Available online at: http://e-jurnal.lppmunsera.org/index.php/JSMI

Jurnal Sistem dan Manajemen Industri

ISSN (Print) 2580-2887 ISSN (Online) 2580-2895

Maximum covering location problem to select facility location for operation timbang in the City of Iloilo, Philippines

Anak Agung Ngurah Perwira Redi[1*], Roland Ross Faina Flame[2], Anak Agung Ngurah Agung Redioka[3], Winarno[4], Adji Chandra Kurniawan[5]

[1] Department of Industrial Engineering, Sampoerna University, Jl. Raya Pasar Minggu No.Kav. 16, Jakarta 12780, Indonesia

[2] Department of Industrial Engineering, Mapua University, 658 Muralla St., Intramuros, Manila 1002, Philippines

[3] Department of Accounting Information Systems., STMIK Primakara, Jl. Tukad Badung No.135, Bali 80226, Indonesia

[4] Department of Industrial Engineering, Universitas Singaperbangsa Karawang, Jl. HS.Ronggo Waluyo, Karawang, West Java 41361, Indonesia

[5] Department of Logistics Engineering, Universitas Pertamina, Jl. Teuku Nyak Arief, RT.7/RW.8, Simprug, Jakarta 12220, Indonesia

ARTICLE INFORMATION

Article history:

Received: March 22, 2022
Revised: October 26, 2022
Accepted: November15, 2022

Keywords:

AMPL
Location analysis
Facility location problem
Maximum covering location problem
Mathematical programming

*Corresponding Author

Anak Agung Ngurah Perwira Redi
E-mail: wira.redi@gmail.com

A B S T R A C T

Operation Timbang (OPT) Plus is one of the Philippines' programs that focuses on nutrition by conducting an annual assessment for 0-59 months old children in barangays to identify the malnutrition data in the area. The barangay is the smallest administrative entity in the Philippines. OPT is a plan of action that estimates the number of malnutrition individuals and identifies those who will get prioritized programs in the community. The Iloilo City Health Office conducted the program in seven districts in the Philippines. The office planned to establish a community centre and playground facility based on the priority/demand areas. Maximum Covering Location Problem (MCLP) is used for this study to determine the optimal location that covers the area. A Mathematical Programming Language (AMPL) is used to apply mathematical programming to the MCLP. The results can be used to identify the optimal facility and the maximum coverage of the demand points. The experiment showed that the facility located in Mandurriao District is the optimal facility location. For Underweight/Severely Underweight children, a maximum total of 646 are covered, and for the Overweight/Obese, 1,041 are covered for the chosen facility. In addition, the findings of the sensitivity analysis indicate that the building of the three facilities in the case study can offer 100 percent of the required coverage area.

1. INTRODUCTION

Nutrition is a vital aspect of health and development. Good nutrition is always related to enhancing all stages of health, more strong systems, better childbirth, a lower risk of noncommunicable diseases, and increased longevity. Malnutrition, including underweight/severely underweight and overweight/obesity, is a global problem, especially in third-world nations. Malnutrition presents significant threats to human health [1]. Non-governmental organizations and government entities collaborate provide the scientific guidance and decision-making tools that can assist nations in establishing their own programs and taking action against all types of malnutrition [2].

In the Philippines, there are three primary nutrition and growth assessment programs for children aged 0 to 71 months. These include a) the National Nutrition Survey of the Department of Science and Technology (DOST), b) the health centre- or facility-based growth measurement and advertisement services provided by the healthcare workers, and c) Operation Timbang Plus or OPT Plus, which is conducted in the barangays every first quarter of the year. The barangay is the smallest administrative entity in the Philippines. These programs provide the Nutrition Council of the Philippines and the Local Government Units with critical information on the nutrition status of the population for use in planning nutrition programs, formulating nutrition policies, and monitoring child and total nutrition [3].

Operation Timbang (OPT) Plus is one of the Philippines' programs that focuses on nutrition by conducting an annual assessment for 0-59 months old children in barangays to identify the malnutrition data in the area. Fig. 1 shows the mechanics and process of OPT Plus. It is the overall scope of the process of OPT Plus Program [3]. These are utilized in action planning, specifically for estimating the number of malnourished individuals and determining which community members would receive priority services. These data can offer government agencies with an overview of the nutritional status of the population and insight into the efficacy of the local nutrition program. OPT Plus's primary purpose is to collect data for nutritional monitoring and evaluation of local nutrition initiatives [4]. In particular, as outlined by the National Nutrition Council, it strives to:

1. Identify households with children who are below or above average weight;
2. Identify and assess children with below and above average weights who require assistance;
3. Detect infant and kid development delay as soon as feasible;
4. Encourage parents to get their children frequently weighed;
5. Determine locations and individuals with top priority for local government feeding programs;
6. Provide nutrition and health services/projects to youngsters with below-average weights; and
7. Evaluate the performance of the local nutrition program.

The evaluation team consists of the Rural Health Midwife, the BNS and other Barangay Council members, the BHWs, and the Day Care Worker (DCW). Weighing and measuring height are surveyed when and where it is convenient: in a barangay hall or daycare centre of each barangays [4].

The Iloilo City Health Office of the City of Iloilo is responsible for conducting the OPT Plus in Iloilo City, Philippines. Last 2021, the office also completed its OPT Plus program last. They collected 35,778 respondents aged 0-59 months old children from the seven districts of Iloilo City: City Proper, Molo, Arevalo, Lapaz, Lapuz, Jaro, and Mandurriao. The daTheed from identified and quantified preschool children classified as underweight, severely underweight, overweight, stunted, severely stunted, tall, wasted, severely wasted, and obese. The next objective is determining priority areas and individuals for program planning purposes. A community centre is established to cater to the identified underweight and severely underweight, and a playground for the overweight and obese [5].

Numerous studies have been proposed by using different types of models to optimally solve facility location problems [6]-[8], especially in the field of healthcare facilities [9]. Tirkolaee et al. [10] Designing a closed-loop face mask supply chain during the COVID-19 pandemic. Aghighi et al. [11] design the probabilistic location-routing-inventory problem for perishable items with rescinding and balking. Furthermore, Tirkolaee et al. [12] proposed a new two-tiered hierarchical structure optimization of allocation-routing for green energy-effective logistics systems. Then, they refined it to address the sustainable fuzzy multi-trip location-routing for healthcare waste management during the COVID-19 [13]. In addition, Torkayesh et al. [14] proposed a multi-objective optimization network concept for sustainable healthcare waste management. One crucial factor affecting facility location effectiveness is determining the distance between demands and the candidate facilities [15], [16]. The maximum set covering problem (MCLP) is a generic model used many times to optimize facilities' coverage in terms of their services. This study has been reported to be successful in recommending new facility locations, such as selecting the area of public facilities [17], waste collection facilities [18], [19], military facilities [20], and medical test facilities [21]. The most

http://dx.doi.org/10.30656/jsmi.v6i2.4599

common approach to solving MCLP is the exact solution approach [22], [23]. Following the success of these studies, we are using the model to strategically determine the location of OPT plus in the region under the Iloilo City Health Office.

In this study, the MCLP is used to formulate the problem. Then, it is coded in A Mathematical Programming Language (AMPL) and solved the model by using CPLEX as an exact solver to optimize the community centre and playground location within the five districts based on the demand and distance per proposed location in every section.

The remainder of this paper's material is structured as follows: In Section 2, we discuss the mathematical formulation of the MCLP used to select the OPT plus facility. Section 3 discusses the outcome and analysis of the computational experiment. Section 4 presents the conclusion and recommendations for future research.

2. RESEARCH METHODS

The objective of MCLP is to locate several facilities on a network so as to maximize the required population or demand. If a facility serves a demand node, it is located closer to the demand node than the defined threshold. This predetermined threshold is commonly referred to as the coverage radius, which has a direct impact on the solution. It occurs when there are insufficient funds or resources to meet the demand of all nodes.

The description begin with some assumptions to initiate the model presentation of this article. When at least one facility is within a predetermined distance of a node, it is presumed that the node is covered. Additionally, each node could function as a host facility. In other words, the set of nodes is similar to the set of prospective facilities (Assumed that there are a set of demand nodes I and a set of candidate sites J). In addition, it is expected that each node must satisfy a given level of demand. Additionally, proximity of the people to these facilities is desired.

The mathematical model is based on the MCLP of Church & Revelle [24]. In addition, a form of MCLP is taken into account. The MCLP mathematical program is shown as follows. First, we define problem input:

i and I comprise the index & demand nodes.
j *and* J are the index & set of qualified facility locations.
h_i indicates the population or demand at node i.
d_{ij} is the fastest route (or amount of time) between demand node I and facility node j.
DC is the distance (or time) need for coverage.
P is the number of facilities to be established.
a_{ij} is a binary variable which equals if candidate site j can cover ($d_{ij} < DC$) the demand nodes i and zero otherwise.

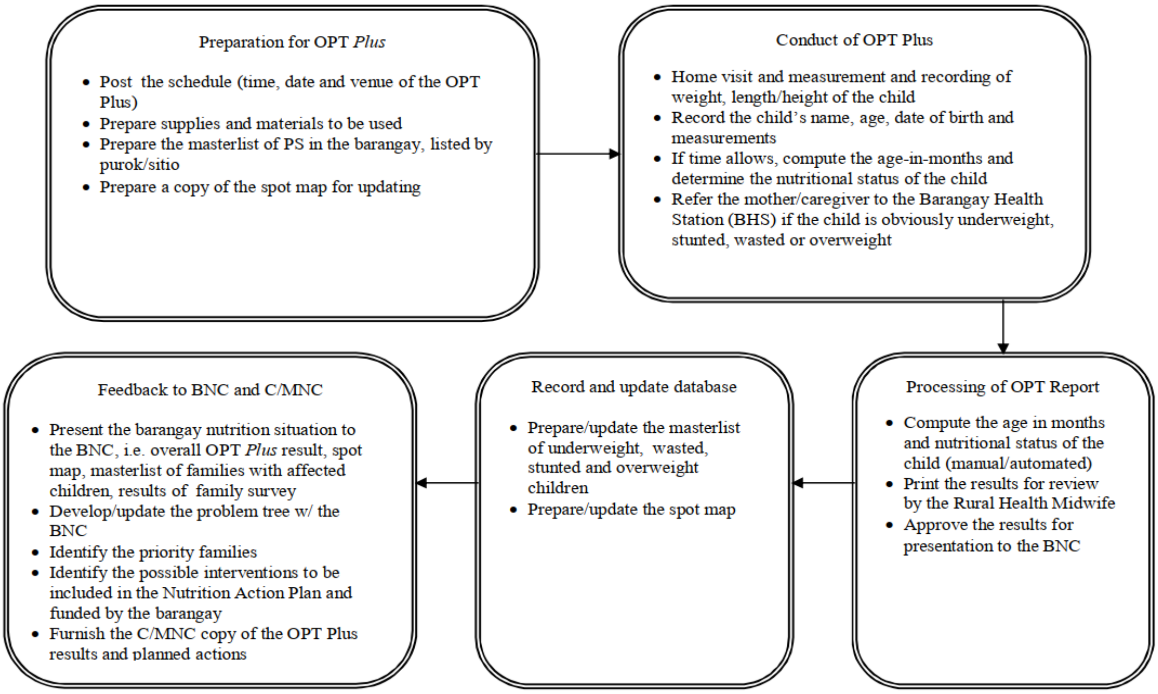

Fig. 1. Procedure and overall process of OPT plus

Then, the decision variables are:
X_j is The value of a binary variable is one when a facility is located at the j^{th} node and zero otherwise.
Z_i is a binary variable equal to one if node I is served by one or more facility within f and zero otherwise.

The objective function (1) maximizes the number of covered demands.

$$\text{maximize obj.} = \sum_{i \in I} h_i Z_i \qquad (1)$$

Subject to:

$$Z_i \leq \sum_{j \in J} a_{ij} X_i \qquad i \in I \qquad (2)$$

$$\sum_{j \in J} X_j \leq P \qquad (3)$$

Constraints (2) state the demand $i \in I$ unable to be covered until at least one facility that covered the demand node is chosen. Constraints (3) Limit the number of utilized facilities to no more than *P*. There is an application of AMPL in this paper for the exact solution of MCLP. AMPL (A Mathematical Programming Language) is a known modelling language for large-scale problems [25].

3. RESULTS AND DISCUSSION

3.1. Case Problem and Description

Iloilo City Health Office is planning to establish a temporary community centre and playground as an annual program-related Nutrition that can ideally cater to the area's districts. Specifically for OPT Plus, this program will provide supplementary and appropriate health and nutrition services for malnourished preschoolers. With the help of the MCLP model, establishing the community centre and playground will be optimally identified. A facility with 10 Km of vehicle transportation coverage is proposed for this project. The data gathered per barangay were arranged and classified per district concentrated as demand points for the problem. Fig. 2 shows the sections of Iloilo City with corresponding points.

Fig. 2. Seven districts points of Iloilo City

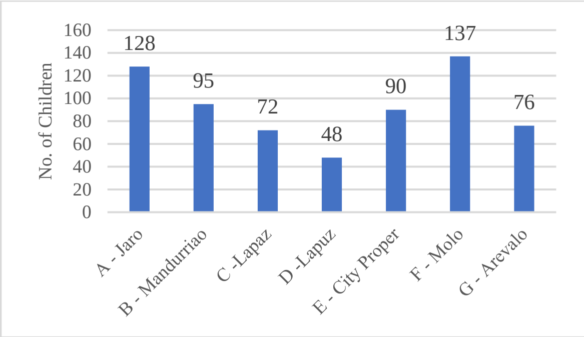

Fig. 3. UW/SUW per district of Iloilo City

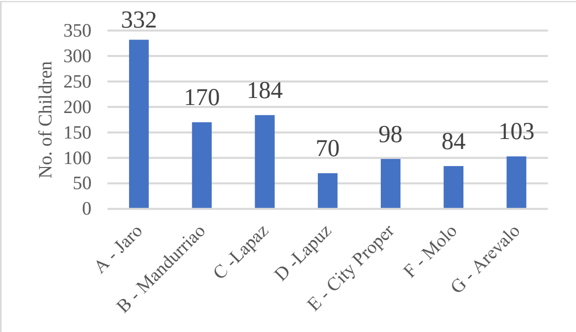

Fig. 4. OW/Ob per district of Iloilo City

From the 1st quarter survey of the Iloilo OPT Team in 2021, Fig. 3 shows the number of children evaluated with underweight/severely underweight (UW/SUW) conditions per district. While Fig. 4 shows the number of children assessed with overweight/obese (OW/Ob) conditions per district. This data is used as the demand values per district to optimize community centre and playground facility locations. Major daycare centres per district were identified for the facility location proposed by the city office. Distances from each point (in Km) of the daycare centre per district were determined through google maps, considering the use of road routes for vehicle transportation in Fig. 5 and Table 1.

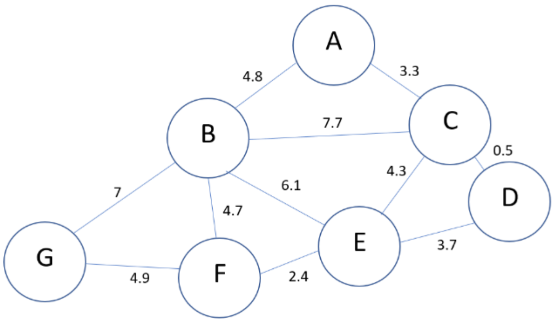

Fig. 5. Distances (Km) among district points in Iloilo City

http://dx.doi.org/10.30656/jsmi.v6i2.4599

Table 1. Day care centers and their locations

Point	District	Name	Exact Location	Near Points
A	Jaro	Jaro Day Care Center	Railroads line St., St. Brgy. Ma. christina Jaro, Iloilo City, 5000 Iloilo	B,C
B	Mandurriao	Brgy. Dungon-C Day Care Center	Mandurriao, Iloilo City, 5000 Iloilo	A,C,E,F, G
C	Lapaz	Lapaz Day Care Center	Zone 3, Divinagracia, Lapaz, Iloilo City, 5000 Iloilo	A,B,E,D
D	Lapuz	Urban Poor Day Care Center	Block 5, Lapuz, Iloilo City, 5000 Iloilo	C,E
E	City Proper	Iloilo City Proper Multi-Purpose Day-care Center	MHR4+QGJ, Brgy. Bay Bay Tanza, Iloilo City Proper, Iloilo City, 5000 Iloilo	B,C,D,F
F	Molo	Molo Day Care Center	Bgy, Molo, Iloilo City, 5000 Iloilo	B,E,G
G	Arevalo	Arevalo Day Care Center	Osmeña St, Mohon, Arevalo, Iloilo City, 5000 Iloilo	B,F

3.2. Computational Results

According to the given data from the case description. Data parameters are identified:

1. *i*, *I* – 7 Districts (demand nodes) – A, B, C, D, E, F, G.
2. *j*, *J* – 7 Day Care Center per District (facilities) – A, B, C, D, E, F, G.
3. h_i (the population or demand at node *i*) & d_{ij} (the shortest distance from demand node *i* to facility at node *j*) – please see Figures 7 & 8.
4. *f* The distance (or time) standard within which coverage is expected) – 10 Km.
5. *P* (The number of facilities to be established) – 1 for community centre (UW/SUW) and 1 for playground (OW/Ob).
6. a_{ij} (A binary variable which equals if candidate site *j* can cover the demand nodes *i* and zero otherwise).

For a_{ij}, using the given D_c = 10 Km corresponding to d_{ij}, the results are shown in Table 2 (1 – means covered by 10 Km radius, 0 – means not covered).

Table 2. a_{ij} for seven disctricts of Iloilo City

Coverage	A	B	C	D	E	F	G
A	1	1	1	1	1	1	0
B	1	1	1	1	1	1	1
C	1	1	1	1	1	1	0
D	1	1	1	1	1	1	0
E	1	1	1	1	1	1	1
F	1	1	1	1	1	1	1
G	0	1	0	0	1	1	1

The mathematical programming language AMPL is used to code the mathematical formulation and solve by using CPLEX to determine the maximum covered demands and demands nodes and identify one facility for community centres and playgrounds. The AMPL utilises the concept of separation between model and data. A model file data was first established, and the parameters, decision variables, objective functions, and constraints were translated into AMPL. The first step is to solve the parameters defined in the mathematical formulation into the AMPL mathematical programming language. Next is to rewrite the data into AMPL based on UW/SUW and OW/Ob (varying demands but same demand and facility locations). Then, the mathematical optimization problem can be easily solved [26].

The result shows that Facility B is the optimal location for establishing the community centre and playground. All of the demands are covered for the chosen optimal facility B. For Underweight/Severely Underweight children, a maximum total of 646 are covered; for the Overweight/Obese, 1,041 are covered for the chosen facility. These are solved by one iteration only. All demand numbers are covered by Facility B with 10 Km coverage.

Further sensitivity analysis is conducted on different coverage radius and the number of facilities to the coverage percentage of the optimal results. Fig. 6 shows the sensitivity analysis on the effect of coverage radius on coverage percentages with P equals one. The result shows that the greater the coverage radius, the greater the coverage percentage can be obtained with the same number of facilities. Fig. 7 depicts sensitivity analysis on the effect of the number of facilities (P) to coverage percentages with a coverage radius of 2.5 Km. It is reported that with this setting, the minimum number of facilities needed equals 3. Using facilities more than that will result in the same demand coverage percentage.

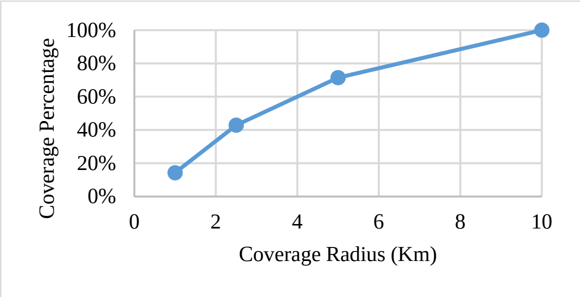

Fig. 6. Sensitivity analysis on the effect of coverage radius on coverage percentages with P=1

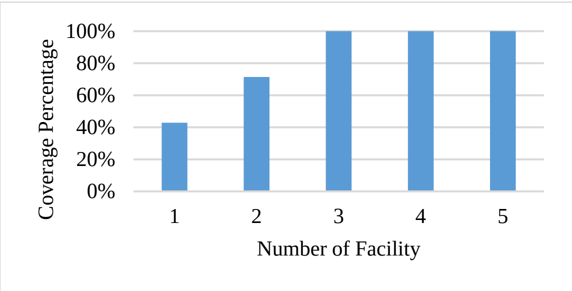

Fig. 7. Sensitivity analysis on the effect of the number of facilities (P) on coverage percentages with a coverage radius equal to 2.5 Km

The Iloilo City health officials can use this to locate their annual temporary community centre and playground in the district of Mandurriao, Brgy. Dungon-C Day Care Center. With this facility point, PUVs and private vehicles from other sections can easily access and offer common short routes in every other community.

3.3. Managerial and Theoretical Implications

Customers are often assigned to facilities based on their proximity to the facility. Much research has been done on models to help people decide where to put things like public facilities. This study enriches the knowledge pool by demonstrating the relevance of applying a mathematical optimization model, the Maximum Covering Location Problem (MCLP), to determine the optimal location that covers the area served by the community centre and playground facility.

In addition, this study allows practitioners to benefit from the theoretical and methodological knowledge of researchers, on the one hand, and it also helps researchers better understand the context, main concerns, difficulties, and limitations from a practical point of view, which is why it is important for this study. Another thing worth noting is that new models deal more closely with practical and important issues like where public facilities are.

4. CONCLUSION

In this paper, MCLP is coded in AMPL and solved using CPLEX. The approach to the problem is an exact solution using mathematical programming. There are further assumptions made, such as a node being covered if there is at least one facility within a predetermined distance. In addition, each node could serve as a facility host. In other words, the set of nodes and the set of potential facilities are identical (*Assumed that there are a set of demand nodes I and a set of candidate sites J*). In addition, it is assumed that each node has a certain amount of demand that must be satisfied. With them, an optimal solution for the location was determined.

The main limitation of our approach is that it cannot deal with a large-scale number of nodes due to the growing complexity of the problem. It is necessary to consider a more sophisticated approach, such as heuristics or metaheuristics algorithms [27], [28]. Furthermore, the demand of each node might be best characterized as an uncertainty parameter using stochastic or fuzzy approaches. Future research may explore using various heuristics/metaheuristics [29], [30]. The other has in-depth specific demand nodes and considers the program's cost, topography and studied coverage. Additional parameters consider validating the suitability of the solution further. Furthermore, to expand the problem not only limited to MCLP but also explore any models that can help further on the OPT Plus program limited to Iloilo City and their nationwide planning programs.

REFERENCES

[1] A. A. N. Perwira Redi *et al.*, 'Facility Location Problem to Identify The Optimal Allocation of Near-Expired COVID-19 Vaccines', in *2022 International Conference on Decision Aid Sciences and Applications (DASA)*, Mar. 2022, pp. 1105–1110, doi: 10.1109/DASA54658.2022.9765157.

[2] World Health Organization, 'Nutrition', *World Health Organization*, 2022. Available: https://www.who.int/health-topics/nutrition.

http://dx.doi.org/10.30656/jsmi.v6i2.4599

[3] Inter-agency Technical Working Group on Child Growth Standards, *Implementing Guidelines on Operation Timbang Plus (OPT+)*, no. 2. 2012. Available: https://www.nnc.gov.ph/phocadownloadpap/userupload/elavapie/OPT

[4] National Nutrition Council, '2017 Operation Timbang Plus Results', 2017. Available: https://www.nnc.gov.ph/related-statistics/operation-timbang-result.

[5] Iloilo City Health Office, 'Nutrition Situation Update Report 2019', 2019. Available: http://enutrition.fnri.dost.gov.ph/site/uploads/2018_ENNS_Dissemination_Iloilo_City.pdf.

[6] R. Z. Farahani, N. Asgari, N. Heidari, M. Hosseininia, and M. Goh, 'Covering problems in facility location: A review', *Comput. Ind. Eng.*, vol. 62, no. 1, pp. 368–407, Feb. 2012, doi: 10.1016/j.cie.2011.08.020.

[7] A. A. Coco, A. C. Santos, and T. F. Noronha, 'Formulation and algorithms for the robust maximal covering location problem', *Electron. Notes Discret. Math.*, vol. 64, pp. 145–154, Feb. 2018, doi: 10.1016/j.endm.2018.01.016.

[8] M. Reinaldi, A. A. N. P. Redi, Y. T. Prasetyo, R. Nadlifatin, P. Jewpanya, and M. Asrol, 'Analysis of Reverse Logistics Model Considering Two Echelon Distribution Network and Drop Box Facilities', in *2022 8th International Conference on E-business and Mobile Commerce*, May 2022, pp. 72–76, doi: 10.1145/3543106.3543118.

[9] A. Ahmadi-Javid, P. Seyedi, and S. S. Syam, 'A survey of healthcare facility location', *Comput. Oper. Res.*, vol. 79, pp. 223–263, Mar. 2017, doi: 10.1016/j.cor.2016.05.018.

[10] E. B. Tirkolaee, A. Goli, P. Ghasemi, and F. Goodarzian, 'Designing a sustainable closed-loop supply chain network of face masks during the COVID-19 pandemic: Pareto-based algorithms', *J. Clean. Prod.*, vol. 333, p. 130056, Jan. 2022, doi: 10.1016/j.jclepro.2021.130056.

[11] A. Aghighi, A. Goli, B. Malmir, and E. B. Tirkolaee, 'The stochastic location-routing-inventory problem of perishable products with reneging and balking', *J. Ambient Intell. Humaniz. Comput.*, pp. 1–20, Oct. 2021, doi: 10.1007/s12652-021-03524-y.

[12] E. B. Tirkolaee, A. Goli, and A. Mardani, 'A novel two-echelon hierarchical location-allocation-routing optimization for green energy-efficient logistics systems', *Ann. Oper. Res.*, pp. 1–29, Nov. 2021, doi: 10.1007/s10479-021-04363-y.

[13] E. B. Tirkolaee, P. Abbasian, and G.-W. Weber, 'Sustainable fuzzy multi-trip location-routing problem for medical waste management during the COVID-19 outbreak', *Sci. Total Environ.*, vol. 756, p. 143607, Feb. 2021, doi: 10.1016/j.scitotenv.2020.143607.

[14] A. E. Torkayesh, H. R. Vandchali, and E. B. Tirkolaee, 'Multi-Objective Optimization for Healthcare Waste Management Network Design with Sustainability Perspective', *Sustainability*, vol. 13, no. 15, p. 8279, Jul. 2021, doi: 10.3390/su13158279.

[15] J. O. Muladi, K. Kristiansyah Dezzano, A. Febrianto, A. C. Kurniawan, N. Ruswandi, and A. A. N. P. Redi, 'Optimasi Rute Kapal untuk Distribusi Spare Parts Menggunakan Vehicle Routing Problem dengan Algoritma Tabu Search', *Go-Integratif J. Tek. Sist. dan Ind.*, vol. 1, no. 01, pp. 1–10, Dec. 2020, doi: 10.35261/gijtsi.v1i01.4316.

[16] A. R. P. Santos *et al.*, 'A Mixed Integer Linear Programming for COVID-19 Related Medical Waste Reverse Logistics Network Design', in *2022 4th International Conference on Management Science and Industrial Engineering (MSIE)*, Apr. 2022, pp. 473–477, doi: 10.1145/3535782.3535845.

[17] A. P. Kamil, H. F. Adzkia, and A. A. N. P. Redi, 'Pemilihan Lokasi Parkir Penyewaan Sepeda Menggunakan Maximum Demand Covering Problem Studi Kasus: Kawasan Monas', in *Seminar dan Konferensi Nasional IDEC*, 2019, no. 2018, pp. 1–7. Available: https://idec.ft.uns.ac.id/wp-content/uploads/2019/05/ID050.pdf.

[18] H. S. Amarilies, A. P. Kamil, H. F. Adzkia,

and A. A. N. P. Redi, 'Maximum Coverage Distance Problem for Dockless Bike Sharing System', in *Proceedings of the 2020 the 3rd International Conference on Computers in Management and Business*, Jan. 2020, pp. 306–309, doi: 10.1145/3383845.3383893.

[19] D. P. Sari, N. A. Masruroh, and A. M. S. Asih, 'Extended Maximal Covering Location and Vehicle Routing Problems in Designing Smartphone Waste Collection Channels: A Case Study of Yogyakarta Province, Indonesia', *Sustainability*, vol. 13, no. 16, p. 8896, Aug. 2021, doi: 10.3390/su13168896.

[20] I. D. Argun, 'An Overview on Set Covering Problems With a Focus on Military Applications', in *Operations Research for Military Organizations*, IGI Global, 2019, pp. 54–66, 2019, doi: 10.4018/978-1-5225-5513-1.ch003

[21] O. J. Taiwo, 'Maximal Covering Location Problem (MCLP) for the identification of potential optimal COVID-19 testing facility sites in Nigeria', *African Geogr. Rev.*, vol. 40, no. 4, pp. 395–411, Oct. 2021, doi: 10.1080/19376812.2020.1838306.

[22] J.-F. Cordeau, F. Furini, and I. Ljubić, 'Benders decomposition for very large scale partial set covering and maximal covering location problems', *Eur. J. Oper. Res.*, vol. 275, no. 3, pp. 882–896, Jun. 2019, doi: 10.1016/j.ejor.2018.12.021.

[23] L. Mrkela and Z. Stanimirovic, 'A bi-objective maximal covering location problem: a service network design application', in *2020 International Conference on INnovations in Intelligent SysTems and Applications (INISTA)*, Aug. 2020, pp. 1–7, doi: 10.1109/INISTA49547.2020.9194660.

[24] R. Church and C. ReVelle, 'The maximal covering location problem', *Pap. Reg. Sci. Assoc.*, vol. 32, no. 1, pp. 101–118, Dec. 1974, doi: 10.1007/BF01942293.

[25] A. A. N. P. Redi *et al.*, 'Simulated annealing algorithm for solving the capacitated vehicle routing problem: a case study of pharmaceutical distribution', *J. Sist. dan Manaj. Ind.*, vol. 4, no. 1, pp. 41–49, 2020, doi: 10.30656/jsmi.v4i1.2215.

[26] A. A. N. P. Perwira Redi, I. Dwi Lasmana, N. Layli Rachmawati, Y. Tri Prasetyo, D. Budiono, and P. Jewpanya, 'Solving Container Stowage Problem using Particle Swarm Optimization Algorithm with Multiple Social Learning Structures', in *2021 3rd International Conference on Management Science and Industrial Engineering*, Apr. 2021, pp. 221–227, doi: 10.1145/3460824.3460858.

[27] P. Jewpanya, J. D. German, P. Nuangpirom, M. F. N. Maghfiroh, and A. A. N. P. Redi, 'A Decision Support System for Irrigation Management in Thailand: Case Study of Tak City Agricultural Production', *Appl. Sci.*, vol. 12, no. 20, p. 10508, Oct. 2022, doi: 10.3390/app122010508.

[28] P. Jewpanya *et al.*, 'An Integer Linear Programming for Hospital Bed Scheduling and Capacity Management', in *2022 4th International Conference on Management Science and Industrial Engineering (MSIE)*, Apr. 2022, pp. 275–282, doi: 10.1145/3535782.3535819.

[29] V. F. Yu, P. A. Y. Indrakarna, A. A. N. P. Redi, and S.-W. Lin, 'Simulated Annealing with Mutation Strategy for the Share-a-Ride Problem with Flexible Compartments', *Mathematics*, vol. 9, no. 18, p. 2320, Sep. 2021, doi: 10.3390/math9182320.

[30] A. A. N. Perwira Redi, R. I. Liperda, B. M. Sopha, A. M. Sri Asih, N. N. Sekaringtyas, and H. B. Astiana, 'Relief Mapping Assessment using Two-Echelon Vehicle Routing Problem with Drone', in *2020 6th International Conference on Science and Technology (ICST)*, Sep. 2020, pp. 1–5, doi: 10.1109/ICST50505.2020.9732812.