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ARTICLES

ASSESSING THE SPATIAL EFFICIENCY IN THE LOCATION OF PRIMARY HEALTH CARE FACILITIES: A LOCAL APPLICATION IN ARGENTINA

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ABSTRACT. If scarce resources are not used efficiently, welfare could be increased without any cost. Efficiency metrics have a long tradition in economics. However, measures of spatial efficiency (SE) are far less common in the literature. In health care, SE is crucial to guarantee population's access to health care providers. We develop a metric of SE of Primary Health Care Centres (PHCCs) location based on the comparison of the minimum distances users must travel to reach a PHCC, considering their current location, against the distances they should travel if all PHCCs were optimally located. We apply this metric to assess the spatial efficiency of the PHCCs of Bahía Blanca City (Argentina). To determine the optimal location of the centres we used a capacitated P-Median model. The annual demand for medical consultations of each demand node was estimated by adjusting the number of inhabitants of that node by a socioeconomic index.

Keywords: primary health care centres, spatial efficiency, Bahía Blanca (Buenos Aires, Argentina).

1 INTRODUCTION

Primary Health Care (PHC) is considered a health strategy capable of improving the health status of the most vulnerable population. In Argentina, it is mainly implemented through the so-called Primary Health Care Centres (PHCC). PHCCs provide low-complexity health care services, both preventive and curative. They also play a crucial role in the execution of different public health policies, such as nutritional education or health promotion programs, and they typically serve

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as the first contact point between patients and the greater health system. An adequate access to PHC services could result in lower costs for the health system by avoiding unnecessary use of specialized care and the prevention of diseases (Fo & Mota, 2012; Peñaloza et al., 2010; Van der Stuyft & De Vos, 2008; Tanser, 2006;).

Two of the most important decisions regarding the provision of PHC services are the *number* and *location* of the facilities to be set up. Both decisions will have a decisive influence on the effective use of such services by the population.

Several authors agreed that efficiency and equity criteria should conduct the location and distribution of health care facilities. *Spatial efficiency* refers to the minimization of the costs (measured by distances or travelling time) faced by the public in order to make use of the facilities. Likewise, the principle of *spatial justice* or *equity* requires the concordance between the availability of services and the population's need of those services. Spatial justice depends on the easiness to access and on the distances variability that separate each individual from the nearest facility, the size of the supply provided by such facility, the temporal availability of the services and, most importantly, the different needs of the potential users (Moreno Jiménez & Bosque Sendra, 2010).

Despite the fact that an adequate location would be beneficial for the population, in Argentina it is hard to find local public administrations who have applied systematic techniques or methodologies (based on efficiency and equity criterions) to locate health care facilities. Instead, the decision to set up a health care centre is the result of historical evolution, which eventually responds to population growth, and not to their needs, characteristics or health problems. Also in many cases, that decision is highly influenced by lobbying activities of neighborhood organizations (Ramírez, 2008).

The mathematical models of location-allocation could be used to provide policy makers a framework to evaluate the population's capacity to access health care centres, allowing the comparison of alternative spatial arrangements (real or hypothetical) in terms of efficiency and equity (Rahman & Smith, 2000). Location models assume that there is a set of potential alternative sites where the facilities may be installed, called *supply nodes*, and a finite number of fixed locations for the users of such facilities, called *demand nodes* (Daskin, 2008). Location models based on median assume that, the smaller the distance that users must travel in order to have access to a supply centre, the more accessible that centre is. Thus, the locational efficacy of the spatial arrangement of supply centres may be evaluated on the basis of the median distance that users must travel (Church & ReVelle, 1976).

The P-Median models assume that a way to measure locational effectiveness is "*to weight the distance between demand nodes and facilities by the associated demand quantity and calculate the total weighted travel distance between demands and facilities*" (Owen & Daskin, 1998, p.425). P-Median models emphasize efficiency when locating facilities in order to minimize the median distance that users must travel to reach a health facility, and the optimal solution will tend to benefit highly populated demand nodes in detriment of demand nodes with smaller populations. In other words, the location decision is about benefiting as many users as possible.

In this paper, we assess the spatial efficiency of the current locations of the PHCCs in the city of Bahía Blanca, Argentina. To do so, we compare the estimated distances users must travel to reach the nearest PHCC under the current deployment of the PHCCs against the distances they should travel if all PHCCs were optimally located. To determine the optimal locations, a P-median model was used. Equity concerns were introduced in the analysis by means of a socioeconomic index, which is used to adjust the population's demand for primary health care services.

Our study is related to previous works in the literature that have tried to assess the spatial efficiency of different types of health centres. Schneider (1967) developed a spatial efficiency index that resumes the extent to which the diverse forces exerted by different user groups (physicians, administrative employees, impatiens, input suppliers, among others) are balanced or in equilibrium (Schneider, 1967). Cheol-Joo Cho (1993) suggested a procedure for estimating the spatial efficiency considering the user benefits derived from the existing facilities. Naluba & Obafemi (2016) considered that "*efficient location involves to cluster activities and public services together into commercial centres to maximize accessibility and overall affordability*" (p. 144). Hu, Liu & Lan (2019) developed a methodology to simultaneously assess spatial equity and efficiency. The authors measure facility equity as the proportion of residential areas that are served by a health centre to the total residential area. Efficiency is quantified as the proportion of the total residential area to the total accessible areas. None of the abovementioned papers has used location allocation models to assess spatial efficiency. However, some authors have applied this methodological approach but they study spatial efficiency of facility location.

Fo & Mota (2012) developed two basic uncapacitated location models to compare the current spatial deployment of the PHCCs in São Paulo (Brazil), with the optimal solutions proposed by each model. They find that both optimal solutions could allow reducing the distances that the population should travel to reach the nearest PHCC. Unlike our study they didn't consider the different needs of medical care of the populations.

Ramirez (2012) used a maximal coverage model and a P-median model to find the optimal locations of new PHCCs in Gran Resistencia (Argentina). Given the current distribution of public health centres, the new PHCC should benefit (in terms of travel distances) the population groups with higher health care needs. Again, unlike our study, the author did not show the setup of the models used, because they were solved using a geographic information system (GIS) software. The potential demand of the PHCCs is estimated assuming that only the population without health insurance be assisted by to them, neglecting that many people with health coverage make use of these PHCC.

The previous work most closely related to ours is Kumar (2004). Using a GIS, he develops a locational efficiency measure to evaluate the performance of the existing spatial arrangement of health facilities in two Indian districts. His study relies on the ratio of actual to optimal performances as a measure of spatial efficiency. The optimal spatial arrangements and simulated travel times under the current spatial configuration were derived from an uncapacitated P-median model.

2 METHODS

2.1 Study site

Bahia Blanca is a medium size city with approximately 320,000 inhabitants located in the south west of the Buenos Aires Province, Argentina. The local government is responsible to provide Primary Health Care Services (PHCSs) to the whole population, although these are mainly demanded by low-income households without health insurance. In 2018, there were functioning 49 publicly run PHCC, 45 of which had at least a general practitioner and a pediatrician or a family doctor. In the remaining PHCC, there was only a nursing service.

2.2 Location Model setup

A P-Median model was used to determine the optimal location of the PHCCs in the city of Bahia Blanca. The model minimizes the total distance the population must travel to access a PHCC. Thus, this model guarantees that the spatial distribution of the health care centres fulfils the spatial efficiency criterion mentioned above (Moreno Jiménez & Bosque Sendra, 2010). Since there is no available information about the distances the population must actually travel to access a PHCC, the model was also used to simulate travel distances under the current spatial arrangement of the PHCCs.

The nomenclature used in the formal presentation of the model is the following:

Sets:

I, set of demand nodes i.

J, set of supply (potential locations) nodes, j.

Parameters:

d_{ij}, distance between the demand node i and the supply node j (km).

h_i, demand of node i, measured in annual medical consultations.

P, number of facilities to be located.

W_{max}, maximum capacity of each PHCC, measured in medical consultations per year.

Decision variables (binary type):

Y_j, takes value 1 if the supply node j is open and 0 otherwise.

X_{ij}, takes value 1 if the demand node i is assigned to the supply centre j and 0 otherwise

The following equations describe the P-Median model:

$$Min\sum_{i}\sum_{j}h_{i}d_{ij}X_{ij} \tag{1}$$

Subject to

$$\sum_{j}Y_{j}=P \tag{2}$$

$$\sum_{j}X_{ij}=1\forall i \tag{3}$$

$$X_{ij}-Y_{j}\leq 0\forall i,j \tag{4}$$

$$\sum_{i}h_{i}X_{ij}\leq W_{máx}\forall j \tag{5}$$

$$Y_{j}\in\{0,1\}\forall j \tag{6}$$

$$X_{ij}\in\{0,1\}\forall i,j \tag{7}$$

Equation (1), is the objective function, to minimize the demand-weighted total distance between demand node i and supply node j. The constraint defined by Equation (2) determines that only P supply centres are open. Equation (3) ensures that each demand node i is only assigned to one supply node j, whereas Equation (4) establishes that the demand node i will only be assigned to the supply centre j if a facility is located at the j node. Equation (5) establishes that each open facility can satisfy a maximum number of annual consultations equal to W_{max}. Equation (6) and (7) ensure the integrality of the solution (Daskin & Dean, 2005; Daskin & Maass, 2015).

2.3 Sets definitions and parameters setting

The set I is composed of the population grouped in the census radiuses, the smallest census units delimited byArgentinean national statistics service (INDEC) in the National Population, Housing and Dwellings Census 2010) (INDEC, 2019). It was assumed that the whole population of every demand node is located at the geographical centroid of the census radius.

In the case of the set J two criteria were adopted: if a PHCC is currently open at a given census radius, its actual location was considered, whereas in those census radiuses considered only as a potential location of a health care centre, it was assumed that such health care centre will be located at the geographical centroid.

The distance d_{ij} between each demand node i and each supply centre j was estimated using Google Maps, considering that: i) the population travels either by car or by motorcycle and ii) they choose the shortest path.

The demand of PHC services was calculated multiplying the number of inhabitants of each node by a socioeconomic index (Australian Institute of Health and Welfare, 2014). Historical data on medical consultations could not reflect the real need of PHC services of the inhabitants. Thus, the use of this data in the model could perpetuate preexisting inequities in the access to PHC services.

In addition, the use of a socioeconomic index introduces in the analysis an equity criterion in the access to health care, which requires prioritizing (in terms of access) the population of those census radiuses that have the greatest necessity of health care.

Socioeconomic indexes may be used to indirectly assess the health care needs of the population, given the strong correlation between the level of economic deprivation and the levels of morbidity (Álvarez-del Arco et al., 2013; Australian Institute of Health and Welfare, 2014; Field, 2000). The complexity of the conceptualization and development of indicators to measure the socioeconomic level is reflected in the heterogeneous composition of the different indexes developed (Álvarez-del Arco et al., 2013). The index used in this work was constructed through a factor analysis of socioeconomic data (related to the dwellings, homes and population characteristics) at census radiuses level. All the statistical information was obtained from the National Census of Population, Homes and Dwellings of the year 2010 (INDEC, 2019).

The variables related to the housing characteristics included: i) the percentage of dwellings constructed with poor resistant or low-quality materials, ii) the dwellings proportion with insufficient access to public services neither possessing water from the public network nor sewage to a septic tank (or sanitary sewer network connection). The variables related to the homes characteristics took into account: i) the proportion of homes that share bathrooms with other homes, ii) the percentage of homes that feature at least one unmet basic needs (UBN) indicator and, iii) the percentage of homes that own a house of their own. Lastly, the variables related to the population characteristics considered were: i) the percentage of people older than six who are not able to write or read, ii) the percentage of people who do not use a personal computer, iii) the percentage of people who has never attended an educational facility, and iv) the percentage of unemployed people. A more comprehensive development of this index can be found in Arnaudo (2017).

The model was instructed to locate 45 PHCC (P=45), leaving aside the centres that only have a nursing service.

The maximum supply capacity of each PHCCs is set at 5,000 consultations per year. Such maximum capacity was estimated assuming that all PHCC are open 5 hours a day and that each medical consultation consumes in average 20 minutes.

2.4 Study Scenarios

Besides the base case, the model was used to analyze the impact of different scenarios on spatial efficiency. Those scenarios were constructed assuming alternative values for two parameters: the number of PHCC to be established or the capacity of each PHCC.

The reason to choose those parameters were different public statements made by local politicians in charge of the PHCCs' management, in which they assured their intention to provide additional staff to some health care centres strategically located (therefore increasing their supply), and to close some facilities which featured idle capacity (Table 1).

Table 1 – Alternative Scenarios. Maximum supply capacity of each PHCC in annual medical consultations (W_{max} Parameter) and Number of PHCCs to be established (P Parameter).

	W_{max} (number of annual consultations)	P (number of PHCCs)
Scenario 0	5,000	45
Scenario 1	5,000	40
Scenario 2	5,000	35
Scenario 3	7,500	45
Scenario 4	7,500	40
Scenario 5	7,500	35

Source: own elaboration.

Scenarios 0, 1 and 2 are set to analyze the effect of a decrease in the number of open PHCC on the distances traveled by the users, maintaining the actual capacity of each PHCC. Scenarios 3, 4 and 5 keep the same number of PHCC open than the base case and scenarios 1 and 2, but increase centre's capacity by fifty percent.

2.5 Spatial Efficiency Evaluation

To assess the spatial efficiency of current PHCC locations, we compare the distances users must travel to reach a PHCC nowadays against the distances they would travel if all PHCCs were optimally located.

Since there was no data regarding the distances actually traveled by the residents of each census radius of the city of Bahía Blanca in order to receive medical attention at a PHCC, this data was simulated using the location model. In this case, the model's task was limited to assigning the population of each demand node to a PHCC, in such a way that all restrictions were verified, and the distance traveled by users was minimized. In addition, considering that there is no exact information about the existing maximum capacity of each PHCC, in order to make a consistent comparison between the simulated current situation and the optimal scenarios, it was assumed that such capacity was 5,000 consultations per year.

The measures of distance considered in the comparisons are:

1. System's total: the sum of the distances traveled by the entire population to attend to a consultation in a PHCC.
2. Average per consultation: the ratio between system's total travel distance by PHCC users and the aggregate demand of medical consultations.
3. Maximum distance from a census radius to the nearest PHCC.

3 RESULTS

The model was implemented and solved using GAMS alongside the CPLEX solver (Brooke, Kendrick, Meeraus, & Raman, 2012). The software was run in a laptop featuring a 1.2 GHz - 4th generation core i5 processor coupled with 6 GB of DDR3 memory. Maps displaying results were elaborated using QGIS (Project, 2019).

In Figure 1, the results of the calculation of the socioeconomic index per census radius are shown, as well as the PHCCs' current location. In order to make the presentation of the results easier, the census radiuses were divided into quartiles, where the first quartile includes 25% of the census radiuses with the lesser socioeconomic index score, and the fourth quartile includes 25% of the census radiuses with the greatest socioeconomic index scores. Figure 1 shows that the census radiuses with higher values of the socioeconomic index are the ones located in the city's outskirts, which seems to correlate with a higher supply of PHCCs. Nevertheless, this apparent correlation between the current PHCCs' location and the need of health care does not necessarily imply that the current locations of the PHCCs are optimal from the point of view of spatial efficiency. To be conclusive about this, it is necessary to analyze the locations of the PHCCs suggested by the optimization model and compare it with the current situation.

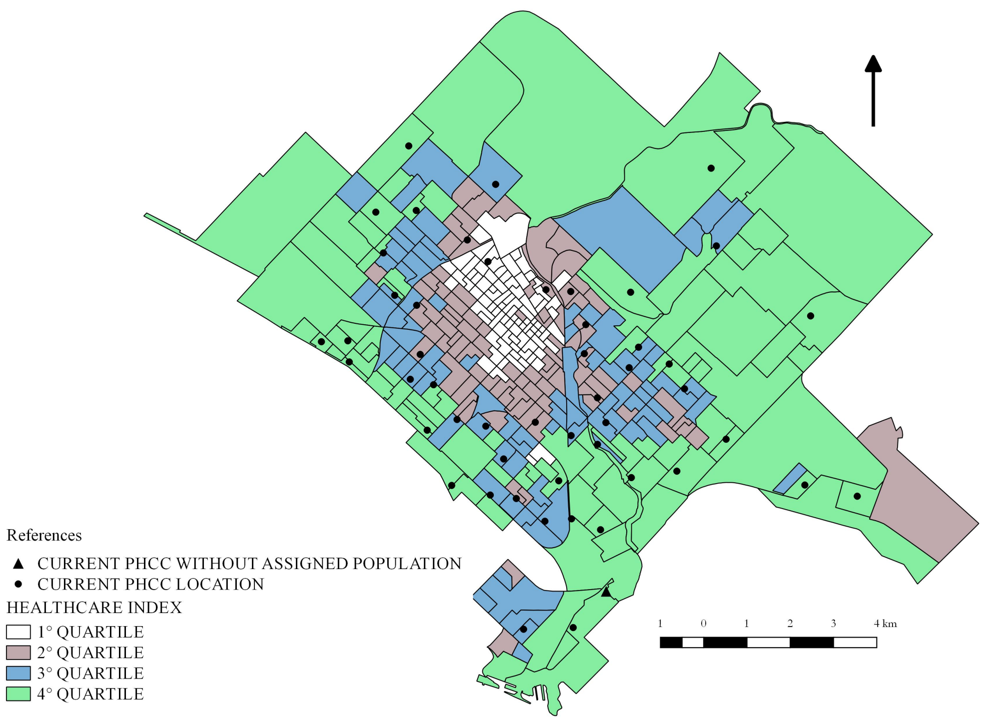

Figure 1 – Census radiuses divided into quartiles according to its sanitary need index score – PHCCs' current location.

Source: own elaboration in QSIG software.

The first remarkable result is that, despite the fact that the current simulated situation is carried out considering that all PHCC are open, the model does not assign population to one of them (Figure 1). In other words, for the given set of parameters of the model, it becomes redundant. In addition, although there seems to be a high correspondence between the current location of PHCCs and the need of health care, according to the model in all the scenarios analyzed an average of 9% of currently open PHCCs are placed in their optimal locations in terms of efficiency.

Table 2 compares the simulated distance currently traveled by the users with the optimal results of the base case. These results suggest that a reorganization of PHCCs locations (while maintaining the same capacity and number of open PHCCs) could reduce system's total and the average per consultation travel distance by 36.1% and 38.8%. Moreover, the distance traveled by users who live in the census radius located farthest to the nearest open PHCC is reduced to a half.

Table 2 – Distances traveled to attend a PHCC (in km).

	System's total	Average per consultation	Maximum
Current Situation	157,674	1.22	4.20
Optimal (Base Case)	100,733	0.75	2.10
Distance reduction (%)	36.1	38.8	50

Source: own elaboration.

Tables 3 and 4 show the result of the scenario analysis. Table 3 tells what happens with the travel distances when the number of open PHCCs is reduced from 45 (base case) to i) 40 PHCC (scenario 1) and ii) 35 PHCC (scenario 2), while keeping the maximum capacity the same as in the base case (5,000 consultations per year). Table 4 shows the same analysis but assuming that capacity is increased a 50% (up to 7,500 consultations per year).

Table 3 – Travel distances (km) for Scenario Analysis.
Maximum capacity set in 5,000 consultations per year.

	System's total	Average per consultation	Maximum
Current Situation	157,674	1.22	4.20
Base Case (45 PHCC)	100,733	0.75	2.10
Sce. 1 (40 PHCC)	110,130	0.80	2.99
Sce. 2 (35 PHCC)	122,464	0.86	3.89

Source: own elaboration.

The data on tables 3 and 4 show that it is possible to reduce the number of PHCC to be installed and still get improvements in terms of total, average and maximum traveled distances with respect to the current situation. However, it is also observed that, regardless the maximum capacity considered, reducing the number of open PHCC increases the total distance traveled in the system with respect to the base case and scenario 3 (those with the highest number of open

Table 4 – Travel distances (km) for Scenario Analysis.
Maximum capacity set in 7,500 consultations per year.

	System's total	Average	Maximum
Current Situation	157,674	1.22	4.20
Sce. 3 (45 PHCC)	100,333	0.74	2.10
Sce. 4 (40 PHCC)	108,703	0.79	2.27
Sce. 5 (35 PHCC)	118,418	0.87	3.41

Source: own elaboration.

CAPS). Another issue to consider is that decreasing the number of PHCC to be open increases the maximum distance traveled in the system.

4 DISCUSSION

One of the main contributions of this research is to show how mathematical models of location-allocation can be used to evaluate the spatial efficiency of past location decisions regarding PHCCs and other public facilities.

Moreover, our research can be related to the Efficiency Frontier literature. Techniques such as Data Envelopment Analysis (DEA) or Stochastic Frontier Analysis use a sample of firms to construct an efficient production frontier, based on the best observed practices. This frontier is used to benchmark the actual performance of an institution in terms of its technical and allocative efficiency. In a similar fashion, the optimal solution identified by the p-median model is used in this study to benchmark the performance of a set of locations of PHCCs in terms of its spatial efficiency.

Although there are other works in the literature aimed at evaluating the spatial efficiency of a set of PHCCs (or other public facilities) most of them do not use mathematical programming techniques to determine the optimal locations. The only previous work that applied our same procedure to measure spatial efficiency (Kumar) developed an uncapacitated model to obtain the optimal solution, while we used a capacitated one. In small, highly populated areas, this difference could be crucial.

When assessing the conclusion of this paper, some limitations of the analysis must be considered. First, the optimal situation implicitly assumes the possibility of relocating all existing PHCCs, which is unrealistic. Second, the distances currently traveled by the population to access the PHCCs had to be simulated. As long as the capacity constraint is not binding, this procedure implicitly assumes that people always attend the nearest facility. It is evident that this is not necessarily true, as the inhabitants have the possibility to choose freely the facility they wish to attend. However, this option was chosen given that the information of effectively traveled distances is not available. Third, it must be considered that it was assumed that the quality of each PHCC services as well as their opening hours is identical, so that the choice of a centre by the users will depend only on the distance. Last, it is only considered that the population travels by own vehicle, being desirable to incorporate the possibility of public or pedestrian transport.

The model developed in this paper could also be used to decide the optimal locations of a set of PHCCs from scratch, in a context in which every user is assigned a PHCC to which he or she must attend in a mandatory way. This kind of institutional rule (lack of free choice of PHC provider) is not uncommon in Argentina, and many cities manage their PHCC facilities in this way. This application of the model will allow to omit the first three limitations mentioned earlier, having the authorities the responsibility to guarantee the same level of quality in all centres. The model could also be modified to analyze where to optimally locate new PHCCs, given the current location of the existing centres, or it could be instructed to re-localize a limited number of centres.

This research can be extended in diverse directions. An evident alternative would be to estimate the distances currently traveled from a field study, taking a sample of the population that attends the city PHCCs and registering their place of residence. Data obtained from a population's sample could also be used to refine the assessment of the population's needs, gathering relevant information not available in the census. Another possibility consists in postulating a function of attendance probability to PHCC related to the distance that the residents of each node must travel, where longer distances would be associated with lower attendance probabilities. Last, the model should be modified to include the probability that the population uses alternative means of transport.

5 CONCLUSIONS

The purpose of this work was to analyze the efficiency of the spatial allocation of the public PHCCs in Bahía Blanca city, Argentina. The relevance of this analysis is justified by the existence of numerous studies that have proved that the distances that potential users must travel can be decisive in facilitating (and ensuring) their attendance to a PHCC. Accordingly, an incorrect spatial distribution can reduce the effectiveness of the PHCC policies, which ultimately translates into a lower status of the population's health and/or higher costs for the health system, given the need to assist illness situations that could have been prevented or mitigated.

The analysis explicitly included an objective of equity in access to public health services, as more consideration was given to the demand nodes with the higher percentage of the population in conditions of socio-economic vulnerability. The choice of socio-economic variables to estimate the index of health care need was justified by: i) positive association between poverty and illness, and ii) the fact that the most vulnerable populations generally lack health insurance, since they usually work in the informal economic sector.

The results indicate that the spatial disposition of the PHCC facilities in Bahía Blanca city is inefficient. In particular, the distances traveled by the population (considering their different needs of medical attention) could be reduced up to 39%, taking as reference the optimal solution of the base case. In this instance, with a similar budget, the population's geographical accessibility would improve. Likewise, comparing the current situation with scenarios 1 and 2, in which a lower number of PHCCs are installed and a similar maximum capacity of attention as at present is supposed, there is evidence that the arrangement efficiency could improve with lower costs for the health system. In this way, the accessibility of the population to health services could be enhanced with less economic effort by the public sector.

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