Civil Engineering and Architecture 11(3): 1558-1568, 2023 http://www.hrpub.org
DOI: 10.13189/cea.2023.110335

Optimizing the Distribution of Public Transportation Stops Using GIS: A Case of Amman City in Jordan

Maram Alharbi, Mohammad Hassan*

Faculty of Engineering, Al-Ahliyya Amman University, Amman, 19328, Jordan

Received November 10, 2022; Revised January 3, 2023; Accepted January 28, 2023

Cite This Paper in the Following Citation Styles

(a): *[1] Maram Alharbi, Mohammad Hassan, "Optimizing the Distribution of Public Transportation Stops Using GIS: A Case of Amman City in Jordan," Civil Engineering and Architecture, Vol. 11, No. 3, pp. 1558 - 1568, 2023. DOI: 10.13189/cea.2023.110335.*

(b): *Maram Alharbi, Mohammad Hassan (2023). Optimizing the Distribution of Public Transportation Stops Using GIS: A Case of Amman City in Jordan. Civil Engineering and Architecture, 11(3), 1558 - 1568. DOI: 10.13189/cea.2023.110335.*

Abstract In the context of developing multi-modal transit systems in major cities, transit station distribution is a crucial indication for implementing public transportation services. This paper presents an optimization method for bus stop locations to improve the accessibility level and reduce the transportation cost and distance. This paper assesses the existing geographic distribution of bus stop locations in Amman city the capital of Jordan, to evaluate transport accessibility, and to determine the optimal locations of bus stops from a set of candidate locations. The minimized impedance location-allocation model for transportation problems is used as a network analysis method to design a new distribution of bus stops; the current accessibility ratio of 34 stopping points covering 135 out of 300 facilities increased from 45% to 69% of the total facilities within the study area, covering 208 services of available facilities. Optimizing bus stop locations will lead to an increase in the use of public transportation systems versus private vehicles, which will improve the levels of service, reduce traffic congestion and lower air pollution.

Keywords Transportation, GIS, Transport Accessibility, Bus Stops

1. Introduction

1.1. Overview

Transportation plays an essential role in urban planning. It includes transportation systems that convey people to their destinations. Public transportation represents the artery and nerve of life in cities in general and capitals in particular. Transport in general and the public transportation sector in particular are receiving attention from planners, traffic authorities, researchers, and specialists, as well as the majority of urban residents. The Literature Review has shown the position of transport accessibility to enhancing the sustainability of urban arrangements, Enhancing livability and quality of life of the citizens [1]. A challenging issue in transportation planning is to measure sustainability by developing and applying appropriate indicators that cover the sustainability concept. One of the primary concerns of social sustainability is ensuring equal access to various services and opportunities [2]. Bus-related transportation networks must be considered while enhancing transportation. Bus-related transport networks represent the majority of public transportation in many developing countries. The demand for public transport and the quality of life in cities would improve if appropriate plans for urban bus transportation were implemented. This will reduce private car use and significantly reduce traffic congestion in cities [3].

Many technologies were used to evaluate the level of accessibility and optimize bus stop locations. The Geographic Information System (GIS) software utilized in this study is ArcGIS10.8, which was developed by the Environmental System for Research and Innovation (ESRI) and is widely used commercially around the world. ArcGIS has established itself as a helpful computer-based tool for spatial description and manipulation as a widely used geographic decision support system. Analysts will benefit from using spatial operators to extract new information from GIS data. GIS data is classified into three types: raster, vector, and tin. The raster data structure provides the most robust modeling environment and spatial analysis operators. In the terms of GIS software, a map will have only one coordinate system, either geographic or projected. The "WGS84 projection," for example, is a geographical projection [4].

Tome et al. [5] described a GIS-based accessibility analysis method for assessing community facility accessibility in medium-sized cities. A study methodology was applied using the road network and public transport data from Covilhã municipality in Portugal. The ARC-GIS® Network Analyst extensions are used to handle and organize data collected on websites to build the network dataset and perform network analyses. Moniruzzaman et al. [1] presented a comparison and evaluation of the current accessibility of various geographic units in the Perth Metropolitan Area by public transportation and private car. The same study also includes 34 activity centers identified by the Australian government. Authors used two methods in the mentioned study: the first was an isochrones-based accessibility measure used to model accessibility in the Perth Metropolitan Area in Western Australia. Second, using six node-place dependent indicators to prioritize the regional units that are already best served by public transportation. Zhang et al. [6] proposed a new approach for assessing the adequacy of public transportation-based access to health facilities by taking into account spatial heterogeneity. The authors were effective in identifying census areas with limited public transportation access to health facilities.

Accessible bus stop locations are required to build a connected city. Chien et al. [7] noted that the locations of bus stops are commonly used to determine the accessibility of bus services, which has a significant impact on the performance and level of service provided by public transport systems. They developed a mathematical model to optimize the bus stop location problem. Zhang et al. [6] defined distance decay as the spatial contact between two geographical positions decreasing as the distance between them grows. Algharib [8] used same model that used in this paper, a location-allocation model is called "minimized impedance problem". The population and fire frequency were used as demands, and the problem was applied in this study by using the existing fire stations as candidate locations. Applying this concept seeks to reduce the overall distance or time that firefighting units must travel to reach demand spots (fire locations). Garcia-Palomares et al. [9] also used the same model to determine the optimal location of stations in bike-sharing programs, the authors use location–allocation models in different scenarios and with different solutions. In this research, the resulting findings are compared with the two most popular methods for location-allocation modeling: minimizing impedance and maximizing coverage. Ibrahim [10] in his paper used a location allocation model within GIS analysis tools that is effective in resolving spatial issues. The aim is to analyze public hospitals in Khartoum locality accessibility problems. The results showed that public hospitals were dispersed unevenly, and that 30% of populous regions had difficulty getting to hospitals.

Since 60% of the hospitals in the area were founded there, they are mostly located in the northern portions of the community. As population grew more densely throughout the research region, the hospitals' coverage ratio per population decreased; public hospitals did not.

To improve the objectives in this paper, the authors used a method called "minimize impedance problem", which is one of the location-allocation tools.

1.2. Research Problem

A lot of traffic and environmental problems were generated in study area, such as traffic congestion and high rates of pollutants' emissions such as carbon and nitrogen oxides. If we aim to design a sustainable public transportation system, it is important to consider the accessibility impacts and bus stop locations within the optimizing process of enhancing the public transportation system.

1.3. Study Objectives

1- Analyzing and assessing the accessibility of public transportation stations as an indicator of the efficiency of their spatial distribution, using spatial and network analysis in geographic information systems.
2- Analyzing the geographical characteristics of the locations for public transportation stops in the study area.
3- Proposing the best locations for public transport stops in the study area.

2. Methodology

2.1. General Framework

The following points are the methodology utilized to reach the research objectives:

1. Choosing a suitable study area.
2. Gathering all of the needed data.
3. Digitizing the locations of major facilities and bus stop locations in the study area using ARC MAP 10.8 within a geographic information system environment.
4. Using location allocation models to evaluate the accessibility level in the study area in its current situation.
5. Applying a relocation process to bus stop locations.
6. Creating a new location allocation model using the relocation bus stops layer.

7. Comparing the results of the scenario analysis before and after the implementation of the relocation process.

This methodology can be applied to Amman, as the region suffers from poor distribution of public transportation stops. Thus, the method can be generalized anywhere else.

2.2. Study Area

Al-Jami'ah district located in Amman city, The Al-Jami'ah district includes Queen Rania Street, Al-Madina Al-Monawara Street, Ahmed Al-Trawnah Street, and a portion of Yajouz Street. According to the Jordanian department of statistics report [11], the population of Al-Jami'ah district is about 842170 people. The study area is also served by several different and varied public transportation lines, such as public buses owned by individuals and buses owned by the Greater Amman Municipality. Study area appears in Figure 1.

2.2. Data Collection

Data in this research is presented as shown in Table 1.

Table 1. Research Data

Name	Type	format	Source
Bus stop locations	Vector (Points)	Geographic coordinate points (X, Y).	Field data and Greater Amman Municipality
Transportation layer	Vector (Lines)	Shape file (ARC GIS format).	Greater Amman Municipality
major facility locations	Vector (Points)	Geographic coordinate points (X, Y).	Amman Explorer and Google Earth
Study area image	Satellite image	Imagery format (.Tiff)	ARC MAP 10.8 Base map

1. Bus stop locations were gathered from the site as geographic coordinate points.
2. Greater Amman Municipality offers a transportation layer.
3. The main facility locations were generated using Amman Explorer and Google Earth.
4. High-resolution satellite image within ARC MAP 10.8 Base map with imagery format (.Tiff) was used.

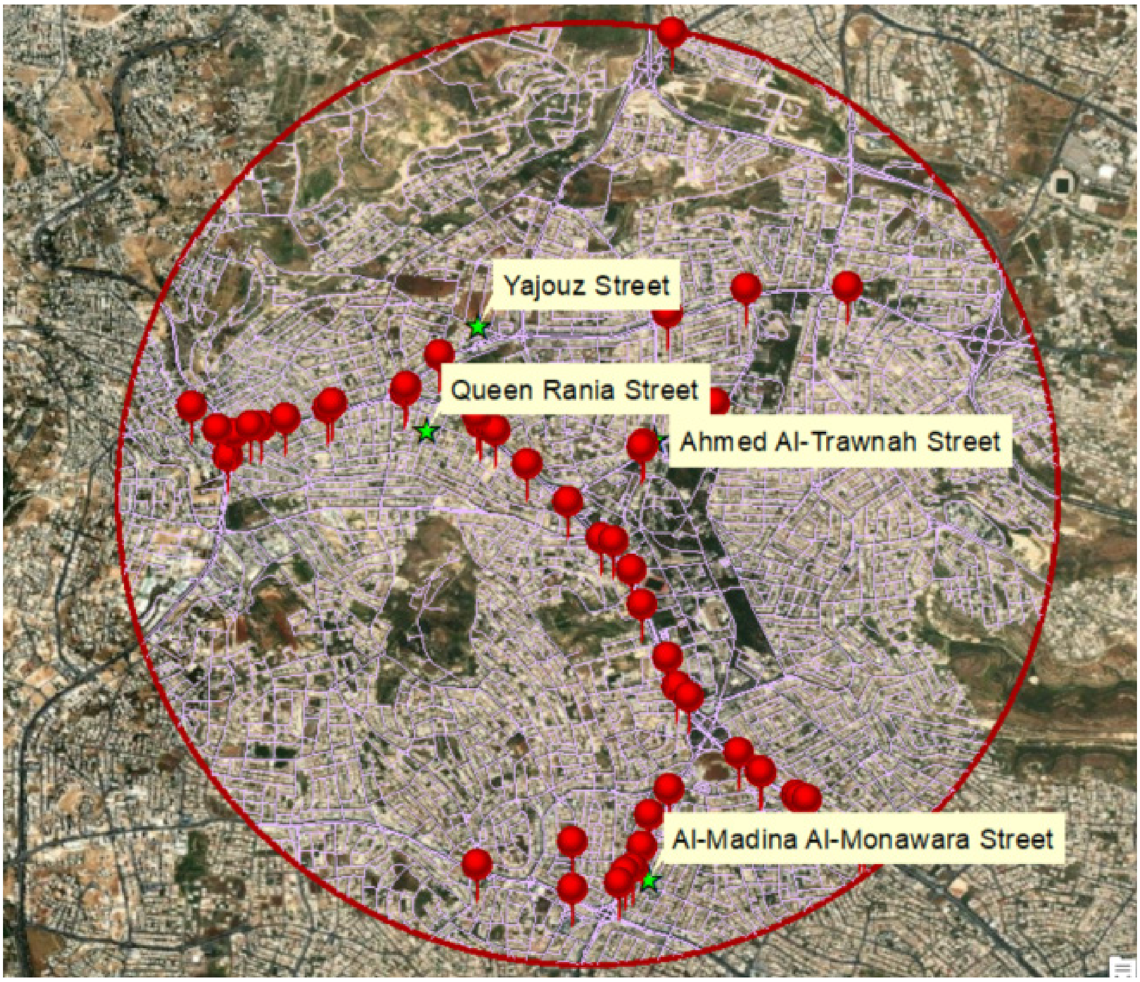

Figure 1. Study Area.

2.3. Location Allocation Model

The location-allocation model assists in deciding which facilities to operate from a group of facilities based on their possible interaction with demand points.

The primary objective is to:

1. minimize the overall distance among demand points and facilities.
2. maximize the number of demand points covered within a certain distance of facilities.
3. maximize an apportioned amount of demand that decays with increasing distance from a facility.
4. increase the volume of demand captured in a competitive environment of friendly and competing facilities.

The Location-Allocation technique can be used to handle a variety of problems that are similar but separate. There are two steps to resolving these issues. To begin, a feasible set of locations must be chosen from a set of facilities. Second, demand for these facilities must be apportioned. The rules for locating the facilities will differ depending on the type of problem we are attempting to solve [12].

The location allocation method is one of the network analysis methods, and to start location allocation analysis, we need to create a network data set. It's a transportation network consisting of a set of linked lines (roads) connecting a set of nodes; they define the connectivity of the network.

The input data for this model are the bus stop layer that defines the spatial locations of bus stops (the services) and the facilities layer that defines the spatial locations of main facilities (the demand) in the study area. The bus stop locations layer represents 48 locations, and the facilities layer represents 300 facility locations. These 48 bus stop locations must serve all 300 demand points. In this study, we applied a location allocation model to evaluate the accessibility level in the study area. The locations of each of them were added to the location allocation model in Arc GIS 10.8

2.3.1. Minimize impedance problem

The main goal of this model is to minimize overall transportation costs, and it usually uses time or distance as impedance. It is worth noting that minimizing transportation costs is one of the most important goals that intelligent transportation systems (ITSs) seek to achieve.

It is also called the P-Median problem model. This approach aims to reduce the overall weighted distance between demand sites and nearby facilities as much as possible. This model's optimization strategy is based on exchanging or replacing potential sites (chosen and candidate) between demand points (main facilities) and service points (bus stops) [13].

2.4. Optimizing Bus Stop Locations: Proposed Redistribution:

The relocation of some bus stops would be useful in attracting greater demand and improving the quality of public transportation supply, with accessibility as the primary requirement. According to the result of the minimized impedance model and the average nearest neighbor ratio, an optimization process to the current distribution was applied by relocating the 14 unselected bus stop locations that are shown in Table 2. The unselected bus stop locations are in the optimal solution. These points are typed as candidate points in the facility type field and do not have a demand count.

Table 2. Unselected bus stop locations in the optimal solution

Object ID	Shape	Facility Type
751	Point	Candidate
758	Point	Candidate
767	Point	Candidate
770	Point	Candidate
771	Point	Candidate
775	Point	Candidate
778	Point	Candidate
782	Point	Candidate
783	Point	Candidate
786	Point	Candidate
788	Point	Candidate
790	Point	Candidate
794	Point	Candidate
796	Point	Candidate

This study used ArcGIS 10.8 software to apply the minimized impedance model with the specified impedance cutoff to assess the current locations of bus stops and to find out if there are any facilities unreachable by the existing bus stops.

According to the highway capacity manual [14], walking distance is defined as 0.4 km from a bus stop. Any site within 0.4 kilometers of a deviating fixed-route bus stop is considered covered. So, we used this value of 0.4km as the impedance cutoff in the location allocation model and assign 48 as the number of bus stop location in (facilities to choose) tap.

2.4.1. Optimization Procedure: (Redistribution Procedure)

General conditions for the public transport stop locations were mentioned in the highway capacity manual [14]. By having a GIS or precise bus stop data, approximating this region can be done by outlining on a map all of the area within 400m of a bus stop. This estimate is based on normal bus stop spacing (at least four stops per kilometer).

According to the Jordanian Traffic Institute of the Directorate of Public Security (2021), the following conditions were used to measure the bus stop locations:

1. The location of the bus stop should be commensurate with the movement of pedestrians and their gathering points, and the bus stop location should serve commercial activities and the movement of passengers.
2. The distance between bus stop locations should be between 400 and 600 meters, but no less than 300 meters.
3. In the event that there is a bus stop location near the main intersections organized by bridges, tunnels, and traffic lights, it must be at least 150 meters away from the edge of the intersection.

The following is the procedure to redistribute the unselected bus stop locations:

1- Keeping the bus stop locations that were chosen as the optimal solution.
2- Removing the bus stop locations that were not selected.
3- Replace them with new bus stop locations in more suitable locations to increase the number of covered facilities.

- Using Arc Map 10.8, in the area that has uncovered facilities, in the optimal solution, two buffer zones of 400m and 600m were generated from the nearest chosen bus stop location.
- A buffer zone with 150m was created from a bridge, tunnel, and traffic light if the optimized bus stop locates near one of them.
- a new bus stop location was located on the same route in the intersection of the area within the buffer zones according to the previous conditions but not less than 300m from the reference bus stop.
- All procedures were repeated to locate the new bus stop locations.
- Implementation the New Distribution and Comparing the Result

3. Analysis and Result

This chapter evaluates the level of accessibility before and after the relocation process, and explains the results.

3.1. Location Allocation Model:

Six location allocation models are available in ArcGIS 10.8 to solve different types of problems based on different assumptions. (1) Minimize Impedance, (2) Maximize Coverage, (3) Minimize Facilities, (4) Maximize Attendance, (5) Maximize Market Share, and (6) Target Market Share.

This study applied the minimized impedance model that is supported in the network analyst extension in ArcMap 10.8. These two models were chosen because their goals fit the results we seek to achieve, as explained in the next sections.

3.2. Minimizing Impedance Problem

By solving the problem using a location allocation model to minimize impedance problems, the model finds the optimal solution for the set of the facilities and the demand points. The optimal solution represents the maximum number of bus stop locations that can serve the maximum number of facilities within the conditions that are defined in the model.

In the optimal solution solved by the module, with the old distribution, 34 stop locations out of 48 and 135 facilities out of 300 are presented. The Network Analyst message shows the number of facilities (bus stops) and demand points (main facilities) used in the optimal solution.

Table 3. The attribute data table of bus stop locations.

Object ID	Shape	Name	Facility Type	weight
97	Point	Location1	Chosen	1
98	Point	Location2	Candidate	1
99	Point	Location3	Chosen	1
100	Point	Location4	Chosen	1
101	Point	Location5	Chosen	1
102	Point	Location6	Chosen	1
103	Point	Location7	Chosen	1
104	Point	Location8	Chosen	1
105	Point	Location9	Candidate	1
106	Point	Location10	Chosen	1
107	Point	Location11	Chosen	1
108	Point	Location12	Chosen	1
109	Point	Location13	Candidate	1
110	Point	Location14	Chosen	1
111	Point	Location15	Chosen	1
112	Point	Location16	Chosen	1
113	Point	Location17	Chosen	1
114	Point	Location18	Candidate	1
115	Point	Location19	Chosen	1
116	Point	Location20	Chosen	1
117	Point	Location21	Candidate	1
118	Point	Location22	Candidate	1
119	Point	Location23	Chosen	1

As a result, in the attribute data table of the bus stop location within the location allocation layer, all points that have the value (chosen) in the facility type field represent the 34 bus stop locations that were selected in the model. The 14 bus stop locations that have the value of (candidate) in the facility type field but were not selected in the solution will not result in a better solution because they are redundant. As shown in Table 3.

And in the attribute data table of the main facilities within the location allocation layer, the points that have the value (1) in the allocated weight field, represent the 135 facilities locations that were selected in the model. The 166 facilities locations that have a value of null in the allocated weight field were not selected in the solution, as shown in Table 4.

Table 4. The attributes data table of the main facilities

Shape	Name	Weight	Allocated weight
Point	dinar teller	1	<Null>
Point	Western Union	1	<Null>
Point	Location1	1	1
Point	Sameeramis hotel	1	1
Point	Location 2	1	<Null>
Point	Location 3	1	<Null>
Point	Location4	1	<Null>
Point	Ibis Amman	1	<Null>
Point	Location 5	1	1
Point	Location 6	1	<Null>
Point	Location 7	1	<Null>
Point	Oasis Roundabout	1	1
Point	Location 8	1	<Null>
Point	Location 9	1	<Null>
Point	Location 10	1	1

The demand points (facilities) within the cutoff distance (400 m) of the bus stop locations were selected in the optimal solution, but the furthest away were not selected. One of the facilities was measured at 230.13m from the bus stop, and it was selected as one of the points in the optimal solution because it was within 400m.

The optimal solution resulting from the minimized impedance model has chosen the optimal number and locations of the bus stops and facilities in the current distribution. The percentage of accessible facilities was 45% and the percentage of inaccessible facilities in the model was 55% of the total number of the facilities, as shown in Table 5.

Table 5. Results of Location Allocation Problems for the Covered and Uncovered facilities within 400m

	Accessible Facilities	Inaccessible Facilities	Total
Facilities	135	165	300
Percentage %	45%	55%	100%

3.3. Optimization Implementation

A new layer was created in Arc Map 10.8 which represents the new distribution as shown in Figure 2. And to view the differences between the old and new distribution, a map in Figure 3 was created by adding the old bus stop layer and the new relocation bus stop layer to the layout. The red points represent the old distribution of bus stop locations and the green points represent the new distribution. The points that have the same locations in red and green are the selected bus stop locations.

The Location Allocation method (minimized impedance model) was implemented after the relocation process. The new relocation layer was loaded into the location allocation layer as a facilities layer and the main facilities layer was loaded as a demand layer. Then the model was solved with the new input data.

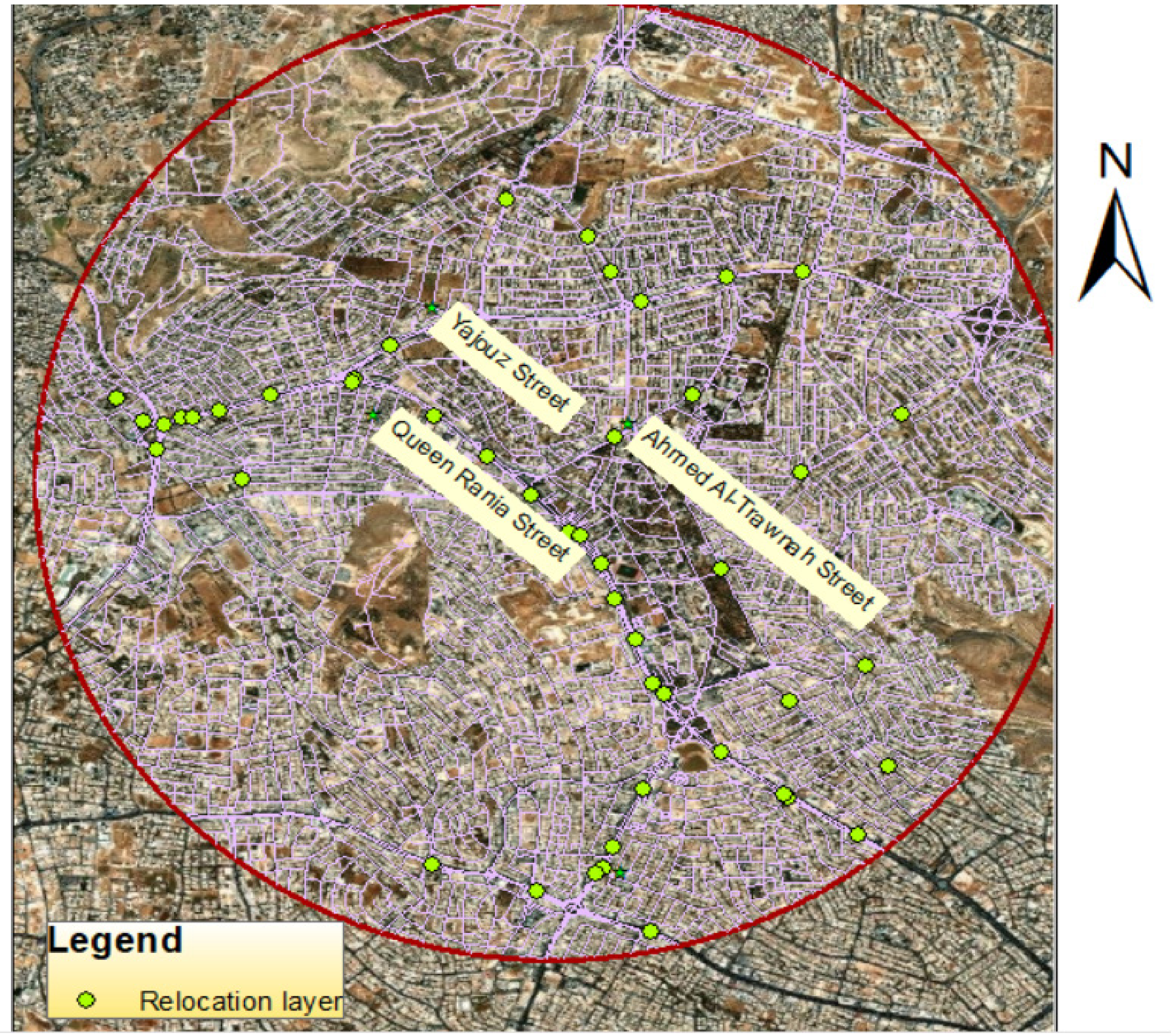

Figure 2. Redistribution bus stop layer

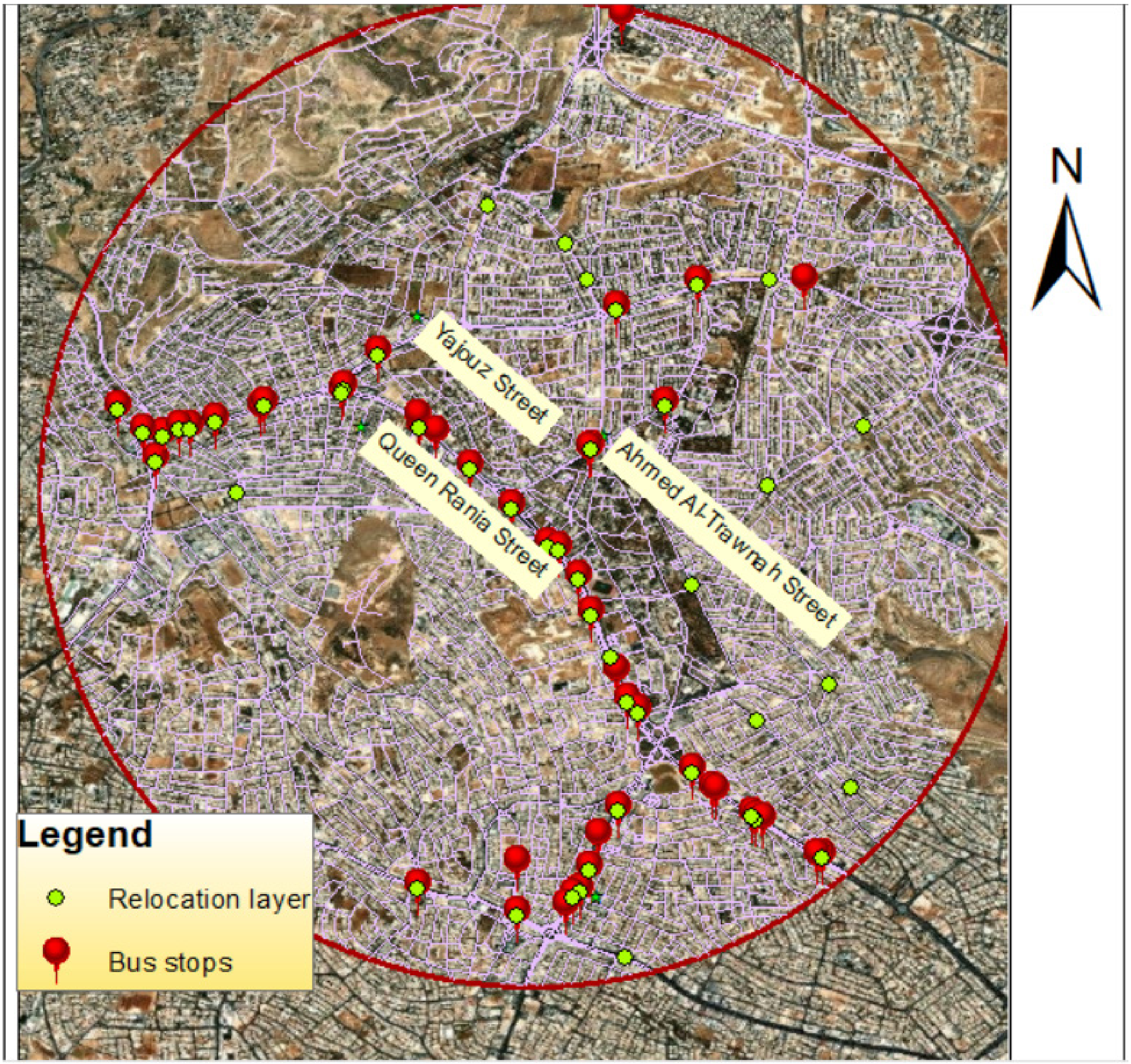

Figure 3. The differences between the old and new distribution

The final results of the minimized impedance model that was implemented after applying the optimization process were:

All bus stop locations (48 bus stop locations) were selected in the optimal solution and have the value (Chosen) in the (Facility Type) field in the attribute data table of the bus stop within the location allocation layer as shown in Table 6. The attribute data table of bus stop locations

The number of facilities accessed has increased. And the number of utilities became 208 instead of 134 in the previous distribution of bus stop locations.

Reducing overall transportation costs, which in this case study is distance. The distances from each bus stop location to any accessible facility are measured and presented as a line on the location-allocation layer, and the value of this distance is in the attribute table of the line within the (Total length) field as depicted in Table 7.

Table 6. Attributes data table of bus stop locations

Object ID	Shape	Name	Facility Type
145	Point	Location1	Chosen
146	Point	Location2	Chosen
147	Point	Location3	Chosen
148	Point	Location4	Chosen
149	Point	Location5	Chosen
150	Point	Location6	Chosen
151	Point	Location7	Chosen
152	Point	Location8	Chosen
153	Point	Location9	Chosen
154	Point	Location10	Chosen
155	Point	Location11	Chosen
156	Point	Location12	Chosen
157	Point	Location13	Chosen
158	Point	Location14	Chosen
159	Point	Location15	Chosen
160	Point	Location16	Chosen
161	Point	Location17	Chosen
162	Point	Location18	Chosen
163	Point	Location19	Chosen
164	Point	Location20	Chosen
165	Point	Location21	Chosen
166	Point	Location22	Chosen
167	Point	Location23	Chosen
168	Point	Location24	Chosen
169	Point	Location25	Chosen
170	Point	Location26	Chosen
171	Point	Location27	Chosen
172	Point	Location28	Chosen
173	Point	Location29	Chosen
174	Point	Location30	Chosen
175	Point	Location31	Chosen
176	Point	Location32	Chosen
177	Point	Location33	Chosen

Table 7. The attribute table of resulted lines

Name	Facility Type	Demand Count	Total-Length
Location1	Chosen	5	668.496
Location2	Chosen	3	906.52
Location3	Chosen	3	321.5
Location4	Chosen	10	712.12
Location5	Chosen	4	844.849
Location6	Chosen	1	126.066
Location7	Chosen	2	67.238
Location8	Chosen	4	1329.595
Location9	Chosen	7	1514.121
Location10	Chosen	5	1175.599
Location11	Chosen	1	57.115
Location12	Chosen	3	427.651
Location13	Chosen	2	107.950
Location14	Chosen	5	653.526
Location15	Chosen	1	197.015
Location16	Chosen	8	1377.162

The overall distance is equal to (157218.28m) in the old distribution. But, the overall transportation cost (distance) in the new distribution was computed. It equal to 42898.15m and it was reduced.

4. Comparing the Results

According to assessing the old distribution, the result of the location allocation model (minimized impedance) indicated that 55% of the total number of facilities was inaccessible and that 14 bus stop locations were not chosen in the optimal solution of the model.

Those fourteen (14) unselected bus stops have been relocated to reach a larger number of facilities using the optimization process. Each new bus stop was relocated, and the location allocation models were reapplied. As a result, the percentage of accessible facilities increased to 69%.

Explaining the effect of adding bus stops on access and measuring this for each re-location was done separately. The number of accessible facilities and the percentage of accessible facilities were increased as shown in Table 8.

In order to get a better perception of the effect of the optimization that we have done, we make a comparison between accessibility of the old distribution and the results we obtained after implementing the optimization.

And as it is clear that the access rate has become 69% and the number of places that can be reached by the bus stops has become 208, which is shown in Table 9.

Table 8. Accessible facilities after relocation process

The number of bus stops	number of accessible facilities	percentage of accessible facilities
34	135	45%
35	148	49%
36	152	51%
37	155	52%
38	160	53%
39	164	55%
40	172	57%
41	176	59%
42	179	60%
43	185	62%
44	192	64%
45	197	66%
46	200	67%
47	204	68%
48	208	69%

Table 9. Results of Location Allocation Problems Before and After.

		Accessible Facilities	Inaccessible Facilities	Total
Before	Facilities	135	165	300
	Percentage %	45%	55%	100%
After	Facilities	208	92	300
	Percentage %	69 %	31 %	100%

4. Conclusions

The research applied a useful GIS tool, location allocation models, within a cutoff distance of 400m. Accessibility represents 135 facilities out of a total of 300, which is 45% of the total facilities in the study area. After the reimplementation of the location allocation model on the bus stop locations layer with the new distribution, accessibility increased by 24%, reaching 69%. The number of accessible facilities increased to 208 out of a total of 300.

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