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Research Article

Equitable distribution of neonatal intensive care unit: a healthcare planning case study

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Abstract

Background and objectives: The regionalization is a suitable approach to reduce the cost of health services and to increase the number of patients covered by special services. Since the establishment of the Neonatal Intensive Care Unit (NICU) needs expensive equipment and experts, it is critical to find the optimal number and location for NICU beds and referral networks.

Methods: The geographical access to NICU beds was investigated by collecting the annual demand and the distance between cities at first. The demand consisted of the number of neonates that were born under 32 weeks of gestational age or having less than 1500 gram birth weight in one province of Iran. Next, the location of the available hospital has defined on the map. A maximizing coverage model was developed to find the optimal location for NICUs by ArcMap software. Scenarios of reducing NICU centers were built to simulate real situations for policymakers. Coverage and average traveled distances were then calculated for each scenario. The results were compared with the natural journey of pregnant women and the available distribution of resources in the province.

Results: The results revealed that reducing the number of NICU centers has had no direct impact on average traveled distance. A comparison of the optimal result with the natural journey of pregnant women represented a long distance traveled. The data also showed that 64% of neonates were born outside of their residential cities, and 31% of them were born outside of their provinces, although the occupation rate of available NICU was less than 50% on average.

Conclusion: The effect of reducing NICU centers on total coverage and average transportation was studied in this paper. The proposed methodology with the objective of equity in access can be used as a referral model to other resource allocation cases in health care.

Keywords: Regional Health Care, Location-allocation Problem, Equity of Access, Neonatal Intensive Care Unit, Resource Distribution

Background and Objective

Presently, the countries are no longer evaluated by annual growth of income; instead the child mortality is the criteria in current years1. According to WHO statistics, among 130 million newborns per year in the world, about 4 million neonates died within their first 28 days of birth[1] . It has been shown in 1 that 63.2% of under-five deaths occurred within the first 11 months of birth. Therefore, an improvement of perinatal services will be an effective step in reducing mortality rates. Perinatal care consists of three levels. Level 3 provides advanced neonatal supportive cares; generally, 3-5% of newborns need which. Having NICU beds at this level of service is mandatory. Level 2, provides medium care for newborns that need indirect and less nursing cares. Level 1 is intended for serving low-risk and healthy newborns and mothers [3].

From a health perspective, social justice means equality in the distribution of access to services in a society. Some of these services are provided by special hospitals and local and urban health centers. Finding the optimal geographic location for services and determining their coverage are considered the most critical issues[4]. Relationships between

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hospitals must be importantly remarked in locating services. Environmental factors such as population density, distance from service centers, economic constraints, and social incompatibility should also be considered when constructing these centers[5].

Perinatal service regionalization was first introduced in 1976[6]. The regionalization of services is a possible approach to improving the quality of the health system[7]. The regionalization of structured systems defines the selection and transmission of the patient to predetermined centers[8]. The purpose of regionalization is to provide higher quality care services for more quantity of patients[7]. For a successful regionalization health system, four conditions must be well implemented, 1) service quality should be non-homogeneous; 2) hospitals with lower levels of service will have access to the resources available for hospitals with a high level of services; 3) the service center should be different from other centers, maybe in terms of equipment, process, and also personnel capability; 4) patients who need service regionalization should be transferable, too[8].

The number of 40 articles was thoroughly reviewed in (9), and effective solutions to improve perinatal outcomes were divided into three categories including, perinatal service regionalization in 17 items, improving the related servant equipment in 12 articles, and other service quality improvement factors in 11 articles. Neonates born outside perinatal centers might be at risk because of transmission speed and inappropriate centers. Tanou et al.[10], investigated the impact of geographical access to regional health facilities on maternal healthcare in Burkina Faso. Kong et al., reported that standardizing the newborn transmission process, skilled doctors, support and advisory center, and also professional acceptance of transferred neonates would cause infant mortality rate decreased from 5.11% to 2.82% in Beijing of China[11]. Hohlagschwandtner et al., shown that maternal transmission has been less risky than neonatal transmission as examining mothers who have been hospitalized in a Vienna educational center[12]. Herwartz et al., evaluated the efficiency of hospital regionalization through the uncertain boundary analysis in Germany[13]. According to 17 reports of NICU in Canada, regionalization has caused an increase in maternal transmission when requiring level three of perinatal care. Hence, the risk of death has been less than high-risk perinatal transmission[14]. Stwart et al., proposed that the maternal and neonatal emergency services should be integrated to improve neonatal regionalization outcomes. As well, the referral, triage, and transmission system need to be improved simultaneously[15]. In (16), the number of 24 articles were considered reviewing impacts of regionalization on the reduction of trauma services, including mortality rates. Rashidian et al. (17) reviewed 53 research papers performed on the perinatal service regionalization, stating that only 8 papers in the US, Canada, and France have studied the regionalization. These articles differed in design, type of interview, and study space, and only three papers have used the time series. As the conclusion for this research, those articles were less biased, and among which, only one article represented the significant impact of regionalization on reducing infant mortality. Harrison et al., investigated the relationship between NICU bed supply and individual odds of admission, considering maternal and newborn characteristics[18]. Kats et al. investigated regionalization in the national level as a possibility to share health resources between counties[19]. In Iran, Rashidain et al. studied the regionalization of perinatal services. They concluded that regionalization reduced traveled distance from 125 to 109 km[6]. Moreover, Marandi et al. reported

establishing and equipping NICUs as one of the critical factors that affect on reduction of maternal and neonatal mortality[20].

The optimization through a mathematical model is an appropriate methodology to solve the location-allocation model in healthcare services. The application of location-allocation models in healthcare services was reviewed in (21,22) specifically for the case of developing countries (23). The ambulance location (24), location-allocation resources to trauma centers (16), HIV centers[25], vaccine clinic[26] , organ transfer network location[27] , optimal location of blood-banks[28] , treatment service network[29], emergency systems network design[29], health facilities network design[30], hospital services with uncertain demand[31], detection of preventive centers[32], mobile healthcare units[33], location of perinatal facilities[34] , allocation of neonatal intensive care units[35] , and increase network capacity in Veterans Health Administration[36] are some examples of location-allocation models in the health systems.

In the present paper, regionalization was studied as an approach for infant death reduction. A lot of time was spent on finding the real issue, dominating it, and interviewing professionals and experts to define the problem accurately. Useful parameters were identified and modeled by a developed maximizing coverage, and the optimal solution of location-allocation was presented finally. The optimal solution was also compared with a real solution and available resource allocation in one province of Iran as a case study. To the best of author's knowledge and considering papers reviewed, the current research has had a novel approach to the perinatal care service regionalization. The main contributions of this study compared with previous research have been so that:

- using the annual weight and gestational age data of neonates as the demand of cities
- The potential demand was considered by the residential city of expectant mothers instead of birth city
- The natural journey of pregnant women in and out of the province to give birth compared with the optimal solutions
- Distances between facilities inserted as a constraint to classical maximal covering model
- The current situation (mortality rate, distribution, and occupation rate of NICU) compared with optimal distribution of NICUs
- The effect of different numbers of facilities on the average distance traveled by pregnant women and the percentage of demand coverage was investigated in various scenarios to give insight to the policy-makers.

Methods

The present study was aimed at supporting decision-makers to decide about the distribution of NICU beds in a particular province of Iran. For this purpose, the current number of existing NICU beds, occupation rates of these beds, infant mortality rate by city of residence, and the natural traveled distances by pregnant women are discussed in the expert team. To present the optimal solution, different location-allocation models investigated. Maximizing covering location-allocation model was defined in health care problems with different objective functions, including coverage, cost, distance, time, efficiency, and other factors such as accessibility[37]. One category of location-allocation is the p-median model. In this model, the optimal locations of a number p of hospitals are determined to supply N customers by the object of minimizing the sum of distances from patients to hospitals[38]. One relevant policy in the ministry of health and medical education of Iran is to improve the equity of access to health care services. According to this principle, the p-median coverage model was implemented to solve the problem. After interviewing with an expert team, new constraints were added to the

classical p-median. In this model the maximum distance from patient to the hospital, the minimum distance between selected hospitals are considered. Moreover, the effect of different values of p on the average distance traveled by patients and the percentage of demand coverage was investigated in different scenarios. The potential number of demands for each city was extracted from the annual data of IMAN databank of the ministry of health and medical education separately by birth weight and gestational age. The sets, parameters, and decision variables used in the p-median model are as follows:

Sets:

I ϵI: The set of demand points.

j,j´ϵ J : The sets of candidate locations.

Input parameters:

w_i: The demand at point iϵI.

d_{ij}: The travel distance from demand point I ϵI to candidate location jϵ J.

d_{ij}:: The travel distance between two candidate locations j,j´ϵ J.

P: The number of candidate locations to be established.

R: The minimum travel distance between two candidate locations j,j´ϵ J.

D: The maximum travel distance from demand to locations

Decision variable

$$x_{ij}\begin{cases}1 & if\ demand\ point\ i\epsilon I\ is\ assigned\ to\ a\ facility\ at\ candidate\ location\ allocates\ to\ facility\ j\\ 0 & otherwise\end{cases}$$

$$y_j, y_j\begin{cases}1 & if\ a\ facility\ is\ establisedat\ candidate\ location\ j\epsilon J\\ 0 & otherwise\end{cases}$$

Objective function

$$\text{Min}\ \sum_i \sum_j w_i d_{ij}\, x_{ij} \qquad [1]$$

- Subject to

$$\sum_j x_{ij} = 1 \qquad i\epsilon I \qquad [2]$$

$$x_{ij} - y_j \le 0 \qquad \forall i\epsilon I\ , j\epsilon J \qquad [3]$$

$$\sum_i y_j = P \qquad [4]$$

$$d_{jj}\, y_j\, y_j \ge R\, y_j\, y_j \qquad \forall\, j, j\epsilon J \qquad [5]$$

$$d_{ij} * x_{ij} \le D \qquad \forall i\epsilon I\ , j\epsilon J \qquad [6]$$

$$x_{ij} \in \{0\ ,1\}\ , \quad \forall i\epsilon I\ , j\epsilon J \qquad [7]$$

$$y_j \in \{0\ ,1\}\ , \quad \forall i\epsilon I\ , j\epsilon J \qquad [8]$$

In this model the objective function [1] minimizes the demand-weighted total travel distances. Constraint [2] shows that each demand point is assigned to only one facility. Constraint [3] limits assignments to only open facilities. Constraint [4] specifies the total number of facilities to be established. Constraint [5] puts limitation on minimum distance between selected facilities. Constraint [6] determines maximum distance from demand to the facility. Constraints [7] , [8] are integrality constraints.

The model was validated by sample data in Lingo software. But to show the location-allocation of NICU on the map, this model solved by the network analyst extension in ArcMap software for different number of P.

According to (39), desire lines refer to tracks covered across grassy spaces where walked unintentionally by people while formal pathways are ignored, and that is, “ultimate unbiased expression of natural human purpose.” This expression also can be used in other selection patterns chosen by people in the real situation. In

the health service selection, the desire line may cause the patient to go to the further hospital instead of the nearest one. To find out the total traveled distance, pregnant women's residential cities were compared to birth cities of neonates. The solution was also compared with the occupation rate of the available NICU.

On the other hand, since the NICU establishment cost is considerable, and NICU needs experts to work efficiently with equipment, it is not economical to distribute beds evenly in hospitals. To reach the objective of regionalization, scenarios of reducing the number of hospitals were built to show the effect of reducing the number of hospitals on demand coverage, and average distance traveled. The flow chart of the research methodology is diagrammed in Figure 1.

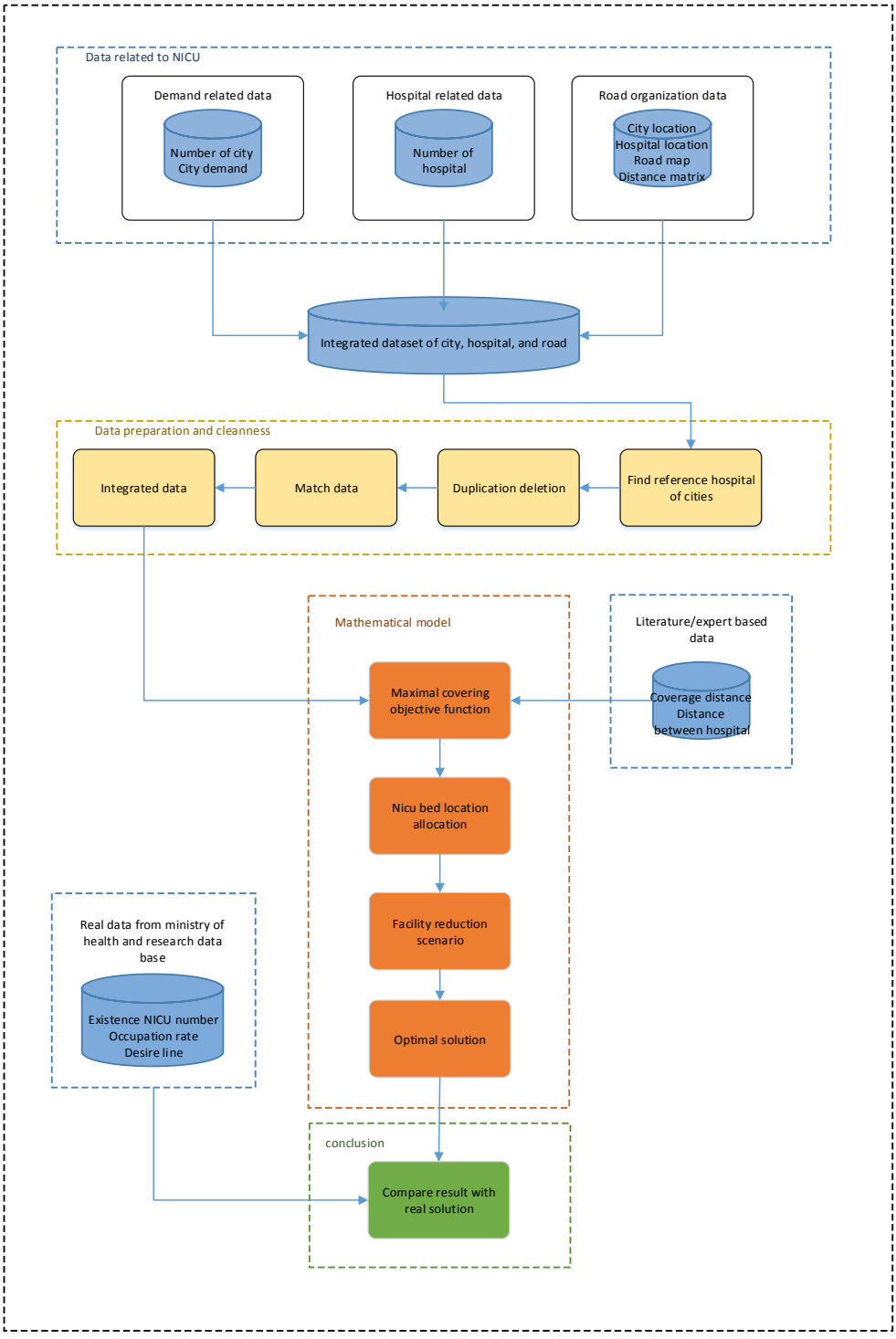

Fig1. Research methodology of the proposed model to find the optimal solution of NICU bed location-allocation

Results

Description of the selected province

Bushehr is the seventh vast province of Iran, with an area of 27653 square kilometers. By 707 kilometers maritime boundary, Bushehr is a

strategic province being along with the coastal region on the Persian Gulf, the coast of the south-western frontier of Iran. Its population is around 1,163,400. Bushehr has ten important cities, and the capital city of this province is also named Bushehr, which is mapped in Fig 2.
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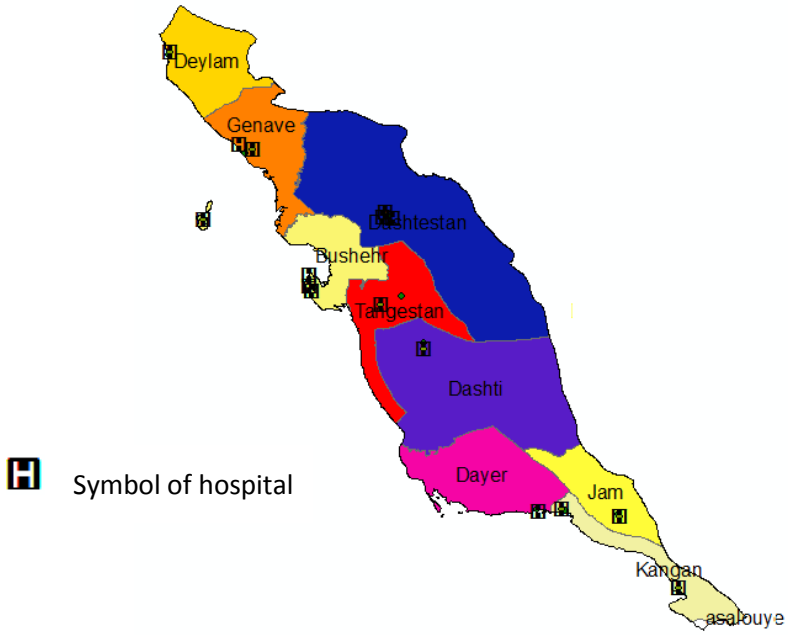
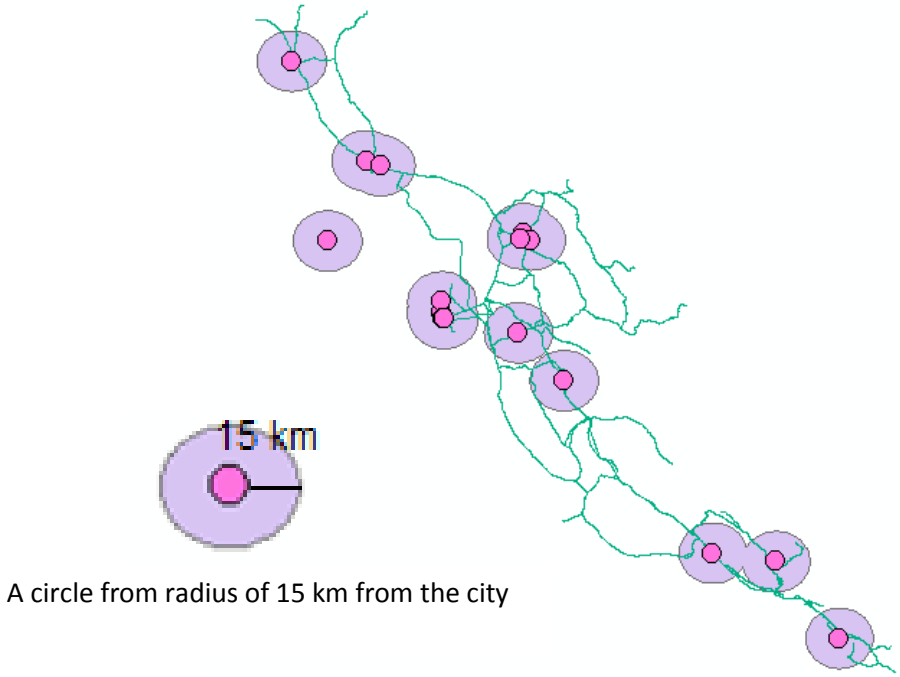


Fig 2. Bushehr province and its cities are illustrated with different color, hospitals of this province depicted with H symbol

Facility (hospital)

According to the health policy of Iran, most provinces have one university that manages governmental hospitals of that province. The University of Bushehr dominated the hospitals of this province. There are 16 hospitals in Bushehr. According to the expert's decision, the equipped hospital should be located within a distance of 15 km from each other to emit any overlap. A circle with a radius of 15 kilometers was shaped around the hospital to display overlay. As depicted in Fig. 3, there are six overlaying hospitals in the same city.



A circle from radius of 15 km from the city

Fig 3. Overlay of hospitals in Bushehr province with a coverage radius of 15 km.

Demand

The percentage of demand by the city was extracted from the IMAN databank. This yearly demand consisted of neonates, whose mothers were residence in Bushehr province. According to the literature, neonates with a weight of fewer than 1500 grams or under 32 weeks of gestational age were highly expected to need intensive care services or Level III care service. Hence, demand was reduced to neonates with mentioned features. The percentages of demand by the city are demonstrated in Table 1.

Table 1. Demand percentages by the city in Bushehr province

Name of City	Demand Percent
Bushehr	40*
Dashtestan	20
Genave	13
Dashti	11
Tangestan	8
Asalouye	3
Kangan	2
Jam	1
Dayer	1
Deylam	1

*40 percentage of neonates were born in Bushehr

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Desire line

Finding the desire line, i.e., the distance between expected mother's residence city and birth city of neonate, reveals that, 64% of neonates were not born at their residence cities. Moreover, 31% of them born outside of their residence province. Table 2 indicates the percentage of birth by residence and birth city. The colored cells represent cities of other provinces. For example, according to table 1, 21% of the neonate that is born on Dashtestan needs intensive care services. Table 2 shows that 28% of these neonates served on their residence city, 55% of them transferred to the central city of Bushehr province, and 18% of them transferred to Shiraz that is the central

city of the neighbor province and 232 km away from Dashtestan. Based on extracted data, expected mothers traveled 183 km on average in and out of the province to serve. Also, they are moving on average, 87 Km in the province.

Table 2. Percent of movement of expected mothers from residential city to other cities to give birth

residence city	birth city										Percent Mismatch
	Dashtestan	Bushehr	Behbahan	Parsian	Tangestan	Dashti	Deylam	Shiraz	Kangan	Genave	
Bushehr		57						42%	1%		43%
Dashtestan	28%	55%**						18%			73%
Genave		24%						36%		40%	60%
Dashti		73%				14%		14%			86%
Tangestan	6%	69%			6%			19%			94%
Asalouye				33%				33%	33%		100%
Kangan		67%						33%			100%
Jam									100%		100%
Dayer		100%									100%
Deylam			50%				50%				50%

** 58 percent of expectant mothers resided in Dashtestan city traveled to Bushehr city to give birth.

In the presented optimal NICU bed allocation, it was assumed that each province needed to serve their residence so that the result would be compared with total distances traveled by expectant mothers inside the province.

The desire line based on the real data of pregnant women's movements is mapped in Fig. 4. The more full arrow represented more amounts of neonates transferred from residence to birth cities.

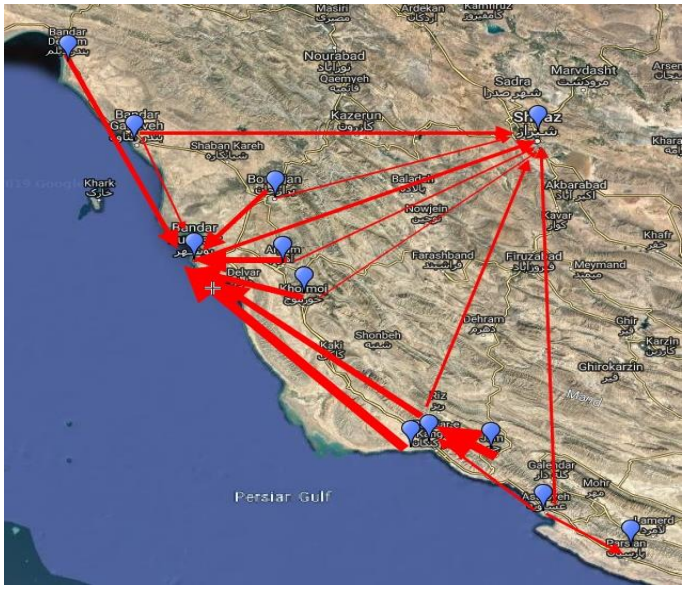


Fig4. Desire line of pregnant women in and out of the province to give birth, lighted color arrows indicate more movement.

Existing resource distribution

It is necessary to know how many beds still exist in the province and what their occupation rates are. According to the ministry of health and medical education of Iran, there are 34 NICU beds in Bushehr province with an occupation rate of 48% on average. The detailed data by cities are shown in Table 3.

Table 3. Number and occupation rate of existed NICU beds in Bushehr province

Name of City	Number of NICU bed	Occupation Rate
Bushehr	20	47
Dashtestan	6	53
Kangan	8	63

Mortality rate

According to the IMAN databank, totally, around 25% of neonates need level III of services died in one year in Bushehr province. Based on the literature, regionalization is an effective method to reduce mortality. Hence, finding an optimal location of NICU beds and managing relationships of hospitals is really critical. The death percentages of cities are separately displayed in the table 4. According to the table 4, the worst situations occurred in two cities of Dashtestan and Deylam having, unfortunately, one out of two neonates died in one year. Although, there have been 6 NICU beds in Dashtestan that are useless half the time.

Table 4. Percentage of mortality in the city

Name of the city	Mortality percent
Bushehr	26
Dashtestan	27
Genave	35
Dashti	25*
Tangestan	22
Asalouye	38
Kangan	16
Jam	26
Dayer	7
Deylam	13

*25 percent of yearly borne neonate in level III died in the city of Dashti

Optimal solution

To optimize the location-allocation NICU bed problem, the proposed maximize covering model was solved with the constraint that each demand should access at least one service (100% coverage). The study of related literature has specified that developed countries, like the USA, locate NICU in agent hospitals to cover the demand in the catchment area of 250 km. The interview with NICU policy-makers in Iran revealed that the accepted catchment area for each center should be at most 150 km. The distance between candidate hospitals was also assumed 15 km. Since NICU equipment is highly expensive and needs expert to work with the equipment, there is a trade-off between the opened center and average distance traveled within scenarios. Each scenario represented which hospital should be deactivated according to demand and distance, as well as how the weighted travel distance would change through deactivating centers. The aggregate result of the scenarios is represented in the table 5.

Table 5. Result of location-allocation of NICU beds by the different number of P

Scenario number	Number of the active hospital - p	Total weighted traveled distance	Percent coverage	Average traveled distance
1	10	0	100	0
2	9	45,913	100	22,956
3	8	104,874	100	34,958

Scenario number	Number of the active hospital - p	Total weighted traveled distance	Percent coverage	Average traveled distance
4	7	245,148	100	49,029
5	6	634,711	100	79,338
6	5	1,151,338	100	47,972
7	4	3,009,536	100	65,424
8	3	5,260,593	100	61,169
9	2	4,759,540	96	33,517
10	1	4,619,265	82	32,994

Table 5 shows that the total weighed traveled distance increases by reducing NICU centers. Moreover, all scenarios cover 100% of demand in a radius of 150 km, except scenarios number 9 and 10. In the solution number 9, Asalouye and Jam are out of access, and in scenario number 10, Genave and Deylam are out of services. In this regard, these scenarios cover 96% and 82% of demand, respectively. Because of demands loss, the total weighted traveled distance decreased after scenario number 8. The average traveled distance was calculated in the final column of the mentioned table to help policy-makers making better decisions about reducing the number of hospitals. This column represents the average traveled distance of pregnant women in cities without the NICU center, as an acceptable criterion for decision-makers. With this respect, when there are nine active NICU centers, pregnant women who resided in cities without the NICU center, traveled around 23 km on average to reach such centers. Comparing obtained solutions with these criteria revealed that in scenario number 6, expectant mothers traveled less when locating 5 NICU centers than locating 7, 6, 4 and, even 3 centers. This criterion in distinct scenarios is depicted in Fig. 5..

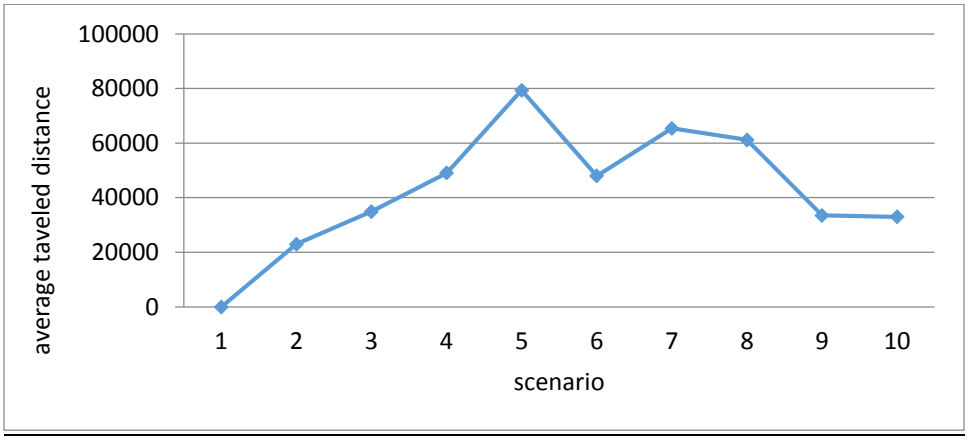
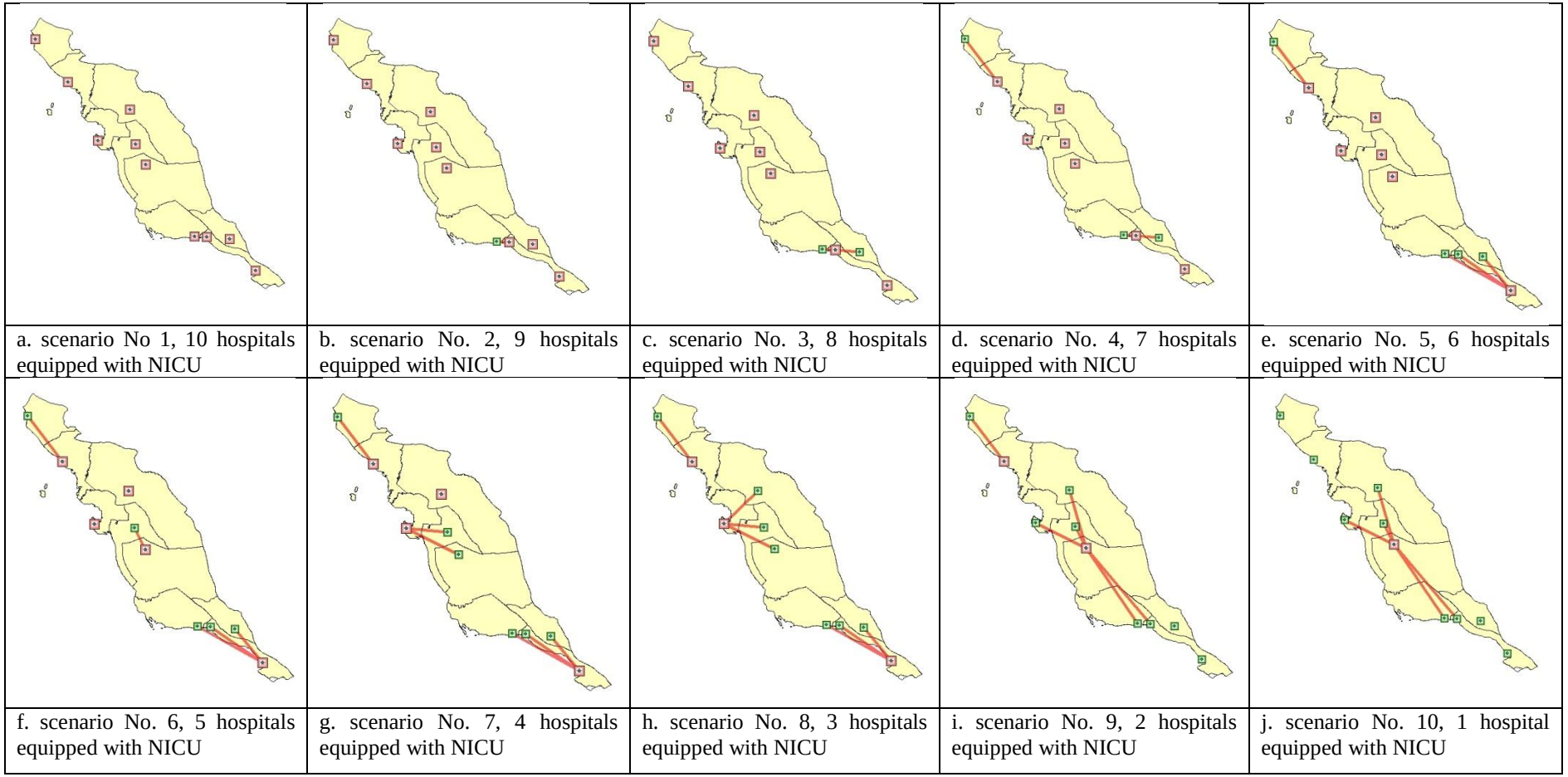


Fig 5. Average traveled distance for all scenarios separately

The chosen location for NICU establishment and allocation of NICU centers to other cities is represented in Fig. 6



a. scenario No 1, 10 hospitals equipped with NICU	b. scenario No. 2, 9 hospitals equipped with NICU	c. scenario No. 3, 8 hospitals equipped with NICU	d. scenario No. 4, 7 hospitals equipped with NICU	e. scenario No. 5, 6 hospitals equipped with NICU
f. scenario No. 6, 5 hospitals equipped with NICU	g. scenario No. 7, 4 hospitals equipped with NICU	h. scenario No. 8, 3 hospitals equipped with NICU	i. scenario No. 9, 2 hospitals equipped with NICU	j. scenario No. 10, 1 hospital equipped with NICU

Fig 6. Location-allocation of NICU centers in each scenario depicted in map a-j

Conclusion

The expenses of the establishment and maintenance of the NICU are very high. Additionally, a skilled workforce is needed to work with the equipment. NICU establishment may not be effective unless planned by the perinatal service. To provide cost-effective NICUs, it is necessary to organize their location to cover a region complying needs of not only the intended hospital but also neighboring hospitals. The goals of the NICU are to improve critical care for sick neonates and maintain their lives to reduce mortality.

These objectives can be achieved by considering the Bushehr province as a case study. Desire line was extracted from yearly data of permanent residence of pregnant women and where their neonates born. Comparing data of desire line and occupation rate of NICU beds revealed that although there are sufficient NICU beds in this province, mothers travel a long distance to give birth.

To examine all possible situations in the provision of service, ten scenarios were defined to simulate the coverage and distances by deleting NICU centers one by one. Aggregated results in Table 6 represented that when the number of NICU reduced to 2 and 1 centers, total coverage decreased to 96% and 82% for scenarios numbers 9 and 10, respectively. Hence, if policy-makers decide to omit centers according to these two scenarios, restriction of total coverage in distance of 150 km violates. In this situation, alternative solutions like mobile NICU or expanding physical service coverage by introducing helicopter transport are recommended.

Another controversial issue is pregnant women journey to out of province or out of the residence cities. The factors that affect these movements should be observed in future research. The data show there are 34 NICU beds in Bushehr province. These resources are out of use, around 50% of the time. Nevertheless, expectant mothers prefer to travel to neighboring cities or even neighboring province. According to the extracted data, 26 % of pregnant women traveled out of the province. It is essential to mention that, 8 out of 10 scenarios presented in this paper are feasible. The worst scenario is scenario number 7 with 4 active centers, in which expectant mothers travel on average 65 km to reach such centers. However, this scenario is much better than the real-world situation that expectant mothers move 183 km on average in and out of province to reach NICU centers.

Managerial insight

This research gives new insight to policy-makers about NICU implementation with the following comments:

- Scenarios of reducing NICU centers were built to simulate the effect of different number of facilities on the average distance traveled by patients and the percentage of demand coverage to support decision makers

- The optimal solution of all scenarios presented that some other factors, comprising implementation cost, expert's preference to work in small cities, the reliability of road for transportation, and other alternative solutions such as helicopter or existence of mobile NICU, should be considered by decision-makers to choose the best scenario.

- According to the geographical shape of Bushehr province, if policy-makers decide to continue with the available distribution of resources, i.e., three NICU centers, the present study has proposed the location of these centers in Genave, Bushehr, and Asalouye to support northwest, central, and southeast demands, respectively.

- After regionalization implemented, it is necessary to inform experts and pregnant women carefully. According to (40), some patients and beneficiaries think neonates need the highest level of the facility, whatever their level of disease is.

- Another critical factor that should be observed is the quality of services. For example, 27% of level III neonates died in Dashtestan, although there are 6 NICU beds in this city. Therefore, scheduling a continuous learning program for workforces and experts is a critical issue.

- We recommend strengthening of existing perinatal health program with promoting positive attitudes towards residence healthcare facilities among pregnant women.

Regionalization is an economical way to allocate precious resources equally between demands. This research tried to optimize the location of services and the allocation of resources to other cities. Execution of regionalization may be difficult, science some centers may resist losing resources. It is necessary to educate and inform decision-makers about the advantages of regionalization. Sometimes, pediatricians force expectant mothers to give birth in a particular hospital, and sometimes expectant mothers' perception causes they to move to centers with a higher level of services. In some provinces, tribal ethnic concerns also may affect this movement. The detailed scientific study of important factors that affect expectant mothers to move to another city or province is a suggestion for future works. There are also some peak times in Iran when expectant mothers prefer to give birth through cesarean. These ways of thinking may cause queue in the peak time of operation that can be added to the model as a queue restriction. This analysis can also be used in a situation where policy-makers need to decide about the location of specialized treatment centers like neonatal eye center or neonatal heart center. This method can be used in other provinces of Iran or neighboring provinces.

Competing interests

The authors declare that they have no competing interests.

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.

Abbreviation

NICU: neonatal intensive care unit; IMAN: Maternal and Neonatal record; HIV: human immunodeficiency viruses.

Acknowledgment

Not applicable.

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