Reconfiguring State Health Services Logistics : Patients Flow Optimization

Cassius Tadeu Scarpin; Maria Teresinha Arns Steiner*; Pedro José Steiner Neto**
UFPR – Programa de Pós-Graduação em Métodos Numéricos em Engenharia
*Coordenação do Curso de Engenharia de Produção; ** Departamento de Administração
CP: 19081-CEP: 81531-990, Curitiba, PR, Brasil

Summary
This paper presents an optimization to the flow patients for state health services offered to Parana State citizens and also analyzes a new optimized configuration for it. In Brazil, medical care is controlled by state officers, and is provided throughout a centralized planning managed by state governments in every one of Brazil's 28 states. Since geographical area is a key factor in most states, and range of services are not the same for every unit, patients demanding my have to be transported to another facility, located in the same state. A new proposition is made for state division into smaller regions, with a service level assigned for each municipality. Cities with lower levels offer just basic procedures, and patient in need of a more specialized service are sent to higher level cities. The assignment for the groups of cities must be based on size of population, health facilities, road availability and patient transportation routes should be planned for each procedure in every facility. For the regional division, a branch-and-price algorithm was used, using the column generation algorithm for each node in the branch-and-bound tree. The results obtained were considered very consistent.
Keywords: *logistics, p-medians problem; branch-and-price algorithm; flow of patients; hierarchical configurations.*

1. Introduction

Logistics is on a permanent challenge to provide the availability of products and/or services when and where they are needed. A basic issue of logistics management is how to structure systems and/or distribution configurations capable of supplying markets geographically away from production sources, and at the same time offering better service levels in terms of stock availability or supplying capacity in smaller time intervals [1].
Facilities Location Problems are made up by a wide class of problems all dealing with decisions about the best configuration to install facilities to supply the demand of a population. The classical model that is used to represent problems in this class is the p-medians problem, which searches for p points (medians) in a n-node network, considering them as the facilities and trying to minimize the sum of the distances from the $(n – p)$ demand points to the p medians.
The 399 cities that belong to the state of Paraná, Brazil, form a graph that can be structured in order to define the p-medians, in which the cities are considered as the points in the graph and the roads between them the arcs. The regionalization of health systems is a proposal that allows the organization of cities into hierarchical divisions so as to make displacement easy for those patients who need medical care away from their cities of origin [5]. In this work we propose to optimize the flow of patients within the state according to its present regionalization (division) and also, a new form to define the seat cities, building the hierarchical divisions (new division) in an optimized way, based on the classical problem of the p-medians.
To solve the flow optimization problem an algorithm was developed to organize the information contained in the several databases of the *Secretaria Estadual de Saúde do Paraná* (*SESA*, State Secretary of Health of Paraná) and, based on this information, optimizes the flow of patients. To solve this problem the branch-and-price method was used based on the traditional branch-and-bound method [9], by applying to each node in the tree the column generating method that uses the lagrangean/surrogate relaxation as a stabilization alternative. The regionalization of the health system in the state has as one of its objectives the improvement in the optimization of the flow of patients [3].
This work is organized as follows: in Section 2 we present a full description of the problem, dividing it into two parts: the problem of the flow of patients and the problem of the regionalization of the health system in the state of Paraná. In Section 3 we describe the algorithm that was developed to optimize the flow of patients using the present regionalization and we also post a few comments about the branch-and-price algorithm (already known by everyone) used to obtain feasible solutions for the p-medians problem. The implementation of the methodology developed for the flow of patients, as well as for the state regionalization, is introduced in Section 4 and, finally, the conclusions and suggestions for future works are in Section 5.

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2. Description of the Problem

The *Sistema Único de Saúde do Estado do Paraná* (*SUS*, Single Health System of the State of Paraná), through *SESA*, is trying to find a solution for the problem of the flow of patients who do not find the needed medical procedure in their city of origin and must be taken to another city in the state. So that forwarding is effective there must be an organizational system that establishes to where the person should be taken. This orientation process for the patients must be defined by *SESA* and carried out by the municipal secretaries of health [10]. This forwarding must occur as fast as possible so that the patient's disease does not get worse or even so that there is no risk of contagion, if such is the case [6]. Besides, there must be an optimization of the resources involved in transporting those patients, such as vehicles and employees.

The health system in Brazil has three levels of resolution for the medical services rendered in the state: low, medium and high complexity [2]. *SESA* distributes the resolution levels for procedures into groups of cities, as follows: a certain number of cities form a group that is called micro-region where is the seat city that is responsible for the low-complexity procedures; micro-regions are aggregated into larger groups called regions, in which the seat city is responsible for the medium-complexity services; the union of regions for an even larger group of cities that is called macro-region in which the seat city is responsible for those medical procedures of high complexity that the state offers [4].

Considering this context, the general problem can be divided into two parts: the first one is about establishing a flow of patients with the purpose of supplying an optimized solution for the patient by using the state's present regionalization. This solution shall indicate the city (that has the procedure the patient needs and the capacity for it) to which the patient shall be taken, in such a way that displacement is minimum, thus assuring that services can be rendered as quick and as satisfactorily as possible. The second part is regarding the regionalization of the health system in the state, optimizing the hierarchical division of the state (by defining the seat cities for micro-regions, regions and macro-regions) and improving even more the aforementioned optimization of the flow of patients.

Each city in the state of Paraná receives a certain amount from *SUS*, to be used in health and according to the medical procedures that the city offers from a set of registered services (around 6,000). There are cities that do not have a minimum quantity of procedures, even those of low-resolution levels, so they are completely dependent of the seat in their present micro-region. On the other hand, there are cities that have all procedure the public health system offers, so they become attractive for users.

This way, it has been tried to define an organization for the state's health system so that every time a patient must go to another city, he or she will know exactly where to go. Presently there is no such instrument implanted to establish this flow of patients. The municipal secretaries of health do not have specific orientation on to where send their citizens and, as a consequence, they, on their own accord, end by going to the big centers in the big cities.

One way of analyzing the flow of patients is to check the hospital admittance flows, which may be done under two aspects: through the quantity of *Autorização de Internamento Hospitalar* (*AIH*, Hospital Admittance Permits) entrepreneur through the amounts paid for these services. Besides the information obtained at *SESA*, through the *Departamento Nacional de Infra-estrutura do Transporte* (*DNIT*, National Department of Transport Infrastructure), a federal agency, the distances between the cities in the state of Paraná were obtained so they could be used to compute the smallest distance a patient should travel for the needed procedure. Moreover, the data to build the pictures and chart presented in this work were obtained at the *Instituto Paranaense de Desenvolvimento Econômico e Social* (*IPARDES*, Institute of Social and Economic Development of Paraná).

Flow of Patients – Present Situation

When this research was performed, the definition on where the patient should go for the procedures to be rendered was basically made in two ways: the patient himself would decide to look for the procedure needed in some city close by or in a big city, or his city's municipal secretary would direct him or her to the capital of the state, or some other big city, for instance, the cities of Londrina, Cascavel or Maringá, provoking an overload on the hospitals and health units. The consequences of these facts are broadly disclosed in the communication media, such as, for instance, crowded hospitals, long queues, lack of beds, use of corridors for procedures and unhappy citizens who in need of those services.

The last survey *SESA* made detected that the state's capital is being burdened with around 50% of the patients who need service away from their cities of origin. The capacity to produce intra and inter-regional hospital admittance permits (*AIH*) is connected with the quality of service in the health public sector of each region, considering its number of inhabitants [8].

Analyzing the data obtained at *SESA*, we can conclude that the four largest cities (Curitiba, Londrina, Maringá and Cascavel) shared 60% of Paraná's cities (238 cities). The difference between them is in Curitiba's action that deeply extrapolates the limits of its surroundings, promoting hospital assistance to the sparsest areas of the state's territory. Figure 1 (self-explanatory; in attachment), shows the action of these four big centers of hospital services.

Regionalization (state Division) – Present Situation

The big problem to regionalize health is how to divide the state into regions in such a way that they may truly assure the access of the population to the health system and, also, the criteria that should be used to define such subdivisions in order to improve even more the flow of patients.

Figure 2 (the map on the left, in attachment), shows the division by colors of the current six macro-regions with a highlight the shows the seat cities in each one of the macro-regions. The map on the right side of Figure 2 shows the current 22 regional divisions; the regional groups with the same color tone form the macro-regions.

Through Figure 2 one can notice that the hierarchical division is not optimized, particularly the 5th and 22nd regions, and the latter (22nd) has two "isolated" cities from the former (5th).

Another case that may be observed is the 6th region in which cities located in the west portion are closer to Pato Branco than to Curitiba, their macro-region seat. This situation is even more serious in the division into micro-regions: some of the cities belong to more than one micro-region.

In order to find the hierarchical division in an optimized way, in this work was used the branch-and-price method applied to the *p*-medians problem, as has already been mentioned. This way, new seat cities and new city groups can be defined to form health micro-regions, regions and macro-regions. It is clear that by using only the distances between cities one may find situations that would make the implementation impossible, such as, for instance, choosing for seat city in a micro-region a city that does not have the basic services, but is geographically in a strategic position. To avoid this kind of problem "weights" were used for the cities such as, for instance, the number of inhabitants in the cities (it is worthwhile mentioning that this is the criterion the Ministry of Health uses to calculate the number of physicians, hospitals and general health structure), or the number of medical procedures carried out in the cities (which would need more reliable information to demonstrate the reality), or even, "other weights", such as, for instance, the number of heath units or the total service capacity in the cities.

It is worthwhile pointing out that seat cities are, within a hierarchical division, those cities that can render service accordingly the their responsibility, this is, seat cities of micro-regions are responsible for low complexity procedures, seat cities of regions are responsible for medium complexity procedures and seat cities of macro-regions are responsible for high complexity procedures, as has already been mentioned. The algorithm that was used is described in detail in Section 3 in this work.

3. Methodology used to solve the Problem

For the Flow of Patients

As the number of procedures to be controlled is very large (around 600,000) and relationships between them are many, when presenting the input data to the algorithm with the city of origin and the required procedure, a filter is applied so that it may work with only the register that are necessary to assign the patient to his or her destination. Thus, the cities that offer the required procedure are stored together with the data that correspond to these cities, regarding location (to which micro-region, region and macro-region they belong), so that the search is optimized by means of the minimization of the number of registers. It is necessary to obey the hierarchy to search for the required procedure and, therefore, in the first place it checks to see if the city of origin offers such procedure. If the answer is affirmative, it checks if the service capacity still has some availability in the period (week, month or other, as established by *SESA*) and, if the answer is again affirmative, the patient should be directed to his own city and predefined locale, with documented authorization in hands, to perform the procedure.

If it happens that the city of origin does not offer the procedure and/or it is not possible to see the patient within the period and/or it is an emergency procedure, it is necessary to check the availability of procedure/capacity in the cities that belong to the same micro-region of the patient's city of origin and identifying among them the closest city to the city of origin (the place where the patient is), placing it as the 1st option, the second closest as the 2nd option, and so on. In case the micro-region does not have the needed procedure/capacity, those cities that belong to the same region as the city of origin should be listed. In case there is a new negative, search is made among the cities in the macro-region and, if necessary, finally search among the cities that have no link with the city of origin, but have the procedure, with the purpose of finding a city that may render the requested services.

Once it is verified that the procedure can be provided by the 1st option and the authorization is granted (because there is the capacity), the patient is directed to this city. If there is no capacity, the 2nd option is analyzed, and so forth, until a city is found capable of receiving the patient and that forwarding may be authorized. At each negative response from the cities that are considered as possible options, this city is enlisted in a report with the name of the person who refused authorization, so that this way the procedure and capacity limitations of each city may be known. This kind of procedure will allow the emission of a monthly report that cities can send to *SESA* for the appropriate data checking and verification of unmatching data.

The procedure that was previously suggested makes mandatory the searching for service in the cities that are closest to the patient's city of origin and complying with an existing hierarchy between cities. The distances computed between all cities (399 x 399) are based on the Floyd Algorithm [7], which determines the smallest distances between any two points (in this case, two cities) in a graph $G(N, A)$, where N is the set of 399 cities and A is the set of arcs that unites them. The algorithm to optimize the flow of patients of *SUS*, this is, to perform an optimized designation of patients to cities, as previously described, is made up of the following steps [12]:

- input data: patient data, city of origin and required procedure;
- the cities that offer the required procedure, and their data, are filtered;
- if the city of origin is in the filter, it must be placed as 1st option;
- in case the city of origin is not in the filter, those that are, are checked to verify if they belong to its micro-region and do offer the required procedure. They are placed in a list, sorted in ascending order of distance (Floyd's matrix) and, therefore, of option;
- for the cities that are in the filter and belong to its region and macro-region the same search is made regarding distances and progressing with the list of options;
- in case the list remains empty, the process continues analogously with the rest of the cities in the filter;
- in each one of the previous verifications with respect to options, the capacity to offer the service is checked:
  - if it has, grant the authorization and assign the patient;
  - is it does not, include the city in the final report and progress with the list of options;
  - if there is no option (empty list), this is, no city can receive the patient, then:
    - assign the patient for the next period or assign the patient to the adequate state agency for the procedure.

For the Division of the State

In a general way, the branch-and-price method is based upon the branch-and-bound method to obtain feasible solutions for the *p*-medians problem in which the column generation method is used on each node in the search tree, applied to the sets partitioning problem's mathematical model.

In this work, the branch-and-price method uses the lagrangean/surrogate relaxation as an alternative for the traditional lagrangean relaxation applied in sub-gradient optimization algorithms. It is done by using the column generation algorithm for each node in the branch-and-bound tree, like it is presented by [11]. The whole method is presented, in details, in [13].

4. Implementation and Results

For the Flow of Patients

In this section are shown the implementations and the results obtained for the two problems described previously: the optimum flow of patients using the current state division and the optimization in the division of the state.

The methodology that was developed to establish the flow of patients that travel the state after medical services was implemented in *DELPHI*, in a *Pentium* 4 computer, 1*GB RAM*, using the *MySQL* database software.

One can compare the results that were obtained with this methodology and those with the methodology at use in *SESA*. The methodology developed in this work presents several advantages in relation to the one currently used by *SESA*: it brings more service options to patients, the distances patients must travel to be seen is considerably smaller and the big cities are relieved. Next is an illustrative example.

An Illustrative Result

Be a patient in the city of Guapirama (Micro-region 72 – Santo Antônio da Platina, 19th Region - Jacarezinho and Macro-region North – Londrina) who needs the procedure "*Appendicectomy*", code 33005060. Through *SESA*'s methodology this patient has the option of going to the city of Jacarezinho, seat city of the 19th Region, once the Micro-region's seat city, Santo Antônio da Platina, does not offer such procedure, and travel the distance of 47 km, considering only the displacement from Guapirama to Jacarezinho. If he cannot do it in Jacarezinho the patient must go to the city of Londrina, seat city for the Macro-region North, traveling 132 km. If even then he cannot receive this medical procedure, he has as a last option the city of Curitiba (a state reference for all procedures) traveling 274 km.

Through the methodology developed in this work, the patient has 137 cities as options. In current hierarchy and distance they are:

- **Micro-Region 72 – Santo Antônio da Platina**
- Joaquim Távora, traveling 18 km, belonging to Micro-region 72.
- **19th Region - Jacarezinho**
- Carlópolis, traveling 42 km, belonging to the 19th Region.
- Ibaiti, traveling 44 km, belonging to the 19th Region.
- Jacarezinho, traveling 47 km, belonging to the 19th Region.

- Pinhalão, traveling 62 km, belonging to the 19th Region.
- Tomazina, traveling 62 km, belonging to the 19th Region.
- Cambará, traveling 64 km, belonging to the 19th Region.
- Ribeirão Claro, traveling 65 km, belonging to the 19th Region.
- Salto do Itararé, traveling 67 km, belonging to the 19th Region.
- Figueira, traveling 68 km, belonging to the 19th Region.
- Wenceslau Bráz, traveling 72 km, belonging to the 19th Region.
- **Macro-Region North – Londrina (MRNL)**
- Congonhinhas, traveling 55 km, belonging to the MRNL, 18th Region.
- Andirá, traveling 60 km, belonging to the MRNL, 18th Region.
- Bandeirantes, traveling 67 km, belonging to the MRNL, 18th Region.
- Santa Mariana, traveling 76 km, belonging to the MRNL, 18th Region.
- Cornélio Procópio, traveling 81 km, belonging to the MRNL, 18th Region.
- Assaí, traveling 95 km, belonging to the MRNL, 18th Region.
- **And 120 cities more, throughout the state, sorted by hierarchy and distance.**

It can be seen that the service options through the methodology developed bring a better distribution of patients that travel the state after medical services. The way of confirming service for patients in each city, keeping the sequence, would be over the telephone, once the state does not have an integrated computational network between the municipal secretaries of health. However, as soon as state's administration implements this network, this methodology will be even more useful, considering that by making this service available on-line, patients will be able to look for the best option for their needs with the proper confirmation of the consultation being made via email, or even automatically, over the Internet.

For the Division (Regionalization) of the State

On its turn, the branch-and-price algorithm was implemented in PROGRESS FULL, a language that uses the software LINGO 8 (Language for Interactive General Optimizer) through code line to solve the mathematical models the program generates. For the tests that were carried out, a Pentium 4, 2.8 GHz processor, 512 MB RAM, computer was used. Five tests were separated to find the best hierarchical division between cities, defining the macro-regions, regions and macro-regions, and keeping the same current number of divisions (6, 22 and 83, respectively). After these tests were carried out, three proposals for a hierarchical division are presented, using different numbers for the seat cities' divisions. In the two last ones, the criteria for choosing the cities candidate to be division seat cities are changed (explained further down).

For the first test that was carried out, the 22 cities (medians) that are considered as seats of regions were fixed and the cluster were defined through the shortest distance from each city to a median. When using the algorithm true distances between cities were used and this was applied to find the six (among the 22 fixed) macro-region seat cities. Besides, in each one of the 22 regions, 83 micro-regions were defined, keeping the proportionality of cities for each current micro-region.

In the second test, the 83 micro-region seat cities were fixed by designating each group of cities through the shortest distances. Among these 83 cities, the 22 medians considered regional seats were determined through the algorithm. Those cities that are not medians are assigned to a regional according to the formation of their seat cities' clusters. The same way, the six macro-region seats were defined among these 22 cities. In the third test, the macro-region seat cities were previously fixed (current macro-region seats: Cascavel, Curitiba, Londrina, Maringá, Pato Branco and Ponta Grossa), due to the structure that can be found in these cities. The purpose with this is to present a test closer to the feasible by defining the region and micro-region seat cities using true distances.

In the fourth and fifth tests was used the same macro-region configuration of the previous test (3rd), but to define the region and micro-region seat cities were used true distances pondered by the number of inhabitants and by the number of procedures each city offers, respectively.

In the first proposal, the current situation was changed only in relation to the number of macro-region seats, increasing it to seven cities and including the city of Paranavaí. The criteria that were used to choose the city of Paranavaí were: its privileged location in the state's northwest region (the region that most lacks services) and its service capacity that is equivalent to the seat cities already defined. After building the macro-regions the 22 regions were determined, keeping the proportion of cities in each macro-region and, finally, the 83 micro-regions, also considering the current proportion.

The second and third proposals are presented below, both with only five macro-regions, the seat cities being: Cascavel, Curitiba, Guarapuava, Londrina and Maringá. The criteria used to choose the city of Guarapuava as seat of a macro-region (instead of Pato Branco or Ponta Grossa) are: better geographical localization (state's central region) and the service capacity equivalence in relation to the cities that were removed (Pato Branco and Ponta Grossa).

In the second proposal only 18 regional seat cities are chosen among the 40 main cities in the state. These 40 main cities were chosen through the criterion of medical service capacity. The number of 18 cities was determined because of the following fact: from the 40 chosen cities, five were seats of macro-regions, so there were 35 cities left. Half of these, rounding it up, were the number that was chosen for the amount of regional seats. After determining the regions through the algorithm, the 43 seat cities for micro-regions were determined and this number was chosen among the state's 100 main cities.
Finally, in the third proposal the region seats were increased to 22, now chosen among the 50 cities most capable of rendering services, already removed the five macro-region seats. The 43 micro-region seats were determined the same ways as for the first proposal. In this proposal, however, there is no need for the cities that belong to a micro-region to be in a same region, as well as those cities in a region do not have to be in a same macro-region. This way, the algorithm determines the hierarchical divisions with no kind of constraint, this is, the division seat cities are always chosen among the candidate cities, regardless of a higher division and, also, city is seat to a division, it will no longer allowed to be candidate to a lower division. Therefore, each city in the state will always have different options for their citizens to go for medical services in the case that that service can only be rendered in their own cities, or in its division's seat city, as has been discussed with the state Secretary of Health. This way, more options are made available for the cities in less-structured cities, in this proposal *SESA*-PR discussed.

4.1 Results of Tests and Proposals

Figures 3 and 4 (in attachment), show the best results obtained, combining the numerical results and evaluating the choice of the seat cities, considering their structure in the health area. Test 4 was considered as the bets one (Figure 3) and proposal 3 (Figure 4) was considered the one to have the best combined results.
In Figure 3, the map on the left shows the colored division in macro-regions and the seat cities with a highlight color in their respective macro-regions. The map on the right shows the colored division in regions and the micro-regions by reinforcing the borders. The seat cities of regions are indicated with a white dot and of micro-regions with a black dot. The same way is the interpretation of Figure 4, below, in which the cities in white are division seat cities and, therefore, excluded from the cities that are candidate to be seat of lower divisions.
Next, in Chart 1 (in attachment) and for each one of the tests are shown the sum of distances (in kilometers) of the cities in each sub-division for the seat city in each macro-region, region and micro-region. There is also a comparison between the current configuration and the results obtained in the tests and proposals.
In this Chart 1 and using line seven as an example, with respect to proposal 1, one has the following: columns two, three and four show the sum of distances between the cities that compose the macro-region to the seat cities of their macro-regions (34,126 km), regions (18,169 km) e micro-regions (7,725 km), respectively. The fifth column shows the sum of these distances (60,020 km). The three next columns show the differences between the sum of those distances found in the proposal and the sum of those distances found in the configuration *SESA* currently uses. In the macro-regions a difference was found of 11,525 km, in the regions the difference was of 4,405 km and in the micro-regions the difference was of 6,889 km, thus totaling a global difference of 22,819 km, shown in column nine. Column 10 shows the number of macro-regions used in proposal 1 (7), as in columns 11 and 12, which show the number of regions (22) and of micro-regions (83), respectively.

5. Conclusions and Suggestions for Future Works

The methodology that was presented to optimize the flow of patients proved to be very effective and extremely useful, once not only it defines to which city a patient should be taken, considering the hierarchic division of the city of origin, but also keeps control of the medical procedures carried out in each city, in each stipulated period, supplying better information to *SESA*-PR about the service capacity each city has, and indicating service needs a city or even a region may have.
This way, the flow of patients will tend to be more and more regionalized, relieving the main cities, saving with patient public transportation and stimulating the local economies because in many cases relatives use to travel with the patients. Considering that the computational time used to obtain the answer for the flow of patients is very small (approximately two seconds), this tool can be used in a future and possible computational integration of the state's health system to schedule consultations and hospital admittances. Like this, patients could look in the Internet for the service they need and get a quick answer, making it easier to solve their cases.
The new proposal to regionalize health systems (optimized division of states) presented in this work consists in removing the seat cities of higher divisions from being candidates to be seats of lower divisions. This increases the number of service possibilities for patients, who will always have three different cities to go to for services, if used in the current policy in which only seat cities are responsible for procedures in their division.
Another important aspect in the new proposal of an optimized division of the state is the fact that there are less

hierarchic divisions than presently, mainly in the micro-regions, and the total distance in the configuration is equivalent to the current one. The consequence from this fact is that investments in public health will become more effective, balancing the capacity seat cities have for services under their responsibility according to the complexity of procedures, and with less resources, once there are less cities to invest in. On the other hand, citizens will have more service options than presently and traveling a shorter distance, thus improving the performance of the state's public health system.

The computational time to find the medians has great variation when the ratio between *n* points and the number *p* of medians is big. For instance, for 151 points and 6 medians, the biggest case solved here, the algorithm was run for around 6 hours. For the simpler cases, for instance, 23 points and 5 medians, the algorithm took around 1 minute. However, for the *p*-medians problem that was discussed, computational time is irrelevant under the logistic standpoint, because the quality of the solution is much more important than the time it takes to find it.

When evaluating the methodology for flow of patients with an optimization in the division of the state, in proposal 3 for hierarchical division there is a real possibility of improving service in the public health system in the state of Paraná. The smaller number of seat cities, the smaller distance patients travel, more service options, identification of regional needs and greater control over procedure that were performed make up a proposal of improving investments in the health system, optimizing public resources, creating parameters for really necessary investments and increasing patients' satisfaction, rendering services to all those who need, thus trying to reach the state's constitutional purpose that is to supply free quality medical care to everyone.

For future works still remains the comparison of the results found by the branch-and-price algorithm and other heuristic/metaheuristic methods. It is important to point out that every logistic problem can and should be studied by combining existing mathematical tools and considering the specific characteristics of the problems that are found in nowadays world. Therefore, with this combination we may find better practical solutions and also develop mathematical tools more and more effective for searching better solutions.

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Cassius Tadeu Scarpin got his Master´s degree in Numerical Methods in Engineering Graduate Program, on Operations Research area, at Federal University of Parana, Brazil. He is taking his Ph.D.'s degree in this same program.

Maria Teresinha Arns Steiner got her Master's and Ph.D.'s degrees in Production Engineering, on Operations Research area, at Federal University of Santa Catarina, Brazil, and her Pos-Doc, at the Technological Institute of Aeronautics, São José dos Campos, SP, Brazil. She is an Associate Professor at Federal University of Parana. Brazil. She lectures on Engineering Undergraduate Programs and on Numerical Methods in Engineering Graduate Program.

Pedro José Steiner Neto got his Master's degree in Engineering Management at Florida Institute of Technology, USA and his Ph.D.'s degree in Business at São Paulo University, Brazil. He is an Associate Professor at Federal University of Parana. He lectures on Business Undergraduate and Graduate Programs.

ATTACHMENT
Figures 1 to 4 and Chart 1 cited in the text

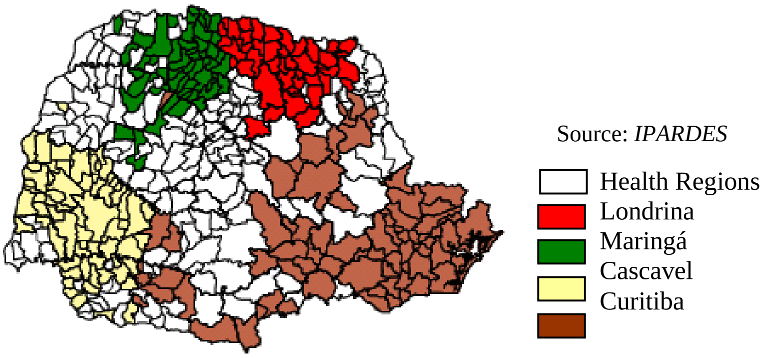

Figure 1. Area of action of the four big cities.

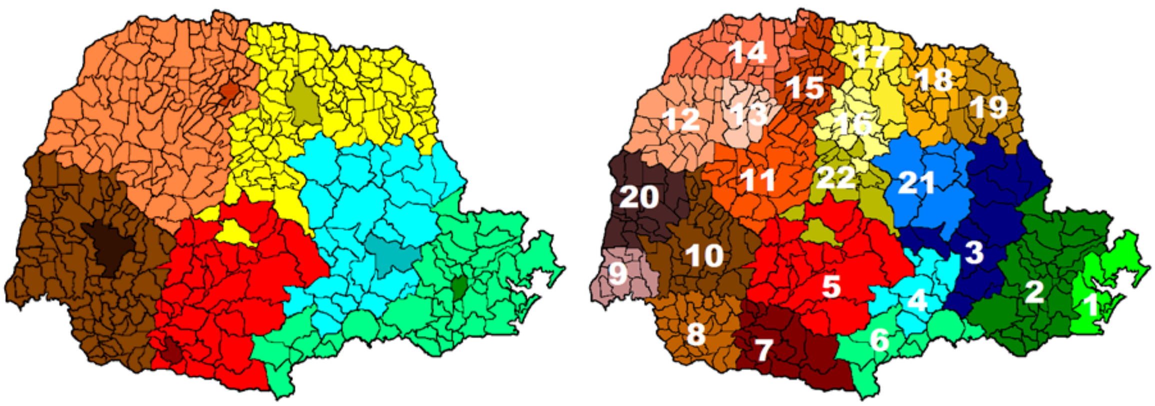

Figure 2. Present hierarchical division: macro-regions (map on the left) and regions (on the right).

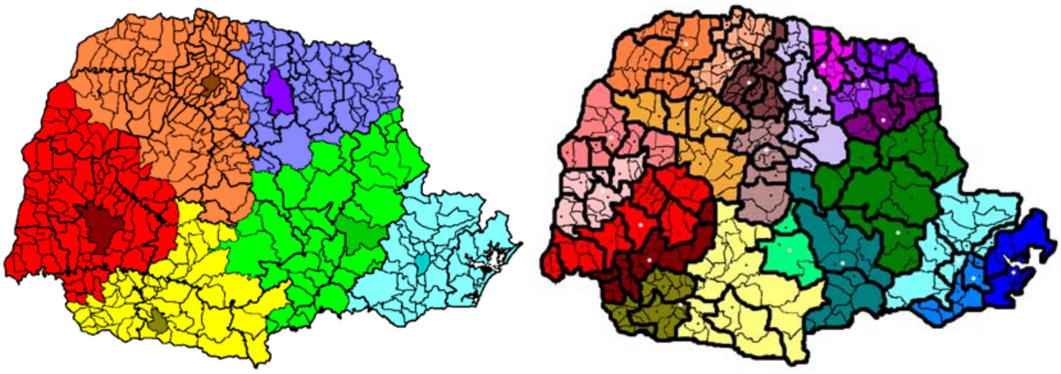

Figure 3. Test 4 – to the left: Macro-regions and to the right: regions and micro-regions

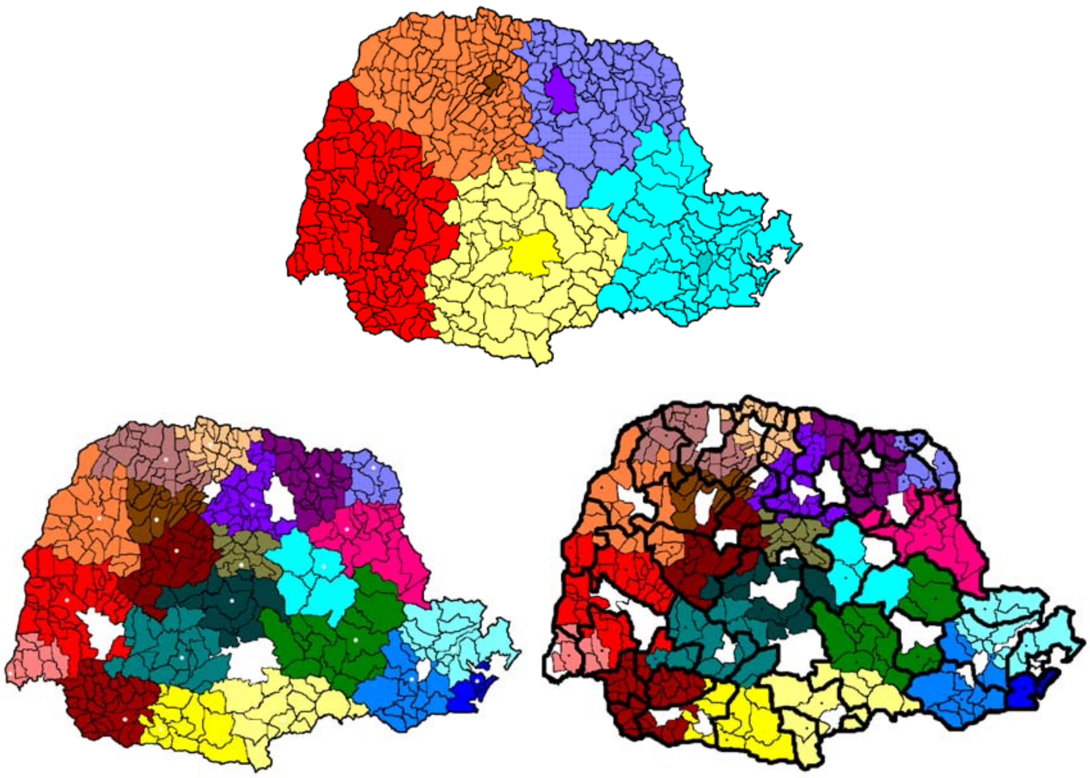

Figure 4. Proposal 3 – on top: macro-regions; left: regions; right: micro-regions.

Hierarchy Configurations	Distance Sum			Total	Difference with respect to current			Total	Number of divisions		
	macro	region	micro		Macro	region	micro		macro	region	micro
Current	45651	22574	14614	82839	-	-	-	-	6	22	83
Test 1	35921	20154	7677	63752	9730	2420	6937	19087	6	22	83
Test 2	38633	21652	10560	70845	7018	922	4054	11994	6	22	83
Test 3	36503	18710	7956	63169	9148	3864	6658	19670	6	22	83
Test 4	36503	21905	10624	69032	9148	669	3990	13807	6	22	83
Test 5	36503	21605	9328	67436	9148	969	5286	15403	6	22	83
Proposal 1	34126	18169	7725	60020	11525	4405	6889	22819	7	22	83
Proposal 2	38728	24910	10736	74374	6923	-2336	3878	8465	5	18	43
Proposal 3	38728	18945	13632	71305	6923	3629	982	11534	5	22	43

Chart 1. Comparison between configurations, numeric results.