JJMIE

Volume 18, Number 4, December. 2024
ISSN 1995-6665
Pages 877- 889
https://doi.org/10.59038/jjmie/180418
Editor-in-Chief: Prof. Ali M. Jawarneh

Jordan Journal of Mechanical and Industrial Engineering

# Optimal Agricultural Product Central Market Location in Jordan

Izdiad Atallah[1], Mahmoud Barghash[2,*], Mazen Arafeh[3], Nader Santarisi[4]

[1]Industrial Engineering department, The school of Engineering, The university of Jordan Amman 11942, Jordan
[2]Industrial Engineering department, The school of Engineering, The university of Jordan Amman 11942, Jordan.
[3]Industrial Engineering department, The school of Engineering,The university of Jordan Amman 11942, Jordan
[4]Industrial Engineering Department Faculty of Engineering Technology and Sciences, Higher Colleges of Technology, DWC. Dubai, UAE.

Received 27 Dec 2023 Accepted 12 Aug 2024

**Abstract**

Food supply chain management is a critical global issue due to its impact on food costs and, consequently, everyone's life. This study aims to optimize the location of central markets for fruits and vegetables in Jordan, which has significant cost implications for various stakeholders including farmers, investors, infrastructure providers, and society at large. Notably, this research is pioneering as it is the first to address central market locations in Jordan. The study focuses on optimizing total costs while satisfying constraints that reflect stakeholders' needs, employment opportunities, accessibility, congestion reduction, and minimizing long-distance travel. The problem is formulated as a mixed integer linear program (MILP) and solved using MATLAB. We conducted a comprehensive process that included problem formulation, data collection, MATLAB programming, and solution determination. Key findings include specifying the optimal locations for the central markets, as well as the quantities to be shipped from farms to each central market and from each central market to retailers. Additionally, a roadmap for improving central market status based on budget and priorities was developed. The study proposes a balanced trade-off between cost reduction and implementation feasibility. It suggests limiting the number of potential central markets to six, resulting in a total cost of 79.52 million JD and achieving a 26.50% savings compared to the current situation. This research provides a practical framework for policymakers to enhance the efficiency of food supply chains in Jordan.



**Keywords**: Mixed integer linear programming, facility location problem, food supply chain, central markets, Jordan..

## 1. Introduction

Food industries are vital for economic growth and employment generation [1,2]. Agriculture, as a major source of national income, forms the backbone of Jordan's economic, social, and environmental development. Since the founding of the Hashemite Kingdom of Jordan in 1946, the agriculture sector has been a crucial driver of these dimensions, significantly contributing to the gross domestic product (GDP) [3,4,5]. According to the Department of Statistics (DOS, 2009), the field crops and other agricultural crops sector ranks among the top nineteen economic sectors out of eighty-one sub-sectors contributing to the GDP. Jordan relies on agriculture to be the economic base of rural development through the investment of available resources [3,4]. As a result, efficient vegetable and fruit supply chains are critical components for ensuring the national economy's long-term growth.

Since the establishment of the Hashemite Kingdom of Jordan, and in response to population growth caused by factors such as migration from neighbouring countries and an increased demand for agricultural commodities at reasonable prices, the idea of establishing a central market for vegetables and fruit has emerged. There is currently one central market in Al- Juwaideh; the investment in this project costs 25 million JD, which is equivalent to 35.26 USD, and annual revenues are estimated to be around 13 million JD, which is equivalent to 18.34 million USD. [6,7].

The agricultural sector is significantly influenced by population growth, which necessitates the expansion of farm production capacities to meet increasing demand levels [8]. On the other hand, significant and continuous changes in the quality of food products throughout the supply chain have distinguished the food supply chain from other supply chains in which commodities must be delivered in more efficient and cost-effective ways from farms to consuming regions[9]. Jordan's population in 2020 was estimated by the Jordanian Department of Statistics (DOS) at 10.806.000 inhabitants in the most recent social report [10], that has doubled more than ten times over the last 55 years. This surge in population growth underscores the essential role of transportation, now a fundamental societal need consuming a substantial amount of oil-based energy, consequently, this contributes to increased carbon dioxide emissions and supply chain costs [11]. As the agricultural value chain has grown increasingly intricate, this complexity has led to challenges in adaptation and

* Corresponding author e-mail: mabargha@ju.edu.jo.

management, creating an imbalance of bargaining power among the various actors within the chain. Consequently, there has been a notable surge in research focused on developing resilient food supply chains and sustainable value chains to address these evolving challenges effectively [12]. This shift has prompted supply chain management to integrate sustainability into its core practices [13]. Both environmental and economic issues significantly impact reverse supply chain management and are considered fundamental to the development of sustainable supply chains [14]. In particular, fuel consumption analysis has become crucial for local governments in Jordan and decision-makers seeking to ensure economic stability and environmental protection [15]. Moreover, the escalating problem of air pollution, largely driven by automobile emissions, has become a critical concern in large and medium-sized cities across various countries, where vehicle exhaust has emerged as a major contributor to air quality deterioration [16].

In light of the critical impact of affordable fruits and vegetables on the environment, health, and economy, there is a pressing need to thoroughly examine and understand the associated supply chain dynamics [17].In the context of supply chain management, the allocation of quotas to distributors is a critical decision-making component, particularly under conditions of distributor and demand uncertainty. These uncertainties add another layer of complexity to the supply chain management of many firms, affecting overall efficiency and cost-effectiveness [18]. In this regard, facility location emerges as a critical aspect of strategic planning for both public and private enterprises [19]. Hence, the facility locations decisions are critical to the efficient and effective operation of a supply chain [20].

Economic analysis is inevitably an important tool in the decision-making process. One engineering economy aspect is devoted to decision making among alternatives [21]. The goal of a facility location problem (FLP) is to locate facilities in such a way that the costs or distances involved are minimized. Inadequate plant locations can result in unnecessary and excessive costs, regardless of how well transportation plans, inventory policies, and information sharing policies are revised, updated, and optimized [20].

The objective of this study is to identify the most efficient sites for fruit and vegetable central markets in Amman governorate, aiming to minimize overall costs while addressing diverse stakeholder requirements. Through an exhaustive review of existing literature, it became evident that no prior research has explored this specific issue within the Jordanian market. To achieve our research goals, we will develop a robust mathematical model and utilize MATLAB to derive optimal location solutions for these central markets. This approach underscores our commitment to pioneering research in this field and providing actionable insights for stakeholders involved in the fruit and vegetable supply chain in Amman governorate.

The SCM methodology strives to maximize profitability through efficiency, achieve customer satisfaction, and enhance value in order to optimize the global logistics network [22].

When establishing a new manufacturing plant or distribution warehouse, transportation costs are a critical factor, as they depend on the distance between the new facility and other related locations, such as raw material depots, feeder factories, or customer warehouses. To minimize overall transportation expenses, it's essential to determine the optimal location of the new facility based on these distances. The weight of materials and the frequency of their movement also play a significant role, as optimal decisions hinge on the cost per distance unit and the number of trips required within a given time frame [23].

The facility location problem in supply chain management is well studied in the literature. Several facility location research focused on developing efficient algorithms to solve complex mathematical models [24,25,26]. Whereas others focused on developing a realistic model to solve the real-life problem arising in several industries including emergency humanitarian logistics [27], healthcare [28], food supply chain [29], fruit and vegetables supply chain [20], wireless charging facilities for electrical vehicles [30] and in obstacle avoidance and travel path determination [31]. The facility location problem in most research is modelled as a hard-mixed integer programming [20,29,32, 33]. Exact techniques are not useful in solving hard-mixed integer programming, as an alternative search technique, such as genetic algorithm [11, 34], and bender decomposition [29, 35] were used to give accurate optimal solutions.

The operational research models had more attention and interest regarding the decisions related to the fresh fruit supply chain are routing, transport, planning, and allocation problems, while integer or mixed integer and linear programming is the predominant modelling technique [36]

The most common method for developing FLP models is to use integer programming (IP). IP is a type of linear programming in which some or all of the decision variables must be non-negative integers. When all of the variables have integer values, the problem is referred to as a pure integer programming problem [37]. The mixed-integer programming (MIP) model, on the other hand, is a variant in which some variables are real, and some are integers, or at least one variable is an integer. It may have a binary variable that can be assigned 1 or 0 to indicate whether an entity is active or not [37,38].Mixed integer programs (MIPs) are known for being difficult to solve. Branch-and-bound and decomposition are two seminal and widely used techniques for solving MIPs [39].

The subsequent sections of this paper are organized as follows: Section 2 outlines the methodology. Section 3 elaborates on the problem definition, followed by Section 4 which introduces the MILP model formulation. Section 5 details the data collection process, while Section 6 presents the results of solving the MILP model for the optimization problem under consideration and the sensitivity analysis. Finally, Section 7 offers the conclusion of the study.

## 2. Methodology

The objective is to find the optimal locations for fruit and vegetable central markets in Amman governorate using the facility location model to minimize the total cost. We tackle this research problem through various steps. In particular, the work will be divided into five sequential phases as depicted in Figure 1. In the first phase, the supply chain of this problem is to be defined and described. Secondly, the facility location model will be formulated using mixed integer linear programming (MILP). After that, the required data is collected from different ministries and governmental institutions. Then, the model is solved using MATLAB. Finally, the results are analyzed. The five phases are discussed below in details.

Phase 1: Define the supply chain structure. This initial phase is considered to be the foundation in defining and obtaining the variables and parameters used in formulating the model. The supply chain structure for the problem is defined and described carefully. In this phase, the suppliers, customers, stages in the chain, assumptions and terminologies will be defined.

Phase 2: Formulate the facility location model using MILP. With a finite set of candidate central markets, the problem is considered to be a discrete optimization problem. This location problem is formulated as a mixed integer linear programming model, the objective function is to minimize the total cost while achieving stakeholders' satisfaction. Total cost includes transportation costs and rental costs of central markets.

Phase 3: Collect Data. Data collection is the process of gathering information on variables of interest to help in solving the research problem. There are different methods that vary by discipline used in data collection, but the emphasis is on ensuring accurate collection of data. Data on the production capacities of farms, capacities of central markets, distances between different locations, unit cost of transportation and many other data will be required to formulate an accurate model that represents the research problem on a realistic basis.

Phase 4: Solve the model using MATLAB. In this phase, the mathematical will be coded in MATLAB. Intlinprog function in MATLAB will be used to solve the mixed integer linear programming, data will be entered into Excel and MATLAB, then will call for the data to solve the problem.

Phase 5: Analyze the results.

In this phase, the solution obtained from MATLAB will be analyzed and the results will be discussed to gain useful insights.

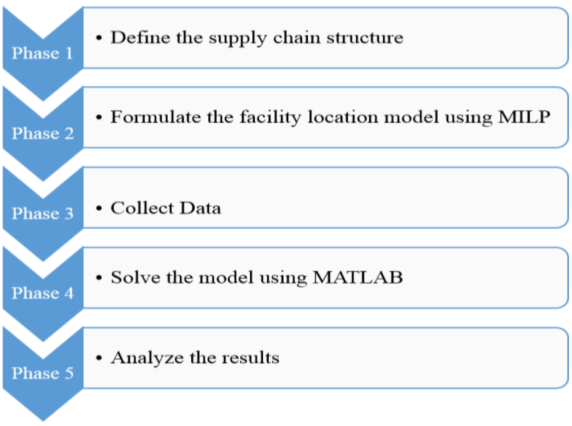



**Figure 1.** The Research Methodology

## 3. Problem Definition

The supply chain starts with farmers growing the vegetables and fruit. The commodities from farms are aggregated to supply central markets. The central markets supply the retailers based on their demand. Customers then buy commodities from retailers' shops and use them in their daily life. The general supply chain for vegetables and fruit in Jordan is defined as shown in Figure 2.

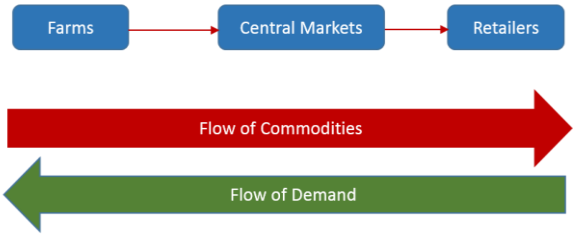



**Figure 2.** Supply chain for vegetables and fruit in Jordan.

The supply and distribution structure are planned and designed according to the specific problem under consideration. It is assumed that the farms are local to the central markets, meaning they are situated at various locations throughout Jordan. According to the Department of Statistics, Jordan is divided into two main regions: the upland and the Jordan Valley. The upland farms are further subdivided into twelve areas, while the Jordan Valley farms are divided into four areas [40, 41].

It is assumed that each farm can serve more than one central market. Figure 3 shows the location of farms on Google Maps as yellow stars, while Table 1 shows a sample of the farms, proposed central markets and retailers with their longitude and latitude lines, the locations were specified using Google Maps.

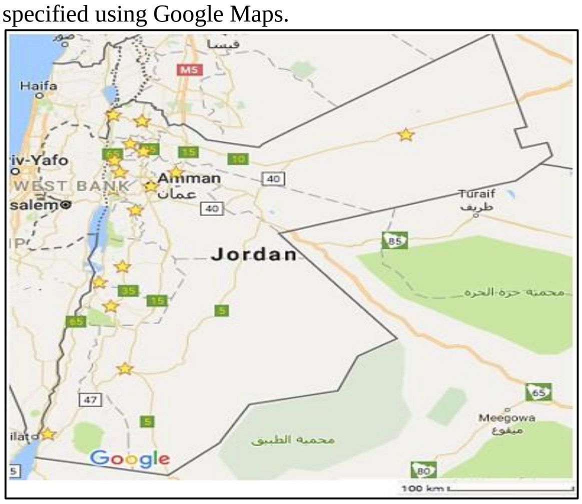



**Figure 3.** Jordanian Farms Locations using Google Maps as yellow stars

The central markets distribute vegetables and fruit crops to retailers, with each market potentially serving multiple retailers and each retailer receiving supplies from various central markets to meet demand. Initially, we identified twenty candidate locations for the central markets through a comprehensive evaluation of multiple factors. This selection process was multidimensional, incorporating expert suggestions and researchers' opinions to ensure the suitability and effectiveness of each location. Additionally, stakeholder consultation was integral to the selection process. We actively sought input from local farmers, retailers, and government officials to understand their preferences and requirements for central market locations. Their insights provided valuable guidance in identifying areas of opportunity and addressing potential challenges.

Additionally, the availability of essential infrastructure was carefully assessed to ensure the feasibility of establishing central markets in each candidate location. Factors such as utilities, and transportation networks were considered to avoid logistical complications and additional costs. Figure 4 shows the locations of potential central markets on Google Maps. According to the latest report conducted by the DOS in 2020, Amman governorate is divided into nine counties; these counties are divided into 112 different localities [10].

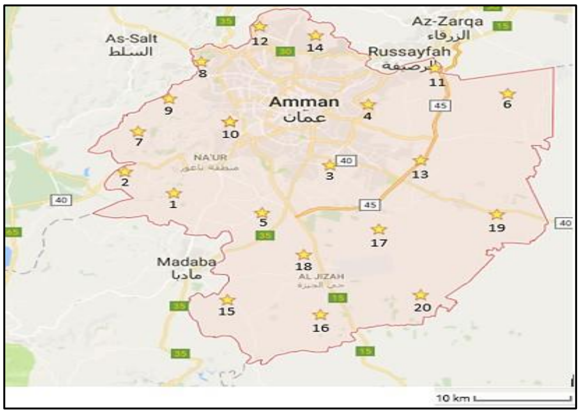



**Figure 4.** The potential locations of central markets as yellow stars.

For our problem, twenty of these localities were combined with other localities due to the lack of their accurate locations. After combining localities, we get 92 different localities with a total population of 4,536,500 inhabitants, which represent 41.98% of the total population of the Kingdom of Jordan. These 92 locations will be assumed the locations of retailers and their demand for vegetables and fruit crops must be satisfied. Figure 5 shows a sample of retailers' locations on Google Maps. Once the retailers are thus identified, the resulting distribution system is formulated as a facility location model with the retailers as customers.

## 4. Model Formulation

Considering the supply chain structure and the underlying assumptions, the research problem is modeled using mixed integer linear programming (MILP). The objective is to minimize total costs, while the constraints are designed to reflect a realistic scenario. This multi-echelon model includes supply from farmers to central markets and then to retailers. Farmers have known production capacities and operate on a multiple sourcing basis, allowing a central market to receive supplies from various farms. Likewise, central markets also follow a multiple sourcing approach, enabling retailers to be supplied by multiple central markets. Retailers have known demand and capacity for commodities.

Given these considerations, the facility location problem is depicted in Figure 6, illustrating the multi-echelon supply chain from farmers to central markets to retailers. The MILP model determines which potential central markets should be established and the quantities to be distributed throughout the supply chain. The objective function and constraints are linear, making it suitable for linear programming. The decision to establish a central market is represented by a binary variable, while the quantities distributed from farms to central markets and from central markets to retailers are continuous variables. Consequently, the model is formulated as a mixed integer linear programming problem.

**Table 1.** A sample of the farms, potential central markets and retailers with their latitude and longitude coordinates.

| No. | Farms | (Latitude, Longitude) |
|---|---|---|
| 1. | Amman | (31.827286, 35.924921) |
| 2. | Irbid | (32.556999,35.848226) |
| 3. | Balqa | (32.075076,35.6644898) |
| 4. | Karak | (31.183215 ,35.688399) |
| Potential central markets | | |
| | Naur | (31.826748, 35.778479) |
| | Naur | (31.857518, 35.722174) |
| | Al Juwaideh | (31.866366, 35.957309) |
| | Al-Naser | (31.953215, 36.001138) |
| Retailers | | |
| 1. | Abdali | (31.970753, 35.908968) |
| 2. | Ras Al Ain | (31.924582, 35.926167) |
| 3. | Al Madenah | (31.955751, 35.944563) |
| 4. | Zahran | (31.955954, 35.894724) |

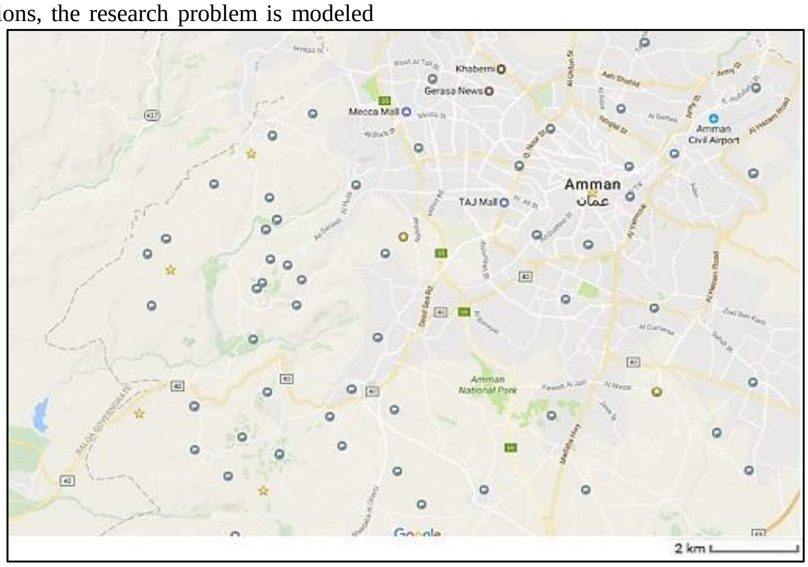



**Figure 5.** Sample of retailers' locations as gray flags.

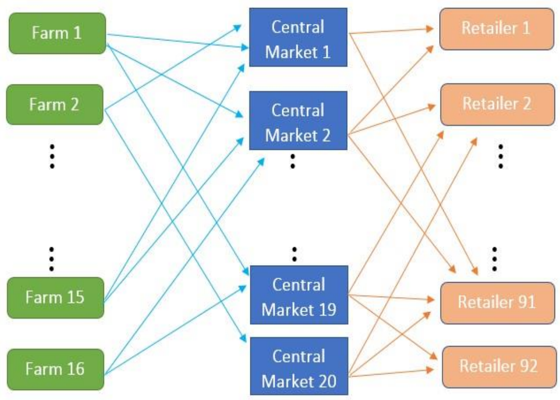



**Figure 6.** Central markets location problem model.

### *4.1. Considerations and Assumptions for the Central market Location Model*

The facility location model is a discrete optimization problem with the potential candidate sites for central markets. The assumptions and considerations are as follows:

A multi-facility location model for which the number of potential central markets is twenty, they are proposed to be in different locations in Amman governorate.

A multi-echelon model with farms to central markets to retailers.

Agricultural production capacities for farms are known.

A single-commodity distribution model, assuming all commodities to have the same characteristics.

The central markets are assumed as multiple sourcing, i.e., one retailer can be served by more than one central market.

The time horizon is static (i.e., the quantity to be shipped between locations doesn't depend on time).

Each of farms production capacities, crop demand, central markets and retailers' capacities, rental costs, and quantities to be shipped through the supply chain are aggregated to represent one year.

Potential central markets are assumed to serve Amman governorate.

Unit cost of transportation differs depending on the type of trucks to be used, for this problem the type of trucks used to move commodities from the farm to the central market is known.

Retailers' capacities are assumed to be larger than the demand in thatregion.

Distances between farms and central markets and between central markets and retailers represent actual routes between locations.

If there is more than one route between any two locations, the average value was calculated and considered, to decrease the risk of inaccurate coordinates of the locations.

Trucks information was gathered from drivers who are working with vegetables and fruit transportation field.

Transportation costs have been calculated from truck characteristics.

Most of the data have been gathered from ministries and governmental institutions represent the latest data they have.

Central markets are assumed to be smaller in area than the current central market in Al Juwaideh; a candidate central market is assumed to extend over 50 Dunam (30% of the Al Juwaideh central market)

Rental cost represents the cost of the land, infrastructure, and buildings.It will be assumed 100,000 JD equivalent to 141,045 USD for all candidate central markets.

For the current situation, the rental cost will be assumed 2,000 JD equivalent to 2,820USD,because Al Juwaideh central market exists and works.

The unit of quantities to be shipped through the supply chain, central markets capacities, retailers' capacities, demand, and farms production capacities are in "ton".

Assume that the unit transportation cost from the central markets to the retailers is 1.3 times the unit cost from farms to central markets, to compensate for traffic and congestion time within cities and truck type, according to drivers who make trips to move fruit and vegetables.

According to interviews performed with fruit and vegetable retailers inAmmangovernorate, the average truckload is 60% of the truck full capacity.

According to interviews performed with farmers in Jordan, the average truckload is 90% of the truck full capacity.

### *4.2. Notations*

- *i*: Farms, $i = 1,2,3,\ldots,16$.
- *j:* Central Markets, $j = 1,2,3,\ldots,20$.
- *k:* Retailers, $k = 1,2,3,\ldots,92$.
- *a:* Unit transportation cost from farms to central markets (JD/ ton. km).
- *b:* Unit transportation cost from central markets to Retailers (JD/ ton. km).
- $RC_j$: Rental cost at central market *j*.
- $d_{ij}$ : Distance between farm *i* and central market *j*.
- $dr_{jk}$: Distance between central market *j* to Retailer *k*.
- $D_k$ : Demand of commodities in Retailer *k*.
- $P_i$ : Production capacity of farm *i*
- $L_i$ : Lower limit to be supplied from farm *i*.
- $W_j$ : Capacity of central market *j*.
- $R_k$ : Capacity of Retailer *k*.
- *TC* : Total supply chain cost.
- $Z_j$: Binary variable to determine whether central market *j* is established or not, if solver had selected Z=1; This central market will be established, then $X_{ij}$ and $Y_{jk}$will then dictate the amount of trade.
- $X_{ij}$: Quantity shipped from the farm *i* to the central market *j*.
- $Y_{jk}$ : Quantity shipped from central market *j* to retailer *k*.

In this research problem, **the objective function** aims to minimize the total cost *(TC)* which is divided into transportation cost and rental cost of the potential central markets.

$$\min TC = \sum_{i=1}^{16}\sum_{j=1}^{20}\left(x_{ij} \times a \times d_{ij}\right) + \sum_{j=1}^{20}\sum_{k=1}^{92}\left(y_{jk} \times b \times dr_{jk}\right) + \sum_{j=1}^{20}\left( z_j \times RC_j\right) \ldots \quad (1)$$

Subjected to:

1. $\forall i \in I, \sum_{j=1}^{20} X_{ij} \leq P_i$, the amount shipped from any farm i to all centralmarkets j is less than or equal to the farm production capacity.
2. $\forall i \in I, \sum_{j=1}^{20} X_{ij} \geq L_i$, each farm has a lower amount to be shipped toAmman's central markets. This constraint represents the realistic situation where every Jordanian farm supply fruit and vegetables to Amman

governorateeven if the demand at Amman governorate is satisfied.

3. $\forall j \in J, \sum_{i=1}^{16} X_{ij} \leq W_j \times Z_j$, the amount shipped from all farms to anycentral markets j is less than or equal to the central markets capacity if it is open.
4. $\forall j \in J, \sum_{i=1}^{16} X_{ij} = \sum_{k=1}^{92} Y_{jk}$, where inflow = outflow, all commoditiesenter any central market from different farms should be distributed to theretailers.
5. $\sum_{j=1}^{20} Z_j \leq 20$, maximum number of potential central markets to beestablished is twenty.
6. $\forall k \in K, \sum_{j=1}^{20} Y_{jk} = D_k$, all amount shipped from all central markets toany retailer must equal to the Retailer demand (Customer satisfaction).
7. $\forall k \in K, \sum_{j=1}^{20} Y_{jk} \leq R_k$,the amount shipped from all central markets toRetailer k is less than or equal to the Retailer's capacity.
8. $X_{ij}, Y_{jk} \geq 0$. Non-negativity constraint (The decision variables for quantity should be non-negative).
9. $Z_j$= 1, central market if j is established, or 0 otherwise.

## 5. Data Collection

Data on the production capacities of farms, capacities of central markets, distances between different locations, unit cost of transportation and many other data will be required to formulate and solve an accurate model that represents the research problem on a realistic basis. Ministries and governmental institutions such as the Ministry of Agriculture (MOA) were visited several times to gather realistic and accurate information and data.Then, an extensive effort was expended to organize and filter information, as well as work to obtain data in an orderly manner for building the MILP model. Farms production capacities were collected from the Ministry of Agriculture and the DOS, where the total production capacity of Jordanian farms in 2019 was 2,290,973 tons [30].

The demand that must be satisfied at retailers' regions is affected by two different factors which are the population of retailers' regions and the average annual consumption of fruit and vegetables for inhabitants of that region. Using the latest report conducted by the DOS in 2020, the population of the 92 localities that represent retailers is4,536,500 inhabitants which represent Amman governorate population, and using the latest survey conducted by the DOS about the average annual consumption of household member from food item in 2013, it was found that a household member living in Amman governorate consumes 205.28 Kg of vegetables and fruit in the year. It was found that Amman governorate consumed 931,252tons of fruit and vegetables in 2020. After determining the retailers' demand, the retailer's capacities will be assumed to be larger than the demand needed in any retailer region.

As reported by the MOA, the annual capacity of Al Juwaideh central market-which extends over 168 Dunam- is 1,000,000 tons. Moreover, as can be noticed from the objective functionequation the unit transportation costs, the distances between locations and the rental cost for any candidate central market are needed to run the model.

Unit transportation cost data were gathered and processed using two different ways, the first one was by asking a driver-who makes trips to transport fruit and vegetables- about how much it costs him to move commodities between locations, and the second way was by calculating the unit cost based on trucks information. According to the driver, the unit transportation cost increases 1.3 times when the trip is within Ammangovernorate boundaries (from central market to region inside Amman governorate) because of time lost in the traffic and the type of the truck, which is KIA/Bongo.

The distances between farms and central markets and between central markets and retailers are specified using Google Maps by entering the coordinates of the locations and then reading the route distance manually because of the lack of an automated procedure of doing that. In many cases, there will be more than one route with different distances. If the routes difference is 10 kilometres or more, we take the average of the routes.

This procedure was used to determine and specify the total of 2160 distances between each farm and each central market and between each central market and each retailer. Table 2 shows a sample of the distances between farms and central markets and the distances between central markets and retailers. Moreover, the rental cost of any candidate central market is divided into three major categories which are land cost, infrastructure, and building costs. The annual rental cost of any candidate central market will be assumed 100,000 JD equivalent to 141,045 USD.

**Table 2.** A sample of distances between Farms and central markets in km.

| Farms / CM | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 24.6 | 32.8 | 11.1 | 34.5 | 11.9 | 46.6 |
| 2 | 122 | 132 | 110 | 100 | 118 | 96 |
| 3 | 61.9 | 59.2 | 50.5 | 58.6 | 53.7 | 68.9 |
| 4 | 129 | 130 | 124 | 144 | 126 | 153 |
| 5 | 214 | 225 | 209 | 228 | 202 | 237 |
| CM/ Retailer | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | 24.6 | 25.2 | 27.6 | 25.1 | 31.9 | 21.5 |
| 2 | 29.4 | 34.1 | 40.7 | 29.4 | 35.8 | 26.3 |
| 3 | 21.8 | 11.1 | 18.5 | 21.9 | 15.1 | 14.1 |
| 4 | 21.5 | 16.8 | 8.7 | 15.3 | 10.4 | 20.6 |
| 5 | 31.8 | 22.6 | 33.7 | 26.8 | 25.2 | 26.9 |

## 6. Results

### *6.1. Solving the MILP*

Initially 20 possible central market locations were selected as shown in Figure 4. These suggested locations were distributed within a widespread area and distances between the farms and retailers were calculated using Google Maps. The proposed central markets are Na'ur (CM1), Na'ur (CM2), Al Juwaideh (Amman current central market CM3), Al-Naser (CM4), Al Ghubaiyah (CM5), Ohud (CM6), Iraq Al Amir (CM7), Al- Hummar (CM8), Al Ghrous (CM9), Al Dmenah (CM10), Al Tatwir (CM11), Abu Nseir (CM12), Near Amman Development Corridor (CM 13), Marj Al Furs (CM14), Al Hraij (CM15), Areinba Al Gharbiyah (CM 16), Dhuheibah Al Gharbiyah (CM 17), Al Qastal (CM18), Al-Muwaqqar (CM 19), Al Quneitirah (CM20).

The mathematical model was coded in MATLAB. The optimization problem was represented in matrix form, then Intlinprog function in MATLAB was used to solve the mixed integer linear programming model, data were entered into Excel, and then MATLAB will call for the data to solve the problem. The optimal solution was found after coding and running the mixed integer linear program model using filtered data collected from various official sources in Jordan. The model was run on 20 different scenarios in which the value of maximum number of potential central markets to be established ($\sum Z$) varies from the current situation, with 1 central market, to 20 (the proposed central markets) to find out the optimal solution in each scenario and to show the improvement/reduction in total cost as the maximum number of allowed central markets changed. Table 3 shows the objective function (total cost), the central markets to be established for the different scenarios, and the corresponding X% as a Proportion shipped amount from all farms to each central market. It clearly shows that as the number of proposed central markets increases, the total cost of the supply chain decreases, leading the optimal solution to stay unchanged from scenario $\sum Z \leq 12$ to scenario $\sum Z \leq 20$ with the same total cost = 78.04 million JD and 12 central markets to be established. It can be noticed that the highest total cost is at $\sum Z = 1$ (which is the current situation) with a total cost= 108.20 million JD.

**Table 3.** Optimal Solutions for Different scenarios when changing $\sum Z$

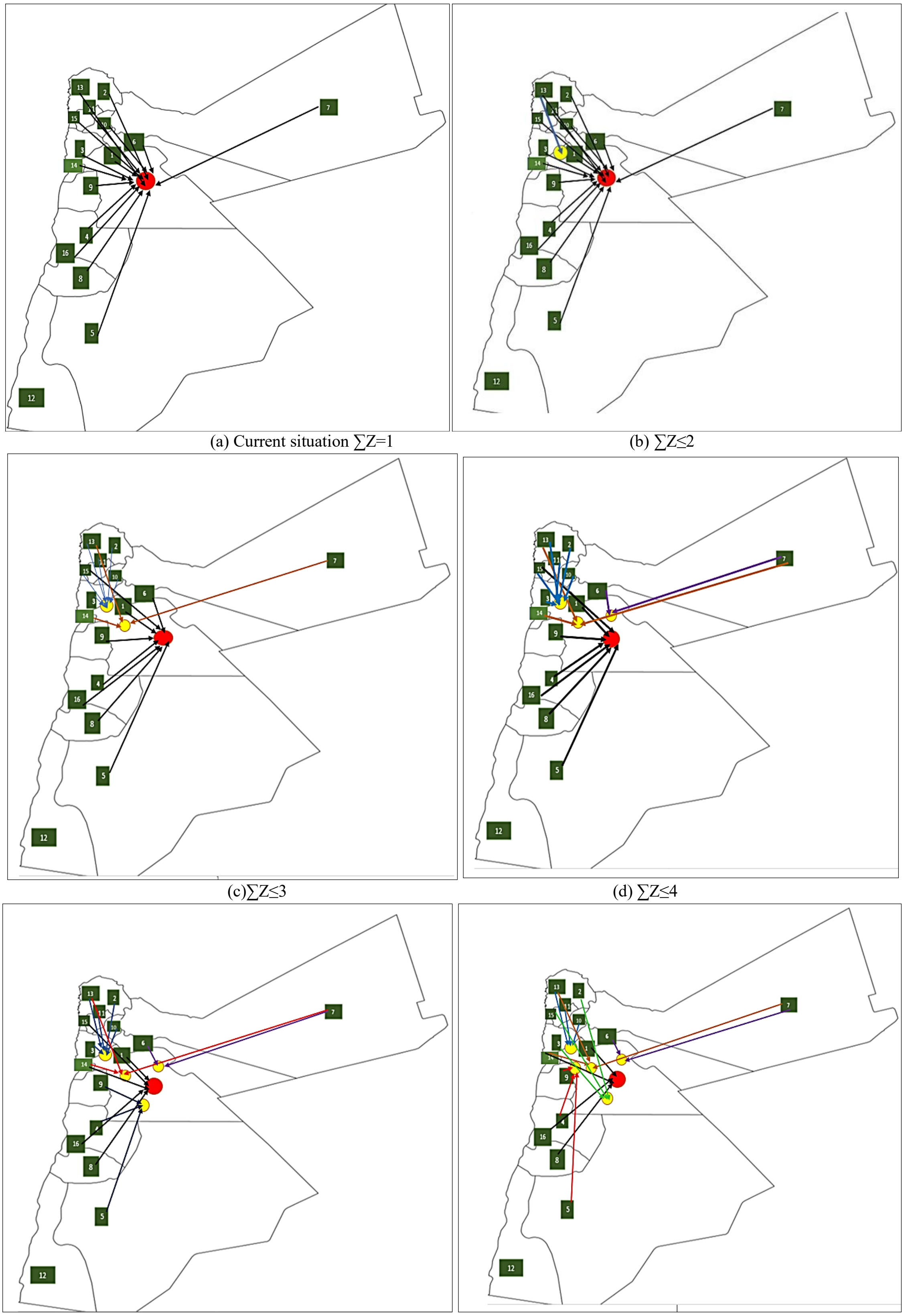
| ∑Z≤ | Objective Function (Million JD) | Potential central markets and corresponding X% as a Proportion shipped amount from all farms to each central market | |
|---|---|---|---|
| 1 | 108.20 | CM3 | 100% |
| 2 | 94.82 | CM3 | 67.7% |
| | | CM12 | 32.3% |
| 3 | 87.01 | CM3 | 35.5% |
| | | CM12 | 32.3% |
| | | CM10 | 32.3% |
| 4 | 82.89 | CM3 | 18.7% |
| | | CM12 | 27.1% |
| | | CM10 | 29.3% |
| | | CM4 | 24.9% |
| 5 | 81.19 | CM3 | 16.9% |
| | | CM12 | 27.1% |
| | | CM10 | 25.9% |
| | | CM4 | 24.9% |
| | | CM18 | 5.1% |
| 6 | 79.52 | CM3 | 16.9% |
| | | CM12 | 16.7% |
| | | CM10 | 23.3% |
| | | CM4 | 24.8% |
| | | CM18 | 5.1% |
| | | CM8 | 13.1% |
| 7 | 79.16 | CM3 | 17.5% |
| | | CM12 | 16.7% |
| | | CM10 | 21.3% |
| | | CM4 | 24.9% |
| | | CM18 | 3.9% |
| | | CM8 | 13.1% |
| | | CM1 | 2.8% |
| 8 | 78.82 | CM3 | 10.7% |
| | | CM12 | 21.9% |
| | | CM10 | 21.7% |
| | | CM4 | 19.6% |
| | | CM18 | 2.5% |
| | | CM8 | 13.1% |
| | | CM5 | 4.6% |
| | | CM13 | 5.7% |
| 9 | 78.55 | CM3 | 10.5% |
| | | CM12 | 21.9% |
| | | CM10 | 19.2% |
| | | CM4 | 19.6% |
| | | CM18 | 2.9% |
| | | CM8 | 13.1% |
| | | CM5 | 4.7% |
| | | CM13 | 5.7% |
| | | CM1 | 2.5% |
| 10 | 78.31 | CM3 | 10.5% |
| | | CM12 | 20.3% |
| | | CM10 | 12.8% |
| | | CM4 | 19.6% |
| | | CM18 | 2.9% |
| | | CM8 | 13.1% |
| | | CM5 | 4.7% |
| | | CM13 | 5.7% |
| | | CM1 | 2.5% |
| | | CM9 | 8.0% |
| 11 | 78.06 | CM3 | 10.5% |
| | | CM12 | 18.2% |
| | | CM10 | 14.8% |
| | | CM4 | 15.5% |
| | | CM18 | 2.9% |
| | | CM8 | 13.1% |
| | | CM5 | 4.7% |
| | | CM13 | 5.6% |
| | | CM1 | 2.5% |
| | | CM9 | 8.0% |
| | | CM14 | 6.2% |
| 12 | 78.04 | CM3 | 10.5% |
| 13 | | CM12 | 18.2% |
| 14 | | CM10 | 14.8% |
| 15 | | CM4 | 15.5% |
| 16 | | CM18 | 0.6% |
| 17 | | CM8 | 13.1% |
| 18 | | CM5 | 4.6% |
| 19 | | CM13 | 3.7% |
| 20 | | CM1 | 2.5% |
| | | CM9 | 8.1% |
| | | CM14 | 6.2% |
| | | CM16 | 2.4% |

*6.2. Optimal number of central markets as a roadmap*

Table 3 can serve as a road map for a step-by-step process of improving the status of central markets based on available budget and priorities. As responsible authorities when planning to establish new central markets in Amman governorate, they can prioritize the establishment of central markets based on total cost in a scientific, systematic and orderly manner. Moreover, it also shows and the corresponding X% as a proportion shipped amount from all farms for each central market to be established.

From Table 3, initially CM3 is what country now have, the model indicated that the best location to add is CM12. So, if the country has decided to proceed, it is better to establish CM12 which will reduce the total cost to 94.82 million JD with 32.3% of the total market sales will go to the new market. Now if more funding is available, it is better to establish CM10 which is expected to have a sale proportion of 32.3% and will reduce the total cost to 87.01 million JD, and so on.

Figure 7 shows that when a new potential market is created (represented by circles), the distribution of arrows representing variable X changes, as do the amounts to be shipped from farms (represented by squares), to achieve the optimal value of the objective function (total cost).



(a) Current situation $\sum Z=1$ (b) $\sum Z\leq 2$

(c) $\sum Z\leq 3$ (d) $\sum Z\leq 4$

(e) $\sum Z\leq 5$ (f) $\sum Z\leq 6$

**Figure 7.** Arrows represent the flow of the X variable from farms to potential central markets, with yellow circles indicating central market locations and green squares representing farms.

Figure 8 shows the decrease in the total cost as the optimal solution is reached at ∑Z ≤ 20 with an objective function = 78.04 million JD and 12 central markets to be established. As a result of trade-off between the improvement in the optimal solution (total cost) and the level of effort, time needed and complexity, the researchers proposed to implement a feasible solution with 6 central markets to be established.

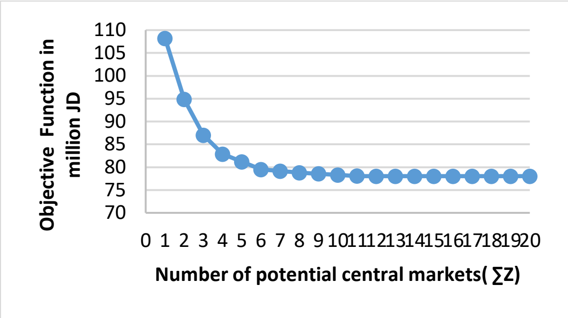



**Figure 8.** The objective function in million JD for different feasible solutions.

At the feasible solution ∑ Z ≤ 6 with an objective function = 79.52 million JD and 6 central markets to be established, the central markets to be established are:

10. Al Juwaideh (CM3)
11. Al-Naser (CM4)
12. Al Hummar(CM8)
13. Al Dmenah (CM10)
14. Abu Nseir (CM 12)
15. Al Qastal (CM 18)

With all farms supplying Amman governorate with fruit and vegetables. The red stars, in Figure 9, shows the feasible solution of the solver at ∑Z ≤6 in terms of locations of the fruit and vegetables central markets. The solution also specifies the quantities to be shipped from each farm to the central markets, and from each central market to the retailers to satisfy the demand.

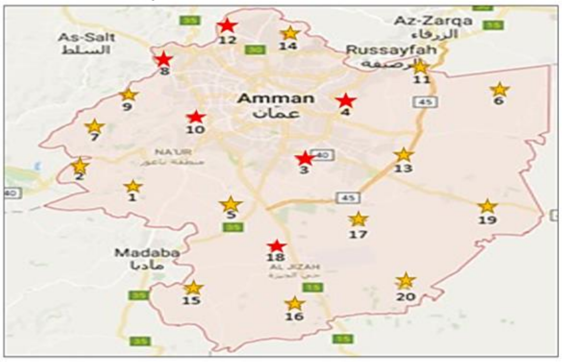



**Figure 9.** The feasible central markets locations at ∑Z ≤6 (red stars)

Furthermore, the researchers investigate the supply chain cost savings of the proposed multiple-markets solution versus the current situation with one central market (Al Juwaideh. Table 4 shows (in USD monetary equivalent values) the comparison and the anticipated saving in the case of ∑Z≤6 to be 26.50%.

Despite the large difference in rental costs, where the current rental cost of the Al Juwaideh central market was assumed to be 2,820 USD and the rental cost for each potential central market was 141,045 USD, the anticipated savings may reach 40.44 million USD, which encourages and supports the implementation of this study.

**Table 4.** Comparison between current and feasible situation at ∑Z≤6.

| Situation | Number of Central Markets | Objective Function | Savings in USD | Savings % |
|---|---|---|---|---|
| Current | 1 | 152.60 million USD | 40.44 million USD | 26.50% |
| Proposed | 6 | 112.16million USD | | |

*6.3. Sensitivity Analysis*

In this section, sensitivity analysis is conducted to evaluate how changes in demand level, unit transportation costs, and fixed costs of central markets affect the optimal solution of a Mixed Integer Linear Programming (MILP) problem. The focus is primarily on understanding which input variable has the most significant impact on the solution.

A. Demand level Change

The demand level was changed each time by a certain percent and the change in the optimal solution will be observed, we conducted 19 different scenarios. The results demonstrate that as demand levels increase, the objective function—which represents the supply chain cost—also increases. Specifically, the number of optimal central market locations rises with higher demand levels, indicating a need for more facilities to meet increased demands. For example, doubling the demand in Amman governorate results in an increase from 12 to 13 optimal locations. Figures 10 and 11 illustrate the correlation between demand variations and the objective function, as well as the number of optimal central markets, respectively. The sensitivity analysis highlights that both the cost and the number of required central market locations are directly proportional to changes in demand levels.

B. Unit Transportation Cost

The second variable to be addressed is the unit transportation cost, sensitivity analysis examines how variations in unit transportation costs impact the optimal objective function and the number of central markets. The analysis focuses on the costs associated with transporting goods from farms to central markets and from central markets to retailers. The unit transportation cost was adjusted incrementally in 19 different scenarios, with all other variables held constant. The results reveal a direct correlation between increases in unit transportation costs and both the objective function value and the number of central markets. As transportation costs rise, the objective function increases due to higher overall supply chain costs, and the model outputs for more central markets to mitigate these costs. Figures 12 and 13 illustrate that as the unit transportation cost increases, the cost of the supply chain and the number of central markets rise, reflecting the trade-off between transportation expenses and central market costs.

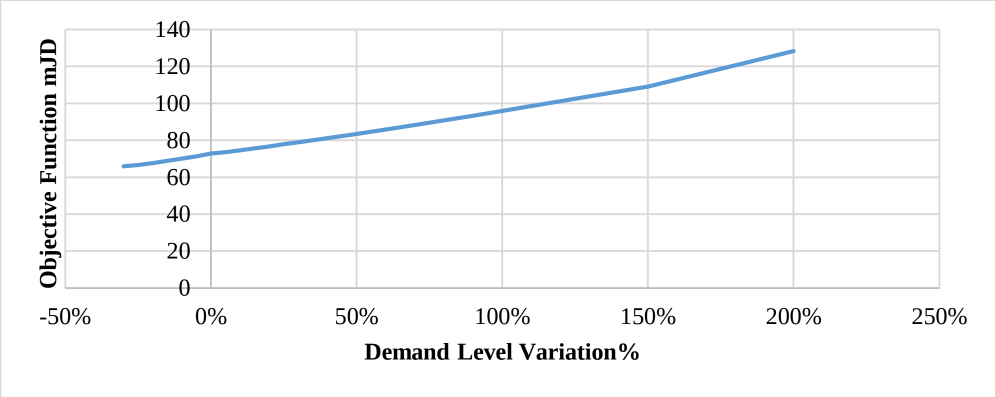



**Figure 10.** Sensitivity Analysis for The Demand Level.

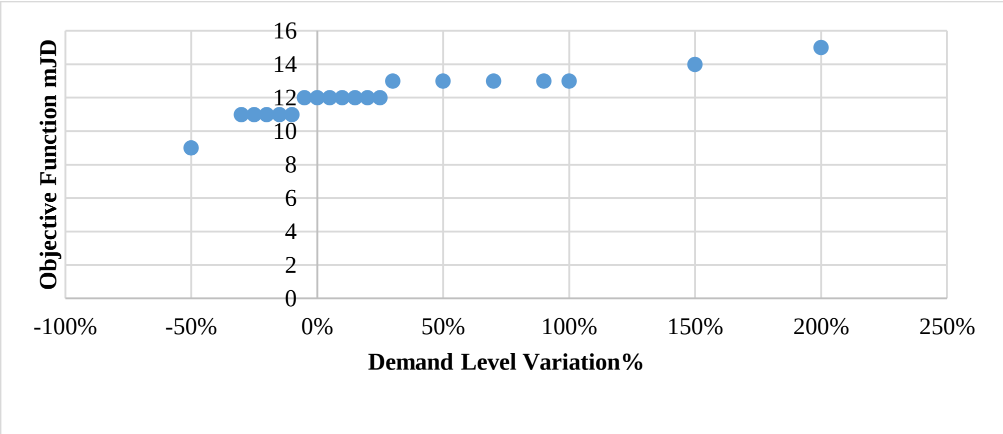



**Figure 11.** Number of Optimal Central Markets as The Demand Level Changed

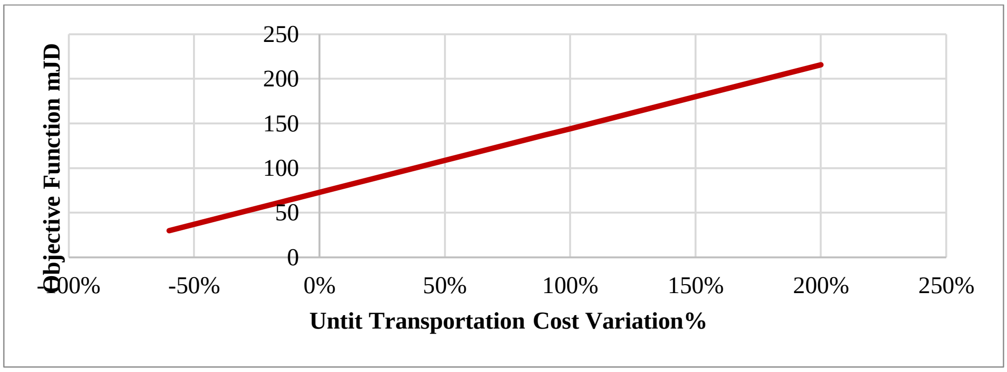



**Figure 12.** Sensitivity Analysis for the Unit Transportation Cost.

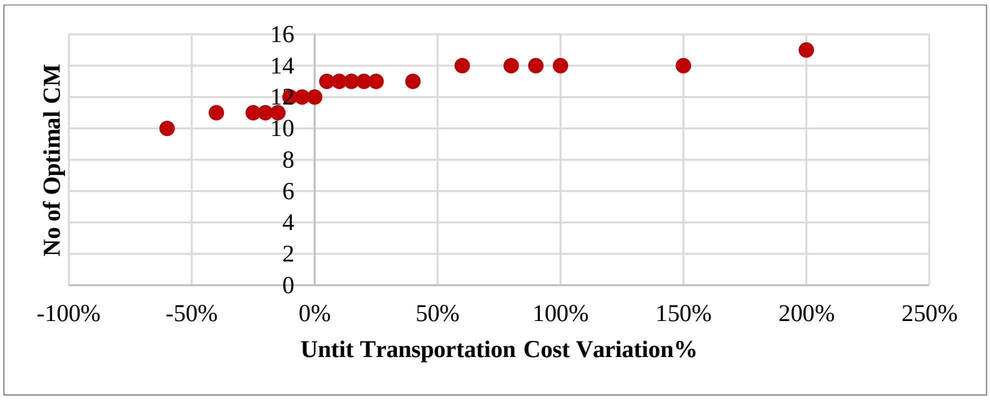



**Figure 13.** Number of Optimal Central Markets as the Unit Transportation Cost Changed.

## C. Fixed Cost Variable

This section of the sensitivity analysis investigates how variations in central market fixed costs affect the optimal objective function and the number of central markets needed. The analysis involves adjusting the fixed cost of central markets by various percentages and observing the resulting changes in the model's outputs. The results demonstrate that increases in central market fixed costs lead to a rise in the objective function, reflecting higher overall supply chain costs. As the fixed cost rises, the number of central markets decreases since fewer but potentially larger and more expensive markets are used to minimize overall costs. Conversely, reducing the fixed cost allows the model to use more central markets, which lowers the objective function slightly but increases the total number of markets. Figures 14 and 15 illustrate the effect of changing fixed cost on both optimal objective function and the number of central markets needed.

## D. Sensitivity Analysis Conclusion

The spider diagram, depicted in Figure 16, displays increments for all selected input variables along the x-axis and illustrates their corresponding outputs through a series of line graphs. The increasing slope in these graphs indicates that as the impact on the supply chain cost rises. Sensitivity analysis revealed that among the three parameters—demand level, unit transportation cost, and central markets' fixed cost—the unit transportation cost has the greatest influence on the supply chain cost. Following this, the demand level has a significant but lesser impact, while the central markets' fixed cost has the smallest effect of the three variables.

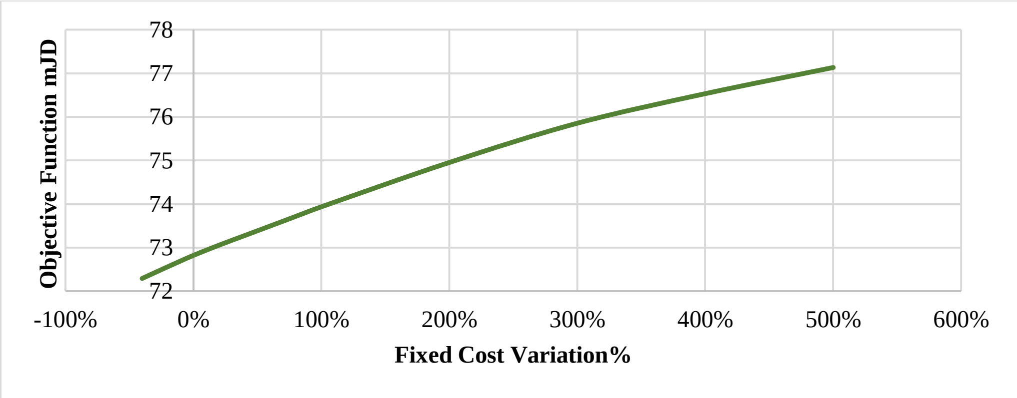



**Figure 14.** Sensitivity Analysis for The Fixed Cost.

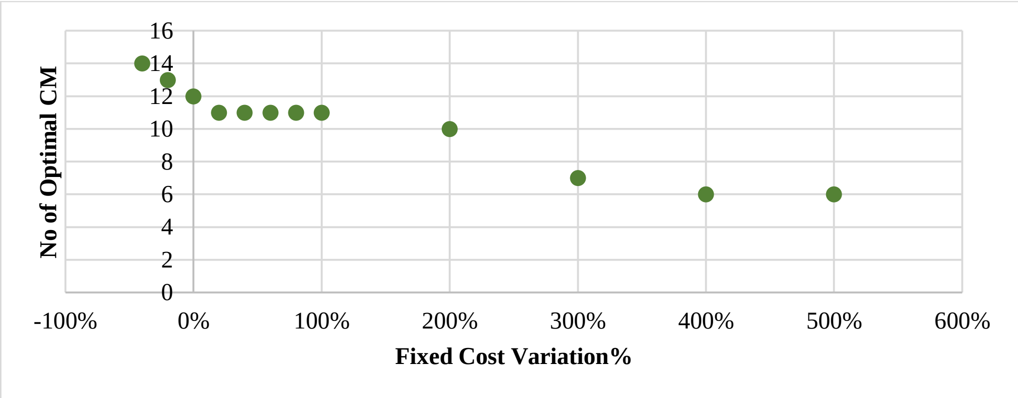



**Figure 15.** Number of Optimal Central Markets as the Fixed Cost Changed

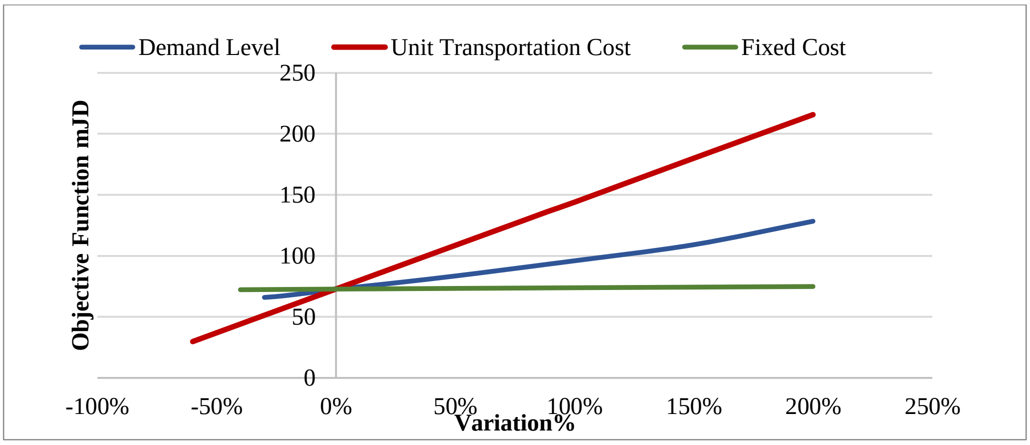



**Figure 16.** Sensitivity Analysis for The Studied Parameters.

## 7. Conclusion

### *7.1. Research Implications*

The application of the facility location problem to the vegetable and fruit supply chain in Jordan has significant implications for improving supply chain efficiency and reducing costs. By developing a multi-echelon, single-commodity facility location model using MILP, we have demonstrated the potential for optimization in central market placement. The identification of twenty candidate locations in the Amman governorate and the subsequent solution of the facility location problem using MATLAB's Intlinprog function provide valuable insights into the optimal allocation of resources within the supply chain. The solution determines which central markets to be established. Moreover, the quantities to be shipped from farms to each central market and from each central market to retailers were specified. Furthermore, a road map for a step-by-step process of improving the status of central market based on available budget and priorities would be developed. The researchers made a trade-off between the reduction in objective function (total cost) and the level of effort, time needed and complexity, and proposed implementing the optimal solution at the conditions of limiting the maximum number of potential central markets to be established at 6, with a total cost of 79.52 million JD and 6 central markets to be established, and 26.50% total savings compared to current status.

### *7.2. Future Work*

Building on the findings of this study, several avenues for future research can be explored. Firstly, incorporating more advanced modelling techniques, such as stochastic optimization or simulation-based approaches, may offer a more realistic representation of supply chain uncertainties and variability. Additionally, conducting sensitivity analyses to assess the robustness of the optimal solution to changes in input parameters could enhance the reliability and applicability of the proposed methodology. Furthermore, investigating the potential integration of emerging technologies, such as artificial intelligence or blockchain, into supply chain decision-making processes could further enhance efficiency and transparency in central market operations.

## References

[1] R. K. Singh, S. Luthra, S. K. Mangla, S. Uniyal, “Applications of information and communication technology for sustainable growth of SMEs in India food industry”, Resources, Conservation and Recycling, Vol.147,2019, pp.10-18.

[2] J. Sharma, M. Tyagi, A. Bhardwaj, “Parametric review of food supply chain performance implications under different aspects”. Journal of Advances in Management Research. Vol.7, No.3,2020, pp.421-453.

[3] MOA, Technical report, Yearbook 2011. Jordan: Jordanian Ministry of Agriculture; 2011.

[4] MOA, Technical report, Yearbook 2015. Jordan: Jordanian Ministry of Agriculture; 2015.

[5] Jordanian Department of Statistics. Sub-agricultural sector (field crops and other agricultural crops) report., Jordan: DOS; 2011.

[6] Jordanian Ministry of Agriculture. Descriptive information about major wholesale markets, Jordan: MOA;2017.

[7] Vegetable and Fruit Central Wholesale Market (March 15 2017). Information on the wholesale market for vegetables and fruits. http://www.awm. gov.jo/dotnet/aboutus.aspx.

[8] H. Etemadnia, S.J. Goetz, P. Canning, M.S. Tavallali, “Optimal wholesale facilities location within the fruit and vegetables supply chain with bimodal transportation options: An lp-mip heuristic approach”. European Journal of Operational Research, Vol.244, No.2, 2015, pp.648–661.

[9] P. Guo W. Cheng, Y. Wang, “Hybrid evolutionary algorithm with extreme machine learning fitness function evaluation for two-stage capacitated facility location problems”. Expert Systems with Applications, Vol.71,2017, pp.57–68.

[10] Department of Statistics. Population Estimates Report, Jordan: DOS; 2020.

[11] Ghasemian, N. Javadian, “A multi objective mixed integer programming model for design of a sustainable meat supply chain network”. Journal of Industrial and Systems Engineering, Vol.13,2020, pp.78-92.

[12] L. Jraisat, M. Jreissat, S. Farhana, B. Luciano, and G. Thaana. "No Actor is an Island: The Role of Partnerships in Sustainable Value Chains.", Jordan Journal of Mechanical and Industrial Engineering, Vol.16, No. 2 ,2022, pp.163-174.

[13] Khaire. “Container Terminal Performance: System Dynamic Approach with Port Capacity Constraints and ESG Integration”. Jordan Journal of Mechanical and Industrial Engineering, Vol.81, No.1, 2024, pp. 59-73

[14] Jayant, P. Gupta, and S.K. Garg, S. K. “Perspectives in reverse supply chain management (R-SCM): a state-of-the-art literature review”. Jordan Journal of Mechanical and Industrial Engineering, Vol.6, No.1, 2012, pp. 87-102.

[15] M.A. Gharaibeh, R. Al-Jarrah, and A. Alkhatatbeh. “A study on the fuel consumption demands of the Jordanian residential sector”. Jordan Journal of Mechanical and Industrial Engineering, Vol.81, No.1, 2024, pp.191-205

[16] D. Liu, S. Li, and H. Liu. “Experimental study on formaldehyde emission from environmental protection and energy-saving alcohol fuel for vehicles”. Jordan Journal of Mechanical and Industrial Engineering, Vol.15, No.1, 2024, pp. 1-6

[17] Boeing, A. Bechthold, A. Bub, S. Ellinger, D. Haller, A. Kroke, E. Leschik-Bonnet, M.J. Mu¨ller, H. Oberritter, M. Schulze, “Critical review: vegetables and fruit in the prevention of chronic diseases”. European journal of nutrition, Vol.51, No.6, 2012, pp.637–663.

[18] B.C.M. Reddya, K.H. Reddyb, C.N.M. Reddyc, K.V.K. Reddyd, “Quota Allocation to Distributors of the Supply Chain under Distributors’ Uncertainty and Demand Uncertainty by Using Fuzzy Goal Programming”. Jordan Journal of Mechanical and Industrial Engineering, Vol.2, No.4,2008, pp.215-226.

[19] S. H. Owen, M.S. Daskin, “Strategic facility location: A review”. European journal of operational research, Vol.111, No.3,1998, pp.423–447.

[20] M. S. Daskin, L. V. Snyder, R. T. Berger. Facility location in supply chain design. In Logistics systems: Design and optimization, Boston: Springer;2005, p. 39–65.

[21] Jaradat, and K.K. Tahboub. “Decision making using multiple rates of return: An alternative approach”. Jordan Journal of Mechanical and Industrial Engineering, Vol. 5, No.2, 2011, pp.193-196

[22] I. TRONNEBATI, andF. JAWAB. “Green and Sustainable Supply Chain Management: A Comparative Literature Review”. Jordan Journal of Mechanical and Industrial Engineering, Vol.17, No.1, 2023 pp.115-126 22

[23] P.K. Dan. "Obstacle avoidance and travel path determination in facility location planning'. Jordan Journal of Mechanical and Industrial Engineering, Vol.3, No. 1, 2009, pp. 37-46 23
[24] Syarif, M. Gen, "Hybrid genetic algorithm for production/distribution system in supply chain". International Journal of Smart Engineering System Design, Vol.5, No.4,2003, pp.289–298.
[25] J. Januardi, Z. P. Ramdhani, R. N. Harnaningrum, "Transhipment model considering environmental cost using mixed integer linear programming: Beef distribution problem". Croatian Operational Research Review, Vol.11, No.2,2020, pp.155-164.
[26] P. Fern´andez, B. Pelegr´ın,A. Lanˇcinskas, J. Zilinskas, "New heuristic algorithms for discrete competitive location problems with binary and partially binary customer behaviour". Computers & Operations Research, Vol.79,2017, pp.12–18.
[27] Boonmee, M. Arimura, T. Asada, "Facility location optimization model for emergency humanitarian logistics". International Journal of Disaster Risk Reduction, Vol.24,2017, pp.485–498.
[28] W. Zhang, K. Cao, S. Liu, B. Huang, "A multi-objective optimization approach for health-care facility location-allocation problems in highly developed cities such as hong kong". Computers, Environment and Urban Systems, Vol.59,2016, pp.220–230.
[29] R. A. Murugaswamy, Multi-echelon facility location model for a food supply chain using benders decomposition, Master thesis. The Pennsylvania State University; 2011.
[30] R. Riemann, D. Z. Wang, F. Busch, "Optimal location of wireless charging facilities for electric vehicles: flow-capturing location model with stochastic user equilibrium". Transportation Research Part C: Emerging Technologies, Vol.58, 2015, pp.1–12.
[31] D.K. Pranab, "Obstacle avoidance and travel path determination in facility location planning." JJMIE Vol.3, No. 1,2009, pp.37-46.
[32] S. Danalakshmi, G. M. Kumar, "Optimization of supply chain network using genetic algorithm". J. Manufacturing. Engineering, Vol.3,2010, pp. 5-30.
[33] Abraham, K. R. Kumar, R. Sridharan, D. Singh, D "A genetic algorithm approach for integrated production and distribution problem". Procedia-Social and Behavioral Sciences, Vol.189, 2015, pp.184–192.
[34] R. Nasiri, R. Zolfaghari, H. Davoudpour, "An integrated supply chain production–distribution planning with stochastic demands". Computers & Industrial Engineering, Vol.77, 2014, pp.35–45.
[35] M. Fischetti, I. Ljubi´c, M. Sinnl, "Benders decomposition without separability: A computational study for capacitated facility location problems". European Journal of Operational Research, Vol.253, No.3, 2016, pp. 557–569.
[36] W. E. Soto-Silva, E. Nadal-Roig, M. C. Gonz´alez-Araya, L. M. Pla-Aragones, "Operational research models applied to the fresh fruit supply chain". European Journal of Operational Research, Vol.251, No.2, 2016, pp. 345– 355.
[37] O. J. Adeleke. Location-Allocation-Routing Approach to Solid Waste Collection and Disposal. Ph.D. Thesis, Covenant University, USA; 2017.
[38] O. J. Adeleke, D. Olukanni, "Facility Location Problems: Models, Techniques, and Applications in Waste Management". Recycling, Vol.5, No.2 ,2020, pp.1-20.
[39] Yildiz, N. Boland, M. Savelsbergh, "Decomposition Branching for Mixed Integer Programming", Operations Research, Vol.70, No.3,2022, pp. 1854-1872.
[40] Jordanian Department of Statistics. Average yield and production of vegetables and fruit., Jordan: DOS; 2019.
[41] Jordanian Department of Statistics (2019b). Irrigated and non-irrigated areas. Technical report, Jordan, 2019