Evaluating the Adequacy of Public Healthcare Centers in Yogyakarta City: A Simulation Study

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Abstract

Sufficient public healthcare centers are a must to ensure that every inhabitant has sufficient access to healthcare services. This present study aims to evaluate the adequacy of public healthcare centers in Yogyakarta City. Agent-based modeling and simulation (ABMS), capable of modeling heterogeneous individuals, the various capacity of the public healthcare centers, and the spatial aspect of the model, was used to simulate the load and unmet demand of the public healthcare centers. The empirical data to parameterize the simulation model were collected from an empirical survey and historical records. The simulation model can reproduce the existing load at the public healthcare centers of Jetis, Ngampilan, and Danurejan I with a non-significant difference. Base scenario simulating individuals selecting the public healthcare center in their respective districts results in the average annual load of 2387 cases and the unmet demand of 82 cases, indicating insufficient capacity, thus implying the need to expand the capacity. Selecting the nearest public healthcare center rather than the one in the respective district results in a shorter traveled distance and less unmet demand but creates an imbalance load among the centers. The trade-off between the load and traveled distance implies the necessity to consider location as well as involved stakeholders, i.e., individuals and the public healthcare centers in planning the future establishment of the public healthcare centers.

Keywords
public healthcare centers, agent-based modeling and simulation, adequacy, Yogyakarta city

1. Introduction

Sufficient public healthcare centers are a must to ensure that every inhabitant has sufficient access to healthcare services. Several studies have been conducted to provide more efficient and effective health services. However, the growing population and increasing need for healthcare services, especially during a particular case such as a pandemic, pose challenges to the public healthcare center. Yogyakarta city, one of the medium-sized cities in Indonesia, has 435,936 inhabitants, an increase of 13% during the last ten years (DIY Central Bureau of Statistics 2021). Due to dynamic conditions, the adequacy of public healthcare centers should be regularly examined. Therefore, this present study aims to evaluate the adequacy of public healthcare centers in providing health services to a population using a simulation study. Yogyakarta city, Indonesia, which consists of fourteen districts, was used as a studied case.

The need for healthcare services can be estimated by the assumption that every individual has a chance to get sick at some point in his/her life, which requires health services to recover from their illness. The public healthcare centers are located in an area so that the population can have comfortable access to the health services when they need them (Murad 2012). Indonesian Ministry of Health policy is that each district should have one public healthcare center to serve the population in the respective district. However, the policy has not been fully implemented. Figure 1 presents the ratio of the number of public healthcare centers to the number of districts in each province of Indonesia. The highest ratio is at D.K.I. Jakarta province with 7.3, whereas the lowest ratio is at Papua province and Papua Barat province with the ratio of 0.73.

Special Region of Yogyakarta (D.I. Yogyakarta) province has a ratio of 1.55, implying that each district already has at least one public healthcare center. Yogyakarta city, one of the cities in the province, has eighteen public healthcare centers. Due to the significant population growth, it is essential to examine the adequacy and accessibility of the existing public healthcare centers.

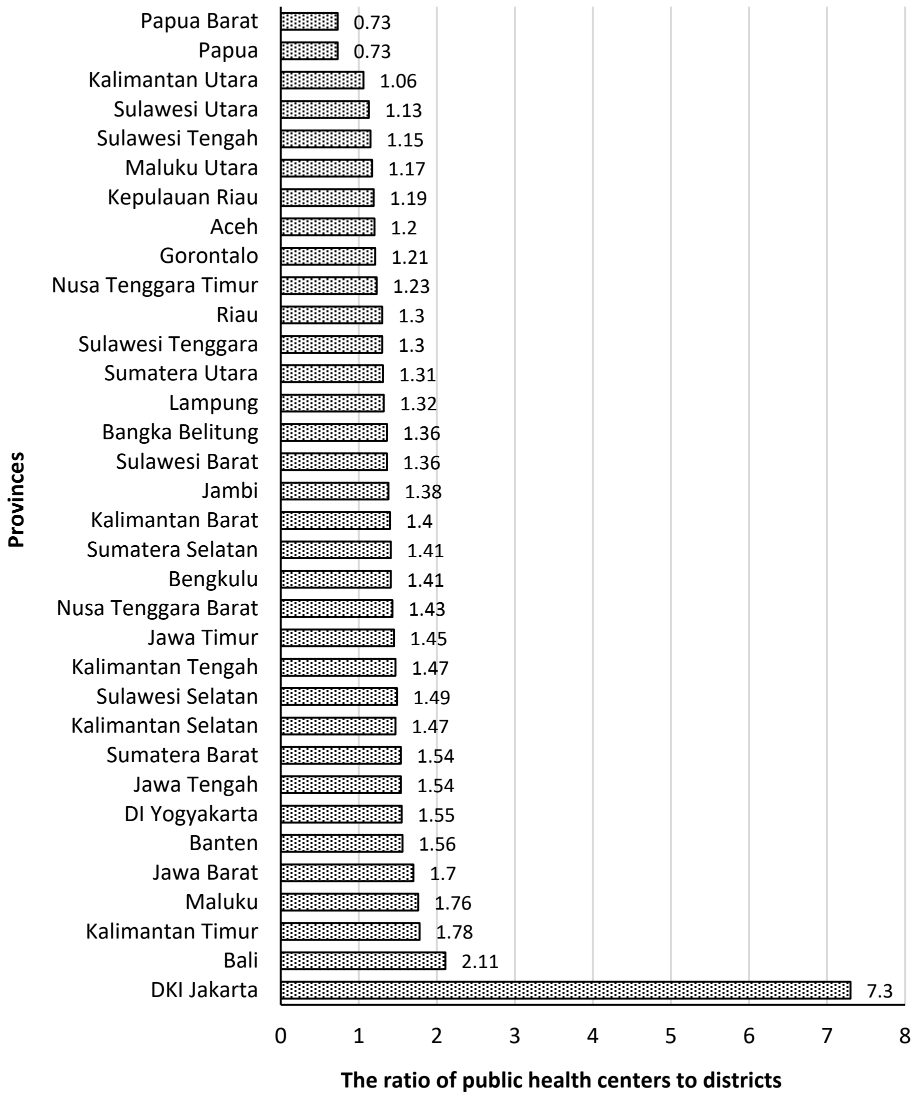

Figure 1. The ratio of the number of public health centers to the number of districts in Indonesian provinces (Indonesian Ministry of Health 2019)

The simulation was selected to model the demand of the population in the region for healthcare services that the existing public healthcare centers should provide. The simulation approach facilitates an intuitive way to model individuals' needs for healthcare services and behavior (in selecting the public healthcare center) into more straightforward logic. The agent-based modeling (ABM) approach was selected because it enables the model of the population heterogeneity in terms of demand for healthcare services and the spatial aspect of the model, i.e., the actual location of the individuals and the public healthcare centers. The ABM has also been widely used in various disciplines such as logistics (Sopha et al. 2020), humanitarian operations (Sopha et al. 2019), and healthcare both at the operational level such as modeling operations and patient flow and at the strategic level such as modeling various interventions to deal with the epidemics/pandemics (Roy et al. 2021).

The present paper is organized into five sections. This section has provided the background of the study, followed by Section 2, presenting the review of the ABM application in healthcare studies and highlights the positioning of the present study. Section 3 describes an ABM developed for the study, followed by the simulation results and scenarios discussed in Section 4. Section 5 concludes the findings and presents avenues for potential research.

2. Simulation in Healthcare Service Operations

Healthcare services involve multiple health providers, uncertainty, and dynamic characteristics, making it a complex system. Due to its complexity, simulation is generally considered as an approach to model and investigate efficient healthcare service operations. The simulation approach in the healthcare service has been widely used to understand the impact of changes in a healthcare service organization, to understand the interdependency among the components in the system, and to explore scenarios in a low-risk and cost-effective manner. Due to its capability to capture and devise effective policies in a dynamic, stochastics, and complex system, the simulation approach is suitable to model healthcare service operations. This section provides a brief description of various simulation approaches in modeling and simulating healthcare service operations.

According to Roy et al. (2021), the simulation literature in healthcare service operations can be classified into different levels of the health service providers, i.e., primary/secondary clinic, tertiary (multi-specialty), quaternary (super-specialty), multiple hospitals, and public health. Mathematical modeling has been used in primary and secondary centers, whereas simulation approaches have been used at the tertiary level hospital. The complexity of the tertiary level and above becomes higher due to multiple service offerings, multiple required resources, and a large volume of patients.

The simulation approach in modeling healthcare operations is varying from managing patient flow, resource planning, allocation, patient admission, utilization of hospital, the performance of clinic operations at a local level, to the network of healthcare services, a virus spread at a global level. Therefore, a different simulation approach is selected depending on the problems, system's characteristics, and the objects to be modeled. Various simulation approaches, i.e., Monte Carlo simulation (MCS), discrete-event simulation (DES), system dynamics (SD), and ABM, and various simulation platforms, have been found in the literature to model healthcare service operations. Some studies, such as Chalal et al. (2013), have further developed the combined simulation approaches, so-called multi-method simulation, such as the combination of DES and SD or the combination of SD and ABM. According to a recent literature review in the period of 2007-2016 by Roy et al. (2021), it appears that DES has been a widely used simulation approach in the literature. However, it seems that ABM and multi-method simulation (MMS) might become prevalent in the near future.

Unlike DES, SD, and ABM, which are dynamic models, MCS can be categorized as a static model because MCS models the system in which it is not changing over time. Nevertheless, the MCS facilitates the stochasticity in the model, which is suitable for dealing with uncertainty. The MCS is based on the repeated random experiments. Very few studies have implemented MCS, such as Torres-Jimenez et al. (2015), who deployed MCS to evaluate the technical efficiency of small healthcare areas with uncertainty.

The DES can model a detailed process at the operational level and better facilitate randomness in the model. the DES is suitable to model at every level of healthcare service, for instance, patient flow in a clinic (Ahmed and Amagoh 2008), emergency operations (Brenner et al. 2010), resource planning and allocation in the emergency department (Zeinali et al. 2015), and performance evaluation of clinic or emergency medical services (Shi et al. 2014, Aboueljinane et al. 2014). Consequently, the application of DES has been quite common in healthcare service operations, particularly in multi-specialty and super-specialty hospitals due to multiple health services and in-depth healthcare processes.

The SD, also known as the top-down approach, simulates a system by representing the dynamic relationship of the system's components through feedback loops, thus representing a non-linear approach. The SD is selected due to its capability to analyze complex and dynamic systems at the macro level, thus appropriate for analyzing policy (Taylor and Lane 1998). The SD has been widely used for modeling epidemics/pandemics, such as recently demonstrated by Sy et al. (2020). Furthermore, the SD has been used to explore critical factors and their relationships in healthcare social sustainability related to patient satisfaction (Faezipour and Ferreira 2013).

The ABM, also known as the bottom-up approach, is a relatively new approach. The ABM is based on the concept of agents, which are autonomous entities that are heterogeneous and interacting with each other. The ABM has been the most appropriate approach for capturing the health system by addressing health workers and patient behaviors, which is suitable for the tertiary level (Roy et al. 2021). Thus, the ABM has been used to model various healthcare service operations. For instance, Jones and Evans (2008) used the ABM to schedule physicians in the emergency department, Lee et al. (2010) simulated vaccine allocation, Charfeddine and Moez (2010) simulated the population with chronic disease and associated healthcare delivery network, Cabrera et al. (2012) improved the emergency departments' performance, and Lu et al. (2014) simulated outpatient scheduling.

Furthermore, some efforts have been conducted to combine the simulation approaches, known as multi-method simulation (MMS), such as combining DES and SD to evaluate operational performance (Chalhal et al. 2013), and model breast cancer screening (Tejada et al. 2014), and combining DES and ABM to simulate emergency department for normal and disaster conditions (Gul and Guneri 2015). Another study has also combined the simulation approach with another method, such as integrating data mining and DES to simulate value-added operations in a hospital emergency department (Ceglowski et al. 2007).

It is worth noting that the public health level is a relatively new context, so that very little research has worked with the operations issues at the public health (Roy et al. 2021). Therefore, this present study contributes to enrich the existing literature by addressing the public healthcare centers concerning the adequacy assessment in meeting the health services required by the population. Because it involves spatial aspect and dynamic nature of the system to be modeled, as well as multiple stakeholders, i.e., individuals with various needs for healthcare services, public healthcare centers with different capacities, the simulation approach of ABM, was therefore selected.

According to the authors' best knowledge, there has been only one study, i.e., Rouzafzoon and Helo (2016) who demonstrated ABM to examine the effect of healthcare location on the operation performance of healthcare service providers. The present study differs from Rouzafzoon and Helo (2016) in two ways. First, the present study examines both the adequacy of the public health centers in providing required health services to the population, whereas Rouzafzoon and Helo (2016) only examine the effect of the location of healthcare service providers. Second, the present study used empirical data in building and parameterizing the simulation model, consequently providing empirical contribution, while Rouzafzoon and Helo (2016) focused on model building without using any actual case data.

3. Methodology

To evaluate the adequacy of public healthcare centers in providing health services to the populace of Yogyakarta city, therefore, a developed simulation model should be able to represent the population needing healthcare services, the public healthcare centers with various capacities, the actual location of both the population and the public healthcare centers, and to model the interaction between the population and the public healthcare centers. The ABM is thus a suitable simulation approach for the present study to meet those required specifications.

The basic principle of the ABM lies in the concept of agents. The agents are defined as autonomous decision-making entities (Sopha and Sekar 2020). The agents are heterogeneous when it comes to attributes and behaviors. The agents also interact with each other and with their environment. The ABM is therefore selected for the study because it can model the heterogeneous individuals regarding their location, required healthcare services, and individuals' behavior in selecting the public healthcare center. The ABM can model the heterogeneous public healthcare centers in terms of their location and capacity. The individual in need of healthcare services selects and visits the public healthcare center to get the required healthcare services. The ABM can also model the interaction between the individuals asking for the services and the public healthcare centers providing the services, which is depending on the available capacity. The individual/population and the public healthcare services are modeled at the individual/agent level (micro-level) in the ABM. The interactions among the individuals/agents are then resulting in an emergent property of the system at the macro-level, i.e., the adequacy of the public healthcare centers for the study. Moreover, the ABM can represent the spatial aspect of the model, i.e., the actual geographical location of the agents. Below is a detailed description of the developed ABM and the respective data for the study.

3.1 Agent-based Modeling for Public Healthcare Centers

The simulation model using ABM was developed to be used as an experimental tool to evaluate the adequacy of the public healthcare centers in Yogyakarta City. Eighteen public healthcare centers which are located in each district in Yogyakarta City were modeled. Four districts, i.e., Umbulharjo, Kotagede, Gondokusuman, and Gondokusuman, have two public healthcare centers. The public healthcare centers operate daily (Monday to Saturday), except Sunday and holidays. The public healthcare centers do not provide inpatient facilities, so the provided services are outpatient. The public healthcare centers provide the patients who require inpatient facilities a recommendation letter to the hospital. Every resident in the district is suggested to visit the public healthcare center in the respective area. Nevertheless, every individual has a right to seek healthcare services elsewhere.

Based on those mentioned above, the developed ABM consists of two types of agents, i.e., the individual and the public healthcare services. The individual is heterogeneous in terms of location and illness. The individual health cycle was developed using the SIR model (Susceptible, Infectious, and Recovered). The motivation for using the SIR model is that it is assumed that everyone can get sick, seek treatment, and eventually recover from illness. The health cycle reoccurs so that after they are recovering, they still have the possibility of getting sick. Once the individuals are ill, they will seek treatment at the public healthcare center. The public healthcare center has two attributes, i.e., location and capacity. Once the capacity is available, the public healthcare center takes care of the individuals and provides healthcare services. The individual agents are mobile as they can move from one place to another, whereas the public healthcare center agent is static.

Both individual and public healthcare center agents are set in a geographical location which was implemented using Geographical Information System (GIS) data in NetLogo software (Wilensky 1999), as shown in Figure 2. The public healthcare centers are located the same as in the existing system, while the individual agents are located randomly but evenly distributed in their respective districts. One individual agent in the simulation model represents 250 people in the existing system. Therefore, the simulation model made of 1,651 individual agents to represent 41,275 people in Yogyakarta City, which were randomly distributed according to the population distribution by district. Table 1 shows that the population distribution and capacity distribution of the existing public healthcare centers are not significantly different. It implies that the capacity of the public healthcare center is proportional to the population in the districts.

Table 1. Population distribution and capacity distribution of the public healthcare center at each district

District	Public Health Center	Population distribution (%)	Capacity distribution of the public health center (%)
Mergangsan	Mergangsan	8	8
Jetis	Jetis	7	8
Tegal Rejo	Tegal Rejo	9	7
Mantrijeron	Mantrijeron	9	8
Kraton	Kraton	5	4
Umbulharjo	Umbulharjo I	17	8
	Umbulharjo II		8
Kotagede	Kotagede I	8	5
	Kotagede II		5
Gondokusuman	Gondokusuman I	10	5
	Gondokusuman II		5
Danurejan	Danurejan I	5	3
	Danurejan II		4
Pakualaman	Pakualaman	3	3
Gondomanan	Gondomanan	4	4
Ngampilan	Ngampilan	5	4
Wirobrajan	Wirobrajan	7	4
Gedongtengen	Gedongtengen	5	5
χ^2 test		$\chi^2 = 3.448$, $df = 13$, $p = 0.996$	

The simulation model was initiated by setting up both the individuals and public healthcare centers to their respective locations, as shown in Figure 2, and assigning their attributes. For each time step, the state of individuals following the SIR model was evaluated. Historical data for illness types were collected from all the public healthcare centers. To simplify the model to a representative but scalable model, only the top thirteen illnesses, i.e., hypertension, non-insulin-dependent DM type 2, acute respiratory infection, pharyngitis, fever, dyspepsia, myalgia, acute nasopharyngitis, cephalgia, arthrosis, gastritis, arthritis, cough, were used in the model. Each individual in the simulation model has a certain probability of getting one of those illnesses. The probability distribution was acquired through an empirical survey of a hundred respondents living in Yogyakarta City, which was conducted specifically for model parameterization.

Furthermore, each illness has a different incubation/sickness period, in which the data was acquired from secondary sources. Using the empirical distribution of illness chance, the individual agent may become ill and seek treatment at the public healthcare center. If the capacity of the public healthcare center is available, he/she receives treatment; otherwise, he/she visits the public healthcare center the next day. After some periods from obtaining services, he/she will recover and heal—the time required for the patient to recover within a specific range is based on the secondary sources. After healing, he/she may become ill again.

The performance indicators of the system are load and unmet demand of the public healthcare centers as a proxy to the adequacy of the public healthcare center and individuals' traveled distance as a proxy to the accessibility to the public healthcare center. The load of the public healthcare center was measured using the number of handled cases in a year. The unmet demand was defined as the number of cases that the centers cannot be handled due to unavailable capacity. The traveled distance is the distance traveled by the individuals from their home to the chosen public healthcare center.

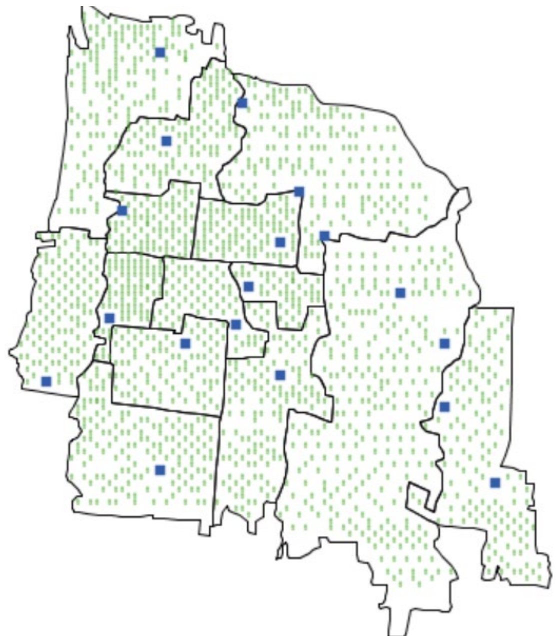

Figure 2. The individuals (green dots) and the public healthcare centers (blue square) during initialization. The screenshot of the simulation model implemented in Netlogo software using GIS data (Wilensky 1999)

The simulation was run for a year or 365 time-steps in which one time-step in the simulation model represents one day in the existing system. The load of each public healthcare center and traveled distance by the individuals were recorded. The simulation was run for 100 replications so that the mean value and standard deviation of the load and the unmet demand of the public healthcare centers and average traveled distance based on those replications are reported.

In order to test that the implemented simulation model was following the conceptual model, verification was conducted through walk-thorough debugging. A set of validation tests was conducted to evaluate the representativeness of the simulation model mimicking the existing system. Therefore, validation tests were conducted on the model input through the empirical survey and historical records, ensuring that all data used in the simulation model was based on the existing system. The output of the simulation model was tested against the independent historical data.

Once the simulation model was verified and validated, scenarios are developed. The base scenario simulated the existing system and the adequacy of the existing public healthcare centers was then evaluated. In addition to the base scenario, the other two scenarios were also developed, considering possible implementations and compatibility with the existing system. Based on the observation, it was found that individuals tend to visit nearby public healthcare centers than the designated public healthcare center in their corresponding district. It is of importance to note that there is no obligation that the individuals should use the public healthcare center in their district. Figure 2 has indicated that some individuals have a shorter distance to other districts' public healthcare centers than their district's public healthcare center. Consequently, to understand the impact of the individual's selection of the public healthcare center on the overall system performance, Scenario 1 was developed. The scenario was basically to examine the impact of the individual's decision-making in opting for the nearest public healthcare center rather than the public healthcare center in his/her district on the load, unmet demand, and traveled distance, thus assessing the effectiveness of the existing locations of the public healthcare centers. It is also interesting to look at the load balance among the public healthcare centers as the capacity of the public healthcare centers in each district had already been determined based on the population in the respective district, as shown in Table 1. Based on the simulation results of the base scenario and Scenario 1, Scenario 2 extends the capacity of the public healthcare center at Mantrijeron district. Scenario 2 was developed to understand the effect of the capacity increase on the system's performance.

4. Results and Discussion

The section is divided into two sections. The first section reports and discusses the results of the output validation test, whereas the second section presents and compares the results of scenarios.

4.1 Validation

Due to limited historical data, the output validation test was based only on the historical load of the three public healthcare centers, i.e., Danurejan I, Jetis, and Ngampilan. Figure 3 presents the simulated and actual average load for the public healthcare centers of Jetis, Ngampilan dan Danurejan I. Statistical analysis of a paired t-test was then carried out to evaluate whether the simulation results were significantly different from the historical data. The result of the paired t-test of $t = 1.31$, $df = 2$, $p = 0.321$ indicates a non-significant difference between the simulated and actual average load of the three public healthcare centers under investigation. It appears that the simulation model can reasonably represent the actual system.

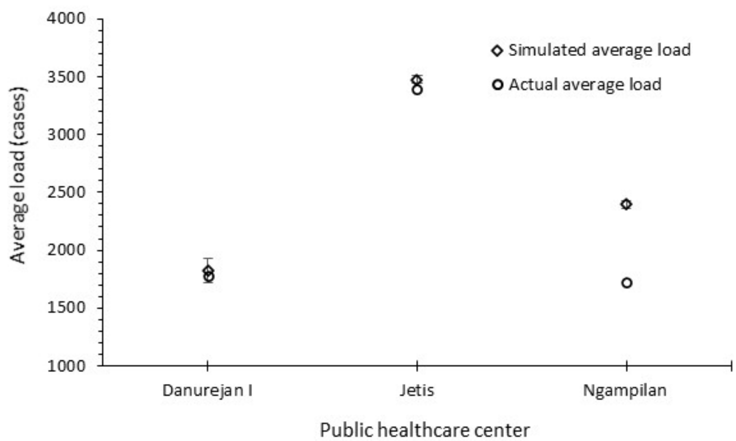

Figure 3. Comparison of simulated and actual average load for the public healthcare centers of Jetis, Ngampilan dan Danurejan I

4.2 Scenarios

Three scenarios with different objectives were developed for the study. The base model was built under the assumption that the individuals in need of healthcare service select the public healthcare center in the district. Scenario 1 was thus built that the individuals select the nearest public healthcare center from their home instead of the public healthcare center in the district. Based on the simulation results, the highest load of the public healthcare center consistently occurs at Mantrijeron district for both base scenario and Scenario 1. Hence, Scenario 2 set an additional public healthcare center at Mantrijeron district. For each of the scenarios, the load and unmet demand of the public healthcare centers were evaluated. In addition, traveled distance was also examined when comparing the base scenario and Scenario 1 because these two scenarios have a similar configuration of public healthcare centers, thus comparable.

Table 2 reports the average load of the public healthcare centers for the three scenarios. It shows that the highest load has been experienced by Mantrijeron public healthcare center, and the least load is at the Mergangsan public healthcare center. It appears that the base scenario has a higher average load than Scenario 1 and Scenario 2. Unsurprisingly, Scenario 2 results in a lower average load due to the additional public healthcare center. Low standard deviation indicates load variance among the public healthcare centers.

It appears that the additional public healthcare center also reduces the imbalance load among the public healthcare centers, as indicated by the lowest load's standard deviation. It is worth noting that the standard deviation of load for Scenario 1 is higher than that of the base scenarios. It implies that selecting the nearest public healthcare center results in an imbalance load among the public healthcare centers. It can be explained by the capacity of the public healthcare centers which have been allocated to match with the population distribution, as shown in Table 1. It implies when the population selects and visits the nearest public healthcare center, it leads to different allocations for the public healthcare centers, thus resulting in an imbalanced load.

Table 2. Comparative analysis of public healthcare centers' load

District and its public healthcare centers	Public Healthcare Centers	Base Scenario – selecting the respective public healthcare center in the district	Scenario 1 – selecting nearest public healthcare centers	Scenario 2 – additional public healthcare center at Mantrijeron district
Mergangsan	Mergangsan	1270	2253	1271
Jetis	Jetis	3475	2657	3473
Tegal Rejo	Tegal Rejo	2129	1445	2122
Kraton	Kraton	2631	2769	2371
Umbulharjo	Umbulharjo I	2913	1051	2628
	Umbulharjo II	2854	1483	2867
Kotagede	Kotagede I	1348	2445	2877
	Kotagede II	1341	2003	1350
Gondokusuman	Gondokusuman I	1758	1210	1328
	Gondokusuman II	1781	2149	1787
Danurejan	Danurejan I	1829	2634	1751
	Danurejan II	1814	1992	1847
Pakualaman	Pakualaman	1637	3042	1797
Gondomanan	Gondomanan	2627	1173	1637
Ngampilan	Ngampilan	2392	4430	2625
Wirobrajan	Wirobrajan	3932	2339	2395
Gedongtengen	Gedongtengen	2494	3853	3932
Mantrijeron	Mantrijeron	4739	4030	2369
	Mantrijeron (new)			2371
Mean value		2387	2387	2260
Standard deviation		945	984	721

Concerning traveled distance by the individuals, the base scenario results in a longer total traveled distance of 19,146 km than Scenario 1, with a total traveled distance of 13,132 km. Although selecting the nearest public healthcare center results in a shorter distance, it creates an imbalance load for the public healthcare centers.

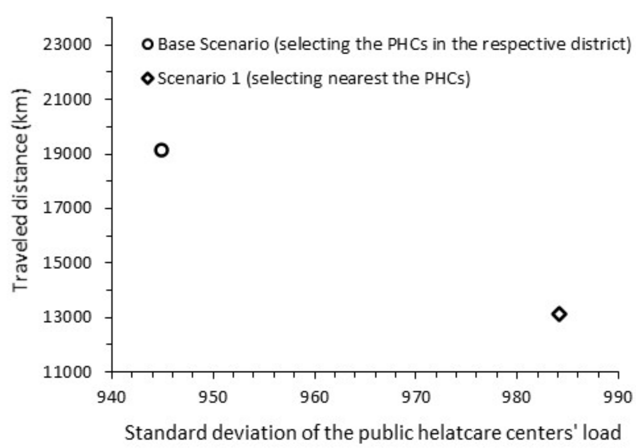

Figure 4. The trade-off between load balance among the public healthcare centers and the individuals' traveled distance

Therefore, there exists a trade-off between the traveled distance and the imbalance load for the public healthcare centers, as shown in Figure 4. It implies that the decision-maker should anticipate the individuals' decision-making in selecting public healthcare centers when planning the location of the public healthcare centers.

In addition to the load of the public healthcare centers, unmet demand was also evaluated to evaluate further the public healthcare centers' operational performance. Table 3 presents the unmet demand of the public healthcare centers for the three scenarios. The table shows that unmet demand exists in all public healthcare centers, which implies that the existing capacity of the public healthcare centers is not sufficient. Surprisingly, the additional public healthcare center at Mantrijeron has not yet sufficed. It is worthy to note that the additional public healthcare center reduces the unmet demand, but the significant reduction of the unmet demand is observed in Scenario 1 – when the individuals select the nearest public healthcare center. It can be justified that the short distance implies a relatively fast response to the demand for healthcare services when needed.

Table 3. Comparative analysis of public healthcare centers' unmet demand

District and its public healthcare centers	**Public Healthcare Centers**	**Base Scenario – selecting the respective public healthcare center in the district**	**Scenario 1 – selecting nearest public healthcare centers**	**Scenario 2 – additional public healthcare center at Mantrijeron district**
Mergangsan	Mergangsan	48	60	48
Jetis	Jetis	52	51	51
Tegal Rejo	Tegal Rejo	137	79	137
Kraton	Kraton	55	56	54
Umbulharjo	Umbulharjo I	397	31	177
	Umbulharjo II	150	29	170
Kotagede	Kotagede I	66	31	72
	Kotagede II	65	20	60
Gondokusuman	Gondokusuman I	111	49	132
	Gondokusuman II	100	30	80
Danurejan	Danurejan I	33	29	40
	Danurejan II	35	20	30
Pakualaman	Pakualaman	16	56	16
Gondomanan	Gondomanan	12	27	12
Ngampilan	Ngampilan	25	83	26
Wirobrajan	Wirobrajan	85	87	87
Gedongtengen	Gedongtengen	32	74	31
Mantrijeron	Mantrijeron	49	49	20
	Mantrijeron (new)			20
Mean value		82	48	67
Standard deviation		88	22	51

The results imply that the current capacity of the public healthcare centers is still not adequate to meet the healthcare services needed by the population. Thus, increasing the existing capacity is necessary. As expanding the capacity through existing public healthcare centers seems to be difficult due to infrastructure constraints, the establishment of additional public healthcare centers becomes an option. The results have indicated that adding a new public healthcare center reduces unmet demand and imbalance load, but on the other hand, it also requires significant investment, which is not the scope of the present paper.

It is worthy to note that the location is an essential aspect of planning public healthcare services. It is also vital to consider population distribution when analyzing the location for the public healthcare center, given the demonstration that selecting the nearest public healthcare drives shorter traveled distance, lower unmet demand yet creates imbalance load among the public healthcare centers. The observable trade-off implies that it is crucial to include involved stakeholders in the system because one solution that increases the performance of a stakeholder may decrease the performance of another stakeholder. Therefore, it is necessary to include different perspectives from different stakeholders to look at the best solution for all stakeholders by understanding and appreciating the trade-offs.

5. Conclusion

Due to dynamic conditions such as population growth, the adequacy of public healthcare centers should be regularly examined. The present study aims to evaluate public healthcare centers' adequacy in providing health services to a population using the ABM implemented in Netlogo. Agent-based modeling and simulation were selected as the simulation approach for the study because of its ability to model heterogeneous populations in terms of location and illness (which determines the required health services), to model public healthcare centers with different capacities, and to facilitate the spatial aspect, i.e., location of both residents and public healthcare centers. Two types of agents, i.e., individuals and public healthcare centers, were modeled. The empirical data used to parameterize the simulation model were collected from the empirical survey and historical records. The simulation model is expected to be used as decision-making to evaluate the adequacy of existing public healthcare centers in meeting the needs of healthcare services and test different scenarios for improvement. Three scenarios, i.e., the base scenario, the scenario of selecting the nearest public healthcare center, and the scenario of adding a new public healthcare center was then developed.

The results show that the existing public healthcare centers have not yet adequate to fulfill the current needs for healthcare services, which implies the urgent need to increase the capacity of the existing public healthcare services. The base scenario indicates that the mean-value of the public healthcare centers' load is 2387 cases with a standard deviation of 945 cases and a total unmet demand of 82 cases. As many individuals prefer to select the nearest public healthcare center, the second scenario was thus built to model this phenomenon and found a higher standard deviation of 984 cases, indicating that it creates an imbalance load among the public healthcare centers compared to the base case. However, the behavior results in a shorter traveled distance and lesser unmet demand. The third scenario on adding a new public healthcare center indicates that the addition would help balance the load. It is worthy to note that the location of the new public healthcare center should be carefully examined to anticipate the behavior of selecting the nearest public healthcare center. The limitation of the study is that it was based on the normal condition, not yet considering an extreme circumstance such as COVID-19 pandemics. Moreover, the study does not include the financial aspect into consideration. Moreover, future studies could focus on exploring scenarios to provide an adequate capacity of healthcare services while facilitating balance load among the public healthcare centers, high accessibility for the population are suggested for future research.

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