A Regionalization Model to Increase Equity of Access to Perinatal Care Services

Zahra Mohammadi Daniali
Islamic Azad University Science and Research Branch

Mohammad Mehdi Sepehri (✉ mehdi.sepehri@gmail.com)
Tarbiat Modares University https://orcid.org/0000-0002-9920-7452

Farzad Movahedi Sobhani
Islamic Azad University Science and Research Branch

Mohammad Heidarzadeh
Tabriz Medical University: Tabriz University of Medical Sciences

Research

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Abstract

Background

Reducing neonatal mortality is one of the most important issue in developing countries. One powerful method to reduce the neonatal mortality rate is increase equity in access to health services by regionalization. This study employs national hospitalized birth data from March 2018 to March 2019 to determine the optimal number and location of Perinatal Care Services (PCS) and to manage the referral network of the region.

Methods

This research has examined effective criteria regarding PCS network design. These criteria include the equipment (number of Neonatal Intensive Care Unit (NICU) and ventilator), experts (number of neonatal expert and fellowship), gravity (actual journey of expectant mothers to hospitals), and the type of university manages hospital. Moreover, distances between demands and PCS were transformed into vehicular travel time according to the maximum speed limit in the country road network. There have been annual 315,992 hospitalized birth data. These data provided separately for each city and three types of service requirements according to the gestational age and birth weight, i.e., under 32 weeks or 1500 gram, between 32-34 weeks or 1500-2000 gram, and over 34 weeks or 2000 gram, which receive services of level I, II, and III, respectively. A model builder tool of ARC GIS software was applied to develop a three-level hierarchical location-allocation model to respond to the maximal demand in 30 (level I), 60 (level II), and 120 (level III) minutes of travel time. The developed model was then applied to serve neonates from uncovered cities. Moreover, the alternative PCS were determined for level III services to present more reliable solutions.

Results

Obtained results revealed that the total 130, 121, and 86 PCS are needed to respond to demands of level I, II, III, respectively, in 373 different cities. The service level III has not covered 39 cities; hence another model assigned nearest PCS to these cities so that the travel distances from which to allocated centers were determined 173 min on average.

Conclusions

Regionalization is an approach to increase spatial accessibility to health services. Finding the optimal location to implement PCS would gradually decrease neonatal mortality and morbidity. It can also reduce expenses of under-used local health centers and give better health care regarding the access to experts. In this way, regional services should be considered as a sustainable health care solution at the policy and decision-making levels of the region, national and universal healthcare network.
One of the most significant pointers of the nation’s improvement is the mortality rate of children less than five years old. According to WHO statistics, among 130 million newborns per year in the world, about 4 million infants died within their first 28 days of birth. One powerful method to reduce the neonatal mortality rate is increase equity in access to health services by regionalization. Regionalization was first introduced in 1976 by four significant associations of US academy. In regional health care planning, all large and small hospitals cooperate to improve the quality of services within the region.

Several reports discussed the advantages of regionalization. Several papers investigated the effect of accessibility and travel time on healthcare outcomes in different cases like prenatal centers, trauma centers, vaccine centers, HIV centers, and cardiovascular centers. Some studies determined the effective criteria to reduce neonatal mortality. Other like Kanter et al. developed the useful criteria to analyze regional hospital services to increase equity in access. Mehta et al. proposed the site for the delivery of infants through the establishment of prenatal regionalization. Some reports like Brown et al. implemented GIS to calculate the time required for maternal ground transport to the nearest hospital at the neonatal service level III. Wong et al. scrutinized the relation of poverty and the mean travel time to nearest hospital on rates of hospital birth in African countries. Vadrevu et al. developed an area-based socioeconomic score to analyze the spatial inaccessibility and inequity of maternal health services in the Indain Sundarbans. Jin et al. designed different scenarios to assess the spatial inequity to healthcare facilities between the urban and rural. Olsen et al. investigated the effect of comprehensive care program on the lower maternal and neonatal mortality. Shen et al. examined the spatial accessibility to county hospitals for county residents of west China. Moreover Kats et al investigated international health regionalization.

The purpose of the location-allocation model has been to find the optimal location of facilities and also to determine optimal referral demands to facilities. Harper et al. proposed a common application of the location-allocation model in the health system network regarding geographical considerations. Zhang et al. improved a model for the preventive health care facility network design considering the congestion in demand points. Andersson et al. investigated the location of medical emergency service using a spatial analysis and optimization method. Gu et al. developed a location allocation model to improve the equity and efficiency of access to elderly healthcare services.

Hierarchical models involve facilities at several levels that have significant relationships with each other. Jang et al. applied a mixed-integer linear program to address the problem of allocating capacities to a two-level hierarchical NICU service system in Korea. A combination of maximal covering and p-center models was developed by Baray et al. to improve regional patient access to different levels of services. Tao et al. measured the spatial accessibility to hierarchical health care facilities in varied catchment area in China. Zarrinpoor et al. proposed a hierarchical model to design the treatment service network. Rashidian et al. conducted a research to study the regionalization of prenatal services to reduce the average distance of demands from facilities. Galvão et al. proposed a three-level hierarchical
regionalization model for locating the maternal and infant facilities in Rio de Janeiro. They developed the previous model by putting a constraint on the capacity. Ghaderi et al. determined the optimal location of health facilities and inter-hospital networks considering the budget constraint.

Since 1984, improving the structure of the primary healthcare system in the Islamic Republic of Iran, leading to a dramatic decrease in infant, maternal, and neonatal mortality rates. In this country, the infant mortality rate has changed from 135 in 1974 to 13 deaths per 1000 live births in 2017. But according to Khajavi et al., healthcare facilities are not equitably distributed in this country. In the present study the regionalization of the PCS implemented to increase equity in access in the case of Iran. The differences of the current study and previous ones, which have also been as contributions of this research, are defined as follows. The effective criteria have been discussed by the expert team to give a comprehensive model. For example, the actual journey from city of residence to city of birth has been considered as the gravity criteria. Moreover, different birth weight and gestational age of neonate have been used to determine the potential demand in different levels of services. Next, the regionalization of PCS has been modeled in several conditions. In these models, travel distance converted to travel time considering maximum speed limit of different roads. In one model, the alternative centers was determined for service level III to enhance the reliability of solution. Generally, according to the best of author's knowledge, this comprehensive method has not been investigated yet, especially in the case of PCS on the national level.

**Methods**

**Study area and required data**

The present study has determined the optimal location of PCS in Iran. With 82 million residences and an area of 1,658,195 km², this country is the 18th most populous and 17th largest country in the world. To tackle the real-world problem, by interviewing the experts, characteristics of the problem were indentified. These characteristics are discussed in the following section with respect to four categories of demand, facility, network, and model.

**Demand layer**

There are two references for neonatal demand in national databank of Maternal and neonatal records (IMAN registry) based on the residence and birth city. For the objective of equity in access, the number of neonates in the residence city was considered as the potential amount of demand.

In Iran during 2018-2019, a total of 19065, 50862, and 245056 neonates were hospitalized with condition of under 32 w or 1500 gr, between 32-34 w or 1500-2000 gr, and over 34 w or 2000 gr, which receive services of level I, II, and III, respectively. Mothers of these neonates have residence in 373 different cities.

**Facility layer**
There are 1076 medical centers in Iran. The effective criteria to select level III services were determined through interviewing experts. According to the expert's opinion, the weight of level III services was influenced by the following criteria:

- **Equipment**

  The two most essential pieces of equipment that affect neonate mortality were identified as the number of ventilator and the number of NICU bed.

- **Expert**

  The number of neonatal expert and neonatal fellowship directly affect the neonatal mortality.

- **University type**

  There are three types of medical universities in Iran with three different ranks that manage hospitals. These rankings influenced by the scientific status of the university's faculties and students. This ranking may also lead to decreasing mortality. According to the last ranking 4, 6, and 20 hospitals were categorized as type 1, 2, and 3, respectively.

- **Gravity**

  With regard to the analysis of IMAN registry databank, it was specified that some mother-to-be prefer to give birth out of their residence city. For gravity, the following equation was applied to determine the attraction of cities for childbirth.

  \[
  \text{The attraction of the city } A = \frac{\text{Number of neonates that residence out of the city } A}{\text{Total number of birth in the city } A}
  \]

These mentioned criteria are summarized in Figure 1.

- **Weight of criteria**

  In this research, an AHP method with 9-Likert scale was applied to find the weight of hospitals related criteria. Using this method, experts were asked to declare their opinion about the relative importance of criteria to each other. The final weights of the factors were extracted using the expert choice software. The final weight of the 14%, 13%, 48%, and 25% was assigned for university type, equipment, experts, and gravity, respectively.

  Three types of universities i.e., I, II, and III also considered as 30, 70, and 100 respectively. The city without medical university missed the point of university type. Cities without medical university support lost the mentioned score. Finally, the score of each facility was obtained from the cumulative sum of normalized value of each criterion multiplied by the assigned weight.


Network layer

Another critical factor is the distance from the residence to the required services. The first study of data revealed that there had been seven different kinds of roads in a vast country like Iran. For this reason, the maximum allowed speed of 92604 road records extracted from the databank and inserted to the network layer. The following equation was applied to transform the distances to the travel time.

\[
\text{Travel time between two cities} = \frac{\text{Distance between cities}}{\text{Maximum speed allowed of roads between the two cities}}
\]

Finally, different layers of the country border, province, city, hospital, and road network were integrated into the Arcmap software. The integration of different layers is schematically depicted in Figure 2. A map of Iran was downloaded from Wikimedia Commons ("https://commons.wikimediawiki.org/wiki/File:Blank_map_of_Iran.svg").

Model specification

- Model features

This model fell into the category of the nested or successively inclusive hierarchical model. In which, each level of service could provide services of lower levels. The nested feature of the problem is depicted in Figure 3. The minimizing objective was run to find the minimum required facilities to cover maximum demand in a predetermined catchment area.

- Catchment area

The catchment area refers to the distance of a city and the nearest selected facility. According to the experts’ attitudes, in the optimal solution, there should be at least one PCS at the level I, II, and III in 30, 60, and 120 min of travel time from pregnant women.

- Model preparation

The model builder toolbox was applied to develop a flexible model. The advantage of this methodology is that policymakers can change parameters easily. Moreover, the model builder is user-friendly, and also working with it does not require any specialized computational programming knowledge. Figure 4 depicts the prepared toolbox flowchart to select locations for level III PCS.

Research methodology

Herein, the required data were extracted from different databank. Data cleaning was done in the next phase to prepare layers of the demand, facility, and network. Required data of catchment area, criteria, and weight of criteria were extracted by interviewing the expert, and using the literature. The different layers of data were then integrated. Eventually, the model was solved by the Arcmap software. The sequences of research methodology are diagramed in Figure 5.
Results

After necessary layers were integrated and combined in the Arcmap software, several models were applied for the location-allocation of PCS in different conditions.

- **Solving the maximal covering model with the minimum facility in services level I, II and III**

The hierarchical maximal covering model was solved by minimizing the facility objective function to find optimal location-allocation of PCS. The results are displayed in the map represented in figures 6a and 6b, and 6c, respectively.

The results revealed that 130, 121, and 86 PCS were needed to support the demand of services level I, II, and III in 30, 60, and 120 min distance coverage, respectively.

According to the results, 96% of the demand level III would be covered in less than 120 min by 86 service centers. The number of 39 highlighted points in the map c in Figure 6 represents cities that are not allocated to services level III. These cities are located further than 120 min from services. Hence, a new model was solved in the following to cover these demands.

- **Solving the model for uncovered cities in service level III**

Herein, 39 highlighted cities with 645 level III demands were not allocated to the facilities. It is implied from the map c in Figure 6 that most of them are small border towns. A new maximal covering model was implemented to cover these demands and to find the optimum allocation of these towns to services without catchment area constraint. The results are depicted in Figure 7.

The result indicated that pregnant women that live in these 39 cities must travel 173 min on average to reach the nearest facility.

- **Solving the maximal covering model to find alternative PCS in level III**

To increase the solution flexibility, the developed model was applied to present alternative PCS in level III. The allocation of alternative centers is crucial for cities at an equal distance from two or more services. The results of applying this objective function are mapped in Figure 8.

In this solution, the alternative services were allocated to 140 cities.

Conclusions

The objective of this study was to find the optimal place for PCS to increase equity in access. For this purpose, the annual hospitalized weight and gestational age data of neonates who were born in 373 different cities of Iran were collected at first. Consequently, the data of available hospitals with essential criteria based on expert's attitudes were obtained. Then, the characteristics of the country's roads network were extracted from another databank. After the required data were integrated, the flexible model was
made as a toolbox by Arcmap software to find numbers, locations and referral network of PCS in three
different levels. The results revealed that the demand would be responded to in level I, II, and III by
implementing 130, 121, and 86 PCS, respectively. However, a total of 39 cities were located out of the
distance covered in service level III. For the complete demand coverage, the new model was run for these
uncovered cities to find the nearest PCS. Selected centers are distinguished by red stars in Figure 7. The
average transportation time for this solution was 173 min. It was suggested that PCS covering cities in
more than 120 min needed to be equipped more than other ones. Other solutions were also proposed
comprising the mobile NICU or using the helicopter. Another suggestion for policymakers was continuous
care and education of pregnant women in these 39 cities.

Since the model is implemented in a country like Iran, that is the fifth country with the highest disaster
risk, it determines the alternative allocation of PCS. In this solution, more than one PCS is allocated to
140 cities. These alternative solutions increase the flexibility of the model. Moreover, policymakers can
control patient queuing at care centers.

To validate the outcome, all proposed results were debated in the expert team. In addition, outcomes were
compared with the results obtained in 2008. The differences of the current study and previous ones,
which have also been as contributions of this research, are defined as follows:

- Using the annual weight and gestational age of neonates in national level
- Implementing the essential criteria to determine the weight of PCS
- Using travel time instead of distances
- Considering the actual journey from residence to birth cities as the gravity criterion.
- Presenting alternative PCS in level III to enhance the solution flexibility

As an advantage that has been mentioned earlier in this research, using the proposed method in the
macroeconomic policy of the country would affect reducing neonatal mortality through increasing equity
in access, and reducing huge costs of useless extra NICUs, experts, and other related equipment.
Environmental policies would also support this problem. While the data of expectant mother's
transportation between cities reveal that they should travel a long path to reach suitable centers,
optimization of transportation would help to reduce the release of Carbon dioxide and other harmful
gases that are ejected from car exhausts.

This approach can be used as a comprehensive reference in other cases of healthcare problems, such as
in finding the location of children's heart or eye centers in the country. To develop the study traffic
constraints should be added to the model. Providing a web-based dynamic model that can be changed by
online road constraints should be another issue to develop the research in the future. Finally, the cost-
revenue analysis for implementing expensive equipment like mobile NICU or helicopter has also been
proposed for future works.

Abbreviations
Declarations

Ethics approval and consent to participate

This study was based on administrative data in the public domain. No human subjects were involved.

Consent for publication

This study does not contain any individual person's data.

Availability of data and materials

The datasets used and/or analysed during the current study are available from (heydarzadeh_2013@yahoo.com) on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Conception: MMS, MH, ZMD. Collecting and assembling of data: ZMD, MH. Methodology: MMS, ZMD, MH. Analysis and interpretation of results: ZMD, MMS, MH, FMS. Administrative and technical support: MMS, MH, FMS, ZMD. All authors approved the final version of the manuscript. All authors are accountable for the manuscript's contents.

Authors' details

1Department of Industrial Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran.

2Department of Healthcare Systems Engineering, Faculty of Industrial and Systems Engineering, Tarbiat Modares University, Tehran, Iran.
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**Figures**

![Effective criteria to select level III center](image)

**Figure 1**

Facility related criteria for hospital selection on the expert's attitude
Figure 2

Preparation of different layers to build a network for the location-allocation problem. The original map was downloaded and adapted from “https://commons.wikimedia.org/wiki/File:Blank_map_of_Iran.svg”. This original map is licensed under the Creative Commons Attribution-Share Alike 4.0 International license, which allows us to share and adapt for free with proper attribution.
Figure 3

The nested hierarchical nature of the problem, in which selected facility at a lower level would be a candidate location for the higher level of PCS.

Figure 4

The localized toolbox for finding the location-allocation of PCS in ArcMap.
Figure 5

Research methodology to find the optimal solution for the PCS location-allocation in three levels of services

a. service level I  
b. service level II  
c. service level III

Figure 6
Location-allocation solution for PCS in level I, II and III.

Figure 7

The optimal allocation of 100% of demands to facilities in the service level III
Figure 8

The location-allocation model for alternative PCS in level III