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Optimizing Petroleum Products Distribution Centers Using GFA and AnyLogistix Simulation: A Case Study

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Abstract: *Background*: The Petroleum Products Distribution Company in Anbar Governorate is responsible for securing and distributing petroleum products to various sectors, including transportation, agriculture, industry, and households, through over 100 gas stations. The company has faced significant challenges due to the destruction of its infrastructure caused by past conflicts. These challenges have necessitated strategic decisions to design an efficient distribution network. *Methods:* This study aimed to assist the company in selecting the optimal location for a distribution center by evaluating four potential locations. Three of the proposed locations were suggested by the company: Ramadi, Habbaniyah, and Haqlaniyah. The fourth location, referred to as the GFA DC location, was determined through a greenfield analysis (GFA) experiment using AnyLogistix software (version 3.2.1. PLE) ALX. The simulation experiment in ALX was conducted using product data, fuel station locations, order quantities, distribution center data, and transportation and emissions data. *Results*: The simulation results, taking into account both practical and regulatory constraints, indicated that the Ramadi location was the most suitable for establishing the new distribution center. *Conclusions*: Based on the analysis, the study concluded that the Ramadi location was the optimal site for building the petroleum products distribution center in Anbar Governorate, offering a solution that aligns with the company's goals of improving distribution efficiency and overcoming existing logistical challenges.

Keywords: distribution center; petroleum products distribution; simulation; greenfield analysis; AnyLogistix

1. Introduction

Petroleum supply chains in the estuary sector are a key factor that directly impacts the efficiency of oil product distribution operations, meeting the needs of both local and international markets. The estuary sector represents the vital link between the final refineries and consumers through fuel stations and various distribution centers. The challenge is to ensure a smooth flow of oil products, such as gasoline, diesel, and liquefied natural gas, from refineries to consumers, while reducing costs and minimizing environmental emissions and achieving operational efficiency [1].

Planning supply chains in this sector requires defining flexible strategies for managing logistical facilities, storing products, and selecting suitable transportation methods. Given the importance of this sector in securing the availability of energy and resources for modern

energy needs, it is necessary to develop accurate and advanced methods and planning strategies that contribute to improving performance and achieving sustainability.

Strategic planning in the estuary sector focuses on defining long-term, overarching goals and key decisions that will impact the sector's future performance. This type of planning involves determining the optimal locations for warehouses and gas stations, as well as selecting the most cost-effective and environmentally efficient methods for transferring [2]. In. It also considers the feasibility of building new facilities or updating existing ones to maximize the benefits of resources [3].

One of the key strategic decisions facing supply chain managers during the design phase of the supply chain network is selecting the optimal location for the warehouse or distribution center. This decision entails a significant investment and requires substantial financial expenditures to establish it [4]. It has long-term effects because it cannot be easily and repeatedly changed. Warehouse location is a precursor to the supply chain design process, which has a significant and far-reaching impact on the overall performance of the logistics and distribution system. An optimal location enhances overall operational performance by ensuring efficient product delivery and minimizing transportation costs. It also enhances customer satisfaction by ensuring timely delivery and reducing lead times. The strategic and optimal choice of location is crucial and necessary for both companies and consumers because it directly impacts logistics efficiency and supply chain sustainability [5].

This study addresses the urgent issue of determining the most efficient location for the new petroleum products distribution center, a complex decision due to infrastructure damage, vast geographical coverage, and the need to reduce transportation costs and emissions. Consequently, the primary objectives of this research are to determine the optimal location of a distribution center among four proposed locations, evaluate each site using advanced simulation and improvement tools, minimize transportation expenditures, and reduce emissions while maintaining the provision of effective service. Consequently, this study aims to address the following research question: How can the optimal location of the Petroleum Product Distribution Center in Anbar Governorate be determined to minimize transportation costs and emissions while ensuring adequate service provision? The study assumes the accuracy of the available data related to transportation costs, distances, and emissions, and that the proposed locations are viable within the current infrastructure context. The scope of this research is explicitly limited to the Petroleum Products Distribution Company network within the Anbar Governorate, including comprehensive reviews of proposed distribution center locations. Following this introduction, the paper reviews the relevant literature on improving distribution centers, outlines the methodology and analytical tools, discusses the results, and highlights the key findings, limitations, and recommendations for future research.

2. Literature Review

2.1. Petroleum Supply Chains (PSC)

Supply Chain Management is defined as the coordination of the physical, logical, and financial flows management between the supply chain networks (SCN) [6], whose goal is to deliver the right product, in the right amount, at the right time, for the right customer, meaning to respond to customer demand efficiently [7].

Ref. [8] defined SCM as "the management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at less cost to the supply chain as a whole".

For these reasons, supply chain management is one of the modern and advanced management methods that have emerged and developed rapidly in various industries. It

has become an important and necessary factor in companies' success and ability to control flows and provide exceptional services to their customers to be competitive.

Petroleum supply chains (PSC), or oil supply chains (OSC), are the most complex and advanced of all other supply chains. It is vertically integrated and includes activities from exploration to refining, refineries, and distributing those refined products in an extensive logistical network to consumer markets [3].

The petroleum supply chain (PSC) is divided into three sectors: upstream, middle, and downstream. The upstream sector includes oil exploration, drilling, extraction, pro-duction, and transportation of crude oil.

Some authors, including [9], consider transporting crude oil to be an activity of the downstream sector, and others, including [10], consider it to be among the activities of the middle sector. Regardless of these differences, refining is among the activities of the middle sector. According to [9] the downstream sector includes the storage, distribution, and marketing of refined products.

Transportation infrastructure, refinery, depot, and distribution center (DC) locations, demand patterns, and storage capacities are key factors that affect the efficiency of the oil supply chain network. To design a resilient supply chain that effectively addresses logistical challenges and meets sustainability goals, advanced techniques such as simulation tools and optimization models are increasingly being applied. Recent studies emphasize that integrating simulation with logistics optimization enhances the adaptability of supply chain networks to demand fluctuations, transportation disruptions, and supply bottlenecks, enabling real-time adjustments and improved decision-making [11].

2.2. AnyLogistix Software

ALX is an advanced piece of software from AnyLogic Company that combines both optimization and simulation capabilities to handle the complexities of supply chain management. Thanks to its user-friendly interface, the model can be constructed and analyzed without requiring extensive programming knowledge, only the most basic knowledge [12]. The software features a robust optimizer and a visual map-based interface, enabling the design and maintenance of your supply chain models while enhancing scalability and adaptability for varying levels of complexity [13]. It has also been widely applied to address supply chain disruptions, such as enhancing supply chain resilience [14]. It supports various experiments, a form of stochastic and dynamic simulation used to model disruptions and different scenarios [15]. Integrating operational data with simulation and optimization techniques empowers organizations to improve sustainability and resilience in their supply chains [13,16].

Several studies have utilized ALX to support decisions in various sectors, achieving meaningful results. For example, ref. [15] ALX to analyze the effect of interruption on the design of production and distribution networks. The study focused on the behavior of production demand during periods of turmoil and recovery. This study sheds light on how to simulate the supply chain disorder, providing valuable insights into the recovery strategies that enhance operating performance and reduce costs. Ref. [17] applies the tool to design sustainable logistics networks, and merge the life cycle evaluation methodology (LCA) to evaluate environmental effects through different logistical network scenarios. This study highlighted the program's ability to support a sustainability model in supply chain designs, thereby improving both cost and environmental impact.

In the pharmaceutical sector, ref. [17] utilizes ALX to assess risk in supply chains and enhance the site selection process for new facilities in Mexico. By simulating various supply chain configurations, the study demonstrated how ALX can facilitate the expansion of production facilities, thereby increasing the efficiency of the supply chain. Ref. [18]

expanded the use of ALX during the COVID-19 pandemic to predict the effects of the epidemic's spread on global supply chains. The study employed simulation models to evaluate the disorders caused by epidemics and the proposed strategies to enhance the elasticity of the supply chain, demonstrating how the program can effectively manage crises. Ref. [19] analyzed the effect of COVID-19 on the food supply chain in Germany. Their twin digital approaches enabled them to integrate the disorders in the food retail processes and suggest strategies to optimize elasticity, indicating the ability to adapt to the program across various supply chain sectors. Ref. [20] also utilized ALX in a simulation approach to optimize the distribution of COVID-19 vaccines in Norway. Their study focused on optimizing the cold chain logs, highlighting the ALX ability to improve the temperature-sensitive supply chains. In another related study, ref. [21] utilized the program to redesign vaccine supply chains in three countries, offering insight into how different countries enhanced their vaccine distribution networks through simulation. Ref. [22] applied ALX to analyze the grape distribution network in the Brazilian Valley of São Francisco, with a focus on determining the optimal location of distribution centers (DCS). Their study demonstrated how ALX can enhance agricultural supply chains by improving logistical services and distribution efficiency. In [14], an integrated framework was developed to enhance simulation using ALX, enabling the design of the supply chain to be more flexible. This framework combines planning and control decisions, providing a comprehensive approach to managing the supply chain.

AlX was also used to analyze the supply chain for e-commerce. Ref. [16] used the tool to predict the demand for jewelry products and improve the supply chain for e-commerce. By identifying cities with high financial returns and demanding the product, the study showed how ALX can improve supply chains in the retail sector. Likewise, ref. [22] utilized ALX to optimize food distribution networks, demonstrating its effectiveness in enhancing logistics services across various industries.

In recent years, ref. [23] applied a comparison of simultaneous reopening strategies after supply chain disruptions. Separate multi-term events, simulating the model presented, provided insight into the impact of reopening the facility on the performance of the global supply chain [24]. I proposed a periodic methodology using ALX to enhance the elasticity of supply and sustainability of the supply chain, and to verify the validity of the approach in the study of agricultural food [25]. The program's utility also demonstrated the modeling of supply chain efficiency in logistics services in Antarctica, which improves cost and operational timing. Ref. [26], in their studies on optimizing the distribution network for agricultural food products, used the ALX to confirm that strategic decisions related to the size and location of the facility, such as factories and distribution centers, are pivotal in managing the supply chain, which significantly affects transportation costs, lead times, and responding to demand. They also highlighted that improving the locations of the facility through simulation tools, such as ALX, can enhance efficiency and reduce costs for suppliers, facilities, and clients within a strategic designer distribution network.

Finally, ref. [13] examined the application of ALX to enhance the sustainability of the supply and logistics chain by reviewing case studies. Their studies identified the trends and challenges in enhancing supply chain performance, confirming the increasing importance of tools such as ALX in managing the modern supply chain.

The current literature highlights the use of ALX in various industries, including pharmaceuticals, retail food, and disaster alert, to improve supply chain networks and enhance flexibility. However, there is a shortage of studies that focus specifically on the petroleum sector, especially in the context of making strategic decisions for the optimal distribution center sites. This research aims to fill this gap through the application of green field analyses (GFA) and the simulation techniques in ALX to locate the most effective

distribution center for petroleum products, addressing both operational efficiency and sustainability in a sector with unique logistical and environmental challenges.

3. Methodology

At this stage, primary data were collected through interviews with department managers at the Petroleum Products Distribution Company—Anbar Branch and gas station managers to gather information about filling station data, their locations, demand, costs, selling prices, and other relevant details. ALX was utilized by entering the coordinates of gas station locations (for customers or order nodes), daily recurring order quantities, and storage capacities of 100 active gas stations to determine the location of the proposed distribution center using the GFA method. Next, the DC locations obtained from the GFA results (GFA DC), the Ramadi location, the Habbaniyah location, and the Haqlaniya location were validated for their feasibility using the SIM method. Feasibility was evaluated based on the accessibility of the distribution path given in the SIM results. Moreover, the transportation cost was compared across the four facilities, and the location with the lowest transportation cost was then chosen, as the fixed costs and other costs are equal among the four facilities.

3.1. Case Company

This paper examines the supply chain network structure of a petroleum products distributor in Iraq, specifically in Anbar Governorate. The company is called the Petroleum Products Distribution Company. The company was established in 1959 and is the first government institution to practice distributing petroleum products in Iraq. The Petroleum Products Distribution Company, one of the entities within the Ministry of Oil, serves as a strategic link in the chain of oil industry operations. The importance of its activity stems from the fact that it is linked to citizens' lives, whether for direct consumption or industrial and commercial purposes, to sustain daily life.

The company is responsible for providing petroleum products to citizens, supplying electric power generation stations and private and governmental generators throughout the country with gas oil fuel, and marketing refinery production of liquid gas, gasoline, jet fuel, diesel, and gas oil through the management and operation of sales outlets represented by filling stations distributed throughout Iraq. The Anbar branch is considered one of the main branches of this company and one of the basic pillars for ensuring the stability of fuel supplies in Anbar Governorate, the largest Iraqi governorate in terms of area, which amounts to 138,579 km^2 and constitutes 32% of the total area of Iraq. PPDC-ANBAR plays a pivotal role in distributing petroleum products to over 100 gas stations across Anbar Governorate. It is part of a vast distribution network that provides petroleum products, such as gasoline, diesel, liquefied gas, and kerosene, to various sectors in Anbar Governorate, ensuring the continuity of economic and social life in the governorate and its surrounding areas.

The company has been facing significant challenges for many years, especially after the infrastructure of its facilities was severely damaged due to the events that Iraq has witnessed since 2003 and the subsequent military operations, sabotage, and theft. These damages caused all oil tankers, petroleum product distribution centers, railway lines, and pipelines transporting petroleum products in western Iraq to be out of service. These challenges were exacerbated with the fall of western Iraqi cities and some other cities into the grip of terrorist organizations in 2014 and 2015, which added additional pressure on the company as it sought to secure energy under difficult and complex circumstances (PPDC).

In the face of these challenges, the company must make strategic and tactical decisions to design an efficient and effective distribution network for its new petroleum products. This study will address one of the most important of these decisions: determining the

optimal locations for distribution centers, considering the locations of current and potential customers, the distances between them and the distribution centers, and their needs for petroleum products. The study aims to help the company choose the best location to establish the distribution center from among four proposed locations, three of which were proposed by the company: the Ramadi location, the Habbaniyah location, the Haqlaniyah location, and the fourth location (GFA DC), which will be obtained through the results of the GFA experiment in the AnyLogistix software (ALX). This study also aims to determine the feasibility of the four distribution center locations using the SIM experience with the ALX, through which customer requests can be met at the lowest possible cost, while maintaining the highest levels of efficiency in distribution and reducing the cost and emissions associated with transportation and distribution operations.

3.2. Data Collection

In this part, the most important data collected from the Petroleum Products Distribution Company—the Anbar Branch and gas station managers will be clarified for use in the research.

3.2.1. Gas Station Demand and Location

In Table 1, the periodic demand data for each gas station are presented, which must be met during the simulation. In this study, two parameters were used to define the periodic demand for the fuel station: order interval and quantity. The table also contains the geographical location (latitude and longitude) of each gas station, which is useful for plotting the location of each station in ALX and can therefore be considered with the demand data to determine the location (GFA DC) proposed using the GFA experiment.

Table 1. Gas station demand and location.

Station	Demand		Location		Station	Demand		Location	
	Qun./m^3	Day	Latitude	Longitude		Qun./m^3	Day	Latitude	Longitude
1	150	1	33.43719	43.30053	51	30	4	33.47043	43.4452
2	90	1	33.43055	43.34848	52	30	2	33.42945	43.50579
3	30	2	33.45007	43.20973	53	30	4	33.36122	43.64998
4	30	3	33.2884	42.56695	54	30	1	33.33038	43.72268
5	30	5	33.17003	41.67074	55	30	1	33.357	43.8031
6	30	2	33.36815	43.54516	56	30	2	33.34736	43.68698
7	150	1	33.34995	43.76097	57	30	2	33.35506	43.85264
8	30	1	33.35737	43.83502	58	30	2	33.44765	43.63411
9	30	2	33.40173	43.6956	59	30	1	33.36661	43.75826
10	30	1	33.39673	43.91753	60	30	2	33.38483	43.73429
11	30	1	33.61892	42.85139	61	30	3	33.3375	43.96502
12	30	1	33.88623	42.51917	62	30	1	33.76199	43.72889
13	30	3	34.09489	42.35672	63	30	1	33.41226	43.94692
14	30	3	34.08034	42.38457	64	30	2	33.46929	43.91743
15	30	2	34.37101	41.98389	65	30	3	33.4312	44.04644
16	30	2	34.47605	41.92102	66	30	4	33.12917	43.81344
17	30	1	34.39676	40.9828	67	30	4	33.31154	43.72726

Table 1. *Cont.*

Station	Demand		Location		Station	Demand		Location	
	Qun./m³	Day	Latitude	Longitude		Qun./m³	Day	Latitude	Longitude
18	30	3	34.42872	41.22982	68	30	2	33.31327	43.73234
19	30	2	33.03797	40.28899	69	30	2	33.31976	43.74009
20	30	1	32.7477	39.0234	70	30	2	33.66857	42.80739
21	30	2	32.05065	42.25189	71	30	1	33.65926	42.79165
22	30	4	31.42953	41.46709	72	30	3	33.54597	42.90232
23	30	2	33.41171	43.3124	73	30	4	33.52991	43.05162
24	30	1	33.4216	43.33482	74	30	4	33.52622	42.89656
25	30	3	33.24085	44.0231	75	30	2	34.13888	42.3543
26	30	2	33.41727	43.23899	76	30	3	34.07086	42.31622
27	30	1	33.41701	43.2245	77	30	2	34.35242	41.94865
28	30	1	33.41357	43.21093	78	30	2	34.1246	42.36031
29	30	3	33.39949	43.11707	79	30	4	34.04862	42.35958
30	30	3	33.40503	43.01246	80	30	1	33.03534	40.30774
31	30	3	33.38873	43.08906	81	30	3	33.03916	40.04332
32	30	3	33.57769	42.88743	82	30	3	33.04317	40.91471
33	30	3	33.42368	42.98106	83	30	3	34.35131	41.11939
34	30	4	33.42338	42.97893	84	30	3	34.4143	41.42888
35	30	2	33.42458	43.4167	85	30	4	34.3701	41.20539
36	30	3	33.46566	43.28697	86	30	2	34.36285	41.08859
37	30	4	33.46892	43.28295	87	30	2	34.37573	41.08783
38	30	3	33.43888	43.26878	88	30	4	33.56464	43.3648
39	30	1	33.44096	43.196	89	30	3	33.3914	43.78868
40	30	2	33.49578	43.24572	90	30	2	33.4633	43.27426
41	30	3	33.48388	43.22877	91	30	1	33.53084	43.62855
42	30	4	33.53155	43.17705	92	30	3	34.35043	41.20987
43	30	2	33.42024	43.33488	93	30	3	34.3373	41.12433
44	30	4	33.46159	43.18525	94	30	3	33.23056	43.7547
45	30	3	33.41164	43.19842	95	30	1	33.32143	43.78901
46	30	1	33.41446	43.28219	96	30	1	32.77798	39.03828
47	30	3	33.44709	43.27187	97	30	1	33.34148	43.79888
48	30	2	33.40549	43.4543	98	30	2	33.18051	43.84668
49	30	2	33.39522	43.5177	99	30	1	33.63266	42.83748
50	30	3	33.36728	43.55268	100	30	3	34.38636	41.24101

3.2.2. Product

Table 2 shows information about the product type, purchase price, and selling price to determine the optimal profit from the implemented scenario.

Table 2. Product Detail.

Product Type	Purchase Price/m^3	Selling Price/m^3
Diesel	200,000 IQD	400,000 IQD

3.2.3. Additional Data

Table 3 presents key transportation parameters for truck shipments necessary to implement the ALX simulation, including truck capacity, truck speed, and transportation cost, among others.

Table 3. Key transportation parameters for truck shipments.

Time Period	1 January–31 December 2024
Truck capacity	30 m^3
Truck speed	60 km/h
Truck CO$_2$ Emissions	1.088 kg/km
Transportation cost	150 IQD/m^3/km
Shipping type	FTL

The truck speed value was determined by Iraqi traffic regulations, and the carbon emission coefficient was calculated using the methodology provided by [27].

3.3. Data Processing

Data processing begins with Greenfield's analysis using ALX software to determine the latitude and longitude points of the proposed distribution centers. Greenfield analysis data requirements include filling station data, such as location coordinates and periodic order quantities. The data were entered into the ALX, and the Greenfields analysis experiment, also called the Center of Gravity, was conducted to determine the proposed optimal location for the GFA distribution center based on the locations of the filling stations and order quantities, which results in the following:

In this experiment, the data were processed to determine the location of the proposed distribution center using the GFA method through the ALX. The results of this experiment indicated the location of the distribution center at latitude 33.435243 and longitude 43.336008, or more specifically, this location is situated in the center of Ramadi, the capital of Anbar Governorate, as shown in Figure 1. Despite this, further steps must be taken to verify whether the experiment's results can be implemented, and this is why it is necessary to conduct a SIM experiment.

3.4. Simulation (SIM) Experiment

A SIM experiment was conducted to determine if the results of the GFA experiment are valid. Also, through the results of the (SIM) experiment that was conducted for the four scenarios, a comparison was made between them to find out the best scenario by evaluating the financial aspect, specifically the value of the profit, the cost of transportation, or the length of the total distance, assuming that other costs are equal, such as the cost of establishing a distribution center, the cost of storage, and other facility costs (fixed cost), including the cost of transportation per kilometer, the vehicle capacity, and the vehicle speed. In this experiment, the net profit or the lowest transportation cost is compared among the proposed GFA location, the Ramadi location, the Habbaniyah location, and the Haqlaniya location to assist decision-makers in the company in choosing the best location to increase the company's net profit.
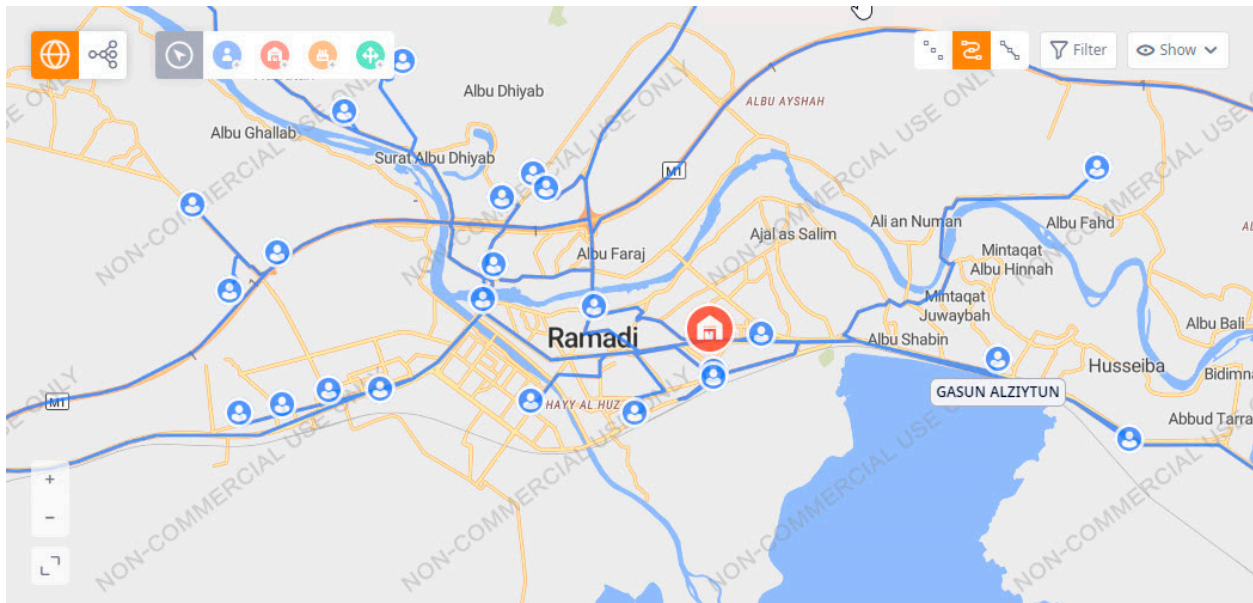
Figure 1. (SIM) Experiment results (GFA DC).

3.5. Greenfield Analysis (GFA)

Greenfield analysis (GFA), also known as center of gravity analysis, is a technique used to determine the optimal locations for new facilities [15], considering factors such as customer locations, distance from warehouses to customers, and customer demands. The optimal location of the warehouse or facility is determined by finding the point where the sum of the distances of all suppliers to the factory (demand point) is at its minimum, weighted by the volume of product flow between each supplier and the potential factory. The distances from customers to the warehouse are calculated to determine the optimal location of the warehouse.

GFA is a method that utilizes a high level of abstraction and minimal detail as input to analyze existing data, including customer locations (order points), demand per customer, the number and locations of distribution centers, and/or service distances.

To design the distribution network for petroleum products in Anbar Governorate, we begin by determining the locations of gas stations and their daily demand, which are the basic parameters related to the Gas Flow Area (GFA). We applied a mathematical model based on GFA, as described by [28]. The ordered pair of coordinates (*xi*; *yi*) represents the location of each gas station, which cannot be changed, as they are the input data or problem information.

In contrast, the coordinates of the distribution center or new warehouse, p, are variable and determined after calculating the data in a way that matches the set parameters. Therefore, (*px*, *py*) are the decision variables in this scenario.

In addition, we assume that the distance value and the transport volume (demand-D) are linearly related to the transport cost, Z. We can see that the possible distances and coordinates of the potential distribution center or warehouse will affect the total transportation cost. The transportation cost from the potential distribution center (*px*; *py*) to the customer's packing station location (*xi*; *yi*) is approximately equal to the distance and demand, as shown in the following equation:

$$Z(p_x; p_y) = \sum_{i-1}^{N} D(xi, yi).d((px, py)) \tag{1}$$

where *N* is the total number of gas station locations *D(xi; yi)* is the demand for gas stations *d*[*(xi; yi)*; *(px; py)*], which is the travel distance from the gas station location (*xi*; *yi*) to the

distribution center (*px; py*) To reduce the transportation cost, it is necessary to change *px* and *py* so that *Z (px; py)* becomes a minimum.

Unconstrained decision variables can determine the optimal point *Z*.

The first derivative *Z′* is determined as follows:

$$\frac{dZ}{dpx} = \frac{Npx}{\sqrt{(xi - p_x)^2 + (x_i - p_y)^2}} - \sum_{i-1}^{N} \frac{x_i}{\sqrt{(x_i - p_x)^2 + (x_i - p_y)^2}} \tag{2}$$

$$\frac{dZ}{dpx} = \frac{Npy}{\sqrt{(xi - p_x)^2 + (x_i - p_y)^2}} - \sum_{i-1}^{N} \frac{y_i}{\sqrt{(x_i - p_x)^2 + (x_i - p_y)^2}} \tag{3}$$

Equations (4) and (5) are used to calculate the optimal location of the distribution center based on demand data [28].

$$p_x = \frac{\sum_{j=1}^{N} \frac{D(x_j;y_j) \cdot x_j}{\sqrt{(px-x_j)^2 + (p_y-y_j)^2}}}{\sum_{j=1}^{N} \frac{D(x_j;y_j)}{\sqrt{(px-x_j)^2 + (p_y-y_j)^2}}} \tag{4}$$

$$p_y = \frac{\sum_{j=1}^{N} \frac{D(x_j;y_j) \cdot y_j}{\sqrt{(px-x_j)^2 + (p_y-y_j)^2}}}{\sum_{j=1}^{N} \frac{D(x_j;y_j)}{\sqrt{(px-x_j)^2 + (p_y-y_j)^2}}} \tag{5}$$

We apply Equations (1)–(5) according to the calculation of the optimal coordinate pair for the distribution center, using ALX, as the calculations involved are complex.

4. Results

4.1. Experiment Analysis

(SIM) Experiments were conducted on each of the four scenarios to obtain the results for each scenario or distribution center as follows:

4.1.1. GFA DC Location

To conduct the simulation experiment (SIM) for the GFA DC location obtained through the greenfield analysis experiment, the necessary data are entered, which include gas station and product data, as well as the coordinates of the GFA DC location, as shown in Figure 1. We can see from the results of the experiment how our supply chain performance is by analyzing the key performance indicators shown in Table 4.

Table 4. (SIM) Experiment results (GFA DC).

CO_2 from Vehicles	1,575,822 kg
Traveled Distance	1,448,366 km
Transportation Cost	6,517,645,674 IQD

4.1.2. Ramadi Location

The same SIM experiment was conducted, but for the Ramadi location. The experiment was conducted using the same previous input data, including costs and coordinates of filling station locations, as well as order quantities. The only difference is the location coordinates of a distribution center, where coordinates were entered for the Ramadi location, as shown in Figure 2. You can view the experiment's results in Table 5. The total costs have increased to 6,749,151,793 IQD, compared to the result of GFA DC, which was 6,517,645,674 IQD.

Likewise, CO_2 emissions increased to 1,631,795 kg, compared to the GFA DC result of 1,575,822 kg, due to the increase in transportation distance.
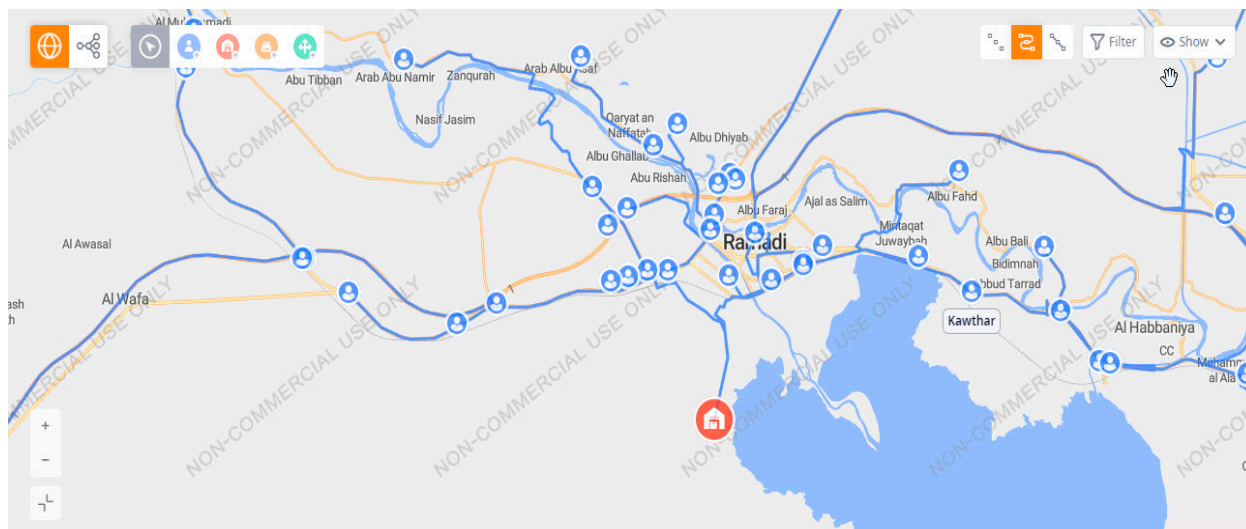

Figure 2. (SIM) Experiment results (Ramadi location).

Table 5. (SIM) Experiment results (Ramadi location).

CO_2 from Vehicles	1,631,795 kg
Traveled Distance	1,499,812 km
Transportation Cost	6,749,151,793 IQD

4.1.3. Habbaniya Location

The same SIM experiment was conducted again for the proposed distribution center (located in Habbaniya). The experiment was conducted using the same previous input data, including costs and coordinates of filling station locations, as well as order quantities. The only difference is the distribution center location coordinates, where the Habbaniya location coordinates were entered. As shown in Figure 3, we can see the results of the experiment in Table 6, which indicate that the total costs were 6,846,310,260 IQD. At the same time, the location changes also led to increased CO_2 emissions from the transportation process (1,655,286 kg).
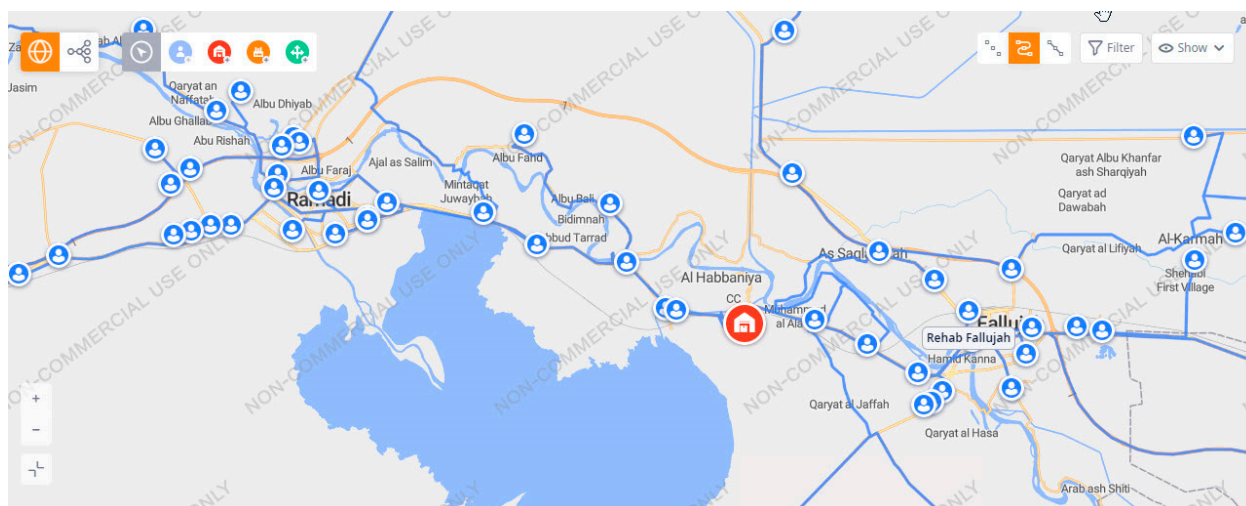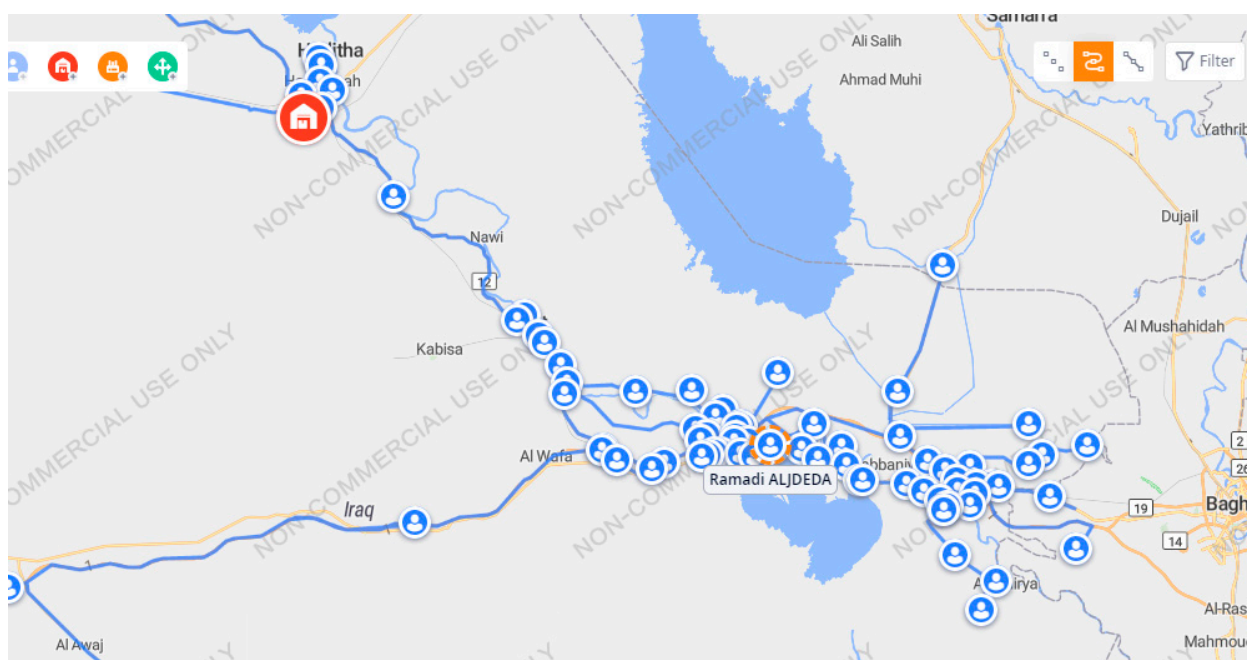

Figure 3. (SIM) Experiment results (Habbaniya location).

Table 6. (SIM) Experiment results (Habbaniya location).

CO_2 from Vehicles	1,655,286 kg
Traveled Distance	1,521,402 km
Transportation Cost	6,846,310,260 IQD

4.1.4. Haqlaniya Location

With the same previous input data of costs and coordinates of filling station locations, as well as order quantities, the only difference in this experiment is the distribution center location coordinates, where the Haqlaniya location coordinates were used. A SIM experiment was conducted for the proposed location (Haqlaniyah location), and as shown in Figure 4, the results of the experiment are presented in Table 7. Notably, the total costs and CO_2 emissions increased significantly. They were (13,662,535,469 IQD) and (3,303,297 kg) on straight.

Figure 4. (SIM) Experiment results (Haqlaniya location).

Table 7. (SIM) Experiment results (Haqlaniya location).

CO_2 from Vehicles	3,303,297 kg
Traveled Distance	3,036,119 km
Transportation Cost	13,662,535,469 IQD

5. Discussion

As shown in Table 8, a comparative analysis was conducted across four distribution scenarios. Although statistical testing was not applicable due to the deterministic nature of the model outputs, a relative difference analysis reveals meaningful insights:

The Ramadi distribution center achieved the lowest transportation cost (6.75 billion IQD) and CO_2 emissions (1.63 million kg), representing a reduction of over 50% in both metrics compared to the Haqlaniya scenario (13.66 billion IQD and 3.30 million kg CO_2).

Table 8. Comparison results.

	GFA DC	Ramadi	Habbaniya	Haqlaniya
CO_2 from Vehicles kg	1,575,822	1,631,795	1,655,286	3,303,297
Traveled Distance km	1,448,366	1,499,812	1,521,402	3,036,119
Transportation Cost IQD	6,517,645,674	6,749,151,793	6,846,310,260	13,662,535,469

The GFA-based optimization (GFA DC) further improved results, lowering costs by approximately 3.4% compared to Ramadi and reducing CO_2 emissions by an additional 3.4%.

Although Habbaniya performed moderately better than Haqlaniya, it remained inferior to both GFA and Ramadi options in all indicators.

Although the GFA DC location proposed through the Green Field Analysis (GFA) experiment achieves the lowest CO_2 emissions, lowest transportation cost and the shortest transportation distance, as shown by the results of the simulation experiment (SIM) in ALX, compared to the locations of other distribution centers, as shown in Table 8. It was found upon ground inspection of the proposed location (GFA DC) that the proposed ground location could not be selected due to the following critical considerations:

- Practical constraints—The land area available for the proposed location is insufficient to accommodate the structural design and storage capacities planned for the distribution center. The petroleum products distribution center requires ample space for storage tanks, operational facilities, and future expansion [5].
- Regulatory restrictions—Government regulations in Iraq prohibit the establishment of industrial facilities, including petroleum product distribution centers, within residential neighborhoods for several reasons related to health, safety, and the environment. These facilities and installations can pose risks such as fires, air pollution, noise, and damage to internal road infrastructure due to the heavy loads of fuel trucks.

The other three locations proposed by the company have sufficient areas to establish the required distribution center. They are located far from residential neighborhoods, with the added benefit of potential future expansion, as the company owns the land. Thus, the fixed costs and other costs are equal for all three facilities; therefore, the comparison is based on the lowest total transportation cost.

On this basis, the Ramadi location is the optimal site for establishing the required distribution center, as it has the lowest total transportation cost among the three locations.

6. Conclusions

This study identifies the Ramadi location as the optimal choice for establishing a petroleum products distribution center in Anbar Governorate, despite the GFA DC location offering lower costs and emissions in simulations. The Ramadi site's advantages in terms of land availability, regulatory compliance, and future expansion potential make it the most feasible option. The use of the simulation model, as shown in this study through ALX, proves to be a valuable tool for understanding the complexities of logistics chains. ALX is a powerful software that combines optimization and simulation to manage complex supply chains. Its user-friendly interface enables model creation and analysis without extensive programming knowledge. ALX enhances supply chain resilience by simulating it, helping organizations improve sustainability and adaptability. However, it comes with certain limitations. First, it is data-intensive, requiring large amounts of detailed data for accurate simulations, which can be challenging to obtain in real-world settings. Additionally, the software relies on manual data entry, which increases the risk of errors in inputting critical information for simulations or optimization. Moreover, the commercial version of ALX is quite expensive, making it challenging for researchers or smaller organizations with limited

budgets to access. Despite these challenges, ALX remains a valuable tool for strategic decision-making in supply chain optimization.

One of the significant limitations of this research is the lack of access to a database, particularly financial data, for the researchers. This required conducting numerous face-to-face meetings with department managers at the company and fuel stations to gather the necessary data for completing the study.

For future research, we suggest extending the analysis to other regions with different logistical challenges, incorporating dynamic demand and disruptions into the model, and integrating additional sustainability metrics such as energy consumption and social impacts to provide a more comprehensive evaluation.

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Data Availability Statement: The data supporting the findings of this study were collected through face-to-face interviews with department managers and fuel station managers, as well as field visits to fuel stations to record their geographic coordinates. The data are available upon reasonable request from the corresponding author.

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