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Spatial distribution of specialized cardiac care units in the state of Santa Catarina

Distribuição espacial de serviços especializados em cardiologia no estado de Santa Catarina

ABSTRACT

OBJECTIVE: To analyze the methodology used for assessing the spatial distribution of specialized cardiac care units.

METHODS: A modeling and simulation method was adopted for the practical application of cardiac care service in the state of Santa Catarina, Southern Brazil, using the p-median model. As the state is divided into 21 health care regions, a methodology which suggests an arrangement of eight intermediate cardiac care units was analyzed, comparing the results obtained using data from 1996 and 2012.

RESULTS: Results obtained using data from 2012 indicated significant changes in the state, particularly in relation to the increased population density in the coastal regions. The current study provided a satisfactory response, indicated by the homogeneity of the results regarding the location of the intermediate cardiac care units and their respective regional administrations, thereby decreasing the average distance traveled by users to health care units, located in higher population density areas. The validity of the model was corroborated through the analysis of the allocation of the median vertices proposed in 1996 and 2012.

CONCLUSIONS: The current spatial distribution of specialized cardiac care units is more homogeneous and reflects the demographic changes that have occurred in the state over the last 17 years. The comparison between the two simulations and the current configuration showed the validity of the proposed model as an aid in decision making for system expansion.

DESCRIPTORS: Health Services. Access to Health Services. Equity in Access. Spatial Distribution.

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Received: 9/19/2013

Approved: 5/7/2014

RESUMO

OBJETIVO: Analisar metodologia para distribuição espacial de serviços especializados em cardiologia.

MÉTODOS: Foi utilizado método de modelagem e simulação de aplicação prática para o serviço de atendimento cardiológico do estado de Santa Catarina, por meio do modelo de *p*-medianas. Considerando-se a divisão do estado em 21 regiões de saúde, foi analisada uma metodologia que propõe a instalação de oito centros de atendimento cardiológico intermediários, comparando-se os resultados de 1996 e 2012.

RESULTADOS: A aplicação com dados de 2012 refletiu mudanças ocorridas no estado, principalmente quanto ao adensamento populacional na região litorânea. A proposta atual apresentou uma resposta eficiente, observada pela homogeneidade dos resultados referentes à localização dos centros de atendimento cardiológico intermediários e às regiões que ficam a eles alocadas, com redução da distância média percorrida às unidades de serviço em regiões com maior densidade demográfica. A validade do modelo foi confirmada na análise da alocação dos vértices medianos propostos em 1996 e 2012.

CONCLUSÕES: A distribuição espacial de serviços especializados em cardiologia apresenta configuração mais homogênea e reflete as mudanças demográficas ocorridas no estado nos últimos 17 anos. A comparação entre as duas simulações realizadas e a configuração atual mostrou a validade do modelo como ferramenta auxiliar na tomada de decisão para a expansão do sistema.

DESCRITORES: Serviços de Saúde. Acesso aos Serviços de Saúde. Equidade no Acesso. Distribuição Espacial.

INTRODUCTION

The political principles governing Brazilian Unified Health System (*Sistema Único de Saúde*) are based on the values of equity, universality, equality, community participation, and actions concerning the healthcare materialization as a right.^a Equality in health and health care services is widely accepted as an important component of public health policies.¹⁶ Effectiveness in improving access to health care services depends on several factors, such as the proper allocation of resources to deficient areas.¹⁶ Minimizing inequalities helps to identify the necessary improvements to ensure that gaps are covered or at least diminished.¹⁶

With the aim of organizing health care services, Santa Catarina State Department of Health redesigned its Master Plan for regionalisation in 2008 in order to ensure accession to a set of health care

actions and services required to sort out people's health problems.^b

According to this plan, the regionalization process decentralizes health care actions and services and stimulates the process of agreement and negotiation among health care managers. Its improvement depends on building regional strategies that consider local realities.^b Specialized health care units play an important role in this integration process so that the patients can undergo the most appropriate treatment and have a faster recovery.

Regionalization depends on a hierarchical classification of healthcare services. Essentially, a flourishing complex network integration requires that decision-makers are close to its users. Integration means the ability to refer a patient from one health care unit to another more complex unit, so that the

^a Brasil. Constituição (1988). Constituição da República Federativa do Brasil: texto consolidado até a Emenda Constitucional nº 66 de 13 de julho de 2010. Brasília (DF): Senado Federal; 2010 [cited 2012 Jul 5]. Available from: http://www.senado.gov.br/legislacao/const/con1988/CON1988_13.07.2010/

^b Secretaria de Estado da Saúde de Santa Catarina. Plano Diretor de Regionalização PDR - 2012. Florianópolis (SC); 2012.

patient will be welcomed, treated, and subsequently referred for follow-up.

The process of decentralizing public health care services has been a source of concern for many researchers, and many problems have been associated with the location of health care units.

In Brazil, Galvão et al¹⁰ have shown many localization models with applicability in public health by analyzing the location of non-emergency units, emergency units, and hierarchically-related services. Scarpin et al^c have proposed the optimization of health care units in the state of Paraná in relation to patient travel within the state as well as service regionalization, leading to new hierarchical configurations. Moreover, Lima^d has developed a methodology to determine the spatial location of intermediate specialized health care units in a specific region, using the specialized cardiac care units in the state of Santa Catarina as a case study. To locate these units, the classic *p*-median model was adopted.^{e,f} Several other studies^{1-6,8,9,14} have adopted this model in its classic form or with some variation.

According to the Organizational Plan for High-complexity Cardiovascular Care in the state of Santa Catarina,^g cardiovascular diseases are a leading cause of death in Brazil and cause one third of all deaths in the state.

The aim of this study was to analyze the methodology used to assess the spatial distribution of specialized cardiac care units.

METHODS

Based on the methodology proposed by Lima,^d a new spatial distribution of intermediate specialized cardiac care units was established. Data from 2012 were analyzed and the results were compared with those from 1996.

Using the basic principles of Christaller's central place theory,⁷ a classification scheme was performed, in which intermediate health care units were included in the system in order to reduce demand for larger health care units, thereby ensuring better care and shorten travel distances.^d

In 1996, the state of Santa Catarina was divided into 260 municipalities with 224 hospitals (public, private, and mixed). Among these, only one public hospital offered specialized cardiac care services.^d

The goal was to locate intermediate health care units, which were designated intermediate cardiac care units (ICCU).^d

To implement these intermediate units, distributed in different parts of the state, Lima^d proposed classifying them into three levels based on the services they offer: level 1: existing hospitals, where emergency care services are provided or the patient makes first contact with the health care team; level 2: ICCU to be implemented, providing health care to the patients coming from existing hospitals (level 1) and requiring specialized exams and services; and level 3: reference centers, capable of supporting care to more complex cases, such as transplants.

This strategy suggests classifying cardiac care units to reduce the volume of patient demand and to provide adequate health care in a more timely manner.

Next, municipalities were selected that could host the ICCU; this selection was conducted under the criteria mentioned by Lima^d in order to allow comparison with the current configuration adopted in the state of Santa Catarina.

The basic criteria considered in selecting the municipalities, as required by the State Department of Health, follows:

- Population size justifying the existence of health care units: municipalities with at least 28,000 inhabitants.
- Existence of hospitals: the selected municipalities were required to have large and/or medium-sized hospitals.

Population size criteria were also considered in order to select the most populated municipalities in each region. When there was not a significant population difference, the most central municipality in the region would be selected.

Models built on geometric models using computational resources are generally used to solve economic problems. Such problems can be classified according to three aspects:¹⁴ practical – problems undertaken by consulting

^c Scarpin CT, Steiner MTA, Dias GJC. Técnicas da pesquisa operacional aplicadas na otimização do fluxo de pacientes do Sistema Único de Saúde do Estado do Paraná. In: Anais do 38º Simpósio Brasileiro de Pesquisa Operacional – SBPO; 2006; Goiânia, Brasil. p. 1066-1074.

^d Lima FS. Distribuição espacial de serviços especializados em saúde [Master's dissertation] Florianópolis (SC): Universidade Federal de Santa Catarina; 1996.

^e Lima FS, Gonçalves MB. Distribuição espacial de serviços especializados de saúde: uma aplicação prática para o serviço de Cardiologia em Santa Catarina. In: Anais do 30º Simpósio Brasileiro de Pesquisa Operacional – SBPO; 1998; Curitiba, Brasil.

^f Lima FS, Gonçalves MB. Logística de serviços públicos: uma aplicação à distribuição espacial de serviços especializados de saúde. In: Anais do XIII ANPET – Congresso de Pesquisa e Ensino em Transportes; São Carlos, SP; 1999. v.1, p.482-493.

^g Secretaria do Estado de Saúde. Plano para a Organização da Rede Estadual de Atenção em Alta Complexidade Cardiovascular em Santa Catarina. Florianópolis; 2005 [cited 2012 Jul 9]. Available from: http://portalses.saude.sc.gov.br/index.php?option=com_docman&task=cat_view&gid=301&Itemid=82

firms to determine the optimal location of industrial and commercial activities; academic – problems evaluated to develop more refined mathematical models; applying – researchers who work with real problems.

This study can be classified as an applying problem, because it contributes to regional planning and involves making decisions about the location and nature of health care units.

The *p*-median model was selected for this study, and is appropriate for cases in which each user travels from his residence to the healthcare facility, minimizing travelled distances by users. This model is suitable for countries with limited financial resources, such as Brazil,^h where it is common, patients and their families, to make large journeys to reach hospitals.

Several methods are available to solve *p*-median problems. The formula used in this study, originally proposed by Revelle & Swain in 1970, was presented by Swersey¹⁵ (1994) and is mathematically represented by an integer linear programming problem expressed as:

Minimize

$$Z = \sum_{i=1}^n \sum_{j=1}^n a_i d_{ij} x_{ij}$$

Subject to

$$\sum_{j=1}^n x_{ij} = 1 \quad i, j = 1, 2, \dots, n \quad (1)$$

$$x_{ij} \geq x_{ji} \quad i, j = 1, 2, \dots, n; i \neq j \quad (2)$$

$$\sum_{j=1}^n x_{jj} = p \quad (3)$$

$$x_{ij} = 0 \text{ or } 1 \quad i, j = 1, 2, \dots, n \quad (4)$$

where:

- a_i is the weight attributed to the node i ;
- $[d_{ij}]_n$ is a symmetrical matrix of costs (or distances);
- x_{ij} is a binary variable, $x_{ij} = 1$ with if the node i is allocated to the median j and $x_{ij} = 0$ if otherwise; $x_{jj} = 1$ if node j is a median and $x_{jj} = 0$ if otherwise;
- p is a positive integer of the facilities to be located. In this model, these facilities are median values;
- n is the number of points considered in the problem.

This formulation assumes that (1) all demand points i must be allocated to a single median j ; (2) a demand point i can only be allocated to a vertex j if this vertex has a median; (3) the total number of medians is p ; and (4) the decision variables can only assume values of 0 or 1.

The *p*-median model was used to define the municipalities proposed to host the ICCU. Therefore, a weight proportional to the total population of the municipality was associated with each network node (in this case, municipalities that can potentially host an ICCU). The attributed weight w is calculated by population $\cong w \cdot 10^2$ inhabitants.^d

The shortest distance using the road network between the selected municipalities was obtained using data from Santa Catarina Department of Infrastructure and Santa Catarina State Center for Information Technology and Automation.¹ Hence, these data were used to construct the current distance matrix.

The municipalities selected to host the ICCU (network vertices) were located within a specific district, herein referred to as regional health administrations. Therefore, the average distance traveled by users to reach the candidate municipality within each regional administration was considered (non-zero) and calculated using the expected value of the average travel distance to each health care unit. The expected distance was calculated by:¹¹

$$E[D] = c\sqrt{A_0} \quad (5)$$

where c is a constant of proportionality and A_0 is the total area of the regional administration.

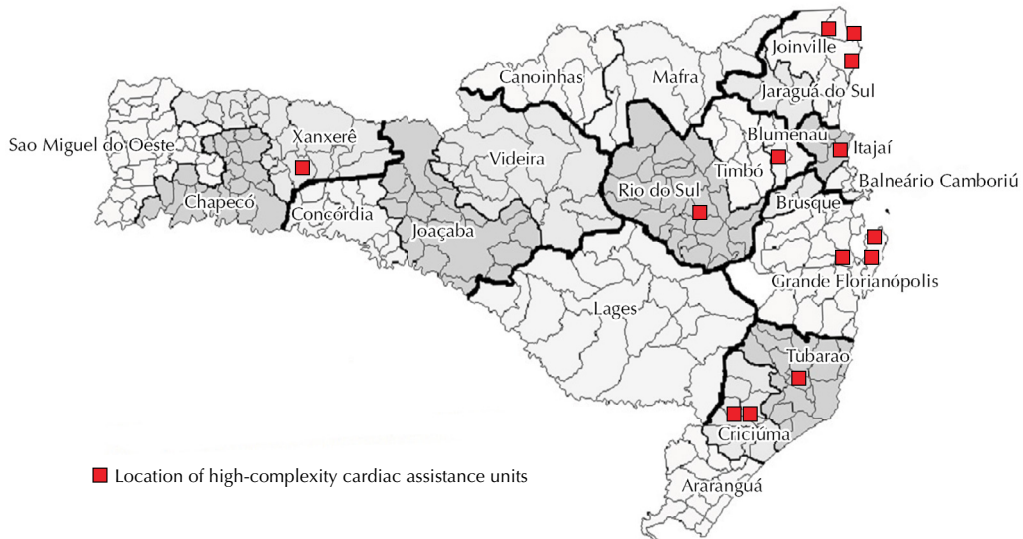
Equation (5) indicates that the expected value is proportional to the area of the regional administration. Furthermore, the value of the constant of proportionality depends on three factors:¹¹ (a) location of the health care unit in the regional administration, (b) geometry of the region, and (c) metrics used (rectangular or Euclidean).

To determine the diagonal of the distance matrix of a health care unit positioned at the center of the regional administration using Euclidean metrics, a value of $c = 0.38$ ¹¹ was suggested. In general, it was considered that the evaluated regional administration would have a compact and convex format and the municipalities potentially hosting the ICCU would be located approximately at the center of each regional administration.

Considering that actual distances were used in this study, a value of 1.3 was used as a correction

^h Souza JC. Dimensionamento, localização e escalonamento de serviços de atendimento emergencial [PhD thesis]. Florianópolis: Universidade Federal de Santa Catarina, Centro Tecnológico; 1996.

¹ Centro de Informática e Automação do Estado de Santa Catarina. Mapa interativo do Estado de Santa Catarina: tabela de distâncias. Florianópolis; 1996 [cited 2012 Jul 3]. Available from: <http://www.mapainterativo.ciasc.gov.br/tabeladistancias.php>



Source: Adapted from data collected by the Department of Health of Santa Catarina.^c

Figure 1. Map of regional health administrations and location of the cardiac care units. Santa Catarina, Southern Brazil, 2012.

coefficient.¹² Therefore, the expected value of the distance used to form the main diagonal of the matrix is obtained by

$$E[D] = (1,3)(0,38)\sqrt{A_0} \quad (6)$$

where is the total area of the regional health administration. This area was obtained using data from the Brazilian Institute of Geography and Statistics.^j

In 2012, the state of Santa Catarina comprised 293 municipalities grouped into 21 regional health administrations and nine geographical macro-regions, according to State Department of Health.^b The darker lines in Figure 1 indicate the borders of the nine macro-regions and different shades of gray indicate the regional health administrations. A macro-region comprises one or more regional health administrations, organized and structured to accommodate a part of the medium- and high-complexity health care units.^b These macro-regions should resolve, within their capacity, the problems referred by the regional health administrations, which are the territorial base for planning health care services.^b The state of Santa Catarina has a reference center for high-complexity cardiac care located in Greater Florianópolis and other reference

units distributed in other regions.^k These units correspond to the ICCU proposed in this study.

RESULTS

To resolve the problem of establishing ICCU using the current data (collected in 2012), we divided the state into 21 regional health administrations as shown in Figure 1, showing the existing high-complexity cardiac care units distributed in eight municipalities throughout the state. To represent these administrations, 21 municipalities were selected according to the previously described criteria. The municipalities selected, the code assigned to each municipality, and the associated weight are shown in Table 1. The eight municipalities with a structure adequate for providing high-complexity cardiac care were among the municipalities selected by the model based on the current configuration.

Figure 1 shows a wide area of the state with a low number of specialized cardiac care units: Midwest, High Plateau, and part of the Northern Plateau. This lack of specialized care could be one of the factors influencing user behavior, often driving the population to migrate to coastal areas, with better health infrastructure. According to State Department of Health, the highest population density was found along the coast, where 60.0% of the state

^j Instituto Brasileiro de Geografia e Estatística. Unidades da Federação: Santa Catarina. Rio de Janeiro; 2012 [cited 2012 Jun 26]. Available from: <http://www.ibge.gov.br/estadosat/perfil.php?sigla=sc>

^k Secretaria de Estado da Saúde de Santa Catarina. Plano para a Organização da Rede Estadual de Atenção em Alta Complexidade Cardiovascular em Santa Catarina. Florianópolis; 2005 [cited 2012 Jul 9]. Available from: http://portalses.saude.sc.gov.br/index.php?option=com_docman&task=cat_view&gid=301&Itemid=82

Table 1. Municipalities that can host intermediate cardiac care units. Santa Catarina, Southern Brazil, 2012.

Municipality	Code	Weight
Sao Miguel do Oeste	01	2,251.07
Chapecó	02	2,948.91
Xanxerê	03	1,826.35
Concórdia	04	1,186.38
Campos Novos	05	1,668.77
Caçador	06	2,657.12
Lages	07	2,913.72
Blumenau	08	3,706.90
Rio do Sul	09	2,567.50
Indaial	10	1,314.99
Itajaí	11	2,712.99
Balneário Camboriú	12	2,075.13
Sao Bento do Sul	13	2,220.95
Canoinhas	14	1,264.00
Joinville	15	5,996.31
Jaraguá do Sul	16	1,993.10
Brusque	17	1,151.84
Florianópolis	18	9,405.18
Tubarao	19	3,199.22
Criciúma	20	3,720.91
Araranguá	21	1,685.41

population was concentrated.¹ Some regions, including the Midwest, lack specialized care units, often due to lower population densities. However, these regions have medium-size cities and their population density would justify installation of cardiac care units.

The *p*-medians values were determined to locate these care units, so as to minimize the weighted sum of the distances traveled by users. The problem was solved using integer linear programming and the specific solution was reached by implementing the algorithm in C language.

The location of the eight ICCU proposed by Lima^d and the determination of their location using data from 2012 are presented in Table 2. Figure 2 shows the regional administrations that would be served by each unit located (indicated with different shades of gray); Figure 3 shows the solution obtained by Lima^d in 1996 (different hatched areas represent the regional administrations served by each unit). To address this issue using data from 2012 (Figure 2), the macro-region, involving the Far West Region and part of the Midwest Region, established a center in Chapecó that was responsible for regional health care, which did not occur in 1996 when the macro-region of the Far West installed two cardiac

care units (in Sao Miguel do Oeste and Chapecó), as shown in Figure 3.

In the current proposal, the Lages macro-region established a cardiac care unit to assist local users, which did not occur in the 1996 allocation when this macro-region referred users to another unit located in Curitibaanos, which also served the Joaçaba region.

In the new proposal (Figure 2), the Brusque region, which was a part of the Florianópolis macro-region, would be served by the unit located in Balneário Camboriú, and only the Florianópolis region would be served by the unit located in the state capital.

The North plateau macro-region, which previously was served almost entirely by the unit located in Canoinhas, was divided into two administrations: the Mafra regional health administration would be served by the unit located in Joinville and the Canoinhas' regional health administration would be served by the unit located in Caçador. The Vale do Itajaí macro-region, which in 1996 was meant to be served by the unit in Blumenau (which would serve two regions), would be served by the unit located in Indaial and would not be part of the Foz do Itajaí macro-region.

Another improvement was the fact that the Lages region was selected to host a health care unit, decreasing the average distance traveled by users for this service from 77.4 km in the 1996 model to 62.7 km in the current model – a decrease of approximately 19.0%. Placing a unit in Lages would reflect the present situation, considering the population increase of more than 10.0% in this municipality over the past 17 years. The Southern macro-region was the only one that maintained the same configuration for installing a unit responsible for the regions of Araranguá, Criciúma, and Tubarão.

The total average distance traveled to health care units in the current scenario was 51 km, slightly greater than the distance presented by Lima^d (48.1 km). However, this distance was shorter in most regional health administrations, except in those served by the units in Caçador, Chapecó, and Joinville. The increase in the average distance traveled by users in the regions of Caçador and Chapecó was due to the decreased number of units (from three to two) assigned to the far West and Midwest regions.

In the present scenario, the regional health administration to be served by Joinville would be supported by another administration located in Sao Bento do Sul, which was not a part of the 1996 scenario. The inclusion of this regional health administration led to a small increase in the average distance. The mean distance traveled by users in the state coast significantly

¹ Secretaria de Estado da Saúde de Santa Catarina. Plano Estadual de Saúde 2012-2015. Versão Preliminar. Florianópolis; 2011 [cited 2014 Mar 24]. Available from: http://www.saude.sc.gov.br/materiais/PES_2012_CES.pdf

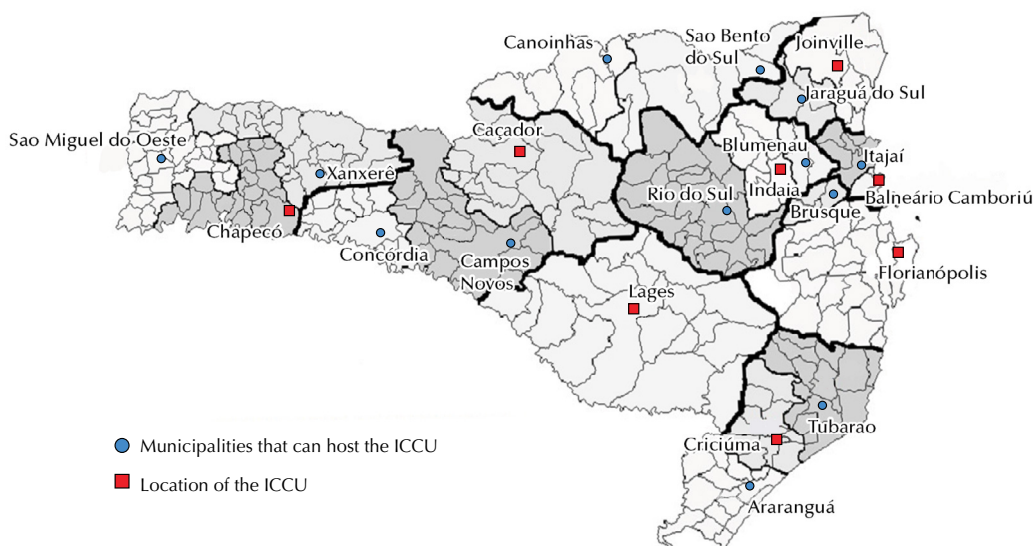
Table 2. Location of the eight intermediate cardiac care units and the current fixed structure. Santa Catarina, Southern Brazil, in 1996 and 2012.

1996		2012	
Median	Allocated vertex	Median	Allocated vertex
Sao Miguel do Oeste	Sao Miguel do Oeste	Chapecó	Sao Miguel do Oeste
Chapecó	Chapecó		Chapecó
	Xanxerê		Xanxerê
	Concórdia		Concórdia
Curitibanos	Curitibanos	Caçador	Caçador
	Joaçaba		Campos Novos
	Lages		Canoinhas
Blumenau	Blumenau	Lages	Lages
	Rio do Sul	Indaial	Indaial
	Itajaí		Blumenau
Criciúma	Tubarao		Rio do Sul
	Criciúma	Criciúma	Tubarao
	Araranguá		Criciúma
Canoinhas	Canoinhas		Araranguá
	Maíra	Joinville	Sao Bento do Sul
Joinville	Joinville		Joinville
	Jaraguá do Sul		Jaraguá do Sul
Florianópolis	Florianópolis	Florianópolis	Florianópolis
		Balneário Camboriú	Balneário Camboriú
			Brusque
			Itajaí
Current fixed structure			
Median	Allocated vertex	Median	Allocated vertex
Xanxerê	Xanxerê	Itajaí	Itajaí
	Sao Miguel do Oeste		Balneário Camboriú
	Chapecó	Florianópolis	Florianópolis
	Concórdia	Tubarao	Tubarao
	Campos Novos	Joinville	Joinville
	Caçador		Sao Bento do Sul
Rio do Sul	Rio do Sul		Canoinhas
	Lages		Jaraguá do Sul
Blumenau	Blumenau	Criciúma	Criciúma
	Indaial		Araranguá
	Brusque		

decreased because of the installation of another unit in Balneário Camboriú. The inclusion of a unit in this region was the product of an increased population density that occurred in recent years.

Considering that the number of cities with adequate cardiac care structure in the state was equal to the number of medians located in the model proposed in this study based on the data obtained in 1996, the allocation was performed on the basis of the current fixed structure of these units.

When considering the current structure, the average distance traveled by users was 50.4 km, which was similar to that obtained in the model used; however, the disparity in the average distance traveled in each region was larger. The average distance traveled in the regions served by units located in municipalities closer to the coast, such as Itajaí, Blumenau, Tubarão, and Criciúma ranged between 13 km and 32 km. In contrast, the patients served by the unit in Xanxerê, in the far West of the state, required to travel an average distance of over 100 km. The lack of a



ICCU: Intermediate cardiac care unit

Figure 2. Location of the eight intermediate cardiac care units. Santa Catarina, Southern Brazil, 2012.

specialized cardiac care unit in Lages, a municipality with more than 150,000 inhabitants, is noteworthy; the average distance traveled in this region was greater than 120 km considering the current structure.

Figure 2 (scenario with current data) shows the improved spatial distribution of specialized cardiac units in the state.

DISCUSSION

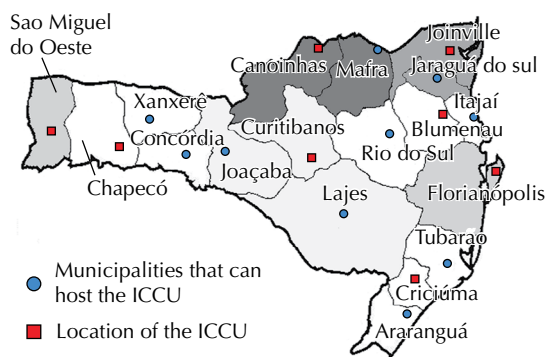
The solution obtained using the current data indicated an increased homogeneity in the location of the ICCU and their respective regional health administrations. It was observed that the Western region was assigned to the ICCU of Chapecó, further justifying the location of the cardiac care unit that has been established in this region.

Furthermore, the increased number of divisions in the state resulted in an improved spatial distribution of intermediate cardiac care units, even while maintaining the same number of units. In some regions, such as Sao Miguel do Oeste, Lages, Joinville, Florianópolis, Criciúma, and Araranguá, the weight assigned to each region was greater than that assigned in 1996 (Table 1). This increased weight is due to the population growth in these regions, which interferes with the spatial distribution of the cardiac care units. The number of intermediate care units

depends on their design; more specialized centers have a greater geographical reach.

The proposed hierarchical model, with more evenly distributed intermediate units, allows most patients to travel shorter distances to receive necessary health care services. This avoids patient isolation in distant municipalities, provides better conditions for family members to accompany patients, and improves the quality of health care services.

With the goal of decentralizing specialized public health care services, the methodology proposed by



Source: Lima^d (1996).
ICCU: Intermediate cardiac care unit

Figure 3. Location of the eight intermediate cardiac care units. Santa Catarina, Southern Brazil, 1996.

Lima⁴ can be considered long-lasting and multidisciplinary and reflects the changes that have occurred in the state, when considering the population increase in recent years, particularly in the coastal regions. A more homogeneous distribution of units can result in a more efficient and effective decision-making.

Pizzolato et al¹³ presented a series of pioneering studies nationwide that used the p -median model and its variants, confirmed the model adopted, and provided reasons for understanding detailed studies on this topic.

The weight of the input data directly affects result analysis. For future studies, we propose the use of an index that reflects the requirement for the type of specialized health care service offered in each region. Therefore,

other attributes can be assessed, including the level of stress in large cities, which increases the likelihood of developing heart complications, which may in turn be an indicator for the types of health care services offered.

The findings of this study can help assist management agencies in making decisions about the best location to install specialized cardiac care units, considering the criteria related to hospital infrastructure and distances traveled by users.

ACKNOWLEDGMENTS

To Dr. Marcia M. Altimari Samed for the critical review and suggestions during the manuscript preparation and to MSc. Louis A. Gonçalves for preparing the optimization code.

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