0.44	10	M
Closeness to other competing asphalt plants.	0.44	11	M
Availability of services (schools, Hospitals, mosques ….etc.).	0.43	12	M

<u>Discussion</u>

Based on the introductory questionnaire's quantitative and qualitative results, the experts have develped new factors related to climate, sustainability, and governmental policies for selecting the optimum location in addition to traditional factors of cost, time, and quality.

It is apparent from the ranking tables that Eleven factors were classified as “High” importance level considered major importance for selecting the optimal location for asphalt concrete unit plant. These “High” importance levels have a Relative Index (RII) range of 0.96–0.81 of essential qualitative and quantitative factors. The factors of “ proximity to sand and gravel quarries,” “ providing modern means of transport dedicated to transporting the asphalt concrete product,” and “ environmental impact and pollution control” were ranked as the highest importance among the factors of “production Process inputs,” “production process outputs,” and “production process requirements” respectively as Table 5-19. In contrast, the “governmental motivations” factor was the highest importance among qualitative factors, having an RII value of 0.81, as shown in Table 5-20.

None of the “sustainability and ability to recycle asphalt concrete waste.” factor is among the top eleven rankings; this shows that the recycling considerations are still at low importance for selecting sustainability. Since these factors were extracted and classified from experts' feedback, duo to they are experts in the asphalt industry. Therefore, for the purpose of proving that asphalt concrete waste recycling is applicable, it is nessesry to include in-depth case studies. As a result, industrial policymakers will be able to make more informed decisions that will contribute to the development of a more sustainable asphalt standard. or Reclaimed Asphalt Concrete (RAP).

Chapter Six: Mathematical Framework

6.1 Introduction

According to the field survey, introductory, and Delphi technique questionnaires, the selection of asphalt concrete unit plant location is affected by several essential quantitative (economic) and qualitative (social and environmental) factors. The degree of the relative importance of each of these factors was determined. It turns out that some of these factors outweigh the importance of others. Accordingly, these factors were used with its relative importance in the selection process.

6.2 Descriptions of the proposed system

The most important descriptions that the proposed system will have:

1. Selecting the optimal location for the plant depends mainly on the objectives required from the location selection process, and these objectives are:
   a. Achieving the highest economic benefits.
   b. Achieving the highest socio-environmental benefits.
   c. Both the above points (a & b).
2. Achieving quick results in the process of selecting the optimal location.
3. Reducing the effort required to select the optimal location.
4. Reducing the cost of selecting the optimal location.
5. It is flexible in the event of developments or future changes.
6. Achieving the required accuracy in the process of selecting the optimal location.
7. Ease of understanding and assimilation by decision-makers in selecting locations for asphalt concrete units plants.

8. Any simple changes can be made and approved to select the optimal location for any other production plant or industrial project.

6.3 Proposed system requirements

Each system has the requirements that need to be brought up to prepare and implement it, and the requirements of the system proposed by the researcher to select the optimal location for the asphalt concrete unit plant are:

1. Determine the purpose of selecting the location of the asphalt concrete unit plant (achieving highest economic benefits, achieving highest socio-environmental benefits, or the both).
2. Preparing all the factors affecting the selection of the optimum location for the asphalt concrete unit plant and determining the relative importance of each factor.
3. Determine all the proposed (alternative) locations for building the plant and obtaining comprehensive information about these locations.
4. Making a comprehensive survey to investigate all the locations of the sources of raw materials required for the asphalt concrete production process, which includes the following:
    a. Locations of filler production plants (cement).
    b. Locations of fine aggregate (sand) quarries.
    c. Coarse aggregate (gravel) quarry locations.
    d. Bitumen source locations.
5. Making a comprehensive survey to investigate all warehouse locations for low fuel material required for the heating process during the production of asphalt concrete.

6. For sustainability, making a comprehensive survey to investigate all candidate locations to replace milled asphalt for recycling purposes.
7. Making a comprehensive survey to know the selling price of the raw material and the low fuel from its sources, and the costs of transporting it in addition to the cost of transporting the milled asphalt based on the quantity and the distance between the source of these materials and location of the plant.
8. Making a comprehensive survey to investigate all the locations of the paving projects that are hoped to be implemented from the plant's production and to determine the quantity to be implemented in each project.
9. Preparing a specific study about the cost of transporting one ton of asphalt concrete per unit distance.
10. The user should be aware of the influence of quantitative and qualitative factors in the location selection process and the relative importance of each factor.
11. Locating all filler (cement) supplying plants, sand and gravel supplying quarries, bitumen supplying refineries, low fuel-supplying warehouses, milled asphalt locations, and paving projects, and determining the distance between them and all available locations for the construction of the plant for comparison between alternative locations.

6.4 Formulation of the structure of the proposed system

The requirements in Paragraph (6-3) were relied upon to formulate the proposed system structure to choose the optimal location for the asphalt concrete unit plant. The process of formulating the system structure went through the following stages:

6.4.1 The first stage (the stage of determining the factors affecting the process of selecting the optimum location for the plant)

This stage is represented in forming an idea through the information presented in the theoretical and survey study to search for the factors affecting selecting the optimal location for the asphalt concrete unit plant. The researcher classified these factors into quantitative factors that directly affect the cost of production in the plant and qualitative factors for evaluating costs that are difficult to determine. The factor rating method was adopted to evaluate locations in terms of qualitative factors, and the linear programming method for evaluating locations in terms of quantitative factors.

6.4.2 The second stage (the stage of studying the factors affecting the process of selecting the optimum location for the asphalt concrete unit plant and calculating the relative importance of each factor)

By examining and studying the factors affecting the process of selecting the location referred to in the theoretical study, the field (introductory) questionnaire and the Delphi technique questionnaire (the experts' questionnaire) and determining the direction of the influence of these factors, their impact was divided into two groups:

1. *Quantitative factors*: a group of factors that directly affect the cost of producing one ton of asphalt concrete and delivering it to the pavement sites when selecting the optimal location for the plant. These factors are considered when selecting the location to achieve the highest profit and the lowest production cost.
2. *Qualitative factors*: a group of factors affecting, in general, the process of selecting the optimal location for the plant, which cannot be measured quantitatively and do not directly affect the cost of production and its delivery to the paving sites or increase the profit. Its impact on the selection process of the plant location considers several socio-environmental considerations to achieve social benefits or when the economic analysis in the alternative locations is ineffective and there is a significant impact of qualitative factors.

At this stage, information on the above factors was collected through the field questionnaire, and then scheduling, analyzing, and discussing the questionnaire data and arranging them according to their relative importance through the opinions of experts in the Delphi technique questionnaire using the equation (5-2) and displaying them as shown in Tables (5-19) and (5-20) from the previous chapter.

6.4.3 The third stage (the stage of developing the accounts of the proposed system to achieve the best socio-environmental benefits)

At this stage, six characteristics (excellent, very good, good, medium, acceptable, and not suitable) were attributed to the qualitative factors in the candidate locations for the construction of the plant on it, and these characteristics were evaluated with certain points. For example, the factor that is characterized by an excellent is evaluated by ten points, very good by eight points, good by six points, the medium by four points, and the acceptable by two points, and it is not suitable for it to be given a value of zero. Then the above points are multiplied by the relative importance of each qualitative factor, and the number of points obtained by the location is collected. The differentiation in this way (factor rating) is to achieve socio-environmental benefits or to achieve qualitative factors, and the location that gets the highest number of points is the best; the expression used to calculate the number of degrees that each location obtains for differentiation:

$$WS = \sum_{f=1}^{F} FW_f \times FS_f \qquad (6-1)$$

Where:

WS :Total points a location obtains from qualitative factors.
FW :The relative importance of each qualitative factor.
FS: Points obtained by the qualitative factor in each candidate location.
F :The number of qualitative factors.

6.4.4 The fourth stage (the stage of building the accounts of the proposed system to achieve the highest economic benefits)

At this stage, the indices of the relative importance of quantitative factors were relied on to build a linear programming model and express realistic relationships with assumed mathematical relationships, which depends on the basics of linear programming to evaluate locations in terms of achieving the lowest production costs and the lowest price for the delivery of one ton of asphalt concrete in project sites paving as follows:

6.4.4.1 Model hypotheses

The most important basic hypotheses that the researcher took into consideration to build the mathematical model are the following:

1. The cost of producing one ton of asphalt concrete varies according to the plant's location.
2. The quantity of asphalt concrete required to be implemented varies according to the site of the paving project.
3. The price of one raw material in each source changes according to the location of the source.
4. The quantity of raw material required for production and transported to the plant location is considered constant to the plant's production volume.
5. The cost of transporting one raw material is considered fixed and depends on the type of raw material (gravel, sand, filler, bitumen), and the cost of transporting it depends on the quantity of transported material to the plant location and the linear distance between the source of the raw material and the plant location.
6. The price of low foul material in each source is fixed.
7. The low fuel quantity used to heat the aggregates is considered constant to the plant's production volume.
8. The cost of transporting low fuel material is considered fixed and depends on the quantity of transported fuel to the plant location and the linear distance between the source of the low fuel material and the plant location.

9. The quantity of reclaimed asphalt pavement (RAP) material included in production and transported to the plant location is considered inconstant according to the required asphalt mixture and sustainability requirements.
10. The cost of transporting (RAP) material is considered fixed and depends on the quantity of transported RAP to the plant location and the linear distance between evacuation (milling) areas and the plant location.
11. The cost of transporting one ton of asphalt concrete is fixed in all directions and depends on the linear distance between the site of the paving project and the location of the asphalt concrete production plant.
12. Each plant receives raw materials and low fuel from the source supplied with the lowest delivery cost at the plant location. Also, each paving project site receives asphalt concrete from the plant that supplies the project with the lowest cost of delivery to the project site.
13. Supplying quantities of raw materials and low fuel from each source are unlimited.
14. The capacity of each plant is unlimited.

6.4.4.2 Building mathematical model

Building the mathematical model of the problem is considered the cornerstone or the first step to the solution; the model gives an entirely integrated view of the problem and the surrounding facts and facts, i.e. simulation and depiction of reality.

The process of asphalt concrete production can be represented by an illustrative scheme (Figure 6-1) that shows the extent to which the building of the mathematical model depends on locating the sources of raw materials (cement, sand, gravel and bitumen), low fuel, and RAP, and the possible locations for the construction the plant, which in turn is considered an intermediate station in which asphalt is produced, and transferred to the sites of implementation of paving projects.

To build the mathematical model, we need to use subscripts that express the reality of an iteration of the case of the alternative locations, as follows:

1. l: Candidate locations for construction of an asphalt concrete unit plant.

   $l = 1, 2, \ldots, L$
2. i: Quarry locations supplied for coarse aggregate (gravel).

   $i = 1, 2, \ldots, I$
3. h: Quarry locations supplied for fine Aggregate (sand).

   $h = 1, 2, \ldots, H$
4. r: Filler (cement) plant locations.

   $r = 1, 2, \ldots, R$
5. k: Locations of bitumen supplying refineries.

   $k = 1, 2, \ldots, K$
6. d: Locations of the low fuel-supplying warehouse.

   $d = 1, 2, \ldots, D$
7. a: Milling areas.

   $a = 1, 2, \ldots, A$
8. j: Paving projects sites (demand areas).
9. $j = 1, 2, \ldots, J$
10. L: Total number of candidate locations for constructing an asphalt concrete unit plant.

11.I: Total number of quarry locations supplied for coarse aggregate (gravel).

12.H: Total number of quarry locations supplied for fine aggregate (sand).

13.R: Total number of filler (cement) plant locations.

14.K: Total number of locations of bitumen supplying refineries.

15.D: Total number of locations of the low fuel-supplying warehouse.

16.A: Total number of milling areas.

The formulation of linear programming is used to mean the process of converting oral description into mathematical expressions. Here represents the relevant relationships among objectives, decision variables (factors), and constraints on resource use (Dubey et al., 2017b). Therefore, a set of quantitative factors will be used in the Delphi questionnaire. These factors are concerned with the sources of raw materials, fuel, and demand zones (sinks) for asphalt concrete product, in addition to sustainability, to represent it in the objective function and constraints, as follows:

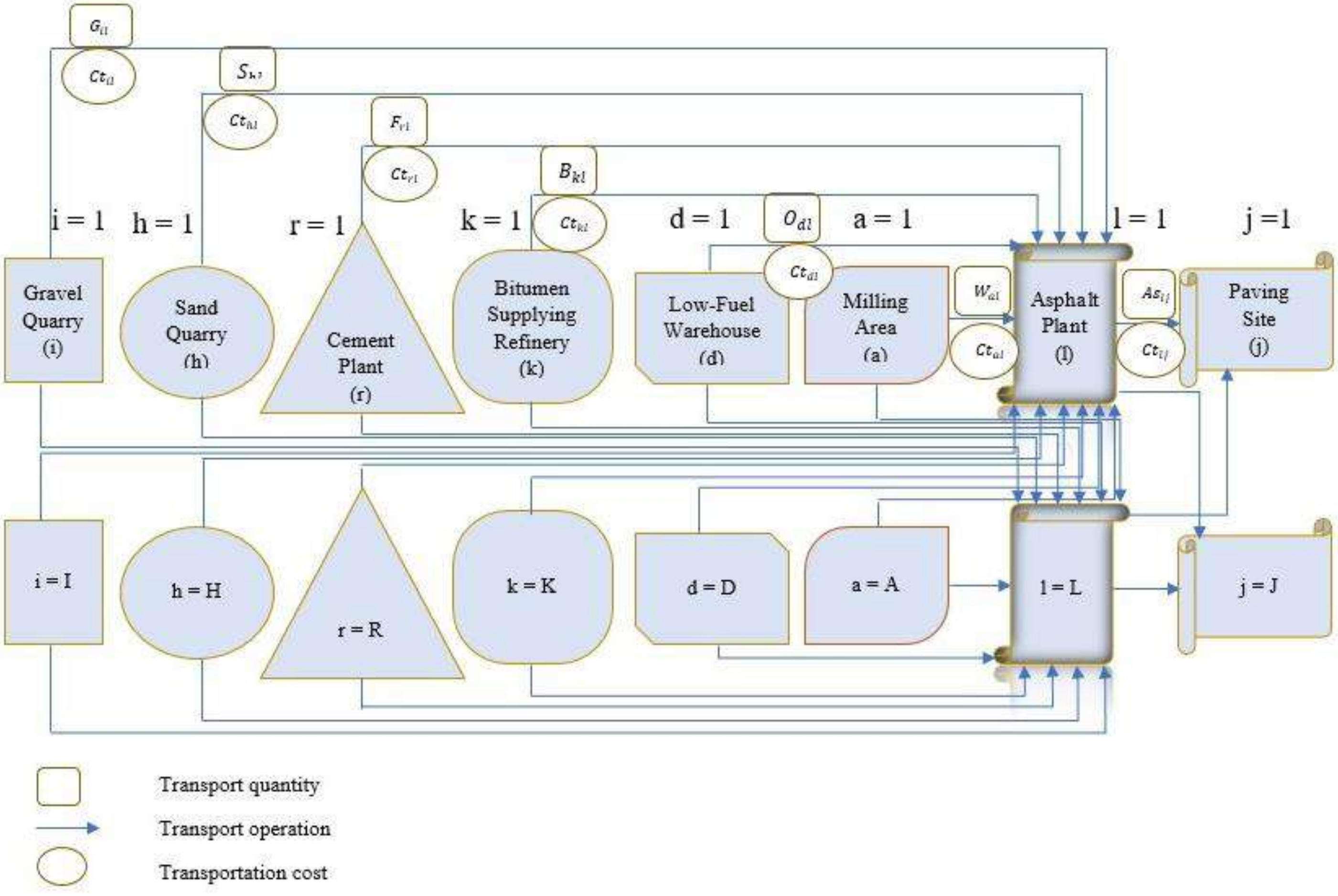


Figure 6-1: Asphalt concrete production process (the researcher).

6.4.4.2.1 Objective Function

This function shows the final result that must be reached by implementing some procedures on the problem's input variables, and the problem's objective function of selecting the optimal location for the asphalt concrete unit plant. It includes each of the variables of the cost of transporting raw materials, the cost of buying the raw material, the cost of transporting fuel, the cost of buying fuel, the cost of transporting the RAP, the cost of transporting one ton of asphalt concrete, the quantity of asphalt concrete required in each paving project, and other input variables that can change between alternative locations. Since RAP is a recycled material brought from milling roads directly, buy cost is zero.

The objective function of the mathematical model of the study problem is the initial selection of the lowest cost of raw materials and fuel from the source for each plant location, and the lowest production cost per ton of asphalt concrete, and to ensure obtaining asphalt concrete at the lowest delivery price at the sites of paving projects with the profit required for the production process, i.e. aims to minimize the average price Delivering raw materials and fuel to the plant and minimizing the cost of delivering one ton of asphalt concrete to the paving sites while minimizing the cost of producing one ton of asphalt concrete at the same plant location. Expression (6-2) shows the objective function of the optimal location selection problem; Tables 6-1 & 6-2 describe the decision variables and parameters used in the objective function's mathematical model, respectively.

$$\begin{aligned}
Min\,[&\sum_{l=1}^{L}\sum_{i=1}^{I}\{(Ct_{il})+(P_i)\}\times\lambda_i\times G_{il}\ + \\
&\sum_{l=1}^{L}\sum_{h=1}^{H}\{(Ct_{hl})+(P_h)\}\times\lambda_h\times S_{hl} + \\
&\sum_{l=1}^{L}\sum_{r=1}^{R}\{(Ct_{rl})+(P_r)\}\times\lambda_r\times F_{rl}\ + \\
&\sum_{l=1}^{L}\sum_{k=1}^{K}\{(Ct_{kl})+(P_k)\}\times\lambda_k\times B_{kl} + \\
&\sum_{l=1}^{L}\sum_{d=1}^{D}\{(Ct_{dl})+(P_d)\}\times\lambda_d\times O_{dl} + \\
&\sum_{l=1}^{L}(Ct_{al})\times\lambda_a\times W_{al} + \\
&\sum_{l=1}^{L}\sum_{j=1}^{J}\{(P_l)+(Ct_{lj})\}\times\lambda_j\times As_{lj}] \qquad (6-2)
\end{aligned}$$

Table 6-1: Description of decision variables in the mathematical model.

No.	Variable	Describition
1	G_{il}	Quantity of transported gravel (coarse Aggregate) from the quarry (i) to the plant location (l).
2	S_{hl}	Quantity of transported sand (fine Aggregate) from the quarry (h) to the plant location (l).
3	F_{rl}	Quantity of transported filler from the factory (r) to the plant location (l).
4	B_{kl}	Quantity of transported bitumen from the refinery (k) to the plant location (l).
5	O_{dl}	Quantity of transported low fuel from the warehouse (d) to the plant location (l).
6	W_{al}	Quantity of milled asphalt (RAP) from the area (a) to the plant location (l).
7	As_{lj}	Quantity of transported HMA from the plant location (l) to the site of paving projects (j).

Table 6-2: Description of parameters in the mathematical model.

No.	Parameter	Describition
1	Ct_{il}	Transportation cost per cubic meter of gravel from the quarry (i) to the plant location (l).
2	P_i	price per cubic meter of gravel in the quarry (i)
3	Ct_{hl}	Transportation cost per cubic meter of sand from the quarry (h) to the plant location (l).
4	P_h	Price per cubic meter of sand in the quarry (h)
5	Ct_{rl}	Transportation cost per ton of filler from the filler production plant (r) to the factory location (l).
6	P_r	Price per ton of mineral filter in the filler production plant (r).
7	Ct_{kl}	Transportation cost per ton of bitumen from the refinery (k) to the plant location (l).
8	P_k	Price per ton of bitumen in the refinery (k).
9	Ct_{dl}	Transportation cost per litre of low fuel from the fuel warehouse (d) to the plant location (l).
10	P_d	Price per litre of low fuel in the warehouse (d).
11	Ct_{al}	Transportation cost per ton of PAP from the milling areas (a) to the plant location (l).
12	P_l	Price per ton of asphalt concrete inside the plant
13	Ct_{lj}	Transportation cost per ton of asphalt concrete from the plant location (l) to the paving projects (j).
14	Λ	The relative importance of factor.

6.4.4.2.2 Constraints

The Availability of raw materials and fuel are the main constraints of the problem of the asphalt concrete plant in terms of their Availability at the plant location to form the final product. There is also a constraint on the use of RAP as below:

1. The quantities of raw materials transported to the plant location (l) are greater than or equal to the quantities required to plug the volume of production, the Expressions: (6-3), (6-4), (6-5), and (6-6) show the mathematical formulation for constraints on the quantities of gravel, sand, filler, and bitumen, respectively:

$$\sum_{l=1}^{L}\sum_{i=1}^{I} QG_{il} \le \sum_{l=1}^{L}\sum_{i=1}^{I} G_{il} \qquad (6-3)$$

$$\sum_{l=1}^{L}\sum_{h=1}^{H} QS_{hl} \le \sum_{l=1}^{L}\sum_{h=1}^{H} S_{hl} \qquad (6-4)$$

$$\sum_{j=1}^{L}\sum_{r=1}^{R} QF_{rl} \le \sum_{l=1}^{L}\sum_{r=1}^{R} F_{rl} \qquad (6-5)$$

$$\sum_{l=1}^{L}\sum_{k=1}^{K} QB_{kl} \le \sum_{l=1}^{L}\sum_{k=1}^{K} B_{kl} \qquad (6-6)$$

Where:

QG_{il}: Quantity of gravel required to plug the Plant production need.

QS_{hl}: Quantity of sand required to plug the Plant production need.

QF_{rl}: Quantity of filler required to plug the Plant production need.

QB_{kl}: Quantity of bitumen required to plug the Plant production need.

2. The quantity of low fuel transported to the plant location (l) is greater than or equal to the quantity required for the production process as in Expression (6-7):

$$\sum_{l=1}^{L}\sum_{i=1}^{I} QO_{dl} \leq \sum_{l=1}^{L}\sum_{i=1}^{I} O_{dl} \qquad (6-7)$$

Where:

QO_{dl}: The quantity of low fuel required for heating aggregate in the production process.

3. The quantity of transported RAP to the plant location (l) is greater than or equal to the permissible limits of the production process as in Expression (6-8):

$$\sum_{l=1}^{L}\sum_{i=1}^{I} QW_{al} \leq \sum_{l=1}^{L}\sum_{i=1}^{I} W_{al} \qquad (6-8)$$

Where:

QW_{al}: The quantity of RAP used in the production process.

4. The quantity of asphalt concrete product is equal to the demand as in Expression (6-9):

$$\sum_{l=1}^{L}\sum_{i=1}^{I} QAs_{lj} \leq \sum_{l=1}^{L}\sum_{i=1}^{I} As_{lj} \qquad (6-9)$$

Where:

$Q\ As_{lj}$: The quantity of asphalt concrete product.

Depending on the objective function and the constraints mentioned above, the researcher used the ready-made POM-QM program to select the optimal location for the asphalt concrete unit plant to achieve the highest economic benefits or quantitative factors.

6.4.5 The fifth stage (the stage of developing the structure of the proposed system)

At this stage, the researcher reached the development of a structure for the proposed system to select the optimal location for the asphalt concrete unit plant, as shown in the flowcharts in Figures (6-2), (6-3), (6-4) and (6-5) as a summary of all the previous stages.

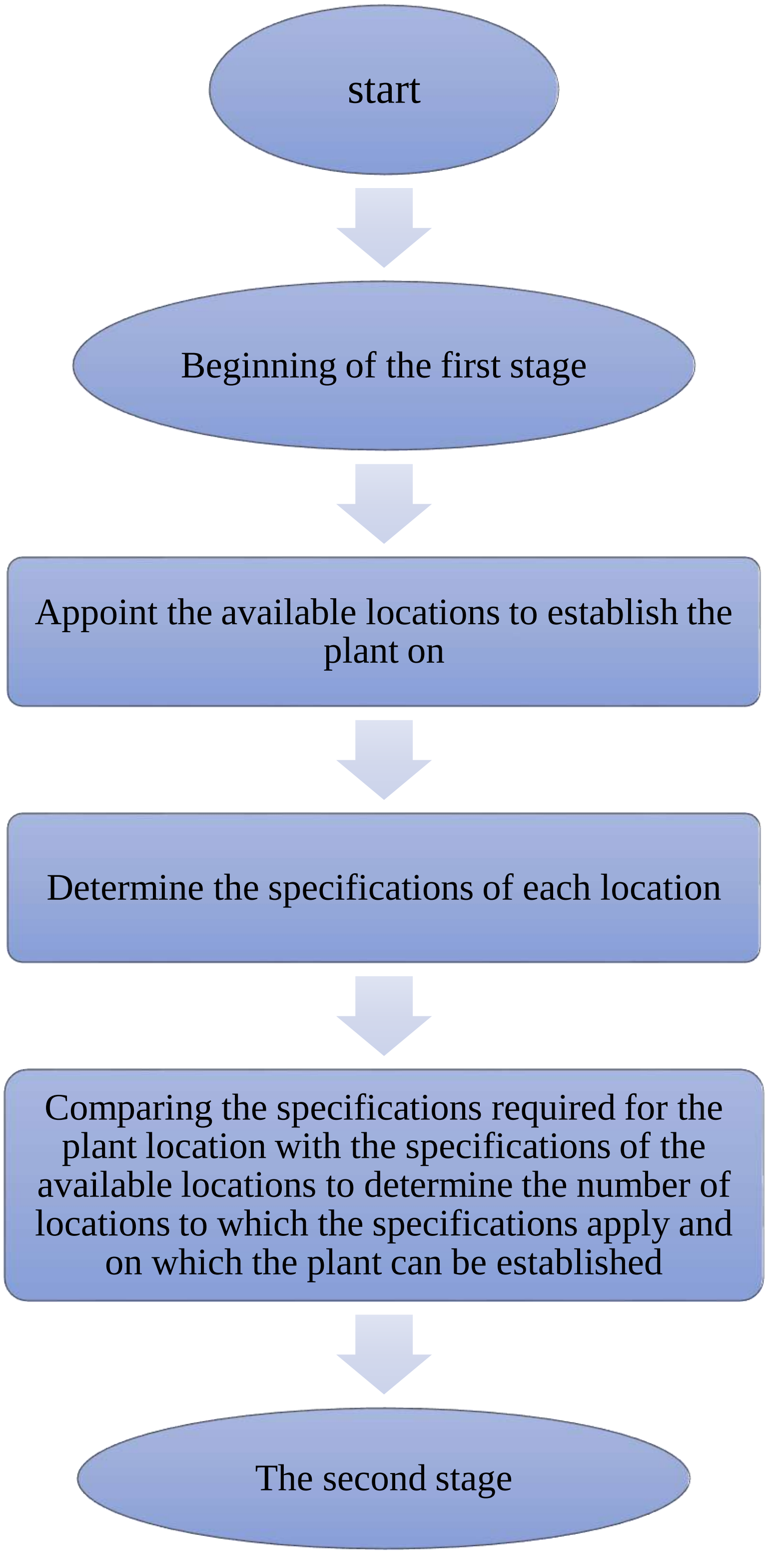


Figure 6-2: Flowchart for the first stage of the system (the stage of sifting the candidate locations for the location of the asphalt concrete unit plant).

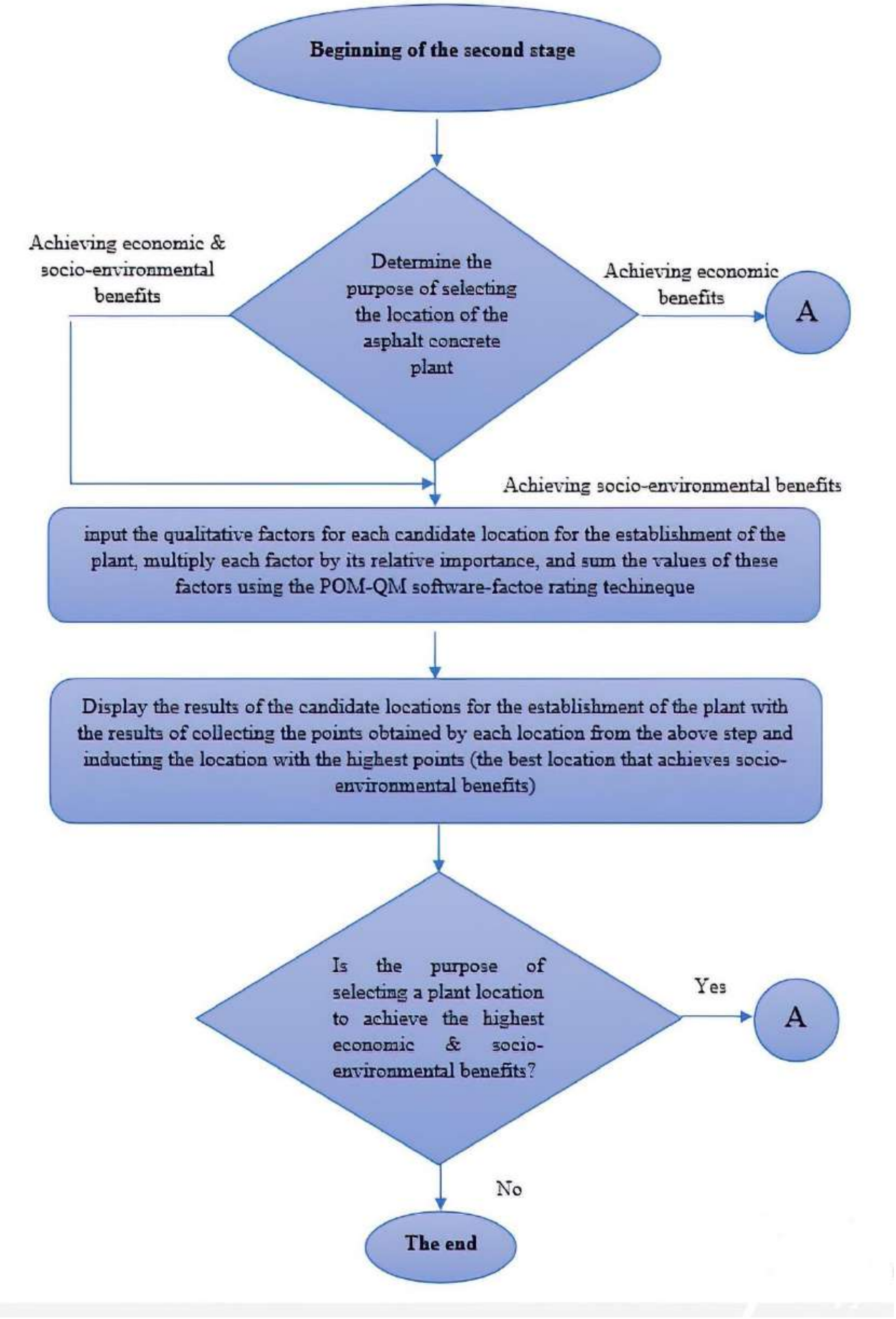
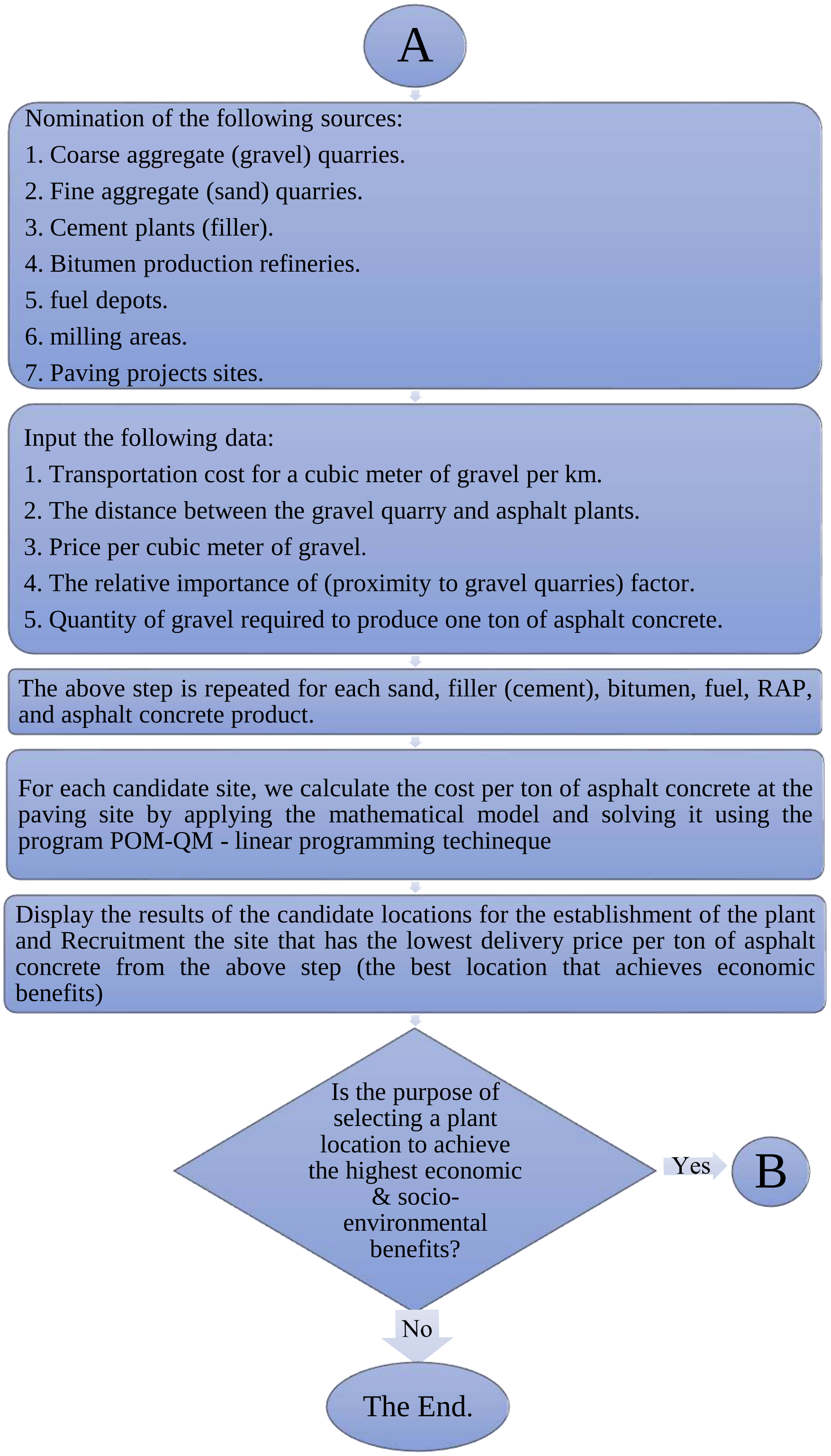


Figure 6-3: Flowchart for the second stage - first case of the system
(*The purpose of selecting a location is to achieve socio-environmental benefits).*



Nomination of the following sources:
1. Coarse aggregate (gravel) quarries.
2. Fine aggregate (sand) quarries.
3. Cement plants (filler).
4. Bitumen production refineries.
5. fuel depots.
6. milling areas.
7. Paving projects sites.

Input the following data:
1. Transportation cost for a cubic meter of gravel per km.
2. The distance between the gravel quarry and asphalt plants.
3. Price per cubic meter of gravel.
4. The relative importance of (proximity to gravel quarries) factor.
5. Quantity of gravel required to produce one ton of asphalt concrete.

The above step is repeated for each sand, filler (cement), bitumen, fuel, RAP, and asphalt concrete product.

For each candidate site, we calculate the cost per ton of asphalt concrete at the paving site by applying the mathematical model and solving it using the program POM-QM - linear programming techineque

Display the results of the candidate locations for the establishment of the plant and Recruitment the site that has the lowest delivery price per ton of asphalt concrete from the above step (the best location that achieves economic benefits)

Is the purpose of selecting a plant location to achieve the highest economic & socio-environmental benefits?

Figure 6-4: Flowchart for the second stage – second case of the system (The purpose of selecting a location is to achieve economic benefits).

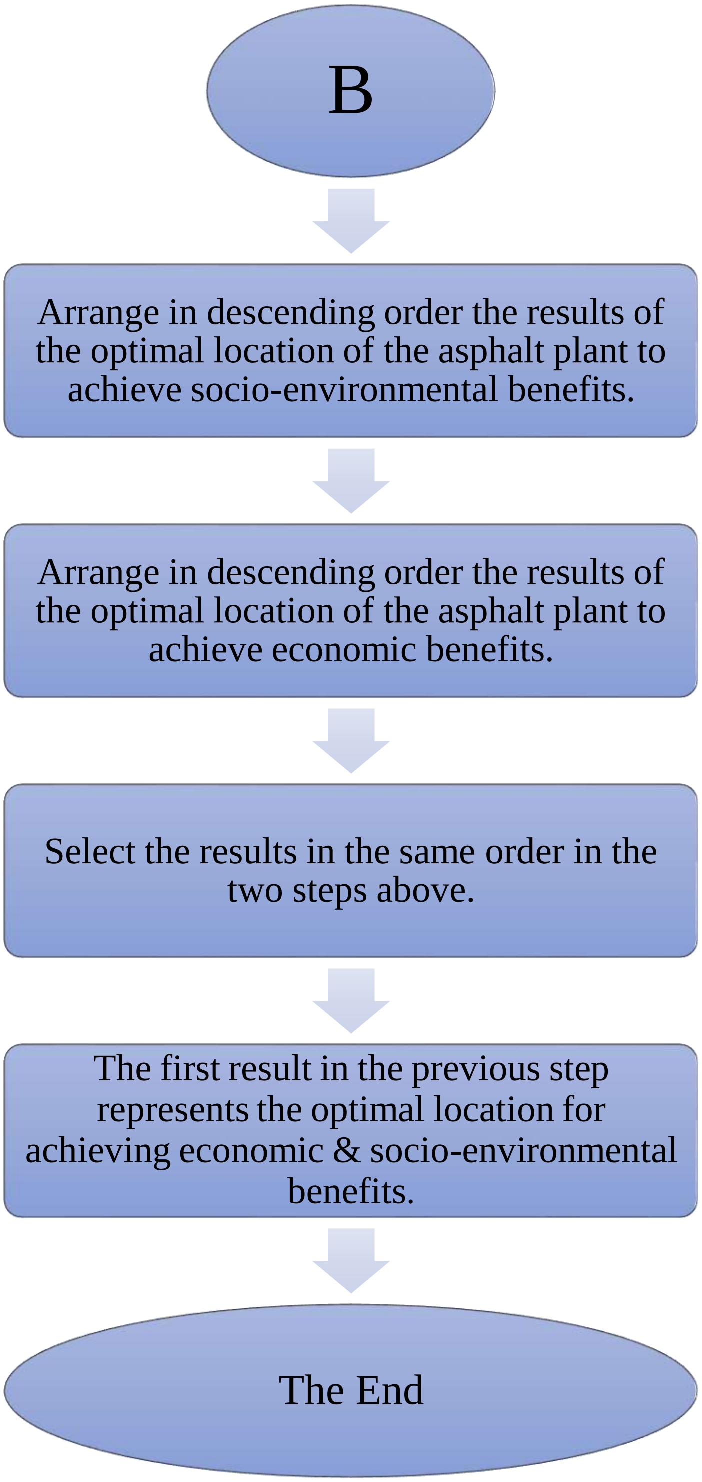


Figure 6-5: Flowchart for the second stage – third case of the system (The purpose of selecting a location is to achieve economic & socio-environmental benefits).

6.5 Application of the proposed system

To apply the proposed system, the researcher selected Al-Hur district-Karbala Province, as a demand area (sink) for the product (asphalt concrete) as an example of an application to assist policymakers in general directorate of municipalities when licensing its construction. In addition, the interest of studying the status of the optimal choice for any plant gives a better opportunity to benefit from the available and renewable resources and thus compete with the prevailing prices and achieve optimal dimensions of sustainability. This example examines the weighting of the most appropriate location among the four candidate locations for establishing a batch-type of asphalt concrete unit plant. These locations are:

- Location 1: Industrial Zone of Razzaza.
- Location 2: Industrial Zone of Al-Sharia.
- Location 3: Industrial Zone of Khan Al-Rubue.
- Location 4: Industrial Zone of Husseiniya.

6.5.1 Attributing the characteristics to the qualitative factors in the candidate locations

The characteristics express the availability of the qualitative factor on the location. It is multiplied by the relative importance of the factor. These characteristics were estimated through the field survey conducted by the researcher for the four Industrial Zones; Table 6-3 describes the six attributed characteristics to the qualitative factors in these Industrial Zones.

Table 6-3: Description of attributed characteristics to the qualitative factors in the candidate locations for establishing asphalt concrete unit plant (the researcher).

Factors	Location 1	Location 2	Location 3	Location 4
Governmental motivations like; tax exemptions facilities for investors and industrial loans.	Very good	Very good	Very good	Very good
Availability of necessary areas for warehouses of raw materials, spare tools, and parking.	Very good	Good	Good	Good
Availability of spare parts for production machinery.	Very good	Medium	Good	Medium
Local laws and regulations.	Good	Good	Good	Good
Impact of climate conditions on the plant locations.	Excellent	Excellent	Excellent	Excellent
The geological nature of the land on which the plant will be built.	Very good	Medium	Medium	Very good
Availability of a good working climate and avoidance of the risks of labour or popular strikes or political security and economic strikes.	Excellent	Excellent	Excellent	Excellent
Factors related to general opinion (Community opinion towards the project).	Very good	Good	Very good	Good
Availability of the housing in the zone.	Good	Medium	Medium	Good
Proximity to the main office or company.	Good	Very good	Medium	Medium
Closeness to other competing asphalt plants.	Excellent	Medium	Medium	Medium
Availability of services (schools Hospitals mosques ….etc.).	Very good	Medium	Good	Good

6.5.2 Calculation of Parameters

The parameters are considered constant values multiplied by the decision variables involved in formulating the objective function and constraints of the research problem. These parameters were calculated through the field survey conducted by the researcher for several plants in Iraq and reflected on the candidate locations (the four Industrial Zones) and demand area as shown in Tables 6-4 & 6-5.

Table 6-4 shows the costs of transporting materials within the production process from their supplying sources to the location of asphalt concrete units plants and the costs of transporting the asphalt concrete from a particular plant location to the demand area for the asphalt concrete product. In contrast, Table 6-5 shows the prices of these materials in their production sources.

These costs were obtained by reviewing the private archives of a set of these plants, as well as the information formed in Appendix A.

Table 6-4: Transportation costs according to the production process system of HMA for the last two years (the researcher).

No.	Material	Cost (ID/km)
1	Aggregate (m^3)	125
2	Filler (cement) (ton)	75
3	Bitumen (ton)	200
4	Low foul (litre)	0.20
5	RAP (ton)	90
6	Asphalt concrete (ton)	60

Table 6-5: Materials prices for the production process system of HMA for the last two years (the researcher).

No.	Material	Source	Price (ID)
1	Coarse Aggregate (Gravel) (m^3)	Al-Ukhaydir Quarries	9.000
		Najaf Quarries	8.000
2	Fine Aggregate (Sand) (m^3)	Al-Ukhaydir Quarries	15.000
		Najaf Quarries	14.000
3	Filler (Cement) (ton)	Karbala Cement Plant	140.000
		Babil Cement Plant	135.000
		Al Kufa Cement Plant	130.000
4	Bitumen (ton)	Karbala Refinery	250.000
5	Low Foul (liter)	Karbala Depot	100
6	Asphalt Concrete (inside plant) (ton)		12.000

To secure the supply of raw materials involved in production with fuel at the lowest possible price, the researcher conducted a geographical survey of the sources of these materials which are close to the candidate locations for the establishment of the plant, as shown in tables: 6-6, 6-7, 6-8, and 6-9, with the distances of the routes between these sources and the candidate plant locations.

Table 6-6 shows two quarries for aggregates (gravel and sand) production (i=1→2, h=1→2), while Table 6-7 shows three cement plants that are relied upon to supply fillers (r=1→3). Table 6-8 shows two refineries with a supply of Bitumen (k=1→2). As for low fuel, there is one depot to supply it (d=1), as in Table 6-9.

Table 6-6: Candidate quarries for aggregate supplying with distances of routes supplying (km).

Locations / **Quarries**	**Location 1**	**Location 2**	**Location 3**	**Location 4**
Al-Ukhaydir 1	50	70	100	100
Najaf 2	70	80	30	110

Table 6-7: Candidate sources for filler supplying with distances of routes supplying (km).

Locations / **Sources**	**Location 1**	**Location 2**	**Location 3**	**Location 4**
Karbala Cement Plant 1	80	90	130	110
Babil Cement Plant 2	42	40	60	25
Al Kufa Cement Plant 3	100	110	60	115

Table 6-8: Candidate Refineries for Bitumen supplying with distances of routes supplying (km).

Locations **Refineries**	**Location 1**	**Location 2**	**Location 3**	**Location 4**
Karbala Refinery 1	45	65	10	75
Daurah Refinery 2	120	120	160	110

Table 6-9: Candidate depot for low foul supplying with distances of route supplying (km).

Locations **Depots**	**Location 1**	**Location 2**	**Location 3**	**Location 4**
Karbala depot 1	15	35	35	55

To achieve sustainability, the researcher make an inventory of several paved areas with deformations in their paving (which need to be re-paved) and located within one urban fabric for recycling their pavement as a reclaimed asphalt pavement RAP (a=1). Table 6-10 shows the distances of the routes between these areas and the candidate plant locations.

Table 6-10: Areas for RAP supplying with distances of routes supplying (km).

Locations	**Location 1**	**Location 2**	**Location 3**	**Location 4**
Milling area 1	10	15	40	35

To apply the model, we have one demand area (sink) and four candidate locations for the establishment of the plant (j=1→4); Table 6-11 shows the distance between the demand area and the candidate locations and Figure 6-6 shows a map that includes the proposed plants' locations and the city's demand area.

Table 6-11: Asphalt product demand area with distances of routes supplying from the plants (km).

Locations	Location 1	Location 2	Location 3	Location 4
Demand area 1	12	10	50	30

Figure 6-6: A map includes the demand area with the four candidate locations for constructing an asphalt plant.

The researcher applied the model to calculate the lowest delivery price on Type I (bases course), with a percentage RAP is 30% within an asphalt mix for each of the four locations. Appendix E shows the detailed calculations for parameters of the mathematical model (objective function and constraints).

6.6 Operating the proposed system

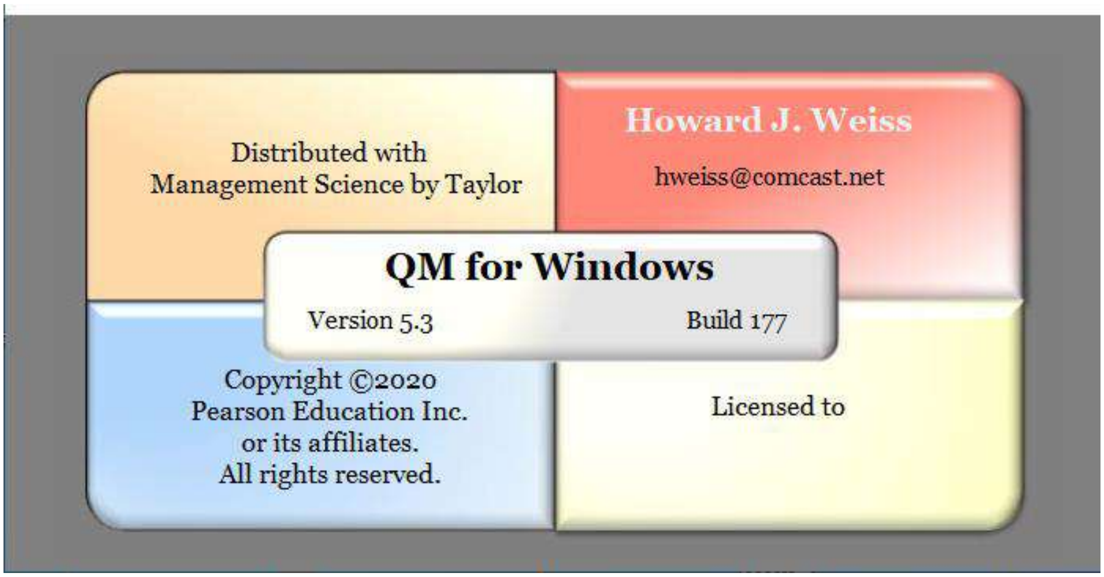
The ready-made POM-QM software was used to operate the proposed system in this study, which aims to select the optimal location for the asphalt concrete unit plant for road projects. Pearson's Decision Science software package: POM-QM for Windows (also known as POM for Windows and QM for Windows) is the most user-friendly software package available in the broad area known as decision sciences, including production and operations management, quantitative methods, management science, and operations research. The software contains 29 models (among them are linear programming and factor rating), and more than 60 submodels, the screens for every model are consistent, so, It is easy to switch between models and use more than one model at the same time. Furthermore, ease of parameters, factors weights, and factors entry scores are ready. Also, the program is flexible in the event of developments or future changes, gives quick results, and ease of understanding and assimilation. For these reasons, the researcher used this program. For further information, the general features of pearson's decision science software package: POM-QM for Windows, were reviewed by Weiss (Weiss, 2018).

6.6.1 Starting the Program

The easiest way to start the program is by entering double-clicking the program icon on the desktop, or using any standard windows means to start the program. After starting, a splash screen will appear, as shown in Figure 6-7.

The program will start a few seconds after the opening display appears, and a screen with instructions on 4 steps to work with the software will appear (Figure 6-8). the version is 5.3 and the build is 177. If the user sends an e-mail asking for technical support, he should include the build number with the e-mail.

The next screen appears as an empty main menu screen (Figure 6-9) to display all screen components.



Distributed with
Management Science by Taylor

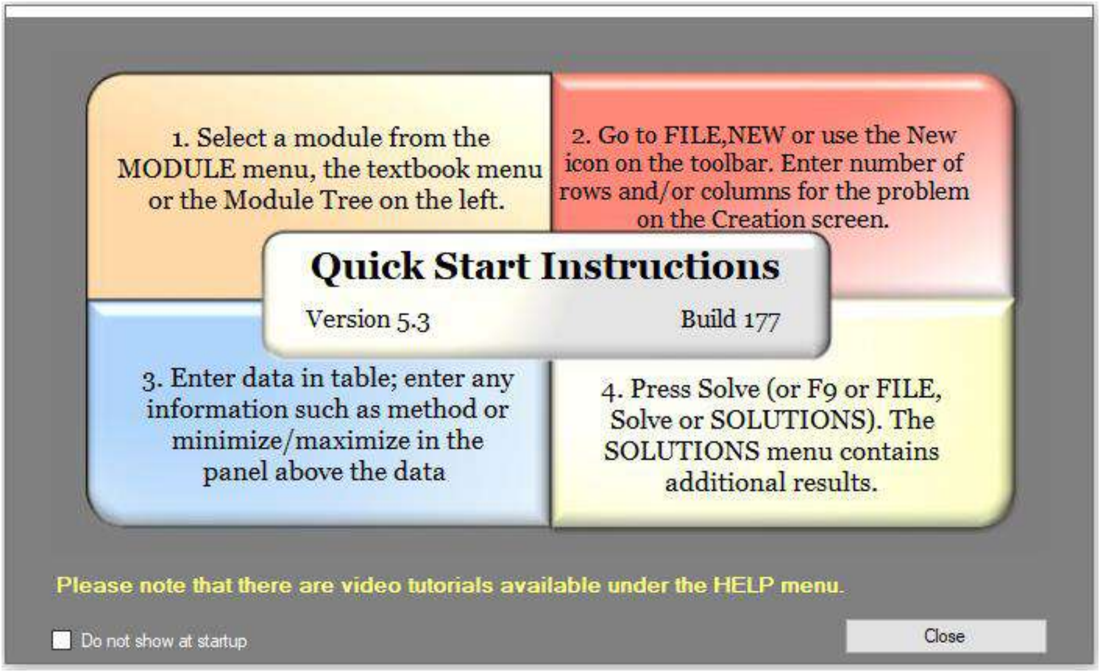
Howard J. Weiss
hweiss@comcast.net

QM for Windows
Version 5.3 Build 177

Copyright ©2020
Pearson Education Inc.
or its affiliates.
All rights reserved.

Licensed to

Figure 6-7: Program splash screen.



1. Select a module from the MODULE menu, the textbook menu or the Module Tree on the left.

2. Go to FILE,NEW or use the New icon on the toolbar. Enter number of rows and/or columns for the problem on the Creation screen.

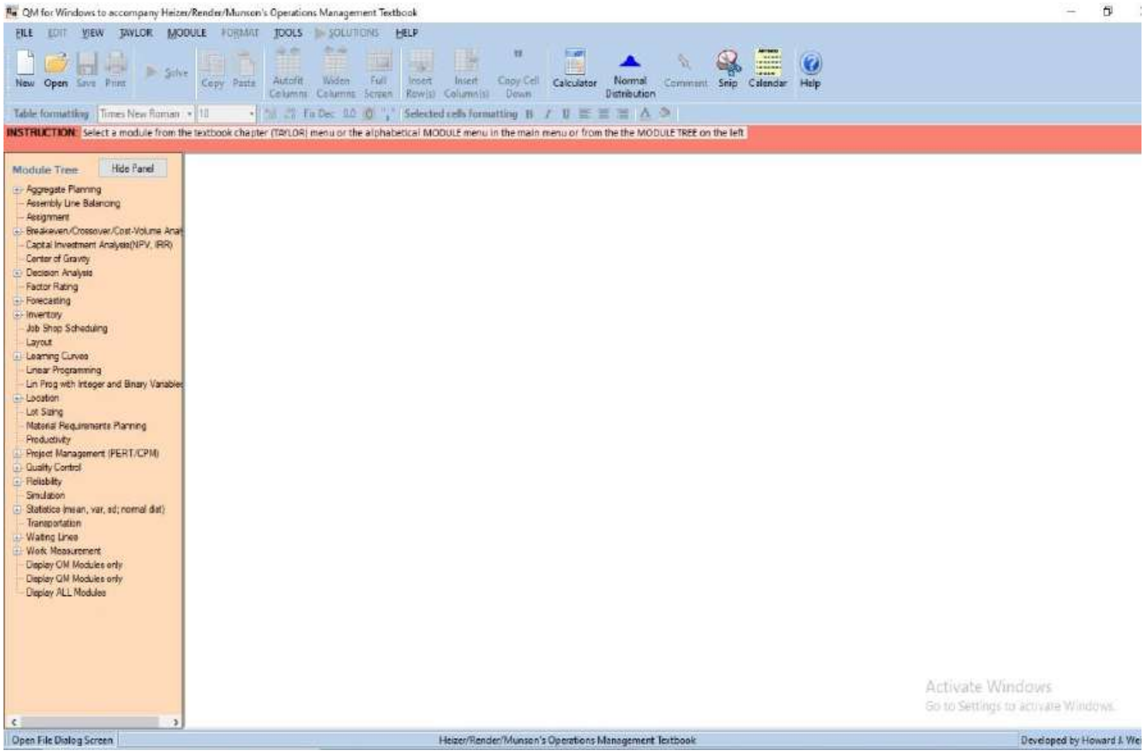
Quick Start Instructions
Version 5.3 Build 177

3. Enter data in table; enter any information such as method or minimize/maximize in the panel above the data

4. Press Solve (or F9 or FILE, Solve or SOLUTIONS). The SOLUTIONS menu contains additional results.

Please note that there are video tutorials available under the HELP menu.

Figure 6-8: Program work steps screen.



INSTRUCTION: Select a module from the textbook chapter (TAYLOR) menu or the alphabetical MODULE menu in the main menu or from the the MODULE TREE on the left

Figure 6-9: Main screen.

6.6.2 Creating a Problem

Generally, The Modules (techniques) Tree on the left side of the screen can be used for creating new problems. In this study, each factor rating and linear programming are detailed as the techniques on which this study is based. The input required for each technique, the options available for modelling and solving, and the different output screens and reports that can be seen are explained.

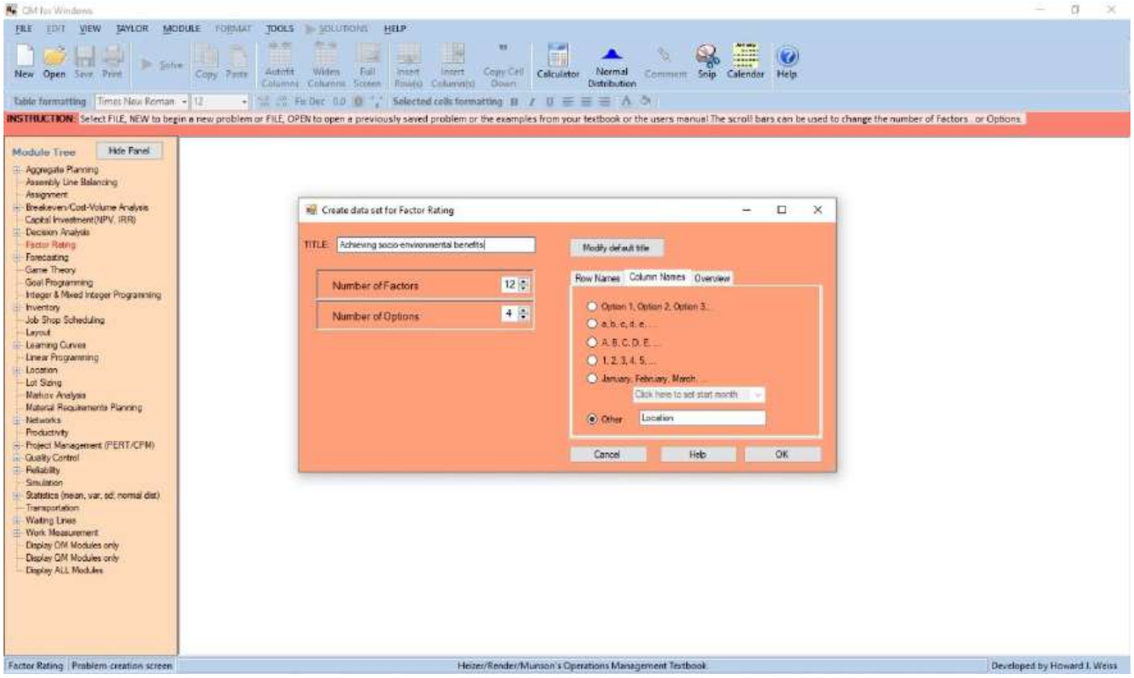
6.6.2.1 Factor Rating (Achieving socio-environmental benefits)

6.6.2.1.1 Entering Data

After selecting the factor rating technique from modules tree, the creation screen will be displayed. We enter the number of factors and locations (options) as shown in Figure 6-10, which are 12 and 4, respectively. The next screen that appears is an empty data screen; we entered Factor Weight (relative importance) for each factor and Factor Score for each location (Figure 6-11).

6.6.2.1.2 Program outputs

After entering the data and being ready to solve the problem, the program is executed by (Solve) tool on the standard toolbar to obtain the mathematical results for the four locations.



INSTRUCTION: Select FILE, NEW to begin a new problem or FILE, OPEN to open a previously saved problem or the examples from your textbook or the users manual The scroll bars can be used to change the number of Factors or Options.

Create data set for Factor Rating

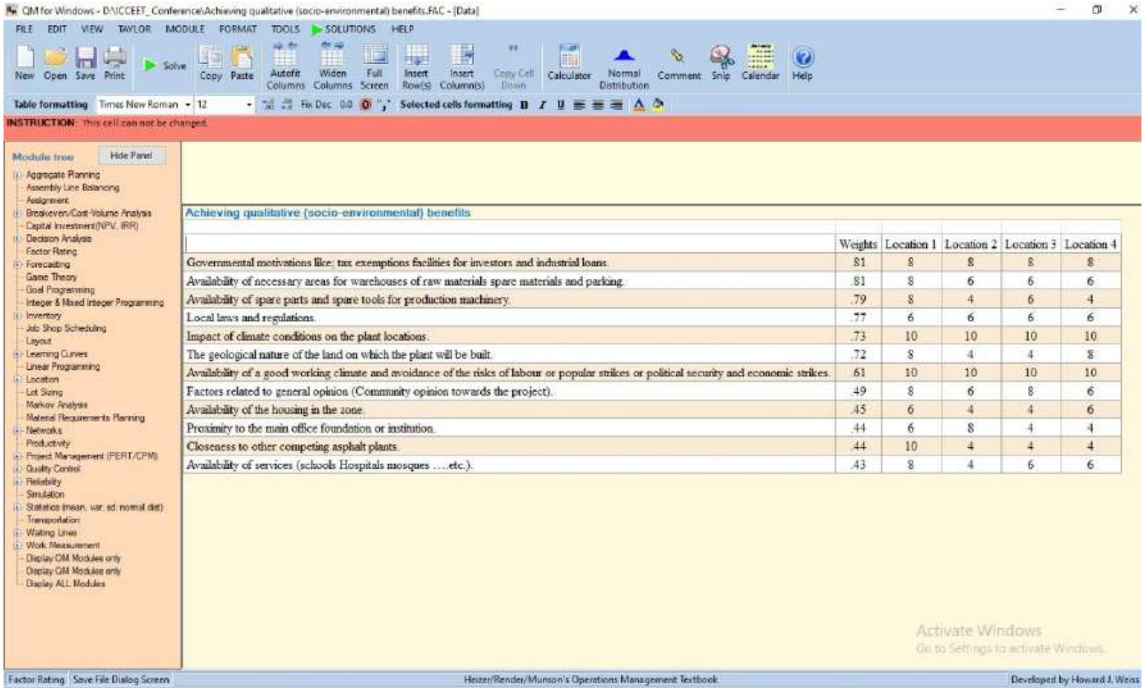
TITLE: Achieving socio-environmental benefits

Number of Factors 12

Number of Options 4

○ Option 1, Option 2, Option 3...
○ a, b, c, d, e, ...
○ A, B, C, D, E, ...
○ 1, 2, 3, 4, 5, ...
○ January, February, March, ...
● Other Location

Figure 6-10: Factor Rating creation screen of the program.



QM for Windows - D:\ICCEET_Conference\Achieving qualitative (socio-environmental) benefits.FAC - [Data]

INSTRUCTION: This cell can not be changed.

Achieving qualitative (socio-environmental) benefits

	Weights	Location 1	Location 2	Location 3	Location 4
Governmental motivations like; tax exemptions facilities for investors and industrial loans.	.81	8	8	8	8
Availability of necessary areas for warehouses of raw materials spare materials and parking.	.81	8	6	6	6
Availability of spare parts and spare tools for production machinery.	.79	8	4	6	4
Local laws and regulations.	.77	6	6	6	6
Impact of climate conditions on the plant locations.	.73	10	10	10	10
The geological nature of the land on which the plant will be built.	.72	8	4	4	8
Availability of a good working climate and avoidance of the risks of labour or popular strikes or political security and economic strikes.	.61	10	10	10	10
Factors related to general opinion (Community opinion towards the project).	.49	8	6	8	6
Availability of the housing in the zone.	.45	6	4	4	6
Proximity to the main office foundation or institution.	.44	6	8	4	4
Closeness to other competing asphalt plants.	.44	10	4	4	4
Availability of services (schools Hospitals mosques ….etc.).	.43	8	4	6	6

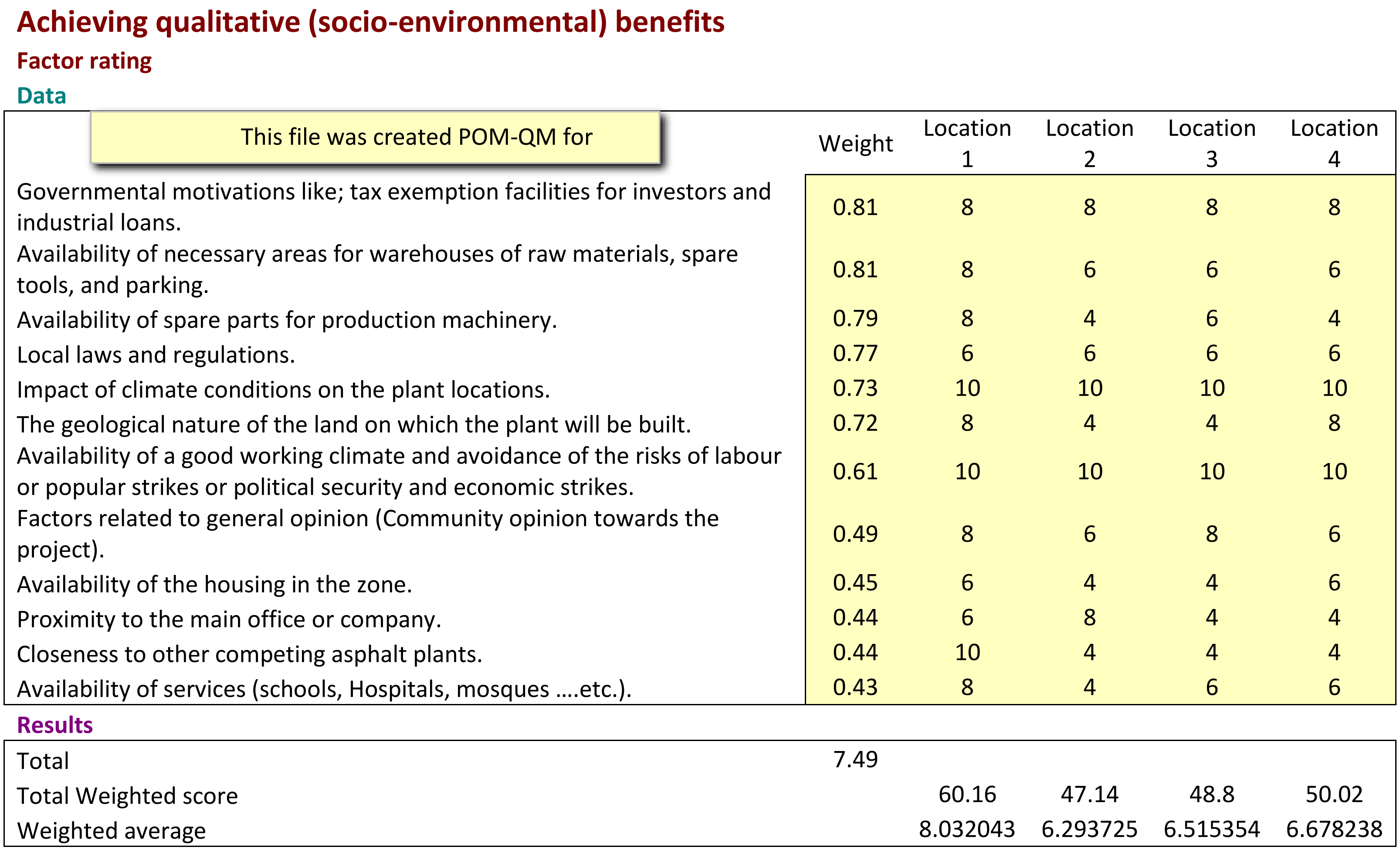
Figure 6-11: Factor Rating Data entry screen of the program.

6.6.2.1.3 View results

The program outputs results either as a POMQMv5 Document, which has extension of (example.lin) or a Microsoft Excel Worksheet which has extension of (.xlsx). Table 6-12 shows the program output as microsoft excel worksheet (.xlsx), Which shows the superiority of location 1 over the rest of the locations; this output is very straightforward and consists of the following: *Total weighted score*. For each location, the scores are multiplied by the weights for each factor; the total is printed at the bottom of each column.

Each *location's weighted average* (total score/total weight) is also display.

Table 6-12: Program outputs for Achieving socio-environmental benefits.



Achieving qualitative (socio-environmental) benefits

Factor rating

Data

This file was created POM-QM for

	Weight	Location 1	Location 2	Location 3	Location 4
Governmental motivations like; tax exemption facilities for investors and industrial loans.	0.81	8	8	8	8
Availability of necessary areas for warehouses of raw materials, spare tools, and parking.	0.81	8	6	6	6
Availability of spare parts for production machinery.	0.79	8	4	6	4
Local laws and regulations.	0.77	6	6	6	6
Impact of climate conditions on the plant locations.	0.73	10	10	10	10
The geological nature of the land on which the plant will be built.	0.72	8	4	4	8
Availability of a good working climate and avoidance of the risks of labour or popular strikes or political security and economic strikes.	0.61	10	10	10	10
Factors related to general opinion (Community opinion towards the project).	0.49	8	6	8	6
Availability of the housing in the zone.	0.45	6	4	4	6
Proximity to the main office or company.	0.44	6	8	4	4
Closeness to other competing asphalt plants.	0.44	10	4	4	4
Availability of services (schools, Hospitals, mosques ….etc.).	0.43	8	4	6	6

Results

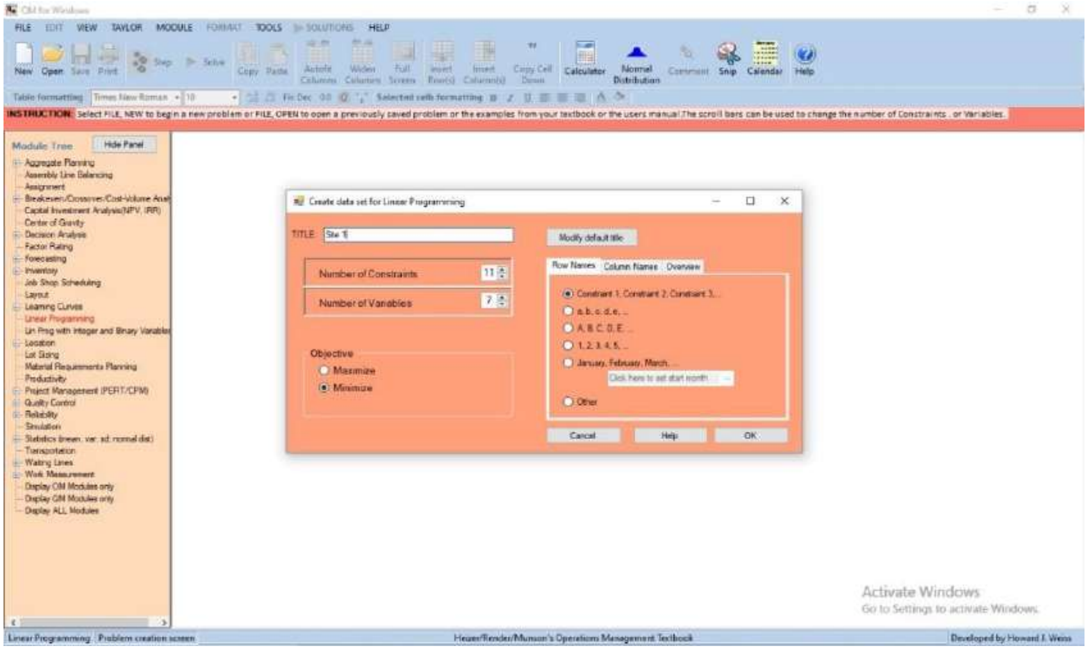
Total	7.49				
Total Weighted score		60.16	47.14	48.8	50.02
Weighted average		8.032043	6.293725	6.515354	6.678238

6.6.2.2 Linear Programming (Achieving economic benefits)

6.6.2.2.1 Entering data

When selecting the linear programming technique from modules tree, the creation screen will be displayed; The top line contains a text box with the problem's title; we enter the candidate location name for the asphalt plant. Then, we enter the number of constraints and variables representing the rows and columns in the linear programming data table. The bottom of the creation screen will have an option for the type of objective function (minimize & maximize); we choose to minimize. Figure 6-12 shows all these details.

The next is an empty data screen which has a data table. we enter the data of objective function and constraints for the candidate location of the asphalt plant; the same is true for the other locations as shown in Figure 6-13.



INSTRUCTION: Select FILE, NEW to begin a new problem or FILE, OPEN to open a previously saved problem or the examples from your textbook or the users manual.The scroll bars can be used to change the number of Constraints , or Variables.

TITLE: Site 1

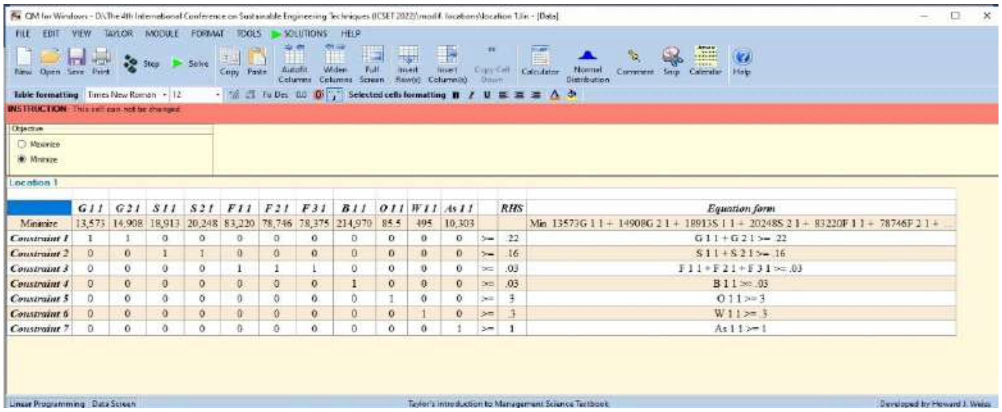
Number of Constraints: 11

Number of Variables: 7

Objective
○ Maximize
● Minimize

● Constraint 1, Constraint 2, Constraint 3, ...
○ a, b, c, d, e, ...
○ A, B, C, D, E, ...
○ 1, 2, 3, 4, 5, ...
○ January, February, March, ...
○ Other

Figure 6-12: Linear Programming creation screen of the program.

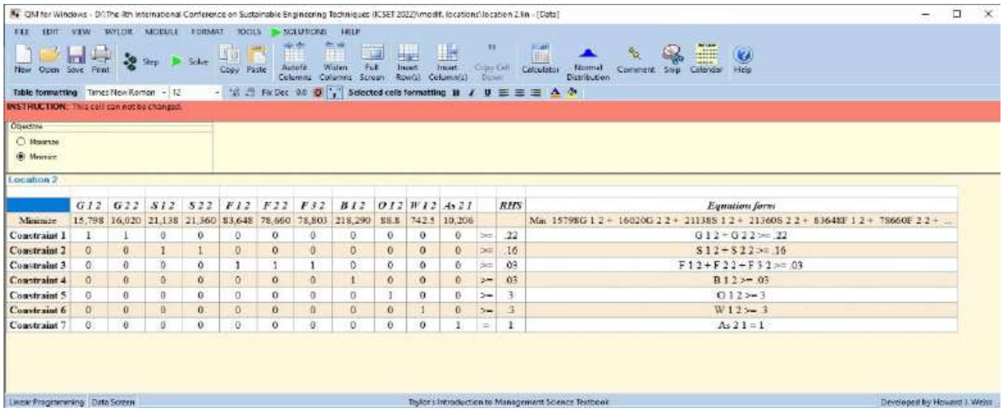


INSTRUCTION: This cell can not be changed.

Objective
○ Maximize
● Minimize

Location 1

	G 1 1	G 2 1	S 1 1	S 2 1	F 1 1	F 2 1	F 3 1	B 1 1	O 1 1	W 1 1	As 1 1		RHS	Equation form
Minimize	13,573	14,908	18,913	20,248	83,220	78,746	78,375	214,970	85.5	495	10,303			Min 13573G 1 1 + 14908G 2 1 + 18913S 1 1 + 20248S 2 1 + 83220F 1 1 + 78746F 2 1 + ...
Constraint 1	1	1	0	0	0	0	0	0	0	0	0	>=	.22	G 1 1 + G 2 1 >= .22
Constraint 2	0	0	1	1	0	0	0	0	0	0	0	>=	.16	S 1 1 + S 2 1 >= .16
Constraint 3	0	0	0	0	1	1	1	0	0	0	0	>=	.03	F 1 1 + F 2 1 + F 3 1 >= .03
Constraint 4	0	0	0	0	0	0	0	1	0	0	0	>=	.03	B 1 1 >= .03
Constraint 5	0	0	0	0	0	0	0	0	1	0	0	>=	3	O 1 1 >= 3
Constraint 6	0	0	0	0	0	0	0	0	0	1	0	>=	3	W 1 1 >= 3
Constraint 7	0	0	0	0	0	0	0	0	0	0	1	>=	1	As 1 1 >= 1

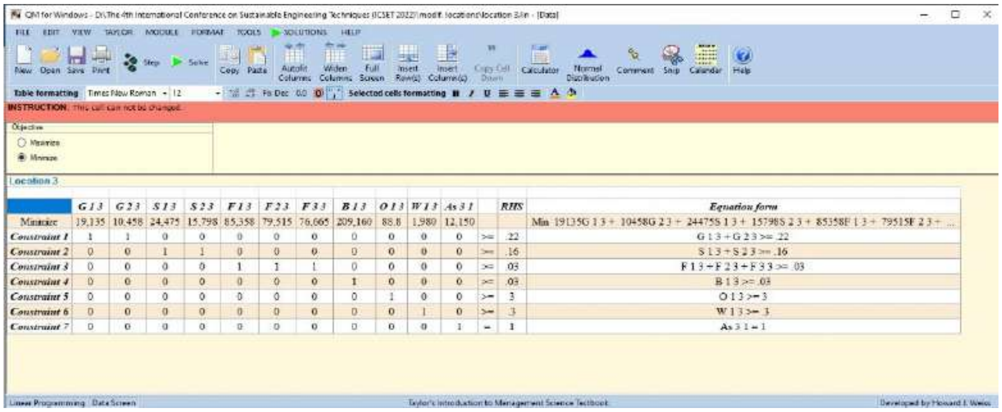


INSTRUCTION: This cell can not be changed.

Objective
○ Maximize
● Minimize

Location 2

	G 1 2	G 2 2	S 1 2	S 2 2	F 1 2	F 2 2	F 3 2	B 1 2	O 1 2	W 1 2	As 2 1		RHS	Equation form
Minimize	15,798	16,020	21,138	21,360	83,648	78,660	78,803	218,290	88.8	742.5	10,206			Min 15798G 1 2 + 16020G 2 2 + 21138S 1 2 + 21360S 2 2 + 83648F 1 2 + 78660F 2 2 + ...
Constraint 1	1	1	0	0	0	0	0	0	0	0	0	>=	.22	G 1 2 + G 2 2 >= .22
Constraint 2	0	0	1	1	0	0	0	0	0	0	0	>=	.16	S 1 2 + S 2 2 >= .16
Constraint 3	0	0	0	0	1	1	1	0	0	0	0	>=	.03	F 1 2 + F 2 2 + F 3 2 >= .03
Constraint 4	0	0	0	0	0	0	0	1	0	0	0	>=	.03	B 1 2 >= .03
Constraint 5	0	0	0	0	0	0	0	0	1	0	0	>=	3	O 1 2 >= 3
Constraint 6	0	0	0	0	0	0	0	0	0	1	0	>=	3	W 1 2 >= 3
Constraint 7	0	0	0	0	0	0	0	0	0	0	1	=	1	As 2 1 = 1

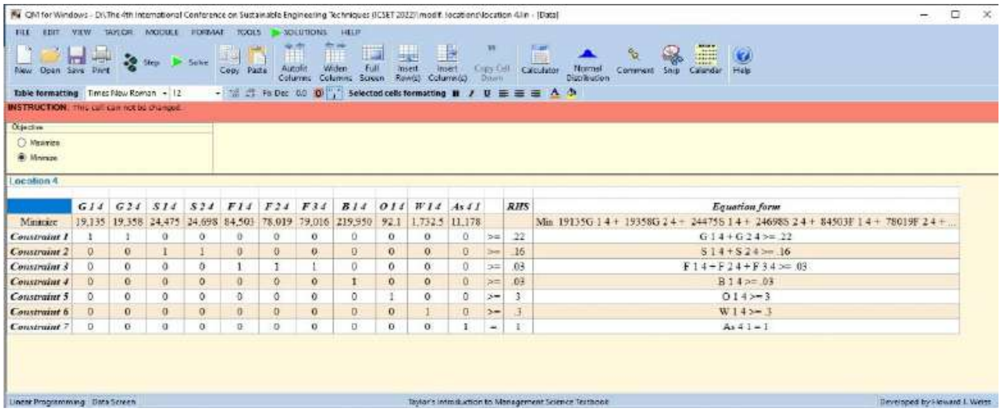


INSTRUCTION: This cell can not be changed.

Objective
○ Maximize
● Minimize

Location 3

	G 1 3	G 2 3	S 1 3	S 2 3	F 1 3	F 2 3	F 3 3	B 1 3	O 1 3	W 1 3	As 3 1		RHS	Equation form
Minimize	19,135	10,458	24,475	15,798	85,358	79,515	76,665	209,160	88.8	1,980	12,150			Min 19135G 1 3 + 10458G 2 3 + 24475S 1 3 + 15798S 2 3 + 85358F 1 3 + 79515F 2 3 + ...
Constraint 1	1	1	0	0	0	0	0	0	0	0	0	>=	.22	G 1 3 + G 2 3 >= .22
Constraint 2	0	0	1	1	0	0	0	0	0	0	0	>=	.16	S 1 3 + S 2 3 >= .16
Constraint 3	0	0	0	0	1	1	1	0	0	0	0	>=	.03	F 1 3 + F 2 3 + F 3 3 >= .03
Constraint 4	0	0	0	0	0	0	0	1	0	0	0	>=	.03	B 1 3 >= .03
Constraint 5	0	0	0	0	0	0	0	0	1	0	0	>=	3	O 1 3 >= 3
Constraint 6	0	0	0	0	0	0	0	0	0	1	0	>=	3	W 1 3 >= 3
Constraint 7	0	0	0	0	0	0	0	0	0	0	1	=	1	As 3 1 = 1



INSTRUCTION: This cell can not be changed.

Objective
○ Maximize
● Minimize

Location 4

	G 1 4	G 2 4	S 1 4	S 2 4	F 1 4	F 2 4	F 3 4	B 1 4	O 1 4	W 1 4	As 4 1		RHS	Equation form
Minimize	19,135	19,358	24,475	24,698	84,503	78,019	79,016	219,950	92.1	1,732.5	11,178			Min 19135G 1 4 + 19358G 2 4 + 24475S 1 4 + 24698S 2 4 + 84503F 1 4 + 78019F 2 4 + ...
Constraint 1	1	1	0	0	0	0	0	0	0	0	0	>=	.22	G 1 4 + G 2 4 >= .22
Constraint 2	0	0	1	1	0	0	0	0	0	0	0	>=	.16	S 1 4 + S 2 4 >= .16
Constraint 3	0	0	0	0	1	1	1	0	0	0	0	>=	.03	F 1 4 + F 2 4 + F 3 4 >= .03
Constraint 4	0	0	0	0	0	0	0	1	0	0	0	>=	.03	B 1 4 >= .03
Constraint 5	0	0	0	0	0	0	0	0	1	0	0	>=	3	O 1 4 >= 3
Constraint 6	0	0	0	0	0	0	0	0	0	1	0	>=	3	W 1 4 >= 3
Constraint 7	0	0	0	0	0	0	0	0	0	0	1	=	1	As 4 1 = 1

Figure 6-13: Data entry screens of a program for each location.

6.6.2.2.2 Program outputs

After entering the data and being ready to solve the problem, the program is executed by (Solve) tool on the standard toolbar to obtain the mathematical model results for the four locations.

6.6.2.2.3 View results

As a factor rating results, the researcher selected a microsoft excel worksheet (.xlsx) type for viewing program outputs; Tables 6-13, 6-14, 6-15 and 6-17 show the final program outputs for each location after the program has solved the model based on the basics of Linear Programming as a table; this Table shows a complete report describing the following:

Optimal values for the variables: The optimal values for the decision variables are given under each column.

Optimal cost: The minimum cost is given in the Table's lower right-hand corner (Here, the lowest delivery price is in location 1 (Table 6-13)).

POM-QM software also generates a sensitivity report that provides the sensitivity ranges for the coefficients (parameters); the values range are arranged with Excel and POM-QM document reports. In Excel, the ranges are expressed as an allowable increase and decrease instead of upper and lower limits in the POM-QM document, Tables 6-17, 6-18, 6-19, 6-20, 6-21, 6-22, 6-23, and 6-24 in Appendix F show sensitivity reports for candidate locations.

Table 6-13: Program outputs for Achieving economic benefits-Location 1.

	G 1 1	G 2 1	S 1 1	S 2 1	F 1 1	F 2 1	F 3 1	B 1 1	O 1 1	W 1 1	As 1 1		RHS
Objective	13573	14908	18913	20248	83220	78746	78375	214970	85.5	495	10303		0
Constraint 1	1	1	0	0	0	0	0	0	0	0	0	>	0.22
Constraint 2	0	0	1	1	0	0	0	0	0	0	0	>	0.16
Constraint 3	0	0	0	0	1	1	1	0	0	0	0	>	0.03
Constraint 4	0	0	0	0	0	0	0	1	0	0	0	>	0.03
Constraint 5	0	0	0	0	0	0	0	0	1	0	0	>	3
Constraint 6	0	0	0	0	0	0	0	0	0	1	0	>	0.3
Constraint 7	0	0	0	0	0	0	0	0	0	0	1	=	1

Results

Variables	0.22	0	0.16	0	0	0	0.03	0.03	3	0.3	1	
Objective												25520.49

Table 6-14: Program outputs for Achieving economic benefits-Location 2.

	G 1 2	G 2 2	S 1 2	S 2 2	F 1 2	F 2 2	F 3 2	B 1 2	O 1 2	W 1 2	As 2 1		RHS
Objective	15798	16020	21138	21360	83648	78660	78803	218290	88.8	742.5	10206		0
Constraint 1	1	1	0	0	0	0	0	0	0	0	0	>	0.22
Constraint 2	0	0	1	1	0	0	0	0	0	0	0	>	0.16
Constraint 3	0	0	0	0	1	1	1	0	0	0	0	>	0.03
Constraint 4	0	0	0	0	0	0	0	1	0	0	0	>	0.03
Constraint 5	0	0	0	0	0	0	0	0	1	0	0	>	3
Constraint 6	0	0	0	0	0	0	0	0	0	1	0	>	0.3
Constraint 7	0	0	0	0	0	0	0	0	0	0	1	=	1

Results

Variables	0.22	0	0.16	0	0	0.03	0	0.03	3	0.3	1	
Objective												26461.29

Table 6-15: Program outputs for Achieving economic benefits-Location 3.

	G 1 3	G 2 3	S 1 3	S 2 3	F 1 3	F 2 3	F 3 3	B 1 3	O 1 3	W 1 3	As 3 1		RHS
Objective	19135	10458	24475	15798	85358	79515	76665	209160	88.8	1980	12150		0
Constraint 1	1	1	0	0	0	0	0	0	0	0	0	>	0.22
Constraint 2	0	0	1	1	0	0	0	0	0	0	0	>	0.16
Constraint 3	0	0	0	0	1	1	1	0	0	0	0	>	0.03
Constraint 4	0	0	0	0	0	0	0	1	0	0	0	>	0.03
Constraint 5	0	0	0	0	0	0	0	0	1	0	0	>	3
Constraint 6	0	0	0	0	0	0	0	0	0	1	0	>	0.3
Constraint 7	0	0	0	0	0	0	0	0	0	0	1	=	1
Results													
Variables	0	0.22	0	0.16	0	0	0.03	0.03	3	0.3	1		
Objective													26413.59

Table 6-16: Program outputs for Achieving economic benefits-Location 4.

	G 1 4	G 2 4	S 1 4	S 2 4	F 1 4	F 2 4	F 3 4	B 1 4	O 1 4	W 1 4	As 4 1		RHS
Objective	21500	19358	24475	24698	84503	78019	79016	219950	92.1	1732.5	11178		0
Constraint 1	1	1	0	0	0	0	0	0	0	0	0	>	0.22
Constraint 2	0	0	1	1	0	0	0	0	0	0	0	>	0.16
Constraint 3	0	0	0	0	1	1	1	0	0	0	0	>	0.03
Constraint 4	0	0	0	0	0	0	0	1	0	0	0	>	0.03
Constraint 5	0	0	0	0	0	0	0	0	1	0	0	>	3
Constraint 6	0	0	0	0	0	0	0	0	0	1	0	>	0.3
Constraint 7	0	0	0	0	0	0	0	0	0	0	1	=	1
Results													
Variables	0.22	0	0.16	0	0	0.03	0	0.03	3	0.3	1		
Objective													29038.82

6.7 Discussion of results

1. From note Table 6-12, We note that location 1 (Industrial Zone of Razzaza) outperforms the rest of the locations from an environmental and social point of view with the highest Weighted Score (60.16) For its superiority in qualitative factors: Availability of necessary areas, Availability of spare parts, The geological nature of the land, and Closeness to other competing asphalt concrete units plants, and the sequence of the rest of the proposed locations for plants, which were selected in the program according to the highest socio-environmental benefits are: Location 4 (Industrial Zone of Husseiniya), Location 3 (Industrial Zone of Khan Al-Rubue), and Location 2 (Industrial Zone of Al-Sharia).
2. From note Tables 6-13, 6-14, 6-15, and 6-16, it becomes clear that the lower right-hand value (Optimal cost), which represents the lowest delivery price, is located in Table 6-13, which means Location 1 (Industrial Zone of Razzaza). Therefore, this Economically is the Optimal Location for the asphalt concrete unit Plant. The Optimal values for the variables are G_{11} (Quantity of transported gravel from Al-Ukhaidir quarries to location 1), S_{11} (Quantity of transported sand from Al-Ukhaidir quarries to location 1), and F_{31} (Quantity of transported filler (cement) from Al Kufa Cement Plant to location 1).The variables' values of G_{21}, S_{21}, $F_{11,}$ and F_{21} in Table 6-13 are equal to zero, meaning there is no transfer of raw materials from these sources to location 1.

   From tracing the values in tables 6-14, 6-15, and 6-16, we find that the sequence of the rest of the proposed locations for plants, which were selected in the program according to the lowest (Optimal) costs, are: Location 3 (Industrial Zone of Khan Al-Rubue), Location 2 (Industrial

Zone of Al-Sharia), and Location 4 (Industrial Zone of Husseiniya), respectively.

The sensitivity report for location 1 is shown in Tables F-1 & F-5 in Appendix F. We notice that the sensitivity ranges for the objective function parameters (13573 and 14908) are provided as an upper and lower limit in Table E-5 but instead show an allowable increase and an allowable decrease in Table E-1. For example, for the parameter ID13573 (Table F-1, B22), the allowable increase of 1335 (Table F-1) results in an upper limit of 14908 (Table F-5), whereas the allowable decrease of 1335 (Table F-1) results in a lower limit of 13573 (Table F-5) in the case of parameter ID14908 (Table F-1, B22).

Reduced costs are the costs resulting from using a resource whose value in the optimal solution is zero. Therefore, using one cubic meter of gravel (Najaf quarries) in location 1 (G_{21}) means an increase in the cost of production by ID 1335 (Tables F-1 & F-5).

The shadow price (or Duality) for gravel is ID13573 per cubic meter. This means that for every additional cubic meter of gravel that can be obtained, the cost will decrease by ID13573. If the manager of the asphalt plant can secure more gravel at ID13573 per cubic meter, how much more can be obtained before the optimal solution mix will change and the current shadow price is no longer valid? The answer is at the upper limit of the sensitivity range for the gravel constraint value, which is infinity due to the researcher's hypothesis, "The capacity of each plant is Unlimited."

This is the discussion of the sensitivity ranges for the coarse aggregate (gravel) and its effect on the optimal solution/ location 1. The same applies to the rest of the locations' parameters (see Tables F-2, F-3, F-4, F-6, F-7, and F-8 in Appendix F).

3. When arranging the results of factor rating and linear programming in descending and ascending orders, the first result is also location 1, which represents the optimal location for achieving economic & socio-environmental benefits.

Chapter Seven: Conclusions, Recommendations, and Future Studies

7.1 Introduction

This chapter includes the conclusions reached through the two parts of the study (theoretical study and field study), which were previously addressed by the study during the previous chapters. The chapter also deals with some recommendations that the researcher sees can contribute to the development of the study. Finally, the chapter contains several proposals made by the researcher concerning conducting future research in light of the results that have been reached.

7.2 Conclusions

The following are the most important conclusions that the researcher reached through what was put forward in the theoretical and field studies:

1. Because there is nowhere else for asphalt to come from, asphalt concrete units plants are a crucial part of every road project's infrastructure. Therefore, the goal of adequately distributing it is to obtain a broad quantitative return within the shortest time, considering the quality and sustainability factors to the greatest extent. The path leading to this goal consists of a series of operations linked to one another. The most prominent of these operations is to provide raw materials at the lowest possible price, recycle asphalt waste, and transfer asphalt concrete to the paving sites at the lowest delivery price.
2. The study presents new factors concerned with climate and sustainability in selecting the optimal location as well as the traditional factors related to the cost, time, and quality; yet, in light of the global transfer towards

climate safety and sustainability, it is necessary for integration the new and traditional factors in the selection of asphalt concrete units plant location.

3. Eleven qualitative and quantitative factors were derived, and all of these factors were ranked as a “High” category, consistently packed with eighteen factors ranked as "High-Medium" and "Medium" categories.
4. None of the "An ability of recycling asphalt waste." factor is among the top ranking eleven factors, this shows that recycling considerations in Iraq are still at low importance for the selection factors.
5. The study showed that there is no clear system approved by the competent authorities to select the optimal locations for the construction of asphalt concrete units’ plants that can be relied upon in selecting the optimal location for the construction of the plant.
6. Not all asphalt concrete units plants are operating, despite suspended paving projects due to the failure to prepare asphalt concrete because of financial shortage and economic problems for the contractors.
7. The reasons for the lack of access to the effective capacities of plants to the design capacities are the fluctuation in the provision of raw materials, the low level of skilled labour or its instability due to the conditions that the country is going through, which negatively affected the level of planning and executive performance of production processes.
8. Weak documentation of previous experiences in terms of costs related to production, transportation, and paving of roads in Iraq.
9. Determining the optimal location of the plant is not a problem that must be addressed only once (i.e., when the plant is being built for the first time). Still, it may appear more than once, especially after the demand for plant products increases due to changing economic, environmental or urban

conditions, that a good location may not be so forever, and several developments may lead to the transfer of the need for paving from one area to another.

7. After applying the proposed system as a practical example to the four zones, the optimal location for the asphalt concrete unit plant was: the Industrial Zone of Razzaza.

7.3 Recommendations

In light of the results obtained from the study and to select the optimal locations for the construction of asphalt concrete unit plants for the purposes of paving projects, the researcher recommends the following points as recommendations for study:

1. The use of quantitative methods represented by the science of operations research in order to solve the problems related to locating, as these methods are the best combination of all the variables involved in formulating the problem, and they also ensure the optimal exploitation of the available human and material resources and thus obtaining the maximum possible economic benefit.
2. Adopting this proposed system as a policy for selecting industrial project locations and generalizing the bases that should be followed in determining the locations of industrial projects and the studies to be implemented for this purpose.
3. The possibility of using the proposed system as a policy to determine the optimal location of the construction plants after making some special developments.

4. According to the importance level of "An ability of recycling asphalt waste.", extracted and ranked from the from experts' feedback among them are asphalt industry experts, so It is intended to have in-depth case studies to verify the relevancy of recycling asphalt concrete waste. As a result, industrial policymakers will be able to make more informed decisions that will contribute to the development of a more sustainable asphalt standard. or Reclaimed Asphalt Concrete (RAP).
5. With the development of means of transporting the Hot Mixtures Asphalt HMA, the location of the asphalt concrete unit plant should be as close as possible to the aggregate quarries to reduce the total costs resulting from transportation because of the aggregate is the most extensive and expensive raw material in asphalt concrete.
6. Paying attention to the documentation processes related to the production processes of asphalt concrete in terms of raw materials costs, transportation costs, production costs at the plant location, and others.
7. To achieve the highest economic benefits, make the relative importance of qualitative factors equal to zero and equal to one for quantitative factors.
8. Large companies with multiple construction products can address the issue of asphalt concrete location using the concept of plant-within-a-plant (PWP). As the term suggests, there are multiple plants within one plant or one location, allowing a construction company to produce different products that compete on different priorities like the products of concrete, pre-cast concrete, and asphalt concrete.

7.4 Suggested future studies

For the purpose of expanding the subject of the study, the researcher suggests the following future studies:

1. Using the goal programming method in selecting the optimal location.
2. Studying the nonlinear behaviour of direct costs and its impact on determining the optimal location.
3. Using the dynamic programming method includes the possibility of using a mobile plant to produce asphalt concrete and selecting the locations of those plants, especially that the required quantity of asphalt concrete is low.

References

AASHTO. (2016). *Standard Specifications for Transportation Materials and Methods of Sampling and Testing* (Thirty-Fif). American Association of State Highway and Transportation Officials.

Ahmed Habib Rasoul. (1999). *geography of Industry*. Dar Al-Nahda Al-Arabiya for printing, publishing and distribution. (In Arabic). https://books.google.iq/books?id=0fR0QgAACAAJ

Al-Ghariri, S. D. (2013). *PRODUCTION & OPERATIONS MANAGEMENT*. zein juridique librairie. (In Arabic)

AL-JASSAR, A. J. (2017). *Applications in Applied Statistics using Minitab 17*. Dar Al Doctor for Administrative and Economic Sciences. (In Arabic).

AL-Jorani, R. K. S. (2017). *Environmental Impact Assessment of Asphalt Factory in Baghdad*. University of Technology.

Al-Jumaili, S. K. R. (2002). *Suggestion of Developing a System for the Selection of Optimum Locations for Precast Concrete Units Plants for Housing Projects in Iraq*. University of Baghdad.

Al-Kenany, K. K. (2008). *Industrial location and spatial development policies* (1st ed.). Dar Safa Publishing-Distributing. (In Arabic).

Al-Kenany, K. K. (2009). *Studies in Industrial Location Theory* (1st ed.). Dar Safa Publishing-Distributing. (In Arabic).

Al-Nasiri, M. H. (2019). *Industrial Localization*. (In Arabic). https://doi.org/Https://youtu.be/2Ri2NnWxQtk

Al-Rawi, M. M. (n.d.). A general model for planning industrial sites in Iraq-a theoretical and applied study. In *Research and Studies Series* (9). (In

Arabic).

Al-Tamimi, H. A. (2016). *production & operations management (Quantitative entrance)* (3rd Editio). Dar Al Fikr. (In Arabic).

Aliverdilou, H., Hajilou, M., Sabokbar, H. F., & Faraji, A. (2021). An Intelligent Method for Industrial Location Selection: Application to Markazi Province, Iran. *Journal of Regional and City Planning*, *32*(3), 267–289. https://doi.org/10.5614/jpwk.2021.32.3.5

ASTM D995-95b. (2010). *Standard Specification for Mixing Plants for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures*.

Bandyopadhyay, S. (2020). *Production and Operations Analysis: Traditional, Latest, and Smart Views*. CRC Press.

Blair, J. P., & Premus, R. (1987). Major Factors in Industrial Location: A Review. *Economic Development Quarterly*, *1*(1), 72–85. https://doi.org/10.1177/089124248700100109.

Bolo, A. Z., Muchemi, A. W., & Ogutu, M. (2011). Diversity in the top management teams and effects on corporate performance. *Business Administration and Management (BAM)*, *1*(3), 82–92. www.primejournal.org/bam.

Boutkhoum, O., Hanine, M., Agouti, T., & Tikniouine, A. (2015). An improved hybrid multi-criteria/multidimensional model for strategic industrial location selection: casablanca industrial zones as a case study. *SpringerPlus*, *4*(1), 1–23.

Brock, J. D. (2016). *"Dryer drum mixer."* 18. http://www.astecinc.com/images/file/literature/Astec-T-119-Dryer-Drum-Mixer-EN.pdf.

Brock, J. D., & Richmond, S. (Jef. L. . (2007). *Milling and recycling*. Astec Industries.

Brown, E. R., Kandhal, P. S., Roberts, F. L., Kim, Y. R., Lee, D.-Y., & Kennedy, T. W. (2009). *Hot mix asphalt materials, mixture design, and construction* (Third Edit). NAPA research and education foundation.

Capello, R. (2015). *Regional economics* (2nd Edition). Routledge. https://doi.org/https://doi.org/10.4324/9781315720074

Chao, H.-K. (2018). Shaping Space through Diagrams: The Case of the History of Location Theory. In *Including a Symposium on Mary Morgan: Curiosity, Imagination, and Surprise* (Vol. 36B, pp. 59–72). Emerald Publishing Limited.

https://doi.org/10.1108/S0743-41542018000036B005

Chen, Y., Okudan, G. E., & Riley, D. R. (2010). Sustainable performance criteria for construction method selection in concrete buildings. *Automation in Construction*, *19*(2), 235–244.

Cyert, Ri. M., & March, J. G. (1963). A behavioral theory of the firm Prentice-Hall. *Englewood Cliffs, NJ*.

David R. Anderson, D. J. S., Thomas A. Williams, J. D. C., James J. Cochran, M. J. F., & Ohlmann, J. W. (2019). An Introduction to Management Science: Quantitative Approaches to Decision Making. In *Journal of the American Statistical Association* (Fifteenth, Vol. 60, Issue 311). Cengage Learning. https://doi.org/10.2307/2283265

Delgado, M., Porter, M. E., & Stern, S. (2014). *Defining Clusters of Related Industries* (No. 20375). https://doi.org/10.3386/w20375

Devulapalli, L., Kothandaraman, S., & Sarang, G. (2019). A review on the mechanisms involved in reclaimed asphalt pavement. *International Journal of Pavement Research and Technology*, *12*(2), 185–196.

Santos, M. B., Candido, J., de Souza Baulé, S., de Oliveira, Y. M. M., & Thives, L. P. (2020). Greenhouse gas emissions and energy consumption in asphalt plants. *Revista Eletrônica Em Gestão, Educação e Tecnologia Ambiental*, *24*, 7.

Drezner, T., & Drezner, Z. (2011). The Weber Location Problem: The Threshold Objective. *INFOR: Information Systems and Operational Research*, *49*(3), 212–220. https://doi.org/10.3138/infor.49.3.212

Drezner, T., Drezner, Z., & Schöbel, A. (2018). The Weber obnoxious facility location model: A Big Arc Small Arc approach. *Computers & Operations Research*, *98*, 240–250. https://doi.org/https://doi.org/10.1016/j.cor.2018.06.006

Drezner, Z. (1979). Bounds on the optimal location to the Weber problem under conditions of uncertainty. *Journal of the Operational Research Society*, *30*(10), 923–931.

Dubey, U., Kothari, D. P., & Awari, G. K. (2017a). *Quantitative techniques in business, management and finance: A case-study approach*. CRC Press.

Dubey, U., Kothari, D. P., & Awari, G. K. (2017b). *Quantitative techniques in business, management and finance: A case-study approach*. Taylor & Francis Group.

Eiselt, H. A., & Marianov, V. (2019). *Contributions to Location Analysis: In Honor of Zvi Drezner's 75th Birthday* (Vol. 281). Springer.

Emara, N. H., & Tawfik, S. S. (1989). *Statistics and its Engineering Applications* (First Edit.). Technology University. (In Arabic).

Faihan, E. A. H. Al. (2018). *Production and Operations Management* (Second Edition). Al Jazeera for printing and publishing. (In Arabic).

Flostrand, A., Pitt, L., & Bridson, S. (2020). The Delphi technique in forecasting– A 42-year bibliographic analysis (1975–2017). *Technological Forecasting and Social Change*, *150* (September 2019), 119773. https://doi.org/10.1016/j.techfore.2019.119773

Garcia Pires, A. J., & Pontes, J. P. (2021). (De) Industrialization, Technology and Transportation. *Open Economies Review*, *32*(3), 527–538.

George, D., & Mallery, P. (2020). *IBM SPSS statistics 26 step by step: A simple guide and reference* (Sixteenth). Routledge.

Ghosh, P., & Lepcha, K. (2019). Weighted linear combination method versus grid based overlay operation method–A study for potential soil erosion susceptibility analysis of Malda district (West Bengal) in India. *The Egyptian Journal of Remote Sensing and Space Science*, *22*(1), 95–115.

Glasson, J., & Marshall, T. (2007). *Regional planning* (1st Editio). Routledge.

Gupta, S., & Starr, M. (2014). *Production and operations management systems*. CRC Press Taylor & Francis Group.

Hafeth I. Naji. (2009). OPTIMUM LOCATION SELECTION FOR ASPHALTIC CONCRETE PLANT BY USING AHP TECHNIQUE. *DIYALA JOURNAL OF ENGINEERING SCIENCES*, *2*(2), 16–44. (In Arabic).

Hanink, D. M., & Cromley, R. G. (2008). Locational equilibria in Weberian agglomeration. *Geographical Analysis*, *40*(4), 401–421. https://doi.org/10.1111/j.0016-7363.2008.00733.x

Hassan, S. A. K., & Mohsen, A. H. (2011). Application of operations research methods to determine the optimal site for a cement concrete plant in Al-Diwaniyah Province. *Journal of Engineering and Sustainable Development (JEASD)*, *15*(1), 30–58. (In Arabic).

Heizer, J., Render, B., & Munson, C. (2017). *Operations management: sustainability and supply chain management* (Twelfth Edition). Pearson.

Hsu, C.-C., & Sandford, B. A. (2007). The Delphi technique: making sense of consensus. *Practical Assessment, Research, and Evaluation*, *12*(1), 10.

Hunter, R. N., Self, A., Read, J., & Hobson, E. (2015). *The shell bitumen handbook* (Sixth edit). ICE Publishing London, UK:

Hurter, A. P., & Martinich, J. S. (2012). *Facility location and the theory of production*. Springer Science & Business Media.

Iraqi Cement State Company. (2022). https://icsc.gov.iq

Ismael, A. J., & Rashid, Y. K. (2021). Spatial Analysis of Asphalt Industry in Kurdistan Region of Iraq (Study in Geography of Industry). *Tweser Jornal*, *4*(2). (In Arabic).

JACOBS, F. R., & CHASE, R. B. (2020). *Operations and supply chain management / the core* (FIFTH EDIT.). McGraw-Hill Education.

Jafari, H., Karimi, S., Nahavandchi, M., & Balist, J. (2015). Nuclear power plant locating by WLC & GIS (Case study: Iran, Hormozgan province). *International Journal of Basic and Applied Sciences*, *4*(1), 132.

Janaby, A. I. T. AL. (2017). *Development of a Blueprint Management Model of road infrastructure in Iraq through the application of public-private partnership using sustainability as a criterion*. University of Baghdad.

Jayraman, V. (2013). *Production and Operation Management.* (First Edit.). JNU, Jaipur.

Jumaah, M. W. (2020). *Impact of Nanotechnology in Implementation of Iraqi Construction Projects*. University of Baghdad.

Kandhal, P. S., & Mallick, R. B. (1998). *Pavement Recycling Guidelines for State and Local Governments: Participant's Reference Book*.

Kim, Y. R. (2009). *Modeling of asphalt concrete*. McGraw-Hill Education.

Kometa, S. T., Olomolaiye, P. O., & Harris, F. C. (1994). Attributes of UK construction clients influencing project consultants' performance. *Construction Management and Economics*, *12*(5), 433–443. https://doi.org/10.1080/01446199400000053

KRAJEWSKI, L., Ritzman, L. P., & Malhotra, M. K. (2019). Operations Management PROCESSES AND SUPPLY CHAINS. In *Processes and Supply Chains, Harlow: Pearson* (Twelfth Ed). Twelfth Ed.

Kumar, S. ., & N.Suresh. (2008). *Production and Operations Management (With Skill Development , caselets and cases)* (second edit.). NEW AGE INTERNATIONAL.

Laporte, G. (2019). Location Science. In G. Laporte, H. Montréal, C. Montréal, QC, S. Nickel, I. for O. Research, K. I. of Technology, G. Karlsruhe, F. S. da Gama, F. of Science, U. of Lisbon, & P. Lisbon (Eds.), *Location Science* (2ed ed.). Springer Nature Switzerland. https://doi.org/10.1007/978-3-319-13111-5

Li, Y. (2007). *Impact of modern logistics on industrial location choice and property markets*. Massachusetts Institute of Technology.

Liu, S., Shukla, A., & Nandra, T. (2017). Technological, environmental and economic aspects of Asphalt recycling for road construction. *Renewable and Sustainable Energy Reviews*, *75*, 879–893.

Malczewski, J. (2006). Ordered weighted averaging with fuzzy quantifiers: GIS-based multicriteria evaluation for land-use suitability analysis. *International Journal of Applied Earth Observation and Geoinformation*, *8*(4), 270–277.

Mallick, R. B., & El-Korchi, T. (2018). *Pavement Engineering: Principles and Practice* (Third Edit.). CRC Press, NY.

Martinich, J. S. (2008). *Production and operations management: An applied modern approach*. John Wiley & Sons.

Melo, M. T., Nickel, S., & Saldanha-da-Gama, F. (2009). Facility location and supply chain management - A review. *European Journal of Operational Research*, *196*(2), 401–412.

https://doi.org/10.1016/j.ejor.2008.05.007

Meroni, F., Flintsch, G. W., Diefenderfer, B. K., & Diefenderfer, S. D. (2020). Application of balanced mix design methodology to optimize surface mixes with high-RAP content. *Materials*, *13*(24), 5638.

Miller, C. C. I. (1991). *Cognitive diversity within management teams: Implications for strategic decision processes and organizational performance.*

Miller, E. W. (1977). *Manufacturing: a study of industrial location*. Penn State University Press.

Mohsen, A. K., & Al-Najjar, M. M. (2012). *Production and Operations Management* (Fourth Ed.). Althakira for publishing and distribution. (In Arabic).

Muhammad Azhar Al-Sammak. (2012). *Industry geography "with a contemporary perspective."* Dar Al Yazardi Scientific Publishing and Distribution. (In Arabic).

Muhammad, M. A. A., & Ibrahim, N. T. (2017). The effect of committee referral tenders decisions to delay projects - (Case - Study in the governorate of Karbala). *Journal of Kerbala University*, *15*(1), 206–232. (In Arabic).

Owen, S. H., & Daskin, M. S. (1998). Strategic facility location: A review. *European Journal of Operational Research*, *111*(3), 423–447.

Perko, H. A., Rupiper, S. J., Helix, W., & Distributers, P. (2000). *Hot-Mix Asphalt Paving Handbook* (Vol. 5).

Qanber, H. (n.d.). *Roads and Bridges Directorate*.

Reid, R. D., & Sanders, N. R. (2020). *Operations management: an integrated approach* (7th Editio). John Wiley & Sons.

Rikalovic, A., Cosic, I., & Lazarevic, D. (2014). GIS based multi-criteria analysis for industrial site selection. *Procedia Engineering*, *69*, 1054–1063. https://doi.org/10.1016/j.proeng.2014.03.090

ROBERTA S. RUSSELL, & TAYLOR, B. W. (2019). *Operations and supply chain management* (Tenth Edit.). John Wiley & Sons, Ltd.

Robinson, R., & Thagesen, B. (2018). *Road engineering for development* (2nd Edition). CRC Press. https://doi.org/https://doi.org/10.1201/9781315273563

Rooshdi, R. R. R. M., Majid, M. Z. A., Sahamir, S. R., & Ismail, N. A. A. (2018). Relative importance index of sustainable design and construction activities criteria for green highway. *Chemical Engineering Transactions*, *63*(2007), 151–156. https://doi.org/10.3303/CET1863026

S. Highway & Bridges. (2007). *General Specifications for Roads and Bridges: Part One-Roads Works* (Revised Ed).

Sami, G., Mahdi, K., Abdelwahhab, F., & Yahyaoui, H. (2020). Site selection for future industrial infrastructure in the province of Constantine (Algeria). *Geomatics, Landmanagement and Landscape*, *1*(1), 23–32. https://doi.org/10.15576/GLL/2020.1.23

Schwenk, C. R. (1984). Cognitive simplification processes in strategic decision-making. *Strategic Management Journal*, *5*(2), 111–128.

Siegel, S., & Castellan, N. J. (1988). Nonparametric Statistics for the Behavioural Sciences, 2nd edn McGraw-Hill Book Company. *New York*, 144–151.

Smith, D. M. (1981). *Industrial location: an economic geographical analysis*. John Wiley & Sons.

Starr, M. K. (2008). *Managing production and operations*. Prentice Hall.

Taibi, A., & Atmani, B. (2017). Combining Fuzzy AHP with GIS and Decision Rules for Industrial Site Selection. *International Journal of*

Interactive Multimedia & Artificial Intelligence, *4*(6).

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science*, *185*(4157), 1124–1131.

Walker, R. (2021). GEOGRAPHY, VON THÜNEN, AND TOBLER'S FIRST LAW. *Geographical Review*, *just-accepted*.

Walsh, J. P. (1995). Managerial and organizational cognition: Notes from a trip down memory lane. *Organization Science*, *6*(3), 280–321.

Wang, L. (2011). *Mechanics of asphalt: microstructure and micromechanics*. McGraw-Hill Education.

Webber, M. J. (2020). *Industrial location*. Regional Research Institute, West Virginia University.

Weiss, H. J. (2018). *POM/QM for Windows* (Fifth Edit). pearson.

Williams, H. P. (2013). *Model Building in Mathematical Programming* (Fifth Edit). John Wiley & Sons Ltd.

Yahia, A. (2020). *Directorate of Road & Bridges Holy Karbala*.

Yonar, F. (2007). *Evaluation of asphalt plants in terms of production and performance stages*. Graduate School of Natural and Applied Sciences.

Zaumanis, M., Mallick, R. B., & Frank, R. (2016). 100% hot mix asphalt recycling: challenges and benefits. *Transportation Research Procedia*, *14*, 3493–3502.

Appendix A

Appendix A. Field survey Form

A1. Information about asphalt concrete production plants.

Plant name	**Owner**	**Location**	**Capacity tph**		**Notes**
			Design capacity	**Effective capacity**	

A2. Raw materials used in the manufacture of asphalt concrete.

- **Coarse aggregate (gravel)**

No.	**Quarry name**	**Location**	**Distance between quarry & plant (km)**	**Maximum quantity to supply (m^3)**	**Price (ID)**

- **Fine aggregate (sand)**

No.	**Quarry name**	**Location**	**Distance between quarry & plant (km)**	**Maximum quantity to supply (m^3)**	**Price (ID)**

- **Mineral filler (cement)**

No.	Plant name	Location	Distance between cement plant & asphalt plant (km)	Maximum quantity to supply (ton)	Price (ID)

- **Bitumen**

No.	Refinery name	Location	Distance between Refinery & plant (km)	Maximum quantity to supply (ton)	Price (ID)

A3. Information about transporting raw materials from supplying sources to asphalt concrete production plants:

- If the plant owner undertakes this task:

a. The number of available means of transport with maximum transport capacity:

b. The cost of transportation (t/km or m^3/km) when the owner does not have a means of transportation:

- If the subcontractor approach of supply is used:

The cost of transportation (t/km or m^3/km):

A4. The means of transporting the product (asphalt concrete) from the plant to the demand areas:

- If the plant owner undertakes this task:

c. The number of available means of transport with maximum transport capacity:

d. The cost of transportation (t/km or m^3/km) when the owner does not have a means of transportation:

- If the subcontractor approach of supply is used.

  The cost of transportation (t/k or m^3/km):

Appendix B

Appendix B. Introductory Questionnaire Form

Note: Put the correct mark in the box that you think is appropriate or determine what you think is appropriate at every word.

General personal information

B1. Company or office name:

B2. Academic achievement:

Bachelor	High Diploma	Master	Doctorate

B3. Job class:

B4. Job title:

Assist. Engineer	Engineer	Senior Engineer	Assist. Chief of Engineer	Chief of Engineers	Older Chief of Engineers	Expert

B5. A number of years of experience:

Less than 5 years	5-10 years	10-20 years	More than 20 years.

B6. Have you participated in the implementation of road implementation or maintenance projects? yes ☐ no ☐

First section\ information on asphalt plants returning to Iraq's public and private sectors.

1. Do you think that the selection of asphalt plant locations in Iraq has been considered to give greater economic revenue?

Always	Often	Sometimes	Rarely	Never

2. Do you think that location of the asphalt plant affects the final cost of production?

Always	Often	Sometimes	Rarely	Never

3. Do you think a program of long-term location distribution should be prepared before setting up asphalt concrete units plants for road projects?

Always	Often	Sometimes	Rarely	Never

4. Do you think that the following reasons were factors that helped to choose the locations of asphalt concrete units plants for road projects in Iraq?

Reasons	Always	Often	Sometimes	Rarely	Never
a. Near the plant from projects of road paving and maintenance					
b. Near the plant from raw materials sources					
c. Near the plant from the transportation network					

Reasons	Always	Often	Sometimes	Rarely	Never
d. Availability of technicians, skilled, and unskilled workers near the plant location.					
e. Availability of the necessary land for building the plant and enough area for stores.					
f. Availability of necessary services for the running the plant as: water, electric power,.... Etc.					
g. Others.					

5. Do you think the costs of asphalt industry are rising for the following reasons:

Reasons	Always	Often	Sometimes	Rarely	Never
a. Distance the plant from projects of road paving and maintenance					
b. Distance the plant from aggregate quarries					
c. Distance the plant from bitumen sources					
d. Distance the plant from filer sources					
e. Distance of plant from the services needed to operate it as water, and electric power, ... Etc.					
f. Disability of recycling the old asphalt waste.					
g. Unavailability of raw materials transportation to the plant location.					
h. Unavailability of asphalt concrete transportation to the projects locations.					
i. Unavailability of necessary labor near the location of the asphalt industrial plant.					
j. Unavailability of spare parts and spare tools for production machinery.					
k. Unavailability of transportation network near the location of the asphalt industrial plant.					
l. High wages of labor near the asphalt plant.					

Reasons	Always	Often	Sometimes	Rarely	Never
m. Others.					

6. Depending on your experience, do you think that reports should be prepared in asphalt production plants that include:

Reports	Always	Often	Sometimes	Rarely	Never
a. Productivity.					
b. Market need or size of the road projects to be implemented or maintained.					
c. Information about the case of equipment and production machinery.					
d. Information about the cost of transporting raw materials.					
e. Information about the sustainability or possibility of recycling previous asphalt waste in the implementation zone.					
f. Information about the cost of transfer the asphalt product to the implementation sites.					
g. Others.					

7. Have you ever informed an organizational system, a mathematical model, or a specific framework for selecting the optimal location for the asphalt concrete plant?

Yes ☐ No ☐

The second section/factors affecting the selection of asphalt concrete unit plant location

The variables below are considered one of the most important factors influencing the decision on the choice of the optimal location for installation plant for the production of asphalt concrete, please indicate the importance of each factor which will be mentioned within each of the following two parts:

Part 1 / Quantitative Factors

First: Factors related to inputs of the production operation

Factor	Very high importance	High importance	Medium importance	Low importance	Unimportant
1. Availability of labour of skilled and unskilled technicians and workers.					
• Availability of raw materials for the production process includes: 2. Proximity to sand and gravel quarries.					
3. Proximity to filler sources.					
4. Proximity to the sources of the bonding material (bitumen).					
5. Sustainability or ability to recycle asphalt materials when doing the maintenance work.					
6. Availability of transportation network					

Factor	Very high importance	High importance	Medium importance	Low importance	Unimportant
to transport the raw materials to the plant.					
7. Availability of spare parts and spare tools for production machinery.					
8. Others.					

Second: Factors related to outputs of the production operation

Factor	Very high importance	High importance	Medium importance	Low importance	Unimportant
1. Proximity to road projects and maintenance					
2. Market need or size of the roads to be implemented or maintained.					
3. An availability of transportation network to transport asphalt products to implementation projects or maintenance.					
4. Others.					

Third: Factors related to requirements of the production operation

Factor	Very high importance	High importance	Medium importance	Low importance	Unimportant
1. Proximity to water supply sources.					

Factor	Very high importance	High importance	Medium importance	Low importance	Unimportant
2. Proximity to electricity supply sources.					
3. Proximity to sewer networks.					
4. Proximity to the sources of fuels and oils.					
5. Availability of necessary areas for warehouses of raw materials, spare materials, and parking.					
6. Others.					

Part 2/ Qualitative Factors

Factor	Very high importance	High importance	Medium importance	Low importance	Unimportant
1. Environmental impact.					
2. Noise.					
3. Transportation availability.					
4. Rubble and production waste.					
5. Climatic conditions.					
6. Availability of services.					
7. Factors related to general opinion.					
8. Local laws and regulations.					

Factor	Very high importance	High importance	Medium importance	Low importance	Unimportant
9. Personal factors.					
10. Proximity to the main office, foundation, or company.					
11. The geological nature of the land on which the plant will be built.					
12. Availability of housing in the area.					
13. Availability of the road and transportation network to transport the raw materials to the plant and transport the asphalt products to the implementation sites.					
14. Others.					

Appendix C

Appendix C. Delphi Questionnaire Form

Introduction to the Delphi method

It is a systematic prediction technique based on the participation of a group of experts in answering questionnaires related to the topic to be foreseen in two or more rounds to achieve consensus in opinions between the responses of the participating experts. The researcher adopts this method to determine the most prominent quantitative and qualitative factors influencing the selection of the optimal location of the asphalt concrete production plant

Public Personal Information

C1. Name of Company, Department, or Institution:

C2. Work Sector:

Public Sector	Private sector

C3. Level of education:

Bachelor	High Diploma	Master	Doctorate

C4. Specialization:

C5. Exact Specialization:

C6. Years of Experience:

Less than 5 years old	5 – 10 years	10 – 20 years old	More than 20 years

Factors affecting the selection of asphalt concrete unit plant location

Dear Expert / The variables below are one of the most important factors influencing the decision on choosing the optimal location for installing a plant to produce asphalt concrete. Please indicate the importance of each factor which will be mentioned within each of the following two parts:

Part I / Quantitative Factors

First: Factors related to the inputs of the production process:

Factor	Very high importance	High importance	Medium importance	Low importance	Unimportant
1. Availability of labor of technicians & skilled & unskilled workers.					
• The availability of raw materials for the production process includes: 2. Proximity to sand and gravel quarries.					
3. Proximity to filler sources.					
4. Proximity to the sources of the bonding material (bitumen).					

Factor	Very high importance	High importance	Medium importance	Low importance	Unimportant
5. Availability of transportation to transport the raw materials to the plant.					
6. Sustainability and ability to recycle asphalt waste.					
7. Other.					

Second: Factors related to the outputs of the production process.

Factor	Very high important	High importance	Medium importance	Low importance	Unimportant
1. Proximity to zones of demand for asphalt concrete product.					
2. Need of the Market or the amount of asphalt concrete required.					
3. Providing modern means of transport dedicated to transporting the asphalt concrete product.					
4. Other.					

Third: Factors related to the requirements of the production process.

Factor	Very high importance	High importance	Medium importance	Low importance	Unimportant
1. Proximity to water supply sources.					
2. Proximity to electricity supply sources.					
3. Proximity to the sources of fuels and oils.					
4. Proximity to sewer networks.					
5. Noise.					
6. The Rubble and production waste.					
7. Environmental impact and pollution control.					
8. Availability of transportation network.					
9. Other.					

Part II/ Qualitative factors

Factors	Very high importance	high importance	Medium importance	Low importance	Unimportant
1. Impact of climate conditions on the plant locations.					
2. Closeness to other competing asphalt plants.					
3. Availability of spare parts and spare tools for production machines.					
4. Availability of the housing in the zone.					

Factors	**Very high importance**	**high importance**	**Medium importance**	**Low importance**	**Unimportant**
5. Availability of services (schools, Hospitals, mosques ….etc.).					
6. Factors related to general opinion (Community opinion towards the project).					
7. Local laws and regulations.					
8. Governmental motivations like; tax exemptions, facilities for investors, and industrial loans.					
9. Availability of a good working climate and avoidance of the risks of labour or popular strikes or political, security, and economic strikes.					
10. Proximity to the main office, foundation, or institution.					
11. The geological nature of the land on which the plant will be built.					
12. Availability of necessary areas for warehouses of raw materials, spare materials, and parking.					
13. Other.					

Appendix D

Appendix D. Answers Analysis of Open Questionnaire

Table D-1: Statistical and analysis of the answers to the closed questionnaire - first section.

Item	5 Always	4 Often	3 S. times	2 Rarely	1 Never
1. Do you think that the selection of asphalt plant locations in Iraq has been considered to give greater economic revenue?	17	26	48	16	1
2. Do you think that location of the asphalt plant affects the final cost of production?	57	43	6	2	0
3. Do you think a program of long-term location distribution should be prepared before setting up asphalt concrete units plants for road projects?	62	29	11	5	1
a. Near the plant from projects of road paving and maintenance	24	34	36	9	5
b. Near the plant from raw materials sources	35	29	33	9	2
c. Near the plant from the transportation network	22	44	24	12	6
d. Availability of technicians, skilled, and unskilled workers near the plant location.	12	32	30	17	17
e. Availability of the necessary land for building the plant and enough area for stores.	56	28	19	2	3
f. Availability of necessary services for running the plant as water, electric power,... Etc.	43	38	17	7	3
a. Distance the plant from projects of road paving and maintenance	48	35	17	5	3
b. Distance the plant from aggregate quarries	41	44	19	2	2
c. The distance the plant from bitumen sources	39	32	26	4	7
d. The distance of the plant from filer sources	18	33	31	16	10
e. Distance of plant from the services needed to operate it as water, and electric power, ... Etc.	26	40	26	14	2
f. Disability of recycling the old asphalt waste.	14	35	25	13	21
g. Unavailability of raw materials transportation to the plant location.	23	34	29	18	4
h. Unavailability of asphalt concrete transportation to the project's sites.	33	37	23	9	6

i. Unavailability of necessary labor near the location of the asphalt industrial plant.	14	31	34	15	14
j. Unavailability of spare parts and spare tools for production machinery.	18	27	41	18	4
k. Unavailability of transportation network near the location of the asphalt industrial plant.	17	41	32	13	5
l. High wages of labor near the asphalt plant.	20	33	24	20	11
a. Productivity.	88	17	2	1	0
b. Market need or size of the road projects to be implemented or maintained.	64	33	9	1	1
c. Information about the case of equipment and production machinery.	63	34	9	2	0
d. Information about the cost of transporting raw materials.	108	55	41	10	2
e. Information about the sustainability or possibly recycling previous asphalt waste in the implementation zone.	36	31	20	8	13
f. Information about the asphalt product's transportation cost to the implementation sites.	57	30	17	3	1
g. Have you ever informed a managerial system, a mathematical model, or a specific framework for selecting the optimal location for the asphalt concrete plant?	Yes			No	
	105			3	

Table D-2: Statistical analysis of the questionnaire answers - Section two (Factors related to the production process inputs).

Item	5	4	3	2	1	Mean	Std. D
	Very high importance	High importance	Medium importance	Low importance	unimportant		
1. Availability of labor of skilled and unskilled technicians and workers.	43	37	15	10	3	3.99	1.081
2. Proximity to sand and gravel quarries.	59	41	7	1	0	4.46	.662
3. Proximity to filler sources.	17	40	32	7	12	3.40	1.168
4. Proximity to the sources of the bonding material (bitumen).	28	36	30	11	3	3.69	1.054
5. Sustainability or ability to recycle asphalt materials when doing the maintenance work.	17	27	26	18	20	3.03	1.343

Item	5 Very high importance	4 High importance	3 Medium importance	2 Low importance	1 unimportant	Mean	Std. D
6. Availability of a transportation network to transport the raw materials to the plant.	30	41	28	8	1	3.84	.949
7. Availability of spare parts and spare tools for production machinery.	32	29	29	16	2	3.68	1.109

Table D-3: Statistical analysis of the questionnaire answers - Section two (Factors related to the production process outputs).

Item	5 Very high importance	4 High importance	3 Medium importance	2 Low importance	1 unimportant	Mean	Std. D
1. Proximity to road projects and maintenance	48	43	22	14	3	4.26	.790
2. Market need or size of the roads to be implemented or maintained.	54	43	11	11	0	4.40	.669
3. Availability of transportation network to transport asphalt products to implementation projects or maintenance.	38	43	14	22	5	4.06	.863

Table D-4: Statistical analysis of the questionnaire answers - Section two (Factors related to the production process requirements).

Item	5 Very high importance	4 High importance	3 Medium importance	2 Low importance	1 unimportant	Mean	Std. D
1. Proximity to water supply sources.	24	35	36	10	3	3.62	1.021
2. Proximity to electricity supply sources.	38	39	21	7	3	3.94	1.031
3. Proximity to sewer networks.	14	19	42	23	10	3.04	1.135
4. Proximity to the sources of fuels and oils.	26	28	39	14	1	3.59	1.023
5. Availability of necessary areas for warehouses of raw materials, spare materials, and parking.	53	40	14	1	0	4.34	.738

Table D-5: Statistical analysis of the questionnaire answers - Section two - Qualitative factors.

Item	5 Very high importance	4 High importance	3 Medium importance	2 Low importance	1 unimportant	Mean	Std. D
1. Environmental impact.	57	39	8	3	1	4.37	.816
2. Noise.	45	36	19	3	5	4.05	1.062
3. Available transportation.	34	40	28	5	1	3.94	.920
4. Rubble and production waste.	15	47	24	10	12	3.40	1.176
5. Climatic conditions.	15	33	34	14	12	3.23	1.181
6. Availability of services.	26	44	25	10	3	3.74	1.017
7. Factors related to general opinion.	19	25	40	17	7	3.30	1.130
8. Local laws and regulations.	37	42	22	5	2	3.99	.952
9. Personal factors.	14	10	51	20	13	2.93	1.133
10. Proximity to the main office, foundation, or company.	10	35	34	21	8	3.17	1.081
11. The geological nature of the land on which the plant will be built.	25	40	24	10	9	3.57	1.186
12. Availability of housing in the area.	13	30	34	16	15	3.09	1.212
13. Availability of the road and transportation network to transport the raw materials to the plant and transport the asphalt products to the implementation sites.	43	40	20	5	0	4.12	.872

Appendix E

Appendix E. Mathematical Model Calculations

E1. Location 1

Min. Z=

$$[(125 \times 50) + (9000)] \times 0.89 \times G_{11} +$$
$$[(125 \times 70) + (8000)] \times 0.89 \times G_{21} +$$
$$[(125 \times 50) + (15000)] \times 0.89 \times S_{11} +$$
$$[(125 \times 70) + (14000)] \times 0.89 \times S_{21} +$$
$$[(75 \times 80) + (140000)] \times 0.57 \times F_{11} +$$
$$[(75 \times 42) + (135000) \times 0.57 \times F_{21} +$$
$$[(75 \times 100) + (130000)] \times 0.57 \times F_{31} +$$
$$[(200 \times 45) + (250000)] \times 0.83 \times B_{11} +$$
$$[(0.2 \times 15) + (100)] \times 0.83 \times O_{11} +$$
$$[(90 \times 10)] \times 0.55 \times W_{11} +$$
$$[(120000) + (60 \times 12)] \times 0.81 \times As_{11}$$

Sub. into:

$$G_{11} + G_{21} \geq 0.22$$
$$S_{11} + S_{21} \geq 0.161$$
$$F_{11} + F_{21} + F_{31} \geq 0.034$$
$$B_{11} \geq 0.03$$
$$O_{11} \geq 3$$
$$W_{11} \geq 0.3$$
$$As_{11} = 1$$

E2. Location 2

Min. Z=

$$
\begin{aligned}
&[(125 \times 70) + (9000)] \times 0.89 \times G_{12} + \\
&[(125 \times 80) + (8000)] \times 0.89 \times G_{22} + \\
&[(125 \times 70) + (15000)] \times 0.89 \times S_{12} + \\
&[(125 \times 80) + (14000)] \times 0.89 \times S_{22} + \\
&[(75 \times 90) + (140000)] \times 0.57 \times F_{12} + \\
&[(75 \times 40) + (135000) \times 0.57 \times F_{22} + \\
&[(75 \times 110) + (130000)] \times 0.57 \times F_{32} + \\
&[(200 \times 65) + (250000)] \times 0.83 \times B_{12} + \\
&[(0.2 \times 35) + (100)] \times 0.83 \times O_{12} + \\
&[(90 \times 15)] \times 0.55 \times W_{12} + \\
&[(120000) + (60 \times 10)] \times 0.81 \times As_{21}
\end{aligned}
$$

Sub. into:

$$
\begin{aligned}
&G_{12} + G_{22} \geq 0.22 \\
&S_{12} + S_{22} \geq 0.161 \\
&F_{12} + F_{22} + F_{32} \geq 0.034 \\
&B_{12} \geq 0.03 \\
&O_{12} \geq 3 \\
&W_{12} \geq 0.3 \\
&As_{21} = 1
\end{aligned}
$$

E3. Location 3

Min. Z=

$$[(125\times 100)+(9000)]\times 0.89\times G_{13}+$$
$$[(125\times 30)+(8000)]\times 0.89\times G_{23}+$$
$$[(125\times 100)+(15000)]\times 0.89\times S_{13}+$$
$$[(125\times 30)+(14000)]\times 0.89\times S_{23}+$$
$$[(75\times 130)+(140000)]\times 0.57\times F_{13}+$$
$$[(75\times 60)+(135000)\times 0.57\times F_{23}+$$
$$[(75\times 60)+(130000)]\times 0.57\times F_{33}+$$
$$[(200\times 10)+(250000)]\times 0.83\times B_{13}+$$
$$[(0.2\times 35)+(100)]\times 0.83\times O_{13}+$$
$$[(90\times 40)]\times 0.55\times W_{13}+$$
$$[(120000)+(60\times 50)]\times 0.81\times As_{31}$$

Sub. into:

$$G_{13}+G_{23}\geq 0.22$$
$$S_{13}+S_{23}\geq 0.161$$
$$F_{13}+F_{23}+F_{33}\geq 0.034$$
$$B_{13}\geq 0.03$$
$$O_{13}\geq 3$$
$$W_{13}\geq 0.3$$
$$As_{31}=1$$

E4. Location 4

Min. Z=

$$[(125 \times 100) + (9000)] \times 0.89 \times G_{14} +$$
$$[(125 \times 110) + (8000)] \times 0.89 \times G_{24} +$$
$$[(125 \times 100) + (15000)] \times 0.89 \times S_{14} +$$
$$[(125 \times 110) + (14000)] \times 0.89 \times S_{24} +$$
$$[(75 \times 110) + (140000)] \times 0.57 \times F_{14} +$$
$$[(75 \times 25) + (135000) \times 0.57 \times F_{24} +$$
$$[(75 \times 115) + (130000)] \times 0.57 \times F_{34} +$$
$$[(200 \times 75) + (250000)] \times 0.83 \times B_{14} +$$
$$[(0.2 \times 55) + (100)] \times 0.83 \times O_{14} +$$
$$[(90 \times 35)] \times 0.55 \times W_{14} +$$
$$[(120000) + (60 \times 30)] \times 0.81 \times As_{41}$$

Sub. into:

$$G_{14} + G_{24} \geq 0.22$$
$$S_{14} + S_{24} \geq 0.161$$
$$F_{14} + F_{24} + F_{34} \geq 0.034$$
$$B_{14} \geq 0.03$$
$$O_{14} \geq 3$$
$$W_{14} \geq 0.3$$
$$As_{41} = 1$$

Appendix F

Appendix F. Sensitivity Reports for the Four Industrial Locations

Table F-1: Program sensitivity report-allowable increase and decrease ranges-location 1.

Variable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
B22	G 1 1	0.219999999	0	13573	1335	13573
C22	G 2 1	0	1335	14908	1E+30	1335
D22	S 1 1	0.159999996	0	18913	1335	18913
E22	S 2 1	0	1335	20248	1E+30	1335
F22	F 1 1	0	4845	83220	1E+30	4845
G22	F 2 1	0	371	78746	1E+30	371
H22	F 3 1	0.029999999	0	78375	371	78375
I22	B 1 1	0.029999999	0	214970	1E+30	214970
J22	O 1 1	3	0	85.5	1E+30	85.5
K22	W 1 1	0.300000012	0	495	1E+30	495
L22	As 1 1	1	0	10303	1E+30	10303

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
U13	constraints	0.219999999	13573	0.219999999	1E+30	0.219999999
U14	constraints	0.159999996	18913	0.159999996	1E+30	0.159999996
U15	constraints	0.029999999	78375	0.029999999	1E+30	0.029999999
U16	constraints	0.029999999	214970	0.029999999	1E+30	0.029999999
U17	constraints	3	85.5	3	1E+30	3
U18	constraints	0.300000012	495	0.300000012	1E+30	0.300000012
U19	constraints	1	10303	1	0	1

Table F-2: Program sensitivity report-allowable increase and decrease ranges-location 2.

Variable Cells

Cell	**Name**	**Final Value**	**Reduced Cost**	**Objective Coefficient**	**Allowable Increase**	**Allowable Decrease**
B22	G 1 2	0.219999999	0	15798	222	15798
C22	G 2 2	0	222	16020	1E+30	222
D22	S 1 2	0.159999996	0	21138	222	21138
E22	S 2 2	0	222	21360	1E+30	222
F22	F 1 2	0	4988	83648	1E+30	4988
G22	F 2 2	0.029999999	0	78660	143	78660
H22	F 3 2	0	143	78803	1E+30	143
I22	B 1 2	0.029999999	0	218290	1E+30	218290
J22	O 1 2	3	0	88.80000305	1E+30	88.80000305
K22	W 1 2	0.300000012	0	742.5	1E+30	742.5
L22	As 2 1	1	0	10206	1E+30	10206

Constraints

Cell	**Name**	**Final Value**	**Shadow Price**	**Constraint R.H. Side**	**Allowable Increase**	**Allowable Decrease**
U13	constraints	0.219999999	15798	0.219999999	1E+30	0.219999999
U14	constraints	0.159999996	21138	0.159999996	1E+30	0.159999996
U15	constraints	0.029999999	78660	0.029999999	1E+30	0.029999999
U16	constraints	0.029999999	218290	0.029999999	1E+30	0.029999999
U17	constraints	3	88.80000305	3	1E+30	3
U18	constraints	0.300000012	742.5	0.300000012	1E+30	0.300000012
U19	constraints	1	10206	1	0	1

Table F-3: Program sensitivity report-allowable increase and decrease ranges-location 3.

Variable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
B22	G 1 3	0	8677	19135	1E+30	8677
C22	G 2 3	0.219999999	0	10458	11042	10458
D22	S 1 3	0	8677	24475	1E+30	8677
E22	S 2 3	0.159999996	0	15798	8677	15798
F22	F 1 3	0	8693	85358	1E+30	8693
G22	F 2 3	0	2850	79515	1E+30	2850
H22	F 3 3	0.029999999	0	76665	2850	76665
I22	B 1 3	0.029999999	0	209160	1E+30	209160
J22	O 1 3	3	0	88.80000305	1E+30	88.80000305
K22	W 1 3	0.300000012	0	1980	1E+30	1980
L22	As 3 1	1	0	12150	1E+30	12150

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
U13	constraints	0.219999999	10458	0.219999999	1E+30	0.219999999
U14	constraints	0.159999996	15798	0.159999996	1E+30	0.159999996
U15	constraints	0.029999999	76665	0.029999999	1E+30	0.029999999
U16	constraints	0.029999999	209160	0.029999999	1E+30	0.029999999
U17	constraints	3	88.80000305	3	1E+30	3
U18	constraints	0.300000012	1980	0.300000012	1E+30	0.300000012
U19	constraints	1	12150	1	0	1

Table F-4: Program sensitivity report-allowable increase and decrease ranges-location 4.

Variable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
B22	G 1 4	0.219999999	0	19135	223	19135
C22	G 2 4	0	223	19358	1E+30	223
D22	S 1 4	0.159999996	0	24475	223	24475
E22	S 2 4	0	223	24698	1E+30	223
F22	F 1 4	0	6484	84503	1E+30	6484
G22	F 2 4	0.029999999	0	78019	997	78019
H22	F 3 4	0	997	79016	1E+30	997
I22	B 1 4	0.029999999	0	219950	1E+30	219950
J22	O 1 4	3	0	92.09999847	1E+30	92.09999847
K22	W 1 4	0.300000012	0	1732.5	1E+30	1732.5
L22	As 4 1	1	0	11178	1E+30	11178

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
U13	constraints	0.219999999	19135	0.219999999	1E+30	0.219999999
U14	constraints	0.159999996	24475	0.159999996	1E+30	0.159999996
U15	constraints	0.029999999	78019	0.029999999	1E+30	0.029999999
U16	constraints	0.029999999	219950	0.029999999	1E+30	0.029999999
U17	constraints	3	92.09999847	3	1E+30	3
U18	constraints	0.300000012	1732.5	0.300000012	1E+30	0.300000012
U19	constraints	1	11178	1	0	1

Table F-5: Program sensitivity report-upper and lower limits-location 1.

Variable	*Value*	*Reduced Cost*	*Original Val*	*Lower Bound*	*Upper Bound*
G 1 1	.22	0	13573	0	14908
G 2 1	0	1335	14908	13573	Infinity
S 1 1	.16	0	18913	0	20248
S 2 1	0	1335	20248	18913	Infinity
F 1 1	0	4845	83220	78375	Infinity
F 2 1	0	371	78746	78375	Infinity
F 3 1	.03	0	78375	0	78746
B 1 1	.03	0	214970	0	Infinity
O 1 1	3	0	85.5	0	Infinity
W 1 1	.3	0	495	0	Infinity
As 1 1	1	0	10303	0	Infinity
Constraint	*Dual Value*	*Slack/Surplus*	*Original Val*	*Lower Bound*	*Upper Bound*
Constraint 1	13573	0	.22	0	Infinity
Constraint 2	18913	0	.16	0	Infinity
Constraint 3	78375	0	.03	0	Infinity
Constraint 4	214970	0	.03	0	Infinity
Constraint 5	85.5	0	3	0	Infinity
Constraint 6	495	0	.3	0	Infinity
Constraint 7	10303	0	1	0	Infinity

Table F-6: Program sensitivity report-upper and lower limits-location 2.

Variable	Value	Reduced Cost	Original Val	Lower Bound	Upper Bound
G 1 2	.22	0	15798	0	16020
G 2 2	0	222	16020	15798	Infinity
S 1 2	.16	0	21138	0	21360
S 2 2	0	222	21360	21138	Infinity
F 1 2	0	4988	83648	78660	Infinity
F 2 2	.03	0	78660	0	78803
F 3 2	0	143	78803	78660	Infinity
B 1 2	.03	0	218290	0	Infinity
O 1 2	3	0	88.8	0	Infinity
W 1 2	.3	0	742.5	0	Infinity
As 2 1	1	0	10206	Infinity	Infinity
Constraint	Dual Value	Slack/Surplus	Original Val	Lower Bound	Upper Bound
Constraint 1	15798	0	.22	0	Infinity
Constraint 2	21138	0	.16	0	Infinity
Constraint 3	78660	0	.03	0	Infinity

Constraint 4	218290	0	.03	0	Infinity
Constraint 5	88.8	0	3	0	Infinity
Constraint 6	742.5	0	.3	0	Infinity
Constraint 7	10206	0	1	0	Infinity

Table F-7: Program sensitivity report-upper and lower limits-location 3.

Variable	*Value*	*Reduced Cost*	*Original Val*	*Lower Bound*	*Upper Bound*
G 1 3	0	8677	19135	10458	Infinity
G 2 3	.22	0	10458	0	19135
S 1 3	0	8677	24475	15798	Infinity
S 2 3	.16	0	15798	0	24475
F 1 3	0	8693	85358	76665	Infinity
F 2 3	0	2850	79515	76665	Infinity
F 3 3	.03	0	76665	0	79515
B 1 3	.03	0	209160	0	Infinity
O 1 3	3	0	88.8	0	Infinity
W 1 3	.3	0	1980	0	Infinity
As 3 1	1	0	12150	Infinity	Infinity
Constraint	*Dual Value*	*Slack/Surplus*	*Original Val*	*Lower Bound*	*Upper Bound*
Constraint 1	10458	0	.22	0	Infinity
Constraint 2	15798	0	.16	0	Infinity
Constraint 3	76665	0	.03	0	Infinity
Constraint 4	209160	0	.03	0	Infinity
Constraint 5	88.8	0	3	0	Infinity
Constraint 6	1980	0	.3	0	Infinity
Constraint 7	12150	0	1	0	Infinity

Table F-8: Program sensitivity report-upper and lower limits-location 4.

Variable	*Value*	*Reduced Cost*	*Original Val*	*Lower Bound*	*Upper Bound*
G 1 4	.22	0	19135	0	19358
G 2 4	0	223	19358	19135	Infinity
S 1 4	.16	0	24475	0	24698
S 2 4	0	223	24698	24475	Infinity
F 1 4	0	6484	84503	78019	Infinity
F 2 4	.03	0	78019	0	79016
F 3 4	0	997	79016	78019	Infinity
B 1 4	.03	0	219950	0	Infinity

O 1 4	3	0	92.1	0	Infinity
W 1 4	.3	0	1732.5	0	Infinity
As 4 1	1	0	11178	Infinity	Infinity
Constraint	*Dual Value*	*Slack/Surplus*	*Original Val*	*Lower Bound*	*Upper Bound*
Constraint 1	19358	0	.22	0	Infinity
Constraint 2	24475	0	.16	0	Infinity
Constraint 3	78019	0	.03	0	Infinity
Constraint 4	219950	0	.03	0	Infinity
Constraint 5	92.1	0	3	0	Infinity
Constraint 6	1732.5	0	.3	0	Infinity
Constraint 7	11178	0	1	0	Infinity

الخلاصة

تعد معامل إنتاج الخرسانة الاسفلتية لأغراض مشاريع الطرق إحدى الروافد المهمة في بناء الاقتصاد الوطني لتأثيرها المستمر في رفد عملية الاعمار بصورة عامة ومشاريع التعبيد بصورة خاصة ، واختيار الموقع الأمثل لهذه المعامل له تأثيرات كبيرة من الناحية الاقتصادية والبيئية والاجتماعية وبشكل مباشر وعلى المدى الطويل .

يهدف هذا البحث الى تهيئة وتحديد عوامل كمية ونوعية (تقليدية ومستدامة) تؤثر بشكل مباشر او غير مباشر على اختيار المواقع المثلى لمعامل إنتاج الخرسانة الاسفلتية والاعتماد عليها في بناء نظام يجري بموجبه اختيار المواقع المثلى لهذه المعامل.

لقد جرى اتباع منهجية علمية مركزة للبحث تضمنت مرحلتين ، مرحلة الدراسة النظرية والتي جرى فيها الاطلاع على البحوث والدراسات ذات العلاقة بموضوع البحث ومرحلة الدراسة الميدانية التي اشتملت على جمع البيانات والمعلومات عن واقع اختيار مواقع المعامل المشيدة في العراق واستطلاع آراء المعنيين عن طريق المقابلات الشخصية وأجراء الاستبيان التمهيدي والاستبيان وفق طريقة دلفي على عينة منتخبة من ذوي الخبرة والاختصاص في مجال الطرق وصناعة الاسفلت من اجل تحديد الأهمية النسبية للعوامل الكمية والنوعية المؤثرة في عملية اختيار المواقع المثلى لمعامل إنتاج الخرسانة الاسفلتية.

ومن ثم تم اقتراح نظام يعتمد العوامل الكمية والنوعية باهمياتها النسبية المستخرجة من نتائج الاستبيان وفق طريقة دلفي، مستخدماً برنامج POM-QM لتسهيل تطبيق النظام الذي يقوم باختيار الموقع الأمثل لمعمل إنتاج الخرسانة الاسفلتية. والنظام المقترح يشمل ثلاثة حالات : تحقيق اعلى فوائد اجتماعية وبيئية , تحقيق أعلى فوائد اقتصادية , تحقيق كلا الحالتين.

تم اختيار الموقع الأنسب من بين أربعة مواقع لإنشاء معمل انتاج الخرسانة الإسفلتية لمشاريع تعبيد وصيانة الطرق في قضاء الحر / محافظة كربلاء كمثال لتطبيق النظام. هذه المواقع هي: المنطقة الصناعية في الرزازة ، المنطقة الصناعية في الشريعة ، المنطقة الصناعية في خان الربع ، والمنطقة الصناعية في الحسينية. حيث تبين عند تطبيق هذا النظام على المناطق الصناعية الأربع أن الموقع الأمثل من حيث الحالات الثلاث سيكون المنطقة الصناعية في الرزازة. تدل الاستنتاجات التي تم التوصل أليها من خلال تحليل نتائج عملية تطبيق النظام المقترح على جدواه الاقتصادية ، كما أنه

يوجه صانعي القرار في صناعة الاسفلت لاختيار الموقع الأمثل والمستدام لمعمل انتاج الخرسانة الإسفلتية في العراق.

جمهورية العراق

وزارة التعليم العالي و البحث العلمي

جامعة كربلاء

كلية الهندسة

قسم الهندسة المدنية

تطوير نظام لأختيار المواقع المثلى لمعامل الخرسانة الاسفلتية لمشاريع الطرق في العراق

رسالة مقدمة الى مجلس كلية الهندسة / جامعة كربلاء وهي جزء من متطلبات نيل درجة الماجستير في علوم الهندسة المدنية / هندسة البنى التحتية

من قبل:
عمار دايم صالح

باشراف :
أ.م.د. حسين علي محمد الحمامي

ربيع الاول - 1444 تشرين الاول - 2022