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Facility Location Optimization Model for Emergency Response in Davao City, Philippines

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Abstract—Healthcare Industry is suffering from the increased number of patients with covid19 and other infectious illnesses in the Philippines. As hospitals become fully loaded, and with some patients unable to travel from their homes due to severe medical conditions, an emergency response plan is deemed necessary. This study will be focusing on the Optimization Model for emergency response in Hospitals at all levels in Davao City, Philippines. Specifically, the researchers aim to identify the optimal hospital locations to support the emergency needs in all barangays (smallest administrative division in the Philippines). All hospital facility locations and the population of each barangay have been identified to analyze the optimum solution for the emergency response. Maximum Set Covering Model using AMPL was utilized to identify the optimum locations of facilities. Based on the results, additional facilities are needed to accommodate all barangays in attaining at least the mean shortest distance of 10KM, from the origin location to the nearest hospital facility.

Keywords: optimization modeling, facility location problem, set covering problem, AMPL

1. Introduction

With the covid19 pandemic crisis that we are currently experiencing, the need for emergency medical care and assistance is increasing, especially in the Philippines. An emergency is an unexpected and difficult or dangerous situation, especially an accident that happens suddenly and requires quick action to deal with [1]. Unforeseen accidents, disasters, and the urgency of patients needing to be transported to hospitals are among the most important duties that the Department of Health and the local government unit must address.

Davao City is one of the most populated cities in the Philippines. According to the Philippines Statistics Authority, Davao City has a population of 1,776,949 as of May 1, 2020 [2]. It has been reported that Davao City was one of the safest cities in the world in 2015. According to the list as of May 2015, Davao City is tagged as the safest city in the Philippines and ninth in the world [3]. Davao placed 9th in terms of Crime Index (19.03%) and Safety Index (80.97%) [3].

Despite being the safest city in the Philippines, road accidents, crimes, health-related injury or diseases, and calamities like floods, earthquakes, and tsunamis might still happen. Davao City has a total land area of 2,444 sq.km., making it the largest city in the Philippines in terms of land area [4]. To provide medical support and security to all residents, the local government has launched central 911. The Davao City Central Communications and Emergency Response Center or the Central 911 is at the forefront of providing primary emergency response services, including medical assistance, search and rescue, fire auxiliary, and k-9 services for the residents of Davao City [5].

Improving the emergency response by having a hospital facility within the shortest range possible in all barangays will help improve the emergency response time and minimize the risk of potential danger to patients. The emergency response includes any systematic response to an unexpected or dangerous occurrence [6]. The goal of an emergency response procedure is to mitigate the impact of the event on people and the environment [6].

Analysis of the city's population distribution and location of current operating hospital facilities will help identify existing hospital facilities that could be improved or augmented. These facilities will be the locations where most of the population will get their medical support given a particular reach coverage. Thus, this study aims to identify minimal hospital locations accessible to the vast population in a given reach coverage. These identified locations must be ready to accommodate surges in emergency support or masses that will need medical assistance in a short period; thus, this study could help them prepare. These locations could also be sites where a supply of products can be stored and services are available – such as vaccination sites. Given the limited resources of the city and hospitals, these sites can help minimize cost travel time while generating a big impact on a significant portion of the population.

Previous studies used different types of models to optimally solve for facility locations, especially in emergency humanitarian logistics. They also showed how emergency ambulance services providers can apply the maximum set covering model to decrease ambulance response times and optimize the coverage of their services. Also, this method was used to recommend new facility locations such as ambulance origins in order to better serve their coverage area.

In addition, the study aims to determine whether a new hospital facility is needed to support emergency patients in need. With the help of this study, the local government, in cooperation with the hospitals, can avoid further complications during transportation, and patients will be attended to immediately with regards to emergency support.

The remainder of this paper is organized as follows: In section 2, we listed the literature review related to the study. Section 3 introduces the problem definition and formulation of the set covering model to locate facilities with the optimum service coverage in a given distance. Section 4 shows how the conduct of the experiment was made. Section 5 presents the results of the experiment. Lastly, Section 6 discusses the conclusion and future research direction.

2. Literature Review

An emergency response plan is a must-have in a particular place, region, or country. There are various researches on how to optimize the process to save lives or reduce the risk of injury and avoid worsening the condition of the patients. One of the techniques used is the optimization technique.

Optimization techniques are often used to look into situations with a specific issue with the objective of improving its condition. One of the applications of optimization techniques is the determination of facility locations. Depending on the circumstance, optimization models can be applied to various sectors in society – business, education, military, utilities, and healthcare. The facility location optimization model uses the location of existing resources and the anticipated resource demand at each location to minimize the distance a patient must travel to get to the resource they need [7].

In 2017, Boonmee et al. published a paper related to the optimization modeling in terms of facility location determination, specifically for emergency humanitarian logistics [8]. The study discussed literature on the different optimization models that can be used for optimization given a set of criteria, constraints, and objectives. Humanitarian logistics involves moving goods and equipment, relocating disaster-affected people, transferring casualties, and moving aid, relief workers, and volunteers [9]. Around two-thirds of funding in each emergency is spent on logistics, highlighting the need for effective and efficient systems [9].

A study conducted in 2019 focused on improving the emergency service performance of ambulance providers in Quezon City – the most populous city in the Philippines [10]. Factors that affect such performance include service times and response times which are highly dependent on the origin of the Emergency Medical Ambulances. Response time refers to how long it takes emergency responders to arrive at the scene of an emergency after the emergency response system has been activated [6]. An extended response time can result in increased and permanent damage, a higher likelihood of fatalities, and greater distress to those involved [6]. As such, response time is often used as a proxy for the effectiveness of an emergency response program [6]. One of the study's recommendations included determining facility locations for ambulance service providers to achieve acceptable response times and maximize the coverage for its services throughout the city [10].

Studies made by Henderson & Mason (2005) [11], Werven (2012) [12], and Swalehe & Aktas (2016) [13] all point out to using modeling and optimization techniques to recommend the addition and relocation of ambulances' origins to decrease response times. In particular, Paulican, A., & Ortega, J. (2013) [14] did a similar study in Davao City regarding its Emergency Medical Service System.

3. Problem Definition and Formulation

This study focuses on the geographic distribution of hospital establishments throughout Davao City. Population density of independent community units called "barangays" were taken into consideration in conducting the study. With the advent of advanced software, the distances from the barangay to the hospitals were taken, following the shortest route that motor vehicles can take, unlike earlier studies that used less accurate distance computation such as Euclidian distance approximation.

Accidents, calamities, and urgent health care may happen anytime and in an unexpected situation. This study suggests that Local Government Units must address the citizens' medical needs in the entire area of its responsibility. A person in need of medical care can take various forms of transportation, such as private motor vehicles, jeepneys, ambulances, buses, taxis, and for-hire services (e.g., grab, uber, etc.). This study assumed that any mode of transportation could be a means to access the closest medical facility that can serve their medical needs.

An example of finding the optimum route is finding the shortest path method. Dijkstra's algorithm is used to find the shortest path from a node (say, node 1) to all other nodes, given that all arc lengths are nonnegative [15].

Set-covering problem is another tool in finding the optimum solution for facility location problems. In a set-covering problem, each member of a given set (call it set 1) must be "covered" by an acceptable member of some set (call it set 2) [15]. The objective in a set-covering problem is to minimize the number of elements in set 2 that are required to cover all the elements in set 1 [15]. An integer linear program (ILP) model [16] can be formulated for the set covering problem. In this case, we used the Maximum Covering Model, a subset of the Set Covering Model to solve for the optimal facility locations.

1) Decision Variables

Zi The value will be 1 if the barangay i is covered. Otherwise, the value will be 0.

2) Objective Function

$$Maximize\ Objective = \sum_{i=I} h_i Z_i \tag{1}$$

3) Subject to

$$Z_i \leq \sum_{j=J} a_{ij} X_j \tag{2}$$

$$\sum_{j=J} X_j \leq P \tag{3}$$

The objective function (1) maximizes the population coverage that a select number of hospitals can serve given a set distance from the patient’s origin. Constraint (2) ensures that a location can be served by at least one hospital if it is accessible given the reach coverage. (3) subjects the number of facilities to activate is less than or equal to the allowed facilities for activation.

4. Computational Experiment

The maximum set-covering problem optimization concept using AMPL was used to analyze the accessibility of the common people seeking emergency or even essential medical services that only the nearest hospital facilities can offer. The experiment was performed on a PC with specifications of AMD Ryzen 5 at 2.1 GHz, 16 Gb of RAM, and running on a 64-bit platform under the Windows 10 Operating System

The impact assessments were computed for all the different levels of service that the hospitals can offer. (Levels 1,2 & 3)

1) Determination of % of the population that can be reached/ served given a particular distance: 3KM, 5KM, 8KM and 10KM

2)Determination of the number of barangays that can be reached/ served given a particular distance: 3KM, 5KM, 8KM and 10KM

3) Analysis of whether there is a need to build another hospital facility in consideration of reducing the distance to travel

4.1. Area of Study

Davao City was selected as the area of study, considering it is poised to become a significant player in its strategic and economic contribution at a national level. The beneficiaries of the study were aimed at the general population of the city. Thus, the census of 2020 was collected to reflect the latest available data on the demographics of the town. According to Philippine Statistics Authority, the total population in Davao City is 1,776,949 from 182 barangays [17]. The city is subdivided into three sections, and the summarized number of barangays in each district is shown in table 1 [18].

Table 1: DAVAO City Barangay List

District	No. of Baranggay
First Congressional District	
Poblacion	40
Talomo	14
Second Congressional District	
Buhangin	13
Bunawan	9
Agdao	11
Paquibato	13
Third Congressional District	
Baguio	8
Calinan	19
Marilog	12
Toril	25
Tugbok	18
TOTAL	**182**

4.2. Hospitals

General Hospitals were chosen as the facility to be assessed and improved to optimize the accessibility of their medical services to the general public. The government has classified the Philippines' hospitals as shown in table III [19].

Table 2: Classification of General Hospitals

<table>
<tr><th>District</th><th>Level 1</th><th>Level 2</th><th>Level 3</th></tr>
<tr><td rowspan="2">Clinical Services for in-patients</td><td rowspan="2">Consulting Specialists in:
Medicine
Pediatrics
OB-GYNE</td><td>Level 1 plus all:</td><td>Level 2 plus all:</td></tr>
<tr><td>Departmentalized Clinical Services</td><td>Teaching/training with an accredited residency training program in 4 major clinical service</td></tr>
</table>

	Surgery		
	Emergency and out-patient services	Respiratory Unit	Physical Medicine and Rehabilitation Unit
	Isolation Facilities	General ICU	
	Surgical/maternity facilities	high risk pregnancy unit	Ambulatory surgical clinic
	Dental Clinic	NICU	Dialysis Clinic
Ancillary Services	Secondary Clinical Laboratory	Tertiary Clinical Laboratory	Tertiary Lab with histopathology
	Blood Station	Blood Station	Blood bank
	1st level x-ray	2nd level x-ray with mobile unit	3rd level x-ray
	Pharmacy		

Table 3: DAVAO City Hospitals

Name of Hospital	Location	Classification
CURE PHILIPPINES, INC.	Lanang J.P. Laurel Ave. cor. Banawe,St., Brgy. Aquino, Davao City	Level 1
DAVAO MEDIQUEST HOSPITAL, INC.	Mac Arthur Highway, Lizada, Toril, DC	Level 1
HOLY SPIRIT COMMUNITY HOSPITAL OF DAVAO, INC.	Sampaguita St., Mintal, Dvo City	Level 1
ISAAC T. ROBILLO MEMORIAL HOSP.	Km. 26 Calinan, Davao City	Level 1
MALTA MEDICAL CENTER, INC.	Km. 14, McArthur Hiway, Toril, Dvo. City	Level 1
ST. JOHN OF THE CROSS HOSPITAL	Rasay St., Toril, Dvo. City	Level 1
METRO DAVAO MEDICAL AND RESEARCH CENTER, INC.	J.P. Laurel Avenue, Bajada, Davao City	Level 2
DAVAO MEDICAL SCHOOL FOUNDATION, INC.	Medical School Drive, Bajada, Brgy. 19-B, Poblacion District, Bajada, Davao City	Level 2
ANDA RIVERVIEW MEDICAL CENTER, INC.	Brgy. 2-A, Magallanes St., Davao City	Level 2
ADVENTIST HOSPITAL-DAVAO, INC	Km. 7 McArthur Hi-way, Bangkal, Davao City	Level 2
GIG OCA ROBLES SEAMEN’S HOSPITAL DAVAO	R. Castillo St., Brgy. Centro, Agdao, Davao City	Level 2
ALTERADO GENERAL HOSPITAL, INC	R. Castillo St., Agdao, Davao City	Level 2
MEDICAL MISSION GROUP HOSPITAL AND HEALTH SERVICES COOPERATIVE OF DAVAO	3rd Avenue, Leon Garcia St., Davao City	Level 2
BROKENSHIRE INTEGRATED HEALTH MINISTRIES, INC.	Brokenshire Heights, Madapo, Davao City	Level 3
DAVAO DOCTORS HOSPITAL	118 E. Quirino Avenue, Davao City	Level 3
RICARDO LIMSO MEDICAL CENTER, INC.	V. Illustre St., Davao City	Level 3
SAN PEDRO HOSPITAL OF DAVAO CITY, INC.	C. Guzman St., Davao City	Level 3
SOUTHERN PHILIPPINES MEDICAL CENTER	J.P. Laurel Avenue, Bajada, Davao City,Davao del sur	Level 3

A list of licensed government and private hospitals as of December 31, 2020, published by the Department of Health were used in the study [20]. Table III shows the list of hospitals in Davao City categorized with the level of Classification. All hospital categories (Level 1, 2 & 3) were included and analyzed as a whole and by ranks – grouped according to the facility's most advanced service. Other medical facilities were not included as they would not have met the minimum basic medical services that a hospital can offer.

4.3. Distance and Routing

Demand and facility nodes were created as points on the map representative of a community or barangay and the hospital sites. The distances from each hospital in all levels to every barangay were collected. A mapping survey was done to check which barangays share common borders. The distance between the nodes was determined through the route between two points as indicated by google maps. The path with the shortest distance was selected for origin-destination nodes with more than one route.

5. Computational Result and Analysis

Maximum set covering problem model was applied to identify the maximum coverage of each hospital with the distance of each barangay. Figure 2 shows the AMPL Model that the experiment applied. AMPL integrates its modeling language with a command language for analysis and debugging and a scripting language for manipulating data and implementing optimization strategies [21].

Table IV shows the maximum population coverage of opening facilities within a reach coverage of 3km distance to the barangays. Activation of five hospital facilities can cater to a maximum of 63 barangays, with 37% of the total population in the city.

Table 4: Coverage for 3KM Reach

COVERAGE (KM)	**No. of Facility to Activate**				
3KM	**1**	**2**	**3**	**4**	**5**
# of Brgy Served	41	50	56	58	63
# of Brgy in Davao	182	182	182	182	182
Brgy Coverage	23%	27%	31%	32%	35%
# of Residents Served	228940	395876	499356	602461	653606
# of Davao Population	1776949	1776949	1776949	1776949	1776949
Population coverage	13%	22%	28%	34%	37%

The number of covered barangays increases when the reach increases. Table IV summarizes the scope of activating hospitals within a 5KM reach. Five facilities can provide the service to 59% of the total population in 79 barangays.

Table 5: Coverage for 5KM Reach

COVERAGE (KM)	**No. of Facility to Activate**				
5KM	**1**	**2**	**3**	**4**	**5**
# of Brgy Served	53	60	69	74	79
# of Brgy in Davao	182	182	182	182	182
Brgy Coverage	29%	33%	38%	41%	43%
# of Residents Served	465135	705418	842080	953318	1039576
# of Davao Population	1776949	1776949	1776949	1776949	1776949
Population coverage	26%	40%	47%	54%	59%

Activation of five hospitals has a coverage of 100 barangays out of 182 total barangays in the city if the reach taken is 8km. The barangay ratio is at 55%, but five facilities within the reach coverage can already serve 73% of the total population in Davao City.

Table 6: Coverage for 8KM Reach

COVERAGE (KM)	**No. of Facility to Activate**				
8KM	**1**	**2**	**3**	**4**	**5**
# of Brgy Served	62	78	89	99	100
# of Brgy in Davao	182	182	182	182	182

Brgy Coverage	34%	43%	49%	54%	55%
# of Residents Served	725071	1038050	1181857	1256454	1297314
# of Davao Population	1776949	1776949	1776949	1776949	1776949
Population coverage	41%	58%	67%	71%	73%

Table VII shows the barangay and population coverage of opening the different number of facilities that can cover within 10KM reach coverage. The results show that opening five hospitals can cater to 114 barangays or 63% of the total number of barangays. In terms of population, it can serve 78% of the total population or 1,387,802 people.

Table 7: Coverage for 10KM Reach

COVERAGE (KM)	No. of Facility to Activate				
10KM	1	2	3	4	5
# of Brgy Served	66	90	103	112	114
# of Brgy in Davao	182	182	182	182	182
Brgy Coverage	36%	49%	57%	62%	63%
# of Residents Served	829420	1179671	1298627	1381636	1387802
# of Davao Population	1776949	1776949	1776949	1776949	1776949
Population coverage	47%	66%	73%	78%	78%

As summary, the activation of more hospitals is needed to serve more populations within a given distance. Tables IV, V, VI, and VII show increasing population coverages as there is an increase in activation from 1 to 5 hospitals. In the same manner, increasing the distance coverage of hospitals yield similar results. Activating one facility with a distance coverage of 3KM, 5KM, 8KM, and 10KM yields 13%, 26%, 41%, and 47%.

Table 8: Maximum Population Coverage

COVERAGE (KM)	3	5	8	10	65
Min Facility to Activate	8	6	6	7	1
Max Population Coverage	41%	61%	75%	79%	100%

In general, the results show that the incremental population coverage decreases for every additional facility to activate for a given reach coverage. Table VIII indicates that reach (KM) coverage 3, 5, 8 & 10 can only cover at a maximum of 41%, 61%, 75%, and 79% of the city population, respectively. The rest of the 21% population will have to travel more than 10KM.

The average distance from a barangay to the nearest hospital facility is 10.5KM. Sixty-five (65) barangays need their residents to travel more than 10.5KM in order to get to the nearest facility. According to a study conducted on the relationship between distance to hospital and patient mortality in hospital, a 10-km increase in straight-line distance is associated with around a 1% absolute increase in mortality [22].

Based on the gathered distance measurements from a barangay to a hospital facility, the shortest distance is 0.16KM. At the farthest end, to reach the nearest hospital, residents of one barangay need to travel at least 65KM. This is also the minimum distance required to cover 100% of the city population as shown in Table VIII. Thus, an additional facility is necessary to shorten the distance traveled by the patients.

6. Conclusion and Future Research

Increasing the distance from the point of origin to the hospital facility can increase the risk of patients' exposure, pain, worsening patient's situation, and could even lead to an increase in mortality rate. Decreasing the distance, on the other hand, will translate to the need of activating and opening more facilities to cover the same population. Given the mean average of 10KM accessibility of barangays to the nearest hospitals, the research suggests opening an additional facility to cater to all barangays in a shorter time and distance.

This study utilized the maximum set covering problem using AMPL to identify the maximum population coverage of activated facilities. In this study, the cost of activating a facility is set to be the same. Thus, the result for both barangay and population coverage may differ when cost and hospital levels are considered.

The study is limited to the distance traveled to the hospital facility from the point of origin. Future researchers may add the travel time to reach the facility with the shortest path. Other locations in the Philippines may also be considered in future research.

7. References:

[1] Collins. *Emergency*. [Online]. Available: https://www.collinsdictionary.com/dictionary/english/emergency

[2] Philippine Statistic Authority. *2020 Census of Population and Housing (2020 CPH) Population Counts Declared Official by the President.* [Online]. Available: https://psa.gov.ph/content/2020-census-population-and-housing-2020-cph-population-counts-declared-official-president

[3] Davao Base. *Davao: Safest City in the Philippines, 9th in the world*. [Online]. Available: https://www.davaobase.com/2015/05/davao-safest-city-in-the-philippines-9th-in-the-world/

[4] National Economic and Development Authority. *Davao City*. [Online]. Available: https://nro11.neda.gov.ph/davao-region/davao-city/

[5] Davao. *Davao City Central 911 Emergency Response Center*. Online]. Available: https://www.davaocity.gov.ph/departments/social-services/central-911/

[6] Safeopedia. *Emergency Response.* [Online]. Available: https://www.safeopedia.com/definition/195/emergency-response

[7] Klise, K., et.al. (2020) "Facility Location Optimization Model for Covid-19 resources". *Sandia National Laboratories*.

[8] Boonmee, C., et.al. (2017). "Facility location optimization model for emergency humanitarian logistics". *International Journal of Disaster Risk Reduction.* pp. 485-498.

[9] Relief Web. Humanitarian Logistics in Emergencies (HLE). [Online]. Available: https://reliefweb.int/training/3770793/humanitarian-logistics-emergencies-hle

[10] Estember, R., et al. (2019). "An Optimization-based Approach Model for the Improvement of the Performance of Emergency Medical Service Ambulances". *International Conference on Industrial Engineering and Operations Management*,

[11] Henderson, S. G., et.al. (2005). Ambulance Service Planning: Simulation and Data Visualisation. Department of Operations Research and Industrial Engineering

[12] Werven, R. V. (2012). "Improving the response time performance of A1-priority calls for UMCG ambulance". *Master* Thesis, pp. 79-81

[13] Swalehe, M., & Aktas, S. (2016). "Dynamic Ambulance Deployment to Reduce Ambulance Response Times using Geographic Information Systems: A Case Study of Odunpazari District of Eskisehir Province, Turkey". *Procedia Environmental Sciences*, pp. 199-206,

[14] Paulican, A., & Ortega, J. (2013). "Location Model in an Emergency Medical Services System of Davao City, Philippines". *IAMURE International Journal of Mathematics, Engineering and Technology*

[15] Winston, W. (2018). *Operations Research: Applications and Algorithms.* [Online]. Available: https://bookshelf.vitalsource.com/books/9789814844956

[16] T. Grossman, et.al. (1997), "Computational experience with approximation algorithms for the set covering problem," *European Journal of Operational Research*, pp. 81-92

[17] Philippine Statistic Authority. *2020 Census of Population and Housing (2020 CPH) Population Counts Declared Official by the Pres.* [Online]. Available: https://psa.gov.ph/content/2020-census-population-and-housing-2020-cph-population-counts-declared-official-president

[18] Davao News. *Davao City Districts and Barangays*. [Online]. Available: https://davaocityinfo.com/davao-city/district/

[19] Scribd. *New Classification of Hospitals and other Health Facilities in the Philippines*. [Online]. Available: https://www.scribd.com/doc/202290167/New-Classification-of-Hospitals-and-Other-Health-Facilities-in-the-Philippines

[20] Department of Health. *List of Regulated Health Facilities and Services*. [Online]. Available: https://hfsrb.doh.gov.ph/list-of-licensed-health-facilities/

[21] AMPL. *Why AMPL*. [Online]. Available: https://ampl.com/

[22] Nicholl, Jon et al. "The relationship between distance to hospital and patient mortality in emergencies: an observational study*." Emergency medicine journal*: EMJ vol. 24,9 (2007): 665-8. doi:10.1136/emj.2007.047654