Location Analysis of Fire Stations in Cagayan de Oro City using Minimum Impedance (P-Median Problem) and Maximal Covering Location Problem (MCLP) with Q-Coverage Requirement Approaches

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Abstract

This study aimed to address the problem of the Bureau of Fire Protection (BFP) in determining the strategic locations of the fire stations in Cagayan de Oro City, Philippines to provide a fast and timely response using the facility location problem (FLP). This study compared two FLP models, namely minimum impedance and the maximal covering location problem (MCLP) to determine the optimal number and the respective best locations of the fire stations without relocation. In addition, a set of adopted performance criteria was employed to evaluate which model fitted the problem. In the integration of the Q-coverage requirement, results identified the backup fire stations of each barangay (village) if the primary fire station is unavailable or responding to other demands. The results revealed that MCLP performed better than the minimum impedance across the average travel distances of 1.19, 3.43, and 4.44 km for Q values 1, 2 and 3, respectively. Moreover, MCLP outperformed each of the three criteria for all of the Q values. Thus, the MCLP provided an efficient application for deciding on the locations of fire stations to minimize the travel distance between demand, primary and backup fire stations, thereby fulfilling its mandate of protecting communities from destructive fires and other emergencies.

Keywords: facility location problem, fire station, maximal covering location problem, minimum impedance, Q-coverage requirement

1. Introduction

Response time is the most critical and crucial factor in emergency services like fire stations. The longer it takes for a fire response team to arrive, the greater the chance of casualties and property damage. According to the Republic Act 9514 (2008) also known as the "Philippine Comprehensive Fire Code of 2008," firefighters are required to arrive and respond at incident locations within five to seven minutes from the receipt of the call. Therefore, routes and locations of fire stations must be selected to arrive at the fire accident site in the shortest possible time. Better techniques for determining high- and low-risk areas can aid in planning for disaster preparedness and resource evaluation when determining the optimum location for a new fire station (Krisp and Karasov, 2005).

According to the Commission on Audit (2018), despite the launching of the Bureau of Fire Protection (BFP) Modernization Program in 2010, some of the fire stations in the country are still not strategically located to provide a prompt and efficient response. This led to an unmet performance indicator target in their quarterly physical report of operations from fiscal years 2018 to 2023 (Department of Interior and Local Government – Bureau of Fire Protection, 2018, 2019, 2020, 2021, 2022, 2023).

Numerous studies have been conducted to provide authorities with strategically positioned emergency services allocation and literature sources that outline its methodologies, algorithms and other spatial analytical tools for various situations with specified restrictions with the aim of locating the optimal sites for facilities that can improve accessibility and reduce the total weighted cost satisfying a set of demands subject to certain constraints (Hale and Moberg, 2003). Different techniques and mathematical approaches were utilized, and the parameters and elements used in emergency services were implemented to improve the quality of their services. Canoy *et al.* (2014) introduced the concept of restrained independent dominating sets for use in problems related to guards and prisoners. Serra and Marianov (1998) explored the issue of locating new facilities with uncertainty and applied it to the fire stations in Barcelona using the p-median-like model with two different objectives, namely MINMAX and regret objectives. Meyer (2011) employed the methodologies of the MINISUM with a maximum distance constraint to relocate fire stations in Toledo, Ohio which would reduce the period of time it took for fire and emergency medical services deployment to reach an emergency. A deterministic P-median model was utilized by Carbone (1974) to reduce the distance between demand and public services like hospitals and childcare facilities. Yang *et al.* (2007) developed a fuzzy bi-objective algorithm and applied it to fire stations in the Derbyshire region of the United Kingdom. A genetic algorithm was utilized, and one of the objectives was to decrease both the total expenditures and the distance between fire stations and accident scenes. Mohammadi *et al.* (2016) recommended a multi-objective stochastic programming approach for earthquake response planning. The model aimed to reduce overall costs, increase coverage and reduce satisfaction level fluctuation. A p-median-based heuristic location model for the city of Carbondale, Illinois was presented and evaluated by Paluzzi (2004). An ideal solution to a traditional p-median problem (P-MP) formulation ensures a minimal average distance between each demand and their nearest facilities (Karatas and Yakıcı, 2019).

As defined by Atta *et al.* (2021), the maximum coverage location problem (MCLP) is a well-known combinatorial optimization issue with several applications in emergency and military services, as well as in public services. According to the conventional definition, MCLP is a single objective problem with the purpose of maximizing the total number of customer requests that can be met by a specific number of operational facilities. In research by Erkut *et al.* (2009), MCLP made the assumption that response times were known and deterministic. Additionally, MCLP assumed that the nearest facility to a demand location is always available. Hamed *et al.* (2023) developed MCLP, a linear mixed-integer problem with a number of constraints, to determine the ideal placement and level of coverage for charging stations over a major metropolitan area. Plane and Hendrick (1977) used the maximum coverage distance model to address a fire station location problem by establishing a hierarchical objective function. The objective function was able to minimize the number of fire stations simultaneously and maximize the existing fire stations within the minimum total number of stations present. Similarly, Hogg (1968) employed a set-covering strategy in Bristol City. Paul *et al.* (2017) developed a multi-objective MCLP formulation to identify local resources to address major catastrophes. The Planar MCLP based on road networks with continuous demand and unequal service zones was studied by Matisziw and Murray (2009); however, the study was restricted to urban areas only. Revelle and Snyder (1995) used two location-allocation techniques to determine the optimal locations of emergency stations that released fire and ambulance service: the MCLP, which determined the optimal locations for ambulance stations, and a facility location-equipment emplacement technique allocation, which was used for fire service allocation. Since ambulance and fire services have various service requirements and cost levels in this investigation, two separate heuristics were applied. Algharib (2011) combined the population and its distribution and fires and their distribution as combination variables in the four types of location-allocation modeling, namely minimize impedance, maximize coverage, minimize facilities and maximize attendance. Hosseini and Ameli (2011) developed a bi-objective model for a problem involving the distribution of emergency service locations under the restriction of maximum distance.

Habibi *et al.* (2008) highlighted the main criteria for fire station location, which included the distance among the stations; the level of fire risk in the different parts of a city; accessibility; coverage area; population; the size of the plot; and directions of city expansion. Meanwhile, Karatas *et al.* (2017) evaluated the performance of three classic location models (P-MP, p-center problem and MCLP) with respect to seven decision criteria under the Q-coverage requirement.

The BFP Cagayan de Oro City District authorities and an initial assessment of pertinent studies have determined that, despite the substantial and extensive research on these two FLP models on emergency services, no study has been conducted to address the challenge of responding to fire incidents that have occurred within the city's prescribed time frame. Moreover, it was also mentioned that the city's modernization program has not been completely implemented due to inevitable factors and that the strategic location of the fire station is still unknown.

Consequently, this paper aimed to present a facility location model approach to finding the optimum number of fire stations and their respective strategic locations through the application of facility location problem (FLP) models utilizing the minimum impedance and the MCLP with Q-coverage requirement. The facility location problem is an area of operations research and computational geometry concerned with the best placement of facilities with the goal of reducing the mean travel distance to the demands. This is to minimize the total aggregate weighted response time without relocating the existing fire stations. Furthermore, FLP is employed in situations where seconds make a difference, with the purpose of protecting people and property from devastation. Moreover, a set of performance criteria was implemented, namely Criteria 1 (C1): mean distance to primary; Criteria 2 (C2): mean distance to primary and backup; and Criteria 3 (C3): mean distance to backups. This study is to provide and contribute potential suggestions for the achievement of the BFP Modernization Program's goals and objectives as well as the fire suppression efforts in Cagayan de Oro City.

2. Methodology

2.1 Study Area

Cagayan de Oro City (Figure 1) is the largest of the region's eight cities and serves as the regional capital of Region 10 (Northern Mindanao). The city ranked among the Top 10 Cities in the Philippines for Fiscal Year 2021, according to the Department of Finance Bureau of Local Government Finance, in terms of the collection efficiency of locally sourced revenues (LSR) and year-on-year growth in LSR (Allanigue, 2022). In addition, the city houses the national government's regional offices and acts as the region's main port of entry and transshipment center. The city has experienced rapid expansion as a result of its urbanization and population growth. The city's population has grown dramatically throughout the years making it one of Mindanao's fastest-growing cities. According to the Philippine Statistics Authority (2021), the city has a population of 728,402 individuals and a density of 1,436 persons per square kilometer as per the May 2020 Census of Population and Housing. The city's population has grown by 7.76% since the 2015 CPH. With a total land area of 57,851 ha, the city, also known as the "City of Golden Friendship," is the largest in the region. It covers 3.4% of the region's land area and 15.96% of Misamis Oriental. It is bounded on the north, south, east and west by the coasts of Macajalar Bay, Bukidnon, Tagoloan and Opol, Misamis Oriental, respectively. The city is divided into two districts and has a total of 80 barangays (villages). The city is currently served by nine fire stations and six fire substations to cover calls and incidents as shown in Figure 1.

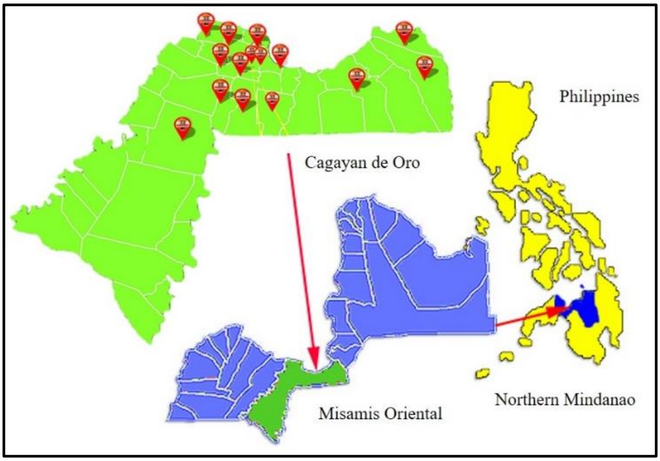

Figure 1. Geographical location of Cagayan de Oro City: existing fire station and fire substation

2.2 Correlation of the Variables

The degree and direction of the correlation between two variables are measured using a Pearson's Correlation Coefficient (PCC) test, often known as Pearson's R. In the work by Schober *et al.* (2018), the PCC test is often utilized with jointly normally distributed data (data that follow a bivariate normal distribution). The test was conducted and revealed that the population had a very strong positive correlation and significant influence on fire occurrence in the city from calendar years (CY) 2016-2021 at +0.9148. In other words, barangays with large populations appeared to have a higher fire incidence than those with smaller populations. Krisp and Karasov (2005) found out that the relationship between population density and fire occurrences in urban areas was not as great as initially presumed. Thus, the population distribution of the demands was an evident choice for fire station location and intervention dependency.

The population served as the weight (h_j) in both facility location models, namely minimum impedance (P-MP) and MCLP. In fact, the BFP Modernization Program placed emphasis on the population ratio in the decision-making of the bureau. Figure 2 shows the city's population versus the fire incident occurrences from CY 2016-2021.

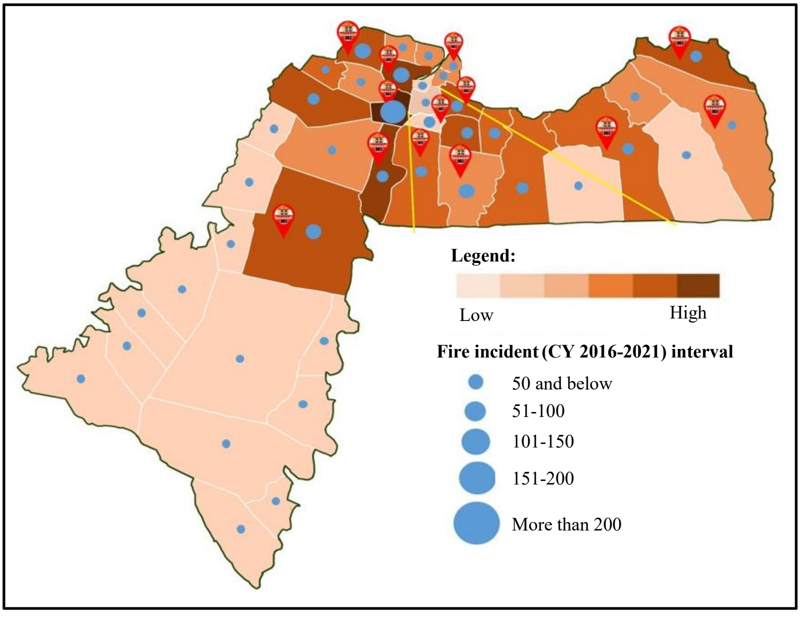

Figure 2. Geographical location of Cagayan de Oro City: population versus the fire incident occurrence in 2016-2021

2.3 Assessment of the Existing Location and Coverage of Fire Stations

This study used a comprehensive database that spans a six-year period from CY 2016-2021 to analyze the frequency of urban fires, classify the primary causes and damages at different time scales and integrate the data from the street level to the urban district, and at the city level. Moreover, this study calculated the average archived response time of each fire station to the barangay under its area of responsibility (AOR) from 2016 to 2021 from the office of the BFP Cagayan de Oro City District Marshal in order to measure and assess each fire station's existing location and coverage. This was to determine which areas of the city were covered and uncovered within the bureau's set response time. If the actual average response time from the primary or the nearest fire station to the demand is less than the bureau's predefined standard and no response time exceeds 7 min, the barangay is defined and declared to be covered. Otherwise, it is uncovered. In the case that a barangay has no fire incident in the same period, the evaluation is based on the coverage of the nearby barangay. In other words, if barangay A and barangay B are neighborhoods, barangay A has no fire incident, and barangay B is assessed as uncovered, then barangay A is likewise considered uncovered.

2.4 Formulation of Facility Location Problem Models with the Q-Coverage Requirement

Unlike the classical FLP, this study considered the Q-coverage requirement problem with primary and backup facility assignments concerning the three performance criteria presented and employed by Karatas and Yakıcı (2019). For each demand, this study named its nearest facility as the primary fire station. In cases where multiple coverages ($Q > 1$) were required, all non-primary facilities, assigned to the demand, were named backup fire stations.

The placement of the fire stations in the city is modeled in this study using the minimum impedance or P-MP and MCLP basic concerns. These two methods offer a number of benefits. The first model, the p-median, is interesting since getting to the closest facility is more convenient when the total weighted distance (which is comparable to the average) traveled is less. The MCLP, on the other hand, establishes what may be covered by a specific number of facilities and is a simple tool for analyzing the marginal coverage brought on by the addition of one or more new facilities.

2.4.1 Minimum Impedance (P-MP) Formulation

The minimum impedance also known as the P-MP model, formulated by Hakimi (1964), has set the foundations for many location problems in the public and private sectors. According to Mu and Tong (2018), minimum impedance is one of the most prevalent location problem models in urban and regional planning. The aim of applying this model was to minimize the total distance or time traveled by firefighting units to reach the demand points (fire locations). The fundamental problem is to find *p* locations that minimize the minimum average distance (or travel time) in a network. Only the network nodes need to be considered as locational candidates since there is always at least one optimal solution that consists of the location of the facilities on the network nodes (Hakimi, 1965). The P-MP model considers that the demand for service at each node and the travel times between nodes are deterministic. This model aims to find the locations of *p* facilities among n candidate locations such that the total weighted distance between all demands and their nearest facilities is minimized (Tansel *et al.*, 1983).

In this study, the following notations were used:

Sets and Indices

$i \in I$:Set of candidate locations for fire station intervention

$j \in J$:Set of demand locations or barangay

Parameters

m = Number of candidate locations for fire intervention ($m = |I|$)
p = Number of candidate facilities or fire stations intervention
n = Number of demand locations or barangay ($n = |J|$)
h_j = Weight of demand j
d_{ij} = Travel distance between locations i and j
Q = Minimum number of coverage (assignments) required

Decision Variables

$$x_{ij} = \begin{cases} 1, & \text{barangay } j \text{ is assigned to fire station } i \\ 0, & \text{Otherwise} \end{cases}$$

$$y_i = \begin{cases} 1, & \text{a fire station is placed at location } i \\ 0, & \text{Otherwise} \end{cases}$$

Mathematical Model

$$Min \sum_{i \in I} \sum_{j \in J} h_j d_{ij} x_{ij} \tag{1}$$

Subject to

$$\sum_{i \in I} y_i = p \tag{2}$$

$$\sum_{i \in I} x_{ij} = Q \qquad \forall j \in J \tag{3}$$

$$x_{ij} \le y_i \qquad \forall i \in I, \quad \forall j \in J \tag{4}$$

$$y_i, x_{ij} \in \{0,1\}, \qquad \forall i \in I, \quad \forall j \in J \tag{5}$$

The objective function (1) minimizes the total weighted distance between demands and their nearest facilities. Constraint (2) restricts the number of sited facilities to p. Constraint (3) ensures that Q facilities cover all demand locations. Constraint (4) ensures that the facilities that are not activated cannot cover any demand. Constraint (5) requires binary output.

2.4.2 MCLP Formulation

The MCLP maximizes the total demands supplied with a given number of facilities and designated budget (Balcik and Beamon, 2008).

In addition to the notation defined in the P-MP problem, for formulating the MCLP problem, an additional set, $N_j = \{ i \in I \mid d_{ij} \le r \}$, where r is the maximum range of a facility, is introduced. This section defines x_j variable as follows:

$$x_j = \begin{cases} 1, & \text{barangay } j \text{ is assigned to a fire station} \\ 0, & \text{Otherwise} \end{cases}$$

Mathematical Model

$$Max \sum_{j \in J} h_j x_j \tag{6}$$

Subject to

$$\sum_{i \in I} y_i = p \tag{7}$$

$$\sum_{i \in N_j} y_i \geq x_j Q, \qquad \forall j \in J \tag{8}$$

$$y_i, x_j \in \{0,1\}, \qquad \forall i \in I, \quad \forall j \in J \tag{9}$$

The objective function (6) aims to maximize the total weighted number of demands covered. Constraint (7) restricts the number of sited facilities to *p*. Constraint (8) ensures that at least Q facilities cover all demand locations. Constraint (9) requires binary output.

Both the P-MP and MCLP models presented above were solved using binary integer programming implemented in Python Programming utilizing its PuLP library. PuLP is a high-level modeling library that makes use of the Python language and enables the user to write programs using expressions that are native to the language eliminating special syntax and keywords whenever feasible. Python is a well-known and well-supported high-level programming language with a focus on rapid growth, understandable code and syntax, and a straightforward object model (Mitchell *et al.*, 2011).

2.4.3 Performance Criteria

This subsection presents the criteria used in comparing the performances and results of both facility location models. These criteria aimed to measure and scrutinize the efficiency of the solutions of the two models in terms of distances between demand locations and facilities and the number of demand locations covered. This study used the three criteria based on the studies of Winarso and Rohim (2018) and Karatas *et al.* (2017). In specific, the definitions of the performance criteria are as follows:

Criteria 1 (C1) – Mean distance to primary: This criterion calculates the average distance between each demand location and the nearest facility. This performance metric, which is commonly used in emergency service location analysis studies, tries to quantify the effectiveness of a particular solution in terms of average travel distance.

Criteria 2 (C2) – Mean distance to primary and backup: The mean distance between each demand and all designated Q facilities is calculated using this criterion. To put it another way, this criterion evaluates a solution's performance in terms of distances to both primary and backup coverage sites.

Criteria 3 (C3) – Mean distance to backups: This criterion assesses the average distance between each demand and the Q-1 backup facilities assigned to it. The major goal of this criteria is to determine how effective backup systems are when the primary is occupied with other tasks. The lowest distance to backup facilities is critical for improving the performance of an allocation strategy, especially when demand is high.

The processes undertaken in this study are described in Figure 3; it begins with gathering relevant secondary data and continues with an assessment of each barangay's coverage and the formulation of FLP models. In the development of the FLP models, the two models differed in their objective functions. The minimum impedance used minimization, while the MCLP used maximization.

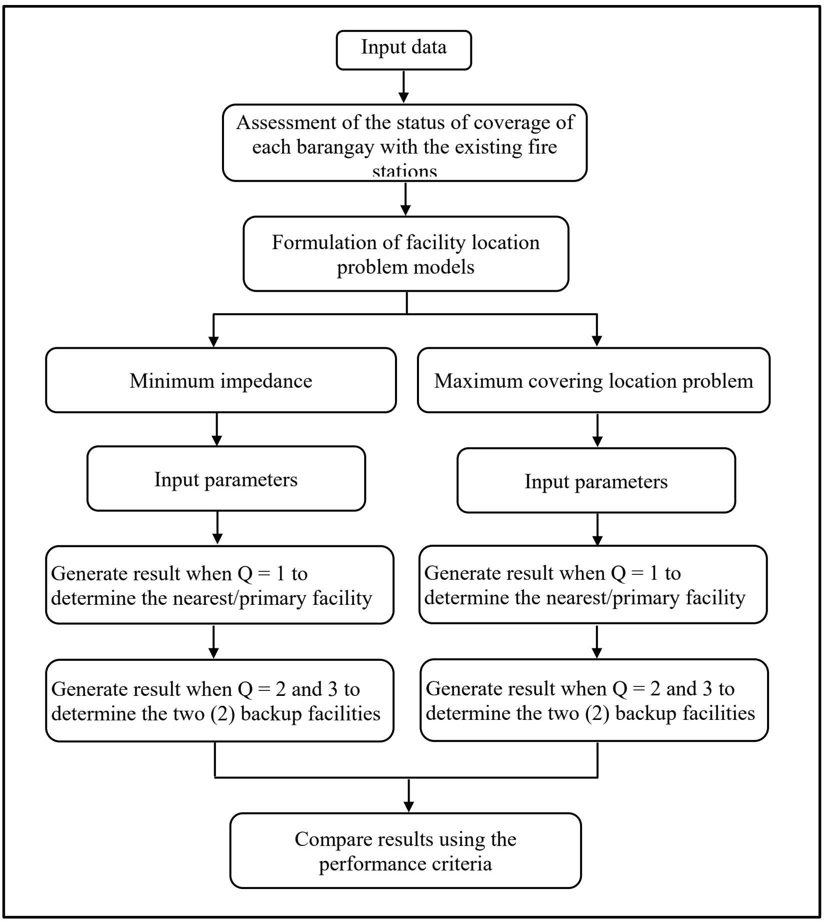

Figure 3. Flow chart of the study

3. Results and Discussion

3.1 Assessment of the Existing Locations of Fire Stations and the Demands

This study employed the actual response time of each barangay to the nearest fire station archived from the monthly reported incident covering the periods from January 2016 to December 2021 to assess the existing locations of the fire stations and to determine which parts of the city were covered and uncovered. As mentioned earlier, a barangay is covered if the average response time from 2016 to 2021 is within 7 min and no response time is more than the predefined standard response time; otherwise, it is uncovered. Additionally, under normal circumstances, the bureau's standard and prevailing response time is 1 min for every kilometer traveled.

Based on the data gathered from the BFP Cagayan de Oro City District Office, more than 50,000 people, or 7% of the population, were uncovered. There were 13 identified barangays that have had a response time of more than 7 min for the past six years. These barangays were mostly from the uptown and west parts of the city. Eighty-five percent of the uncovered barangays were under the AOR of the newly established Station 9 Lumbia Fire Station. Nevertheless, there were no fire incidents that occurred in Besigan, Pigsag-an, Taglimao, Tuburan and Tumpagon from 2016 to 2021. However, it was assumed that these were uncovered since the nearest and adjacent barangay with fire occurrences was also uncovered. Table 1 shows the assessment of the barangay on its coverage. As shown in Figure 4, covered and uncovered barangays are shaded green and shaded red, respectively.

Table 1. Assessment of the covered and uncovered barangay

Category	Population	%	Area (km^2)	%	No. of barangay	%
Covered	678,066	93.09	287.82	43.19	67	83.75
Uncovered	50,336	6.91	218.79	56.81	13	16.25
Total	728,402	100	506.61	100	80	100

3.2 Formulation of the Facility Location Problem Model with the Q-Coverage Requirement

There are several methodologies and algorithms for placing a limited number of available facilities, while others are meant to install an endless number of stations to satisfy all demands. This study compared two widely used classical facility location models, namely the P-MP and the MCLP using the three performance criteria to test and examine the efficiency of the results. Further, the population was used as the demand weights (h_j) of each barangay.

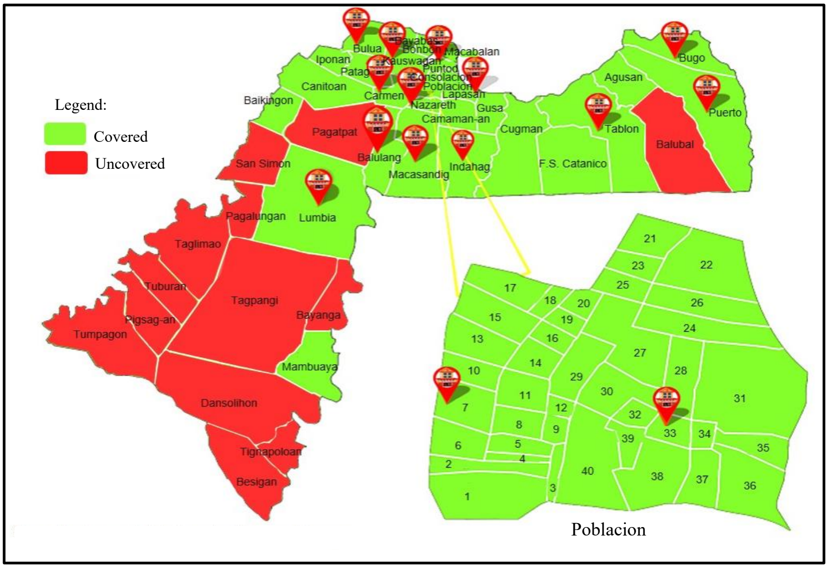

Figure 4. Assessment of the barangay in the city

In the integration of the Q-coverage requirement, this study identified the two backup fire stations of each barangay if the primary fire station is unavailable or responding to other demands. This study considered three what-if scenarios generated by the P-MP model based on the Q-coverage requirement values (Q = 1, 2 and 3). Firstly, scenario 1 occurred when Q = 1, under a normal circumstance where all the primary fire stations were available to respond to any fire incidents within their area of responsibility. Secondly, for scenario 2, when Q = 2, it was presumed that the primary fire station was unavailable or responding to other demands within its area of responsibility. Moreover, it was assumed that the first backup or second nearest fire station was available to respond. Thus, the said fire station was the responding fire station to the fire incident location. Lastly, scenario 3 when Q = 3, was the event where both the primary and first backup fire stations were unavailable or responding to other demands. In this case, the third nearest fire station is then the responding fire station. Likewise, it is assumed that the third nearest fire station was available. Further, because it was more realistic and feasible, no fire station relocation was considered. This analysis assumed that the number of demands and candidates was equal implying that the new fire station can be placed in any of the city's barangays. As a result, $m = n = 80$, with ($m = |I|$) and ($n = |J|$).

3.2.1 Minimum Impedance with Q-Coverage Formulation Result

The minimum impedance aimed to minimize the total travel distance or time traveled by firefighting units to reach demand points (fire locations). The fundamental problem was to find *p* locations that minimize the minimum average distance (or travel time) in a network. Out of 11 proposed new fire stations, seven were located in District 1 and another four in District 2. In the integration of the Q-coverage requirement, this study identified the two backup fire stations of each barangay if the primary fire station was unavailable or responding to other demands. Figure 5 shows that there were a total of 11 proposed new fire stations with the corresponding sites and proposed AORs to cover the entire city using the minimum impedance.

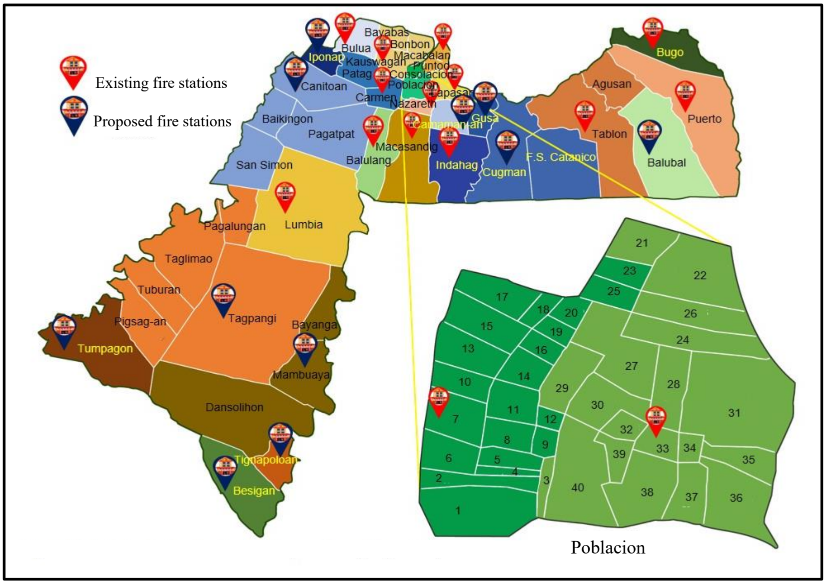

Figure 5. Minimum impedance (P-MP) result

With a standard deviation of 2.03 km, the average distance between existing and proposed fire stations was 1.22 km. The minimum and maximum distances between the demand and the nearest fire station were 0.10 and 11.60 km, respectively. This was when Q = 1.

On the other hand, the average distances were 3.88 and 5.09 km for Q = 2 and 3, respectively. Additionally, the standard deviation of Q = 2 was 4.82 km, while and Q = 3 was 6.13 km. Additionally, for Q = 2 and 3, the corresponding maximum distances were 25.90 and 30.70 km, respectively.

3.2.2 MCLP Problem with Q-Coverage Formulation Result

The MCLP aimed to maximize the total demand supplied with a given number of facilities. In other words, MCLP was used to determine the optimal number of facilities required to achieve coverage across the maximum distance. Figure 6 shows the result using the MCLP model. As with the P-MP result, there are a total of 11 proposed new fire stations with the corresponding sites and proposed area of responsibilities to cover the entire city.

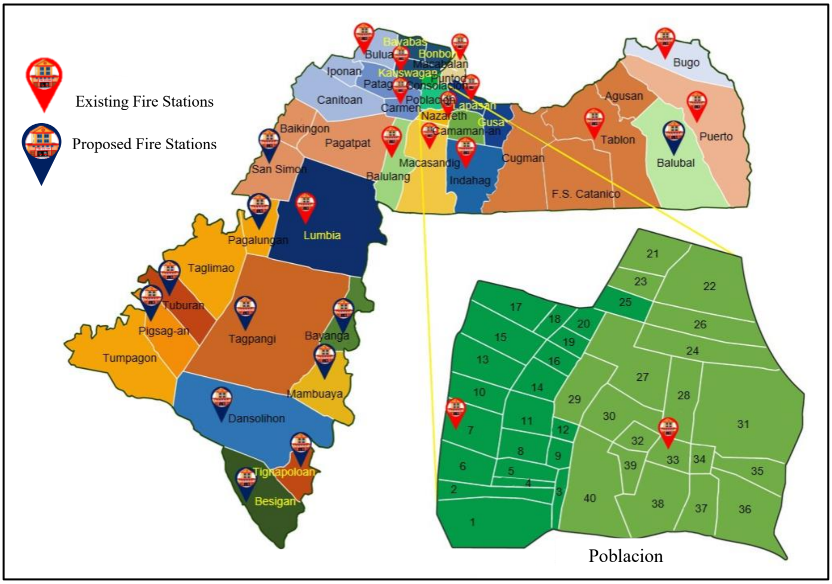

Figure 6. Maximal covering location problem result

When Q = 1, the average distance between the existing and proposed fire stations was 1.19 km, with a standard deviation of 2.68 km. Meanwhile, the minimum distance from the demand to the nearest fire station was 0.10 km, whereas the maximum distance was 21.80 km away.

Contrarily, the average distance of Q = 2 was 3.88 km, while Q = 3 was 5.09 km. The standard deviation was further estimated to be 4.82 and 6.13 km, respectively. In addition, the corresponding maximum distances were 25.90 and 28.0 km when Q = 2 and 3, respectively.

3.2.3 Comparison of the P-MP and MCLP Facility Location Models

Results of both models showed that to cover all the barangays and population in the city, 11 additional new fire stations were still needed. Out of these 11, there were five commonly proposed fire stations from both models, namely Balubal, Besigan, Mambuaya, Tagpangi and Tignapoloan.

One advantage of using the P-MP model is that it gives a $m \times n$ result matrix where all non-zero entries (x_{ij}) are said to be covered by the assigned fire station (y_i). When Q = 1, for example, the results were $y_1 = 0$, $(x_{75,1}) = 1$, and $y_{75} = 1$. This implied that Barangay Agusan did not have its own fire station because it had $y_1 = 0$, but it was still covered by $x_{75,1} = 1$. Since there was a fire station nearby, Tablon fire station (y_{75}=1), which was the nearest fire station, it was the primary fire station of Barangay Agusan (j = 1).

The MCLP model result will only generate the values of x_j (m × 1) and y_i (n × 1). This study determined the top three nearest fire stations in each barangay to identify the primary and backup fire stations. Further, it was observed during the development and application of MCLP, it was unlikely to provide feasible solutions and backup services for Q > 1 when the range (r) was constrained or too small.

Comparisons of the P-MP and the MCLP are shown in Tables 2, 3 and 4 for Q values of 1, 2 and 3, respectively. Observe that in terms of the mean distance between the primary fire stations and the respective barangays, MCLP had a minimum mean distance of 1.19 km when Q = 1 (Table 2). Meanwhile, when Q = 2 (Table 3), MCLP gave the minimum mean distance from the first backup fire station to the respective barangay of 3.43 km. Moreover, results showed that P-MP and MCLP generated the same minimum distance and maximum distance from the first backup to the barangay at 0.80 and 25.90 km, respectively. Likewise, when Q = 3 (Table 4), results revealed that still, MCLP gave the minimum mean distance at 4.44 km, with minimum and maximum distances of 1.0 and 28.0 km, respectively. Further, MCLP gave a shorter mean distance from all the fire stations at 3.03 km with a standard deviation of 4.07 km, while the P-MP mean distance was 3.40 km with a 4.91 km standard deviation. Furthermore, Table 5 shows the comparison of the two models using the three performance criteria. Evidently, MCLP gave the minimum mean results measured in kilometers for all of the Q values and performance criteria.

Table 2. Comparative table of P-MP and MCLP result when Q = 1

FLP model	Q = 1			
	Mean (km)	Standard deviation (km)	Minimum distance (km)	Maximum distance (km)
P-MP	1.22	2.03	0.10	11.60
MCLP	1.19	2.68	0.10	21.80

Table 3. Comparative table of P-MP and MCLP results when Q = 2

FLP model	Q = 2			
	Mean (km)	Standard deviation (km)	Minimum distance (km)	Maximum distance (km)
P-MP	3.88	4.82	0.80	25.90
MCLP	3.43	3.93	0.80	25.90

Table 4. Comparative table of P-MP and MCLP results when Q = 3

FLP model	Q = 3			
	Mean (km)	Standard deviation (km)	Minimum distance (km)	Maximum distance (km)
P-MP	5.09	6.13	1.00	30.70
MCLP	4.44	4.68	1.00	28.00

Table 5. Comparative table of P-MP and MCLP results using the performance criteria

Criteria	Definition	Q = 1		Q = 2		Q = 3	
		P-MP (km)	MCLP (km)	P-MP (km)	MCLP (km)	P-MP (km)	MCLP (km)
C1	Mean distance to primary	1.22	1.19	2.66	2.24	3.87	3.25
C2	Mean distance to primary and backup	1.22	1.19	2.55	2.31	4.48	3.94
C3	Mean distance to backup(s)	-	-	3.88	3.43	5.09	4.44

Unlike other existing studies comparing the two prevalent FLP models (P-MP and MCLP), this study assessed the coverage of the existing fire stations and applied the archived data of the bureau. Moreover, this paper introduced the backup fire stations for each demand in cases where the nearest or primary facility was unavailable; considering backup fire stations are a strategic-level factor in planning for emergency services like fire stations where every second counts. In addition, this study considered the BFP Modernization Program in the formulation and decision process. Furthermore, a set of adopted performance criteria was employed to determine which of the two FLP models best fit the challenges of the bureau.

4. Conclusion and Recommendation

This study determined the optimal number and respective locations of the fire stations in the city to lessen the bureau's response time to fire incidents. Since it was more realistic and feasible, no fire station relocation was considered. The paper utilized the two classical and prevalent facility location models (P-MP and the MCLP) with Q-coverage requirements concerning the three performance criteria.

In this study, the fire stations considered were only the stations (nine fire stations and six fire substations) covered and under the authority of the BFP Cagayan de Oro City District. Thus, privately-owned fire stations and fire trucks were not included. Moreover, fire stations and fire substations were treated as equivalent.

The methodology involved generating multiple Q values (Q = 1, 2 and 3) that served as the primary and two backup fire stations. When Q =1, 2 and 3, the results demonstrated that MCLP outperformed the P-MP in every performance criterion (C1, C2 and C3). Moreover, MCLP generated a minimum average in Q values 1, 2 and 3 with 1.19, 3.43 and 4.44 km, respectively. As a result, MCLP is an excellent choice for government organizations looking for the shortest distance between demand and primary fire stations, as well as the shortest distance between demand and backup fire stations.

Although the correlation test between the fire incidents and the parameter (in this study, the weight was the population) utilized in this study had a very strong positive correlation and a substantial effect on fire occurrence in the city from CY 2016 to 2021, the correlation might not be the same in other metropolitan areas. The results of this study could be dissimilar from those in other areas. Thus, a correlation test must be conducted first to determine the correlation between the weight and the fire incidents in the study area.

While the numerical experiments conducted in this study used data obtained from Cagayan de Oro fire stations, it is worth noting that the models presented in this study can also be applied to solve similar facility location problems in other locations in the Philippines or abroad.

In reality, the government might not have sufficient funding to extend coverage across the country. Additionally, adding fire stations consequently requires employing more firemen, and purchasing more fire engines, personal protective equipment and others. Due to financial constraints, this poses a challenge in maximizing coverage within a targeted service radius given a limited number of facilities. Therefore, for future work, the inclusion of the ranking and prioritizing of the identified optimal locations for the establishment of the fire station may be considered. With this, the bureau is relieved of the requirement to build additional fire stations simultaneously. Additionally, it is interesting to study possible relocations of the existing fire stations to determine the ideal locations of the fire stations in the city. Furthermore, it is a noteworthy notion to include the option of having multiple fire stations in a barangay, particularly in huge and vast areas and locations. Another notable idea is to treat both FLP models probabilistically. The idea of engaging geographic information system mapping and other location-allocation models may provide a more remarkable and realistic approach to locating fire stations. Lastly, a sensitivity analysis may consider identifying the magnitude of variations that have an impact on the mathematical model.

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