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Use of artificial neural networks in applying methodology for allocating health resources

ABSTRACT

OBJECTIVE: To describe the construction of a factor of allocation of financial resources, based on the population's health needs.

METHODS: Quantitative study with data collected from public databases referring to the state of Pernambuco, Northeastern Brazil, between 2000 and 2010. Variables which reflected epidemiological, demographic, socio-economic and educational processes were selected in order to create a factor of allocation which highlighted the health needs of the population. The data sources were: SUS (Brazilian Unified Health System) Department of Computer Science, Atlas of Human Development in Brazil, IBGE (Brazilian Institute of Geography and Statistics), Information System on Public Health Budgets, National Treasury and data from the Pernambuco Health Secretariat between 2000 and 2010. Pearson's coefficient was used to assess linear correlation and the factor of allocation was calculated using analysis by artificial neural networks. The quartiles of the municipalities were defined according to their health needs.

RESULTS: The distribution shown here highlights that all the coastal region, a good part of the *Mata Norte* and *Mata Sul* regions and the *Agreste Setentrional* and *Agreste Central* regions are in Quartile 1, that which has the largest number of municipalities. The *Agreste Meridional* region had municipalities in all of the quartiles. In the Pajeú/Moxotó region, many of the municipalities were in Quartile 1. Similar distribution was verified in the *Sertão Central* region. In the Araripe region, the majority of the municipalities were in Quartiles 3 or 4 and the São Francisco region was divided between Quartiles 1, 2 and 3.

CONCLUSIONS: The Factor of Allocation grouped together municipalities of Pernambuco according to variables related to public health needs and separated those with extreme needs, requiring greater financial support, from those with lesser needs.

DESCRIPTORS: Health Care Rationing, economics. Equity in the Resource Allocation. Decision Making, Organizational. Neural Networks (Computer).

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INTRODUCTION

When looking at current health care policies in Brazil, it is impossible to ignore the 1988 Federal Constitution,[a] which recognized health as a basic human right and the duty of the State. The aim of the legislators was to guarantee the equal and universal right to health by links with economics and not merely with the social area.

To make what is stated in the Constitution a reality, in this particular, it was necessary to involve what had already been structured, such as establishing a health care framework which embraced all Brazilians and operated according to principles of equality.[11]

Equality is a principle which governs distributive functions aiming to compensate or overcomes existing inequalities, considered to be socially unfair and avoidable.[13,b] Equality in health is sustained in the right to health care, which is related with a specific concept of health, i.e., equality in health care is a process which changes its focus and scope in accordance with the results achieved.[c]

Including principles of equality when formulating health care policies is not automatically accompanied by the implementation of policies which result in higher levels of equality in the health care services provided.[1]

It is not just about passing laws, but about putting into practice the rights of the society, won by the 1988 Constitution. The State's obligation, if it does not withdraw from its commitment to society, needs to be carried out, seeking constitutional ideals consistent with its ability to execute them. Implementing public policies in favor of the citizens depends on financial support from federal bodies and on the efficient distribution of these resources.[1]

Allocating federal resources for health care to Brazilian municipalities obeys two criteria, according to the type of care in question. In primary health care, this distribution is according to quantitative population; and, for medium and high complexity medical procedures, resources are passed on according to the services performed. This scenario tends to favor more developed localities and contributes to intensifying inequalities in allocation of and access to health care resources among different regions of the country.[11,d,e, f]

A study by the *João Pinheiro* Foundation showed significant inequalities in the distribution of federal resources earmarked for health care between regions and municipalities.[f] There are social inequalities in access to health care services, in favor of the better-off segments of the population. This inequality is even more in evidence when curative health care is looked at.[6]

Socio-economic and epidemiological differences between municipalities should be taken into consideration when allocating financial resources to health care. Using methodologies which take into account criteria of equality and respect local, municipal and regional peculiarities is of fundamental importance for sustainability and in order to guarantee the rights advocated by the SUS (Brazilian Unified Health System).

Studies have been carried out on allocating resources based on the Brazilian population's health needs. Bearing in mind the lack of such studies specific to the state of Pernambuco, the Research Group on the Political Economy of Health from *Universidade Federal de Pernambuco* created a methodology for allocating financial resources to health care, using analysis by the statistical model of Artificial Neural Networks (ANN) to create a factor of allocation (FA).[g]

The ANN is made up of a layer of input neurons, an output layer and one or more intermediate or hidden layers. This network of connections transmits information in one direction between the neurons.[5,12]

The ANN is flexible as to the specifications of the system, meaning it has a wide variety of uses, including for classification. It is notable for its ability to evaluate itself.[2] The ANN has the ability to correct imprecise data, which makes it efficient in tasks for which it is not easy to formulate a set of rules, such as the proposal of calculating a FA.[h]

[a] Brasil. Constituição (1988). Constituição da República Federativa do Brasil. Brasília (DF): Senado Federal; 1988.
[b] Porto SM, Vianna SM, Ugá MA, Vianna CM, Martins M, Lucchesi PTR, et al. Metodologia de alocação de recursos financeiros federais do SUS: relatório final de projeto REFORSUS. Rio de Janeiro: ENSP/FIOCRUZ; 2001.
[c] Escorel S. Os dilemas da equidade em saúde: aspectos conceituais. Brasília (DF): Organização Pan-Americana da Saúde; 2001. p.7-12. [cited 2009 Oct 15]. Available from: http://biblioteca.planejamento.gov.br/biblioteca-tematica-1/textos/saude-epidemias-xcampanhas-dados-descobertas/texto-83-2013-os-dilemas-da-equidade-em-saude-aspectos-conceituais.pdf
[d] Secretaria de Estado da Saúde de Minas Gerais. Metodologia de alocação equitativa de recursos: uma proposta para Minas Gerais. Belo Horizonte; 2004.
[d] Secretaria de Estado da Saúde de Minas Gerais. Metodologia de alocação equitativa de recursos: uma proposta para Minas Gerais. Belo Horizonte; 2004.
[e] Nunes SA. A alocação equitativa inter-regional de recursos públicos federais do SUS: a receita própria do município como variável moderadora. Brasília (DF): Ministério da Saúde; 2004.
[f] Fundação João Pinheiro, Centro de Estudos Econômicos e Sociais. Gasto federal com assistência à saúde em Minas Gerais: um estudo sobre a desigualdade na distribuição dos recursos financeiros. Belo Horizonte; 1997.
[g] Rosas MA. Estudo sobre metodologias de alocação de recursos financeiros da saúde. Pernambuco-Brasil [dissertação]. Universidade Federal de Pernambuco; 2011. 109p.

This article aimed to describe the construction of the factor of allocation FA of financial resources based on the population's health needs.

METHODS

This study is part of the research project entitled "Equitable allocation of financial resources for health in Pernambuco: a methodological proposal", carried out between 2009 and 2011.[i] The proposal was based on the needs of the population, through constructing a FA for the municipalities of the state of Pernambuco.

Municipalities of the state of Pernambuco which provided the information necessary to create the analysis database were included. Indicators which reflected the population's health needs were chosen to construct the FA. Eighteen variables encompassing demographic, epidemiological, socio-economic and educational issues were selected, these being: infant mortality, mortality under five years of age, early mortality of the elderly, proportional mortality from external causes, mortality due to cardiovascular diseases, mortality due to infectious and parasitic diseases, mortality due to cancer, the percentage of deaths due to unknown causes, proportion of teenage mothers, the proportion of inadequate prenatal care, fertility rate, Gini index, proportion of elderly in the population, literacy rate, financing capacity *per capita*, percentage of people with income *per capita* below ½ minimum wage, percentage of urban households with basic sanitation and proportion of urban households served by garbage collection.

The variables were collected in databases in the public domain: The SUS Department of Computer Science, Human Development Atlas in Brazil, IBGE, Information System on Public Health Budgets and National Treasury, with the exception of the variable of early mortality of the elderly, where the data for the years 2000-2010 the most recent available, were provided by the Pernambuco Health Department.

It was necessary to standardize the configuration of each response based on the variables selected. The data obtained from the municipalities studied were organized by locality using Excel 2007 software. Preliminary analysis of the variables and their description was carried out to obtain a preliminary understanding of the municipalities' situations.

The degrees of correlation between the variables were analyzed using Pearson's linear correlation analysis.

When the preliminary analysis had been carried out on the selected variables, the FA proposed by the was constructed in the following stages:

1) Standardizing the variables: due to the different magnitudes between the variables, all were standardized to have a mean of 0 and a variance of 1.

2) Two fictitious municipalities were created, based on minimum and maximum values from the sample: one "very bad" municipality, which had all the "worst" values for each variable, and one "excellent" municipality, with the "best" values for each variable.

3) After the creation of these two fictitious municipalities, a random sample of 200 municipalities between the "excellent" and the "very bad" was obtained, added to the values of the variable of the two fictitious municipalities, this produced uniform, continuous noise, varying between 0 and 0.01.

4) Half of the sample obtained in the previous stage was randomly selected to tune the ANN; the other half was used in the cross validation of the model. The sample of municipalities studied was used in the network testing stage.

5) The Intelligent Problem solver technique of the neural network packet of the Statistica software version 7.0 (StatSoft, Inc.) was used to obtain the best ANN model which classified the municipalities into two groups, "bad" and "good", considering the type of network (Multilayer Perceptron – MLP, Linear – LN and Radial Basis Function – RBF) and the number of hidden layers. The program provided the five best networks based on validation and test errors. The best network was that which had the lowest validation error.

6) The level of confidence of the classification of a certain municipality in one of the two groups was used as the FA.

This procedure generated the FA for the RGPEH's Artificial Neural Network. Working with secondary data may lead to errors due to not controlling the recording of the variables in question. Moreover, the problem of the year stands out as, for the set of indicators selected in this study it was not possible to find data referring to the same annual period. Thus, it was decided to work with the most recently available data. Public databases which had been used in other methodologies with the same objective as this study were considered.

[h] Brumatti M. Redes neurais artificiais. Vitória; 2010 [cited 2011 May 19]. Available from: http://www.google.com.br/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&cad=rja&ved=0CEAQFjAC&url=http%3A%2F%2Fpbf-traffic-simulator.googlecode.com%2Fsvn%2Ftrunk%2Fsvn%2520checkout%2520pbf-traffic-simulator%2FDocumentos%2FRedes%2520Neurais%2520Artificiais%2Fapostilas%2FREDES%2520NEURAIS%2-520ARTIFICIAIS.pdf&ei=Ow8uUZGkCI3Q9AS074HQCQ&usg=AFQjCNFmxVHcRq9KbpKXCuzCtgWMzZtH6g&bvm=bv.42965579,d.eWU

[i] Pesquisa realizada no período de 2009-2011 pelo Grupo de Pesquisa em Economia Política da Saúde, Universidade Federal de Pernambuco, Recife, PE, Brasil.

Table 1. Analysis of the performance of the five best Artificial Neuron Networks for the different sets of variables.

Profile	Training performance	Validity performance	Test performance	Training error	Validation error	Test error
Linear 16:16-1:1	1.000	0.990	0.426	0.00103	0.00123	0.500
Linear 17:17-1:1	1.000	0.990	0.426	0.00102	0.00118	0.500
RBFa 18:18-6-1:1	0.990	1.000	0.426	0.000727	0.000743	0.521
RBF 18:18-12-1:1	1.000	0.990	0.426	0.000426	0.000502	0.518
MLPb 9:9-10-1:1	0.990	1.000	0.426	0.000000	0.000000	9.250

[a] RBF: radial basis function
[b] MLP: multilayer perceptron

The *Statistica* 7 (StatSoft, Inc.) program was used.

RESULTS

Using the Intelligent Problem Solver technique, the radial basis function was the type of ANN which performed best.

The results for the five best networks indicated by the Intelligent Problem Solver sechnique, and in agreement with the FA, included the profile (number of inputs, hidden and output layers) and levels of accuracy and error in the training, validation and test stages for each network (Table 1).

The variables translated into a network with 18 inputs, 12 hidden neurons, one hidden layer and one output. Table 2 shows the medians and minimum and maximum values for each variable, as well as the municipalities which presented these values.

Table 2. Descriptive statistics for the epidemiological and socio-economic variables of the municipalities in Pernambuco, Northeastern Brazil, 2011.

Variable	Mean	Minimum value	Municipality	Maximum value	Municipality
Infant mortality rate	19.3	3.6 (m_o)[a]	Passira	50.8	Tuparetama
Mortality up to five years	65.4	23.8 (m_o)[a]	Paulista	120.8	Manari
Mortality from external causes	14.3	2.9 (m_o)[a]	Camutanga	36.8	Santa Maria da Boa Vista
Mortality from diseases of the circulatory system	34.4	13.0 (m_o)[a]	Primavera	51.4	Calumbi
Mortality due to infectious and parasitic diseases	5.3	0.0 (m_o)[a]	Moreilândia	16.9	Primavera
Proportional mortality due to cancer	12.6	4.6 (m_o)[a]	Águas Belas/ Mirandiba	27.0	Terra Nova
Total fertility rate	3.1	1.8 (m_o)[a]	Recife	5.1	Santa Filomena
Gini Index	0.4	0.3 (m_o)[a]	Ingazeira e Salgadinho	0.49	Recife
Illiteracy rate	64.0	43.0	Manari	91.6 (m_o)[a]	Paulista
Proportion of teenage mothers	8.5	0.5 (m_o)[a]	Cumaru	19.3	Catende
Proportion of elderly in residential population (= 60)	0.1	0.1 (m_o)[a]	Ipojuca	0.2	Frei Miguelinho
ICMS[b] per capita	107.3	23.2	Caetés	2376.6 (m_o)[a]	Ipojuca
Percentage of deaths from unknown causes	9.6	0.3 (m_o)[a]	Ribeirão	59.2	Paranatama
Financing capacity per capita	46.4	11.7	Jaqueira	780.4 (m_o)[a]	Ipojuca
Percentage of people with income per capita below R$ 75.50	66.3	21.3 (m_o)[a]	Toritama	90.0	Manari
Percentage of households with sanitation	47.6	0.0	Carnaubeira da Penha	47.8 (m_o)[a]	Itapissuma
Percentage of households with garbage collection	77.9	17.7	Manari	99.4 (m_o)[a]	Petrolândia
Percentage of live births with inadequate prenatal care	66.6	29.0 (m_o)[a]	Nazaré da Mata	96.6	Santa Cruz da Baixa Verde
Early mortality of elderly	1653.3	247.5 (m_o)[a]	Itacuruba	3973.0	Xexéu

[a] m_o: excellent municipality
[b] ICMS: tax on movement of goods and services

Table 3. Efficiency ranking of the input variables for classifying the municipalities studied through the radial basis function neural network. Pernambuco, Northeastern Brazil, 2011.

Variables	*Ranking*
Infant mortality rate	17
Mortality up to five years	14
Mortality from external causes	10
Mortality from diseases of the circulatory system	7
Mortality due to infectious and parasitic diseases	12
Proportional mortality due to cancer	8
Total fertility rate	11
Gini Index	9
Illiteracy rate	4
Proportion of teenage mothers	6
Proportion of elderly in residential population (= 60)	15
Percentage of deaths from unknown causes	18
Financing capacity per capita	1
Percentage of people with income per capita below R $ 75.50	2
Percentage of households with sanitation	3
Percentage of households with garbage collection	16
Percentage of live births with inadequate prenatal care	5
Early mortality of elderly	13

In Table 3, the influence of each variable in determining the quartile in which each municipality was placed according to the ANN method is shown.

Statistical analysis allowed the municipalities to be divided into quartiles which represent:

Quartile 1 – Municipalities with fewer health care needs, composed of 97 localities which presented the best results for the variables which represented the economic status of the municipality and its sanitary and health care conditions.

Quartile 2 – Municipalities with medium health care needs, composed of 40 localities.

Quartile 3 – Municipalities with considerable health care needs, composed of 27 localities.

Quartile 4 – Municipalities with major health care needs, made up of 17 localities which presented the worst results for the variables which represented the economic status of the municipality and its sanitary and health care conditions.

The figure represents the geographical distribution of the 184 municipalities of Pernambuco, according to the quartiles indicated by the FA. It is notable that all of the coastal region, a good part of the *Mata Norte* and *Mata Sul* regions and the *Agreste Setentrional* and *Agreste Central* regions are located in Quartile 1. The *Agreste Meridional* region has municipalities in all of the quartiles. In the *Pajeú/Moxotó* region, a large part of the municipalities are in Quartile 1. A similar distribution can be observed in the *Sertão Central* region. In the *Araripe* region, the majority of the municipalities were in Quartiles 3 and 4 and in the São Francisco region they were divided between Quartile 1, 2 and 3.

DISCUSSION

The difficulty in defining and putting into practice a simple criterion for allocating resources which reflects health care priorities and policies and reduces inequalities emphasizes the need to discuss and analyze more

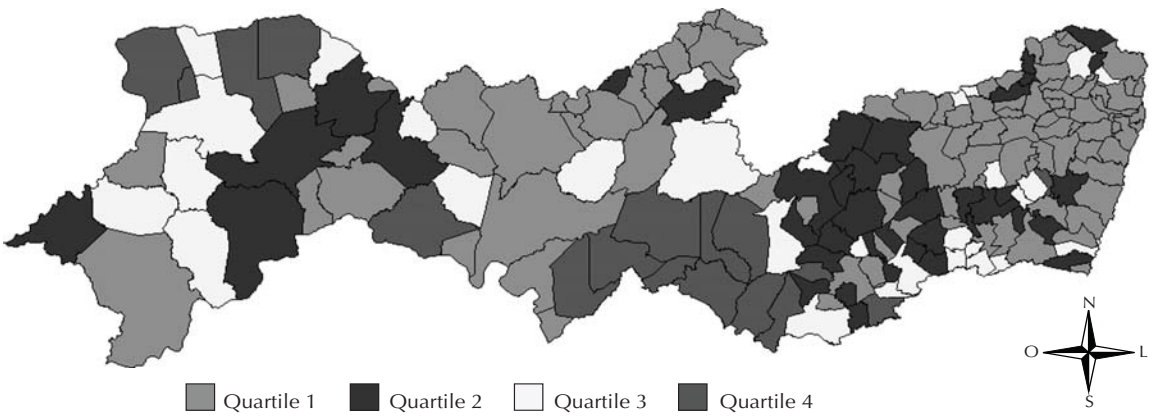

Figure. Distribution of the municipalities studied according to the Factor of Allocation by Artificial Neural Networks. Pernambuco, Northeastern Brazil, 2011.

deeply the allocation of financial resources.[c,j] When thinking about formulas for allocating financial resources for health care, the factor of health care needs should be added to geographical criteria.[7] However, it is in the choice of variables that the main difficulty in creating a FA resides. Putting a specific population's health needs into perspective is a challenge and a limiting factor in approached to allocate financial resources equally, as the true extent and complexity of the topic might not be reached.[7,d]

Some characteristics which should be considered when selecting variables to reflect the population's health needs are: vulnerability to being manipulated by those who manage public policy; true representation of factors of need; exemption from the process of political choice and the availability of reliable data.[d] These characteristics orientate the process of choosing the variables which composed the FA here presented.

The data necessary in order to obtain reliable results came from different years, especially in smaller municipalities, however, the data from the most recent year available was used. The limitation and quality of the data from small municipalities was found in another study.[8] The authors of this study opted to group the regions together in order to carry out the analysis. This option was not available to this study, as the unit of study was the municipality.

The municipalities in Pernambuco show high values for mortality under five years of age and diseases of the circulatory system, percentage of live births with inadequate prenatal care and people with income *per capita* below $ 40.81. This shows the where state's major needs for health care are. The analyses reveal values which positively show the situation in the state of Pernambuco as regards means found for illiteracy rates, percentages of homes which are served by rubbish collections and mortality due to infectious and parasitic diseases.

The municipalities of Manari and Ipojuca stand out as where the minimum and maximums for each value were found. The former, for having the worst levels for the variables: illiteracy rate, percentage of people with income *per capita* below $ 40.81, percentage of homes which are served by garbage collections and mortality under five years of age. The latter showed the best results for the variables: ICMS[k] *per capita* and financing capacity *per capita* (Table 2).

For each of the variables, a value considered excellent was given, in accordance with the sample. The locality which achieved this value was denominated as an excellent municipality (m_e). These data guided the ANN tuning stage.

One of the municipalities studied presented a minimum value for the variable percentage of urban households with basic sanitation, indicating that the health of the inhabitants of this locality was somewhat vulnerable, given that environmental conditions are determining factors in health problems.[9] Another municipality was notable for having the lowest value for the variable mortality due to infectious and parasitic diseases. This suggests a good association with the health care situation in the municipality. However, the possibility that this data was under reported should be considered.

The municipalities in Pernambuco showed high variability in the values of a good part of the variables in the descriptive analysis: the coefficient of infant mortality, ICMS *per capita*, percentage of deaths due to unknown causes, financing capacity *per capita* and percentage of urban households with basic sanitation. This may indicate inter-municipal differences within the state, suggesting the need for differentiated allocation of health care resources suitable to each places circumstances, justifying the adoption of an index which reflects the health needs of each municipality.

Choosing a statistical method for calculating the FA should be considered, due to the scope and complexity of measuring health care needs in a specific population. Using ANN to choose is based on a theoretically structured reference, as they are systems of artificial intelligence which mimic the problem solving processes in the human brain, i.e., they formulate and apply knowledge acquired from past experience in order to solve new problems or situations. This model appeared as an attempt to mathematically simulate the human nervous system, and the network is a representation of the neurons available for the analysis of specific input signals in mathematical terms.[10]

With this functioning, ANN has a wide range of applications in diverse areas of science and technology, including in health. In medicine, researchers use *Multilayer Perceptron* ANN in "Diagnosing Interstitial Lung Injury",[l] "Differential Diagnosis of

[j] Couttolenc BF, Zucchi P. Gestão de recursos financeiros. São Paulo: Instituto para o Desenvolvimento da Saúde/Faculdade de Saúde Pública da USP/ Banco Itaú; 1998. Alocação de recursos: critérios e consequências; p.97-100. (Série Saúde e Cidadania, 10).

[k] ICMS: tax on movement of goods and services

[l] Ambrósio PE, Faria FB, Rodrigues JAH, Martinez JAB, Marques PMA. Sistema computacional de apoio ao diagnóstico de lesões intersticiais pulmonares baseado em redes neurais artificiais. In: Anais do 17. Congresso Brasileiro de Engenharia Biomédica; 2000 set 11-13; Florianópolis, Brasil. Florianópolis: Universidade Federal de Santa Catarina; 2000.

Deficiency Anemia",[m] Classification of nodules in digitized mammograms,[n] Diagnosing the Cardiovascular System,[o] Diagnosing Coronary Artery Disease,[p] with a mean rate of precision of 90 to 99,6%.

This model has the capacity to offer good responses, even with secondary data, which may be confusing or noisy, as the weighting of each variable is adjusted according to the network's learning process. This makes it applicable to a wide range of circumstances.[9]

ANN has been shown to be a powerful tool, adapted to carry out various tasks such as: memorizing, associating, pattern recognition, generalization, and analyzing multi-variate non-linear data, among others.[14] This range of applications is a result of its flexible nature of the system specification.[2,14] ANNs have a statistical base inherent on the impact of input distribution (non-normal) on estimating weighting. The main difference in relation to multiple techniques is the absence of any statistical inference test for the model's adjusted weightings.[2]

The ANN which composed the FA had a good number of hidden neurons, given the complexity of the topic proposed. Neural networks which have few hidden neurons are preferred for their tendency to reach higher generalization powers, reducing overfitting; however, they may not have sufficient ability to model data which involve complex problems.[q] Generalization refers to the network's capacity to produce outputs which are not present at the moment of learning.[3] Despite the validation error values of MLP networks being lower than those of RBF, it was decided not to consider them, given the high test error value, which indicated possible overfitting by the network.

The FA presented constitutes a comprehensive methodological proposal, as it incorporates in its wake not only variables belonging to health but also those which bring socio-economic, demographic and educational dimensions. It is viable to use ANN with a good number of variables, as this statistical technique permits the use of many indicators, given its generalization power. The results show a distribution in which municipalities recognized as needing greater financial support for health care were placed in quartiles considered good (1 and 2). The contrary was also observed, i.e., places which were well supported by resources were placed in quartiles 3 and 4. The proposed FA showed the municipalities in quartile 4 to be well placed, according to their socio-economic and epidemiological circumstances.

The higher quantity of municipalities placed in the quartile with fewest needs led to the conclusion that the FA presented distributed the municipalities, separating those with extreme need for more financial support from those which showed less serious need for financial support.

This study may serve as a reference for comparative research, not just in Pernambuco but extrapolated to other places. The complexities involved in choosing the variables which best reflect the health care needs implies the existence of additional studies using ANNs statistical techniques, which allows the addition of other variables which may express the population's health care needs. It may even relate them to financial data to contribute to the improvement of knowledge and the pursuit of more equitable allocation criteria.

The importance of methodologies for the equitable allocation of health care resources by figures in the public negotiation spaces and definition of the distribution of these resources should be contextualized and used as an instrument to support equitable distribution, bearing in mind other indicators of the dynamic reality of the functioning of the municipal health care system.

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EDITOR'S COMMENT

One of the greatest challenges facing public health care managers is to define a method of allocating resources, in a context in which financial resources are limited, so as to best meet the population's health care needs. The study aimed to respond to this critical question for the public health care manager by providing a method of allocating resources which took into consideration factors which expressed health care needs and determinants of the different levels of local and regional inequality. The study constructed a factor of allocation which guided the distribution of resources more equally, as it took into consideration the socio-economic and epidemiological inequalities which existed between municipalities in Pernambuco. Thus, the study distanced itself from the logic which guided part of federal distribution of resources, which was related to levels of production.

The methodology used in constructing the factor of allocation has the potential to be used/incorporated into the health care system and services. The results presented can be reproduced, encouraging the establishment of a new way of doing things. They indicate the potential to expand the approach beyond the focus on transferring SUS (Brazilian Unified Health System) public resources, with a methodology that can be used in all types of resource transfer between federal authorities - federal, state and municipal.

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