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Using p-median to solve location design problems

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Abstract:

Purpose: This research mostly concentrates on guiding pupils to their secondary schools following their accomplishment in the early elementary education phase. The primary challenge is the establishment of additional schools to accommodate the significant population growth resulting from expansion in emerging areas.

Theoretical framework: Scholarly literature has thoroughly examined the P-Median problem and applied it across various domains, including cluster analysis, quantitative psychology, marketing, the communications sector, sales force design, and political constituency division.

Design/methodology/approach: This study aims to propose a customization form based on the **P**-Median issue, taking into account its properties and structure. The P-Median problem optimizes the allocation of the facility (student school) to the demand point (student home) based on the average distance. This tool determines the best placement for a few schools.

Findings: In this research, of the form (P-Median) and the implementation of math results, which the results showed that sites number (4,3,1) in table No. (4) and knowledge in Table No. (1), the places where schools can be created because they are the most sought -after as they are newly constructed. These new schools can also accommodate the increase in the number of students in other regions.

Research, Practical & Social implications: It is possible to study and develop the proposed model according to new data and in line with the requirements.

Originality/value: The diversity of publishing and studying novel allocation methods increases cognitive capacity, particularly for new, relevant, and helpful issues, because they are practical for distributing the service facilities the country requires.

Authors' individual contribution: Conceptualization — A.S.C.; Methodology — A.S.C.; Formal Analysis — A.S.C.; Investigation — A.S.C.; Data Curation — A.S.C..; Writing — Original Draft — A.S.C.; Writing — Review & Editing — A.S.C.; Visualization — A.S.C.; Supervision — A.S.C.; Project Administration — A.S.C.

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1. Introduction:

Location of facilities, logistics, and allocation of resources are just a few areas where the p-median problem finds application as an optimization problem. Given a set of potential locations for facilities and a set of demand points, the goal is to find the best places to put these facilities so that the distance between them and the point of demand is minimized.

Within the framework of allocation, the p-median issue can be employed to optimize the positioning of resources in order to effectively satisfy demand. To illustrate application of the p-median problem in allocation operations. Consider the following examples:

1. The p-median problem can be used by firms with a substantial number of prospective facility locations to ascertain the most advantageous quantity and placement of distribution centers, warehouses, or factories. By minimizing the overall transportation costs or distances, they may effectively distribute resources and enhance the efficiency of their supply chain network.(Sadeghi et al., 2023)
2. Service Allocation: In fields such as healthcare, education, or emergency response, the p-median problem can be used to allocate services or resources to the population. For example, determining the optimal locations for a limited number of hospitals, schools, or fire stations to ensure adequate coverage and minimize response times.(Murad et al., 2024)
3. Load balancing in computing refers to the implementation of the p-median computation at distributed computing systems to divide jobs or resources among several processors or servers. Optimizing the distance or communication costs between jobs and processors enables the system to enhance load balancing and optimize overall performance.(Cohen et al., 2015)
4. We can employ the p-median problem in political districting to establish fair and condensed election districts. By conceptualizing demand points as population centers and facilities as district centers, it is possible to develop an optimization model that partitions a geographic region into districts that are adjacent, have comparable population sizes, and aim to reduce the overall distance between population centers and district centers.(Hillsman, 1984)

Every year, school administrations and parents face difficulties in enrolling students in secondary schools in the suburbs. It is considered one of the important decisions, which is the distribution of students, the construction of new secondary schools, and so on. Nowadays, since the number of students is increasing every year, the complexity of problems has reached such an extent that even basic methods appear unsuitable. Hence, the necessity to employ analytical algorithms to address site allocation concerns has attracted the attention of decision-makers. By employing various processing approaches, we want to determine the most efficient arrangement for building new high schools that can adequately cater to the population's needs. Site allocation difficulties include making judgments to determine the most optimal layout for building one or more facilities. (School, health center, fire station, etc.) in order to meet population demand (population increase). (Menezes & Pizzolato, 2014) (Herda, 2015) (Murad et al., 2024)

1.1 Literature Review:

Many different types of planning problems can benefit from the P-Median approach, which is why it is attracting so much attention: as (Cintrano et al., 2018), added an official character to the median problem as a correct counter -meter programming issue such as identifying bicycle stations for the purpose of storing them and making them easily accessible, and the division of schools (Ndiaye et al., 2012). The sites of the phone switching center(Cohen et al., 2015) the work of (laporte et al, 2022) on the issue of median P where each facility needs the minimum work burden. (It may be cost, distances or time ... etc.). The work (Ponce, 2016) to address the demand for more versatile logistic models, the Discrete Ordered Median Location Problem (DOMP) was created, this model might be applied to many location issues, such as the p-median or the p-center. (Omar & Morales, 2017) . Using an ordered weighted averaging operator, it provides a versatile formulation in logistics and supply chain management, the p-median problem is a significant subject. The work (Safa et al., 2019) identified and analyzed a closed-loop medical supply chain that is sustainable and efficient with a multi-level p-median approach, focusing solely on the healthcare supply chain model (Dpt, 2021). It is assumed that the precise location of facilities is unknown in a novel version of the facility locating issue, P-Median. Alternatively, the facilities should be situated inside a specific area surrounding their original location. This will allow for a variety of objective functions commonly used in site analysis to be formulated using nonlinear mixed integer programming. The work of (laporte et al, 2022) on the issue of p- median where each facility needs the minimum work burden. (It may be cost, distances or time ... etc.), (Labita & Namoco, 2023) in order to help the Bureau of Fire Protection (BFP) figure out where in Cagayan de Oro City to put fire stations strategically, this study set out to do just that.

This study presents the school location for pupils transitioning from primary to secondary education. We recommend using the P-Median problem to create a personalized form. We have successfully solved the mixed integer linear program using a MILP solution in Lingo to obtain the accurate binary numbers (0–1). Additionally, we have included all schools (or demand points) to demonstrate the successful application of simulation techniques in practical decision support. In this context, "I" represents the number of students who have passed the exam in each school. Facilities or establishment sites are suitable locations for establishing schools, denoted by "J".

The intended outcomes typically involve the establishment of a service facility. However, during the process of improvement, it is possible that the optimal solution may involve a different numerical value. A solution to the P-median problem is defined as a composition that consists of precisely P facilities. To determine the number of facilities that will be located, the appropriate value for P must be selected. The optimal solution is the composition that has the smallest distance.

The target function represents the cumulative distance between all specified demand points and the closest service facility. We estimate the distance based on the specific location's population density.

Section 2 provides a customized form that utilizes the P-Median issue formulation. Section 3 and 4 specifically focus on presenting the outcomes or findings. Finally, we present the summary and conclusions.

2.Materials and Methods:

An important tool in the toolbox of location theorists is the P-Median problem, which calls for an understanding of the following: A school, hospital, fire station, etc., to know how many people use it and where it's located is demanded. The goal is to identify a set of locations that can accommodate the requested number of facilities.

This search utilizes the p-median approach to choose facilities or facility locations that are considered appropriate for developing service facilities. The establishment of service facilities is not feasible outside of these locations. However, during the process of optimization, the achieved solution may exhibit a distinct numerical value.

Finding the best answer to the p-median problem where p is the maximum allowable number of facilities is all that matters to us. The best configuration is the one with the minimum distance. A p-Median problem always has an optimal solution, but there could be multiple minimal distance configurations. (Given different values of p). (Herda, 2016)

1.2 The requisite data for algorithm designed to address the P-Median problem:

• There are a finite number of demand points with specific application values that define the position and quantity of the request that needs to be fulfilled.

• A limited number of service points in the facility. These are the only points in which the facilities can be.

• The spatial separation occurs between the demand of points and the facility sites. Depending on the specific problem at hand, one can derive the calculation from either the network or the distances. Distances can act as barriers, encompassing not only physical kilometers but also temporal durations and financial expenses. (Ndiaye et al., 2012)

Furthermore, it is imperative to select a valid positive number (P) to decide the quantity of facilities to be chosen, in addition to the fore mentioned three primary data collections. The goal is to enhance this service comprehensively. This function assesses the solution's quality and provides a numerical number to represent it. This research presents an algorithm that aims to identify the most favorable solution to the objective function, which seeks to minimize or maximize the value. This study aims to reduce the student's travel distance service. The registration process necessitates assigning each request to its nearest point. The symbol (P) denotes the aggregate count of facilities. The goal is to use the value of (P) obtained from the facilities and distances cut in order to calculate the demand points using the chosen objective function.

2.2 The P -Median model formulates the following:

$i = 1, \dots, m \quad points\ of\ demand, when\ m\ is\ no.\ of\ demand.$

$j = 1, \dots, n \quad facility\ locations\ for\ facilities.$

$k = \quad the\ maximum\ distance\ to\ be\ traveled\ by\ pupil\ .$

$ai =$ *The population represented by the number of learners at demand point i.*

$dij =$ *Calculate the distance between location i and location j.*

$P =$ *the planned number of educational institutions.*

$$x_{ij} = \begin{cases} 1, & if\ children\ of\ school\ i\ \ is\ signged\ to\ site\ j \\ 0, & otherwise \end{cases}$$

$$y_{ij} = \begin{cases} 1, & \text{if school j is selected} \\ 0, & otherwise \end{cases}$$

The objective function is to minimize the overall weighted of distance of the assignment.

$$\text{Min} \sum_{i=1}^{m} \sum_{j=1}^{n} a_i d_{ij} x_{ij} \quad \dots (1)$$

Subject to:

$$\sum_{j=1}^{n} x_{ij} = 1 \quad \forall i = 1, \cdots, m \dots (2)$$

$$\sum_{j=1}^{n} y_j = p \dots \ (3)$$

$$x_{ij} \le y_j \quad \forall i = 1, \cdots, m \forall j = 1, \cdots, n \dots \ 4)$$

$$d_{ij} x_{ij} \le K, \forall i = 1, \cdots, m \forall j = 1, \cdots, n \ \dots \ (5)$$

$$x_{ij} \in \{0,1\} \text{ and } y_j \in \{0,1\} \ \dots (6)$$

$$\forall i = 1, \cdots, m, \qquad \forall j = 1, \cdots, n$$

This form applies when each point signifies a request beyond the facility site, or when a predetermined set of network points restricts the selection of eligible sites. The objective function (1) aims to minimize momentum while reaching a specific destination. If $x_{ij} = 1$, it signifies the assignment of the i point to a specific point in j. The value of $x_{ij} = 1$ implies that the most probable distance, represented by ai, dij, is considered in the overall distance calculation. The initial constraint (2) mandates that each individual designate a specific facility as their point of demand. Constraint (3) limits the precise placement or allocation of facilities P, where P represents the number of facilities to be established. Constraint (4) confirms that only selected sites should receive any allocation for a facility. The constraint (5) denotes the furthest distance that the student can travel, whereas the final constraint (6) limits the variables to the values (0, 1).

3. Methodology:

Population growth and the continuous expansion of areas have put pressure on services, leading to several problems, including the need to build new schools, both primary and secondary. In our research, we focused on the establishment or construction of secondary schools, which relied on two main elements: the weight of demand (the weight of demand refers to whether every primary school graduate finds a school; if yes, the weight represents only the surplus number of students, while in the case of no school being available to accommodate them, it represents the entire number) and the number of students graduating from primary school in that area, as well as the distance students must travel to reach the school. Additionally, the available land for building these schools was considered. In Table No. (1), which represents the demand weight for each neighborhood located in the Slaseal area of Al-Karkh/3, the Pressure Street neighborhood in Al-Ghazaliyah area is added due to its proximity. The residential increase represented the surplus of students in fully serviced areas. Table (2) represents the distances between the targeted areas.

Table (1): Demand points in the regions

Number of the region	Name of the region	Order weight
1.	Dawanam	250
2.	Al-Rawad	200
3.	Al-Salamiyyat	175
4.	Al-Tajiyat	100
5.	Al-Sabiyat	150
6.	Al-Jawadin District	75
7.	Al-Rahmaniyah	04
8.	Al-Ghazaliyah (Al-Daha Street)	07
9.	Al-Shuala	05
10.	Al-Dulai	100
11.	Professors' Neighborhood (Jakouk)	04
12.	Officers Neighborhood (Jakouk)	04

Table (2): Distances between the regions with (km)

regions	Dawanam	Al-Rawad	Al-Salamiyyat	Al-Tajiyat	Al-Jawadin District	Professors' Neighborhood (Jakouk)	Officers Neighborhood (Jakouk)
Dawanam	0	4	6	5	3	4	5
Al-Rawad	4	0	7	4	5	4	5
Al-Salamiyyat	6	7	0	6	4	8	8
Al-Tajiyat	5	4	7	0	4	5	5
Al-Sabiyat	9	8	9	5	6	6	6
Al-Jawadin District	5	5	6	6	4	5	5
Al-Rahmaniyah	4	6	5	7	5	6	6
Al-Ghazaliyah (Al-Daha Street)	5	6	5	8	7	7	7
Al-Shuala	4	4	5	7	4	6	6
Al-Dulai	6	5	8	5	5	3	2
Professors' Neighborhood (Jakouk)	6	4	8	6	6	0	1
Officers Neighborhood (Jakouk)	6	5	8	6	4	1	0

Figure (1): A map of the areas targeted by the research

4. Results:

Table (3): Results from running the program lingo

variable	$x_{(1,1)}$	$x_{(2,4)}$	$x_{(3,3)}$	$x_{(4,4)}$	$x_{(5,4)}$	$x_{(6,1)}$	$x_{(7,1)}$
value	1	1	1	1	1	1	1
variable	$x_{(8,1)}$	$x_{(9,1)}$	$x_{(10,4)}$	$x_{(12,4)}$	Otherwise, values x_{ij}=0		
value	1	1	1	1			
variable	y_1	y_2	y_3	y_4	y_5	y_6	y_7
value	1	0	1	1	0	0	0

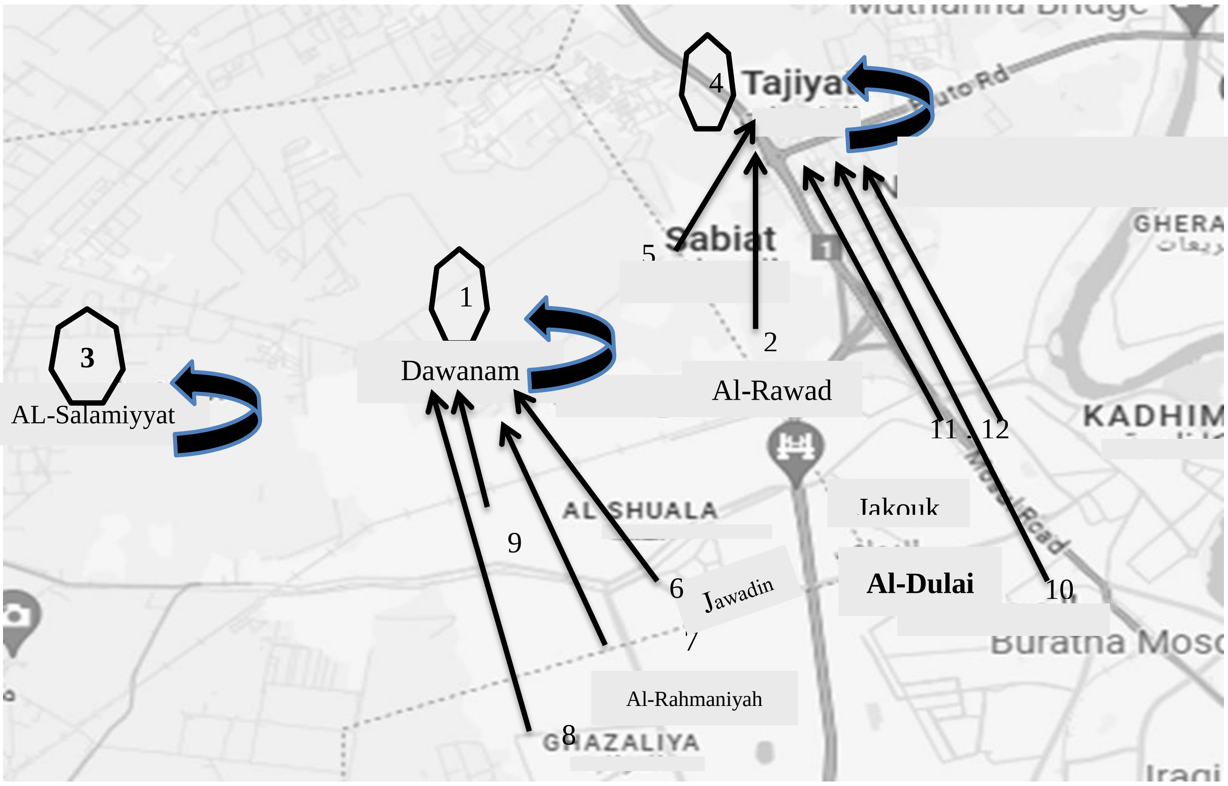

Figure (2): Map of the targeted areas after solving model

Table (4): Final Results

Location	Request
1	1,6,7,8,9
3	3
4	2,4,5,10,11,12

5. Discussion of Results:

Through the data entered the program, which represents a practical number, the following can be clarified:

When choosing the value (P = 3), which represents the number of schools or available sites that can be created, we notice:

1. These schools were established on the site (1, 3, 4), which are more demanding according to the program analysis of the entered data.
2. The students 'excessive tendency for the energies available on other sites, including (9,8,7,6), was to site No. 1.
3. The students 'excessive direction on the available energies on the other site, including (2, 5, 10, 11, 12), was to site No. 4.
4. Data extracted according to the program and the restrictions imposed, taking into account the distance and demand, as well as the ability to create sites (schools).
5. It is possible to choose another value of P, which was 4,5 or less than that according to what is available, and the plans laid down to create new sites or services.
6. Figure No. (2) shows this as the index of the areas in which new schools were established, in addition to the movement of the increase in the number of students and their movement to the schools that were established.

6. Conclusions:

1. This study introduced a model based on the p-median problem. The linear program incorporating mixed integers 0 - 1 was successfully solved, demonstrating the effective application of simulation approaches in aiding real decision-making about the allocation and establishment of diverse service facilities within certain limits.
2. Location analysis is a domain within Operational Research that encompasses a diverse array of mathematical models. A problem is categorized within the location field if a decision concerning the placement of new facilities must be made.
3. These models can be used to develop and assist in decision-making to build a specific service facility and move away from old traditional methods.

Authors Declaration:

Conflicts of Interest: None

-We Hereby Confirm That All The Figures and Tables In The Manuscript Are Mine and Ours. Besides, The Figures and Images, which are Not Mine, Have Been Permitted Republication and Attached to The Manuscript.

- Ethical Clearance: The Research Was Approved by The Local Ethical Committee in The University.

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