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Territorial Amalgamation Decisions in Local Government:
Models and a Case Study from Italy

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Abstract

In the context of general welfare reforms in western economies, a recent trend has concerned the rationalization of administrative structures of local authorities, including a reduction in the number of administrative levels and units (through mergers and amalgamation processes) and the subsequent rearrangement of their boundaries. In this paper, we develop mathematical models to analyze amalgamation and redistricting policy decisions implemented in Italy. Results provided by such models can provide valuable support to stakeholders and policy makers.

1. Introduction

In recent years, in order to reduce public expenditure, central and local authorities have been involved in the rationalization and reorganization of systems providing public services, such as healthcare, education, public administration, justice (Wollmann, 2004; Denhardt et al., 2013). In this context, many actions concerning the restructuring of local government administrative units have been undertaken, with the primary aim of amalgamating political jurisdictions and their public service provision areas (Warner, 2010; Jakobsen and Kjaer, 2016; Teles, 2016). For instance, in the United Kingdom, several structural changes to local government have been implemented in different historical periods (Boyne and Cole, 1998). The most recent round of reorganization actions began in 2006, after the publication of the White Paper 'Reforming Local Government', and focused on the creation of new unitary authorities in parts of the country still characterized by a 'two-tier' system of counties and districts (Leach, 2009; Andrews and Boyne, 2012). At the same time, in Italy there has been a heated debate on local government and administration reorganization. This is testified by a series of reform proposals aimed at merging and rearranging current territorial administrative units (Bolgherini, 2014). In particular, the reform process concerning the restructuring of Italian provinces has been articulated into two main phases. In the first one, the government redefined competences of new provinces, in terms of services that they will have to provide to the population living within their boundaries (Gazzetta Ufficiale, 2014); in the second phase, a first proposal of a new partition of the territory into provinces has been sketched, taking into account a set of requirements in terms of minimum population and extension (Gazzetta Ufficiale, 2012). However, this proposal failed in reaching a consensus due to the

difficulty of combining the need for more efficient territorial configurations and the safeguard of public services accessibility in local communities.
As stated by Meligrana (2005) and Allers and Geertsema (2016), while local government organization is under significant pressure for reform, there is a historical lack of methods and tools that could help officials in making these decisions. As an effect, such decisions are often performed by using ad-hoc procedures.
In this work, the problem of reorganizing Italian administrative subdivisions has been formulated in terms of a *redistricting problem.* In such a problem, an initial district map is already available; more precisely, territorial units (municipalities and/or local communities) of a given region are already grouped in districts (provinces). Within each district, a local authority is responsible for providing many essential services through some facilities (generally located in the chief-town). Specifically, Italian provinces provide the following services to the local populations: highways design, maintenance and upgrades; education planning (staff and resource planning, provision of vocational qualification courses, design, maintenance and upgrades of school facilities); public transport provision; environmental protection (waste, water and energy management and planning, disaster relief services); welfare and social security. Since the aim is to reduce the number of active districts, resulting new local authorities will need to serve wider areas, with some potential effects on the population that should be carefully assessed.
Considering this specific problem, some novel mathematical programming formulations (adaptable to analyze similar problems in different contexts) will be proposed in this paper; also, results provided by these models will be compared to the amalgamation proposals by the Italian government.
The remainder of the paper is organized as follows: the next section is devoted to the description of the Italian administrative system and of the current subdivision of the territory in provinces. Then, an overview of the literature background is provided; subsequently, some mathematical models are introduced to address the specific Italian redistricting problem. Results provided by the application of the different models to a real case study are analyzed and compared. Finally, conclusions are drawn, along with future research directions.

2. The Italian provinces

EUROSTAT (2002) introduced a standard classification for the subdivision of European countries in territorial units, named Nomenclature of Units for Territorial Statistics (NUTS), with the aim of producing comparable administrative units across different countries. For each EU member country, a hierarchy of three levels was defined. Figure 1 shows such subdivision into NUTS 1 (a), NUTS 2 (b), NUTS 3 (c), while Table 1 summarizes information regarding the number and the size of each level for the main EU countries. In most cases, NUTS subdivisions correspond to administrative boundaries; for example, in Italy Levels 2 and 3 correspond respectively to the administrative subdivision in regions and provinces. Comparing figures in Table 1, with reference to Level 3 units, it emerges that Germany is characterized by the highest number of units (529), with the lowest average population and area. This peculiarity may depend on the federal organization of the country, which makes figures related to its subdivision not comparable with those of the other EU countries. However, if compared with more similar countries, Italian provinces (NUTS 3) are the smaller and less populated ones.

(a) NUTS – 1 (b) NUTS – 2 (c) NUTS – 3

Figure 1 – Subdivision of UE countries according to EUROSTAT (2002) Nomenclature of Units for Territorial Statistics (NUTS)

COUNTRY			NUTS 1			NUTS 2			NUTS 3		
	Inhabitants (A)	Area (B)	#	(A1)	(B1)	#	(A2)	(B2)	#	(A3)	(B3)
France	65.447.374	543.965	9	7.271.930	60.440	26	2.517.207	20.921	100	654.474	5.439
Germany	83.000.000	357.023	16	5.187.500	22.313	39	2.128.205	9.154	429	193.473	832
Italy	60.626.442	301.340	5	12.125.288	60.268	21	2.886.973	14.349	110	551.149	2.739
Poland	38.626.349	313.893	6	6.437.725	52.315	16	2.414.147	19.618	66	585.248	4.755
Spain	43.967.766	504.614	7	6.281.109	72.087	19	2.314.093	26.558	59	745.216	8.552
UK	63.181.775	244.820	9	7.020.197	27.202	30	2.106.059	8.160	93	679.374	2.632

Table 1 – Number and size of NUTS 1,2,3 in the main EU countries

Due to the general political and economic context, the current partition of the Italian territory in provinces is considered unsustainable. Hence, the central government has promoted several reform projects aimed at reducing the number of provinces. After several consultations, the implementation of such projects has been articulated in two subsequent steps: (i) the identification of provinces to be suppressed; (ii) the re-aggregation, at a regional level, of suppressed provinces to the remaining ones.

The first step was performed through the definition of some *feasibility requirements* (Gazzetta Ufficiale, 2012); in particular, it was established that provinces with an area lower than 2500 km^2 or a population of less than 350,000 inhabitants should have been deactivated. The re-aggregation process would be then realized by merging provinces (within each given region) in order to form new aggregations satisfying feasibility requirements. Figure 2 shows the current subdivisions of Italy in provinces; provinces satisfying feasibility requirements are highlighted in green, while those not satisfying them are highlighted in red. Figure 3 shows a map representing the new configuration proposed by the Italian government. In the following we will analyze in detail the configuration proposed for one particular region, comparing it to the ones provided by proposed mathematical models.

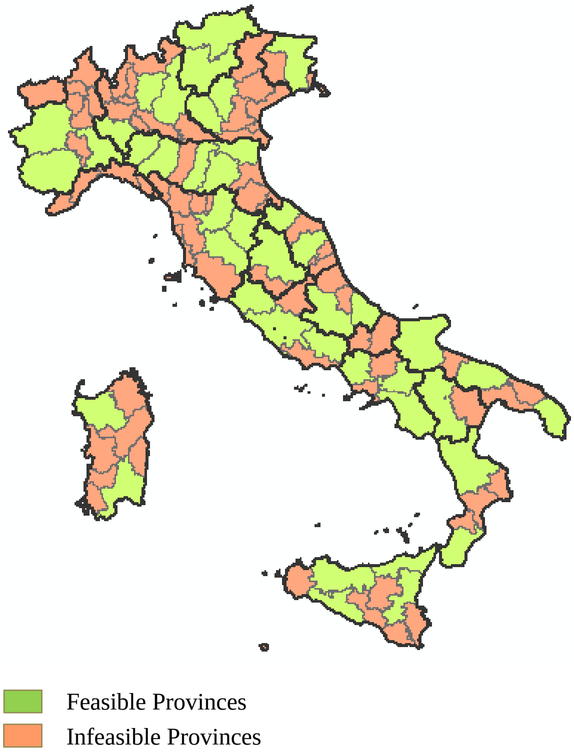

Figure 2 – Feasible and Infeasible provinces

Figure 3 – Government Proposal

3. Literature background

The debate about the optimal configuration of local government, in terms of administrative levels and size of jurisdictions is not new. Oates' (1972) decentralization theorem suggests that smaller administrative districts could provide a better solution for accommodating local needs of cost-effective provision of public services (especially in heterogeneous territorial contexts). However, recent cuts to public expenditure impose the design of jurisdictions that are sufficiently large, by implementing amalgamation processes (often promoted through top-down reform processes). Starting from a reduction in the number of Local Authorities (obtained through merging and boundary alteration processes), these processes seek to rationalize systems providing public services (such as healthcare, education, public administration and justice at a territorial level), with the ultimate aim of taking advantage of economies of size (Allers and Geertsema, 2016).

Amalgamation decisions generally involve an element of territorial design; existing jurisdictions should be merged or undergo a process of boundary alteration in order to create a new territorial design meeting certain conditions.

In the extant literature, the process of creating regions, starting from elementary units is referred to by wide range of names, including *region-building* (Byfuglien and Nordgard, 1973), *regional clustering* (Maravalle and Simeone, 1995), *regionalization* (Wise et al., 1997), *territorial districting*, with the latter being, by far, the most prolific literature stream, as testified by surveys appeared in the last decades (Duque et al., 2007; Kalcsics, 2015).

Territorial districting problems aim at partitioning a given territory in a fixed number of sub-areas, named *territories* or *districts*. The reference territory is usually divided into elementary

units, each of them associated with a set of attributes (e.g., population, area), that have to be grouped in districts in such a way that constraints on their dimension and topology are satisfied. Constraints on the dimensions typically involve limitations on maximum and/or minimum population and/or area to be assigned to each district. Topological properties may involve the *contiguity* of districts (i.e., districts should not be divided into two or more geographically separate entities) and their *compactness* (i.e., the extent to which the shape of a district is spread out from its center and the regularity of its boundaries). Other conditions may include the respect of natural borders or of pre-existing administrative partitions, as well as aspects concerned with socio-economical homogeneity. Territorial districting problems are suitable to describe a wide variety of decision-making issues; hence, a variety of models and algorithms have been proposed in order to deal with applications in the fields of public and private services. In this case, the goal is to design sub-areas for which facilities are responsible for service provision. In this context, many authors dealt with the problem of the school districting, i.e., the problem of identifying the groups of children attending each school (see e.g. Ferland and Guénette, 1990; Schoepfle and Church, 1991); others addressed the problem of organizing the solid waste disposal service, i.e. the partitioning of the streets in which waste need to be collected into sectors that have to be visited by single garbage trucks (Hanafi et al.,1999). In these cases, contiguity and compactness properties are utilized as a proxy for the accessibility of the services provided at district centers.
Another application is related to the design of political districts, i.e., electoral constituencies. In such context, the goal is to partition the territory under consideration in such a way that no political party should be able to take advantage from the territorial subdivision (see e.g. Hess et al., 1965; Williams, 1995; Hojati, 1996; George et al., 1997; Mehrotra et al., 1998; Bozkaya et al., 2003, Ricca and Simeone, 2008; Ricca et al., 2011). In this specific case, constraints about contiguity and compactness have the main aim of ensuring that resulting districts will have regular shapes, as a way to guarantee the impartiality of the map.
Within the political districting body of literature, significant attention has been devoted to *redistricting problems*. Indeed, due to demographic changes, the partition of an area into electoral districts must be constantly reviewed and modified (Williams, 1995, Kalcsics, 2015). As such, redistricting approaches are mainly concerned with the use of local search techniques and/or metaheuristics in the design of an improved district map, by gradually modifying the initial one, for example by swapping units between neighboring districts (Browdy, 1990; D'Amico et al., 2002; Bozkaya et al., 2003).
However, it must be noticed that, within the stream devoted to service-oriented applications, few contributions deal with *redistricting* problems. Among them, Silva de Assis et al. (2013) propose a mathematical model for a redistricting problem applied to the meter reading in power distribution networks. They considered a utility concession area, already partitioned into districts, each assigned to a group of meter readers, performing in situ readings of power consumption from customers. Such map, due to some occurred changes on the demand side (expansion of cities, people migration, and uneven changes of power demand in the suburbs), became inefficient (for example in terms of workload balance). Hence, they formulated a model aimed at modifying the initial partition in p districts, where p can be greater, equal or lower than the current number of districts.

In this work, we want to address a similar problem in which an amalgamation process of local authorities needs to be conducted, due to economic reasons that impose to reduce the number of facilities providing services and, hence, active districts. In such process, the damage on the population in terms of accessibility to the services must be minimized. Coherently to discussed service-oriented territorial districting problems, contiguity and compactness properties will be utilized as a proxy for district centers accessibility.

The following section will propose some mathematical models to deal with the described problem.

4. Optimization models for the reorder of the Italian provinces

In the current Italian local government structure, each region is composed of a certain number of municipalities grouped in *provinces*. Moreover, within each province, a specific municipality (named *chief town*) hosts facilities providing a set of services to the local population. In order to reduce the total management costs, the Italian central government promoted a reorganization of the current administrative structure, by reducing the number of provinces, and, therefore, chief towns. In order to guide such process, some requirements were defined (Corriere della Sera, 2013), in terms of minimum population (300000 inhabitants) and area (2500 km^2) of the provinces. In the following, we will indicate as:

- *Feasible,* a district meeting the defined requirements;
- *Infeasible*, a district not meeting the defined requirements.

The proposed models will have to deal with two different type of decisions:

- *closure decisions*, i.e. the identification of the subset of chief towns to be closed;
- *reallocation decisions*, i.e. the reassignment of territorial units to active chief towns.

Closure decisions will be strongly influenced by the definition of governmental requirements. However, two different approaches were formulated in order to take such requirements into account in the models:

- a *prescriptive approach*, for which all districts not meeting the requirements in the current configuration have to be closed (this is the one adopted by the Italian government in the formulation of its proposal);
- an *optimal approach*, for which the model may decide the administrative chief towns to be closed, provided that in the final configuration all districts meet the given requirements.

In practice, the number of districts in the solution provided by the prescriptive approach is given *a priori*, by the number of feasible districts.

Similarly, also for the reallocation decisions, two different strategies were defined:

- *Merging existing district*s, i.e. reallocating entire closed districts to one of the active chief towns (this is the approach adopted by the Italian government in the formulation of its proposal);
- *Reassigning territorial units*, i.e. performing a reallocation process of single municipalities to active chief towns.

It is obvious that the reallocation of single territorial units generally provides better solutions; however, this approach may require significant reorganization efforts as units initially belonging to the same district could be split into different new districts. Hence, in this case, the negative consequences may outweigh the benefits arising from the reductions of the

number of active districts, as discussed in Andrews and Boyne (2012) and Allers and Geertsema (2016).
By combining these approaches, four classes of redistricting models can be introduced (Table 2).

		Closure Decision	
		Prescriptive	***Optimal***
Reallocation Decision	***Single Territorial Units***	*Prescriptive Reassigning Model (PRM)*	*Optimal Reassigning Model (ORM)*
	Entire Existing Districts	*Prescriptive Merging Model (PMM)*	*Optimal Merging Model (OMM)*

Table 2 – Classes of redistricting problems

Despite the specific adopted approach, a common structure can be traced in the four models, composed by the following main components:

- *objective function*, defined in terms of compactness of the resulting districts. Such objective, usually employed in the districting models, is particularly appropriate as it represents a proxy of users' accessibility;
- *constraints on physical requirements,* in order to take into account the conditions imposed by the decision-maker (for instance, constraints on the minimum and maximum districts' size);
- *reassignment constraints*, to rule the reassignment of territorial units to active districts and chief towns;
- *other constraints*, including further aspects of the problem, such as the contiguity of resulting districts, the respect of pre-existing boundaries, the presence of special districts.

Moreover, a common notation can be introduced:

i	index associated with the generic territorial unit ($i \in I = \{1...n\}$);
j	index associated with the generic existing district ($j \in J = \{1...m\}$);
$J^* \subset J$	set of special districts ($\|J^*\| = q$);
$c_j \in I$	chief town of district j, i.e. unit in which the facility providing services is located;
$\bar{c}_j \in I$	centroid of district j, corresponding to the solution of a weighted $1-$*median* problem within the district j;
r_{ij}	binary label equal to 1 if unit i is initially allocated to district j, 0 otherwise;
d_{il}	distance between units i and l.

Furthermore, the following sets of decision variables have to be defined:

y_j binary variable equal to 1 if and only if the chief town of district j gets closed;

x_{ij} binary variable equal to 1 if and only if unit i is assigned to the chief town of district j.

Formulations are presented assuming that requirements are defined in terms of minimum population and area per each district; therefore, the further notation below has to be considered:

p_i population of unit i;

s_i area of unit i;

$P_j = \sum_{i \in I} p_i r_{ij}$ total population of district j;

$S_j = \sum_{i \in I} s_i r_{ij}$ total area of district j;

P_{min} minimum required population per district;

S_{min} minimum required area per district.

In the following, the mathematical formulations of the proposed models are introduced. In particular, for the sake of clarity, we opted for introducing first the class of Reassigning models and then the Merging ones, describing within each class the Prescriptive and the Optimal approaches. In fact, the merging strategy may be viewed as a particular case of the reassigning strategy and, hence, the related models may be formulated by properly adapting reassigning models.

4.1 Reassigning Models (Prescriptive vs Optimal)

The *Prescriptive Reassigning Model (PRM)* considers the shut-down of chief towns that do not meet the requirement and the subsequent reassignment of the related territorial units (previously part of this suppressed district) to the ones that have been kept active. The *PRM* can be formulated as follows:

$$\min z = \sum_{i \in I} \sum_{j \in J} p_i d_{ic_j}^2 x_{ij} \tag{1}$$

$$P_{min}(1 - y_j) \leq P_j \qquad \forall j \in J - J^* \tag{2}$$

$$S_{min}(1 - y_j) \leq S_j \qquad \forall j \in J - J^* \tag{3}$$

$$(1 - y_j)\, r_{ij} \leq x_{ij} \leq 1 - y_j \qquad \forall i \in I, \forall j \in J \tag{4}$$

$$\sum_{j \in I} x_{ij} = 1 \qquad \forall i \in I \tag{5}$$

$$y_j = 0 \qquad \forall j \in J^* \tag{6}$$

$$y_j \in \{0,1\}; x_{ij} \in \{0,1\} \qquad \forall i \in I, j \in J \tag{7}$$

The objective function (1) is one of the classical measures of compactness, defined as the weighted sum of the square of the distances among each unit i and the chief town of its assigned district j.

Constraints (2-3) represent governmental requirements. In particular, they impose that only districts having an area larger than S_{min} and a population larger than P_{min} can be kept open. Expressions (4-5) deal with reassignment constraints, which rule the reallocation mechanism of territorial units to districts that have been kept active. In particular, constraints (4) impose that only units belonging to closed districts can be affected by reallocation decisions, being redistributed across active districts, while constraints (5) ensure the allocation of each territorial unit to one (and only one) district. Equations (6) represent an example of additional constraints, indicating the presence of a set of special districts that cannot be closed. Finally, constraints (7) define the nature of the decision variables being introduced in the model.

The *Optimal Reassigning Model (ORM)* differs from the *PRM* for the criterion used to select districts to be closed. In this case, every district, apart from the special ones, represents a candidate for the closure. Then, the model is aimed at determining *how many* and *which* chief towns have to be closed, in such a way that the reassignment process will produce new feasible districts. Among all the solutions, the model selects the most efficient one in terms of objective function, minimizing the average distance between each territorial unit and its own chief town (1). In this case, in the formulation, it is sufficient to replace the groups of constraints (2-3) with the following ones:

$$\sum_{i \in I} p_i x_{ij} \geq P_{min}(1 - y_j) \qquad \forall j \in J - J^* \qquad (8)$$

$$\sum_{i \in I} s_i x_{ij} \geq S_{min}(1 - y_j) \qquad \forall j \in J - J^* \qquad (9)$$

Constraints (8) assure that the population of a district which is kept active $(y_j = 0)$ is at least equal to P_{min}, while constraints (9) impose similar conditions on the area.

The *ORM* identifies the minimum number k^* of chief towns to be closed in order to produce feasible districts. However, it is also possible to include in the model an additional constraint about the desired number k of chief-towns to be closed:

$$\sum_{j \in J} y_j = k \qquad (10)$$

Of course, in order to find feasible solutions, k must be larger or equal than k^*.

Both the versions of the model may also include an explicit formulation of the contiguity condition.

4.2 Merging Models (Prescriptive vs Optimal)

In this class of models, the strategy consists of aggregating entire existing districts. With this aim, each *current district* j can be considered as a single *territorial unit* $(I = J)$, with the total population P_j and area S_j concentrated in correspondence of its *centroid* $\bar{c}_j$. Then, here, the terms *territorial unit*, *existing district* and *centroid* can be considered equivalent. In the

current configuration, each centroid $\bar{c}_j$ is assigned to the related chief town c_j; therefore, $\{r_{ij}\}$ is an identity matrix of order m. When a certain c_j gets closed, the related district, as a whole, has to be assigned to another active chief town and, hence, to be merged with another district.
In particular, the *Prescriptive Merging Model (PMM)* closes the chief towns that do not meet the requirements (2-3) and reassigns the related entire districts to the ones that have been kept active.
On the other hand, the *Optimal Merging Model (OMM)* determines the chief town to be closed in such a way that the reassignment of the related districts will produce new feasible districts.
Compared with the mathematical formulations of the *PRM* and *ORM*, the corresponding merging models require the following modifications:

- the objective function (1) has to be modified in order to consider the distance between the centroid of each district $t \in J$ and its assigned chief town, weighted by the total population of the district itself:

$$z = \sum_{t,j \in J} P_t d^2_{\bar{c}_t c_j} x_{tj} \tag{11}$$

- the reassignment constraints (4-5) have to be adapted by considering that each district represents a single territorial unit $(I = J)$:

$$(1 - y_j)\, r_{tj} \le x_{tj} \le 1 - y_j \qquad \forall t,j \in J \tag{12}$$

$$\sum_{j \in J} x_{tj} = 1 \qquad \forall t \in J \tag{13}$$

Also in this case, both the versions of the model may include an explicit formulation of the contiguity condition, which should be now related to entire districts and not to single territorial units.
Table 3 summarizes the characteristics of the introduced formulations.

			Closure Decision	
			Prescriptive	***Optimal***
Reallocation Decision	***Single Territorial Units***		***PRM***	***ORM***
		Objective Function	(1)	(1)
		Physical Requirements constraints	(2 – 3)	(8 – 9)
		Reassignment Constraints	(4 – 5)	(4 – 5)
		Other Constraints	(6)	(6 – 10)
	Entire Existing Districts		***PMM***	***OMM***
		Objective Function	(11)	(11)
		Physical Requirements constraints	(2 – 3)	(8 – 9)
		Reassignment Constraints	(11 – 12)	(11 – 12)
		Other Constraints	(6)	(6 – 10)

Table 3 – Characteristics of formulations of the described redistricting models

5. The case study

The proposed models were tested on a case study concerning the largest Italian region. Lombardia is the most populated region in Italy (almost 10 million inhabitants), characterized by a remarkable number of municipalities (1544 territorial units) currently grouped in 12 provinces (districts) (see Figures 3 and 4). The region is involved in the general reorganization process described in Section 2; Table 4 provides a description of the current configuration, reporting, for each province j, the number of territorial units, the total population, the area and the radius R_{mj} (i.e. the distance between the province chief town and the farthest municipality assigned to it).

Population data for each unit comes from the most recent census figures (ISTAT, 2011), while distances among municipalities have been calculated as shortest routes (in km) on the road network (considering motorways, national and regional roads).

Considering the current configuration (Table 4), only three provinces (Bergamo, Brescia and Pavia) satisfy both the feasibility requirements imposed by the government (i.e. minimum area of 2500 km^2 and minimum population of 350.000 inhabitants). Therefore, a reduction in the total number of districts might produce a more efficient solution.

Figure 3 – Municipalities of Lombardia region

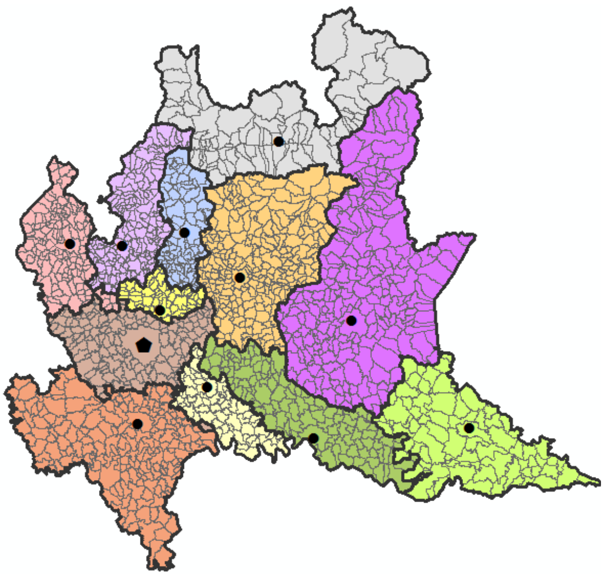

Figure 4 –Provinces (and related municipalities) of Lombardia region

	Districts (Provinces)	Territorial units (Municipalities)	Population	Area (km^2)	R_{mj} (km)
	Bergamo	244	1.086.277	2.745,94	65,63
	Brescia	206	1.238.044	4.785,62	114,68
	Como	160	586.735	1.279,04	63,12
	Cremona	115	357.623	1.770,46	65,13
	Lecco	90	336.310	814,58	41,84
	Lodi	61	223.755	782,99	43,33
	Mantova	70	408.336	2.341,44	59,64
	Milano*	134	3.038.420	1.575,65	59,23

	Monza	55	840.129	405,41	24,88
	Pavia	190	535.822	2.968,64	71,23
	Sondrio	78	180.814	3.195,76	79,62
	Varese	141	871.886	1.198,11	46,00
	Total	**1.544**	**9.704.151**	**23.864**	
	Average	**129**	**808.679**	**1.989,64**	**61,19**

**** Regional Chief Town***

Table 4 – Characteristics of the case study of Lombardia region

5.1 Models Results

The described case study was utilized as a test problem, in order to analyze the solutions provided by the four proposed models, also comparing these to both the current configuration and the governmental proposal. It must be noted that, in all models, Milano was labeled as "special district", due to its role of regional chief town, along with Sondrio, due to the physical characteristics of its territory (mainly composed of Alpine areas and therefore not suitable for mergers with other areas of the region).

Each model has been optimally solved using IBM ILOG Cplex 12.2 on an Intel Core i7 with 1.86 GHz and 4 GB of RAM. Each provided solution has been represented on a map through a linkage with a GIS. All models have been applied without the inclusion of explicit contiguity constraints. Hence, contiguity conditions have been assessed *a posteriori*, through the support of the GIS; and solutions have been heuristically modified in presence of non-contiguities.

In the following, the results provided by each model are examined and discussed. In particular, we first consider the solutions obtained by the prescriptive models and then those by the optimal ones. Finally, solutions are compared among themselves and to the one proposed by the government.

- *Prescriptive Models*

Prescriptive models suppress all infeasible districts (except the special ones) and reassign the related territorial units to the remaining ones (Milano, Bergamo, Brescia, Pavia, Sondrio). While in the PMM version, each closed district is entirely re-assigned to the same chief-town (Figure 6), in the PRM municipalities belonging to the same closed district can be split among different chief towns (Figure 5).

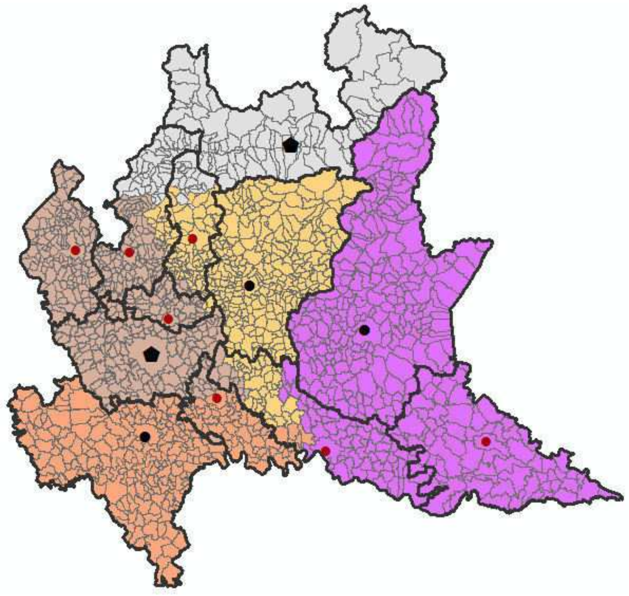

Figure 5 – Map of PRM Solution

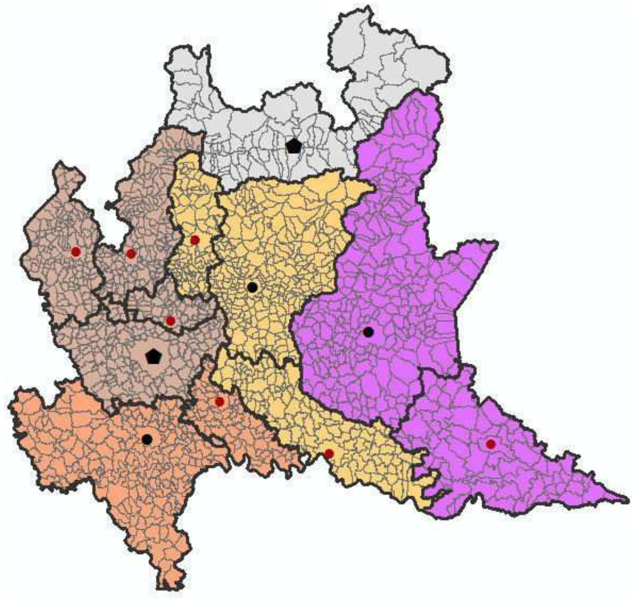

Figure 6 – Map of PMM Solution

	Districts	TUs	Pop.	Area (km^2)	R_{mj} (km)
	Milano	462	5.364.863	4.127,01	119,67
	Bergamo	372	1.539.497	3.920,46	66,63
	Brescia	338	1.825.803	8.228,51	137,21
	Pavia	243	732.128	3.728,52	76,39
	Sondrio	129	241.860	3.859,152	89,01

Table 5 – Characteristics of PRM Solution

	Districts	TUs	Pop.	Area (km^2)	R_{mj} (km)
	Milano	490	5.337.170	4.458,22	119,67
	Bergamo	449	1.780.210	5.330,98	142,68
	Brescia	276	1.646.380	7.127,07	137,21
	Pavia	251	759.577	3.751,63	76,39
	Sondrio	78	180.814	3.195,76	79,62

Table 6 – Characteristics of PRM Solution

The two solutions are characterized by a very limited number of provinces covering very wide areas. In particular, the resulting Bergamo and Brescia districts account for wide areas and a very large R_{mj} value.

- *Optimal Models*

Optimal models identify how many and which districts should be suppressed in order to minimize the objective function. In both cases, the minimum number of districts to be closed in order to obtain feasible contiguous districts is equal to five ($k^* = 5$). Figures 7 and 8 show that the two models close almost the same chief towns. Apart from Milan district (presenting in both the solutions a huge number of inhabitants), the population distribution of the remaining provinces appears to be more balanced in the case of OMM than in the case of ORM. In terms of radius, on the contrary, the solution provided by the ORM appears to be better.

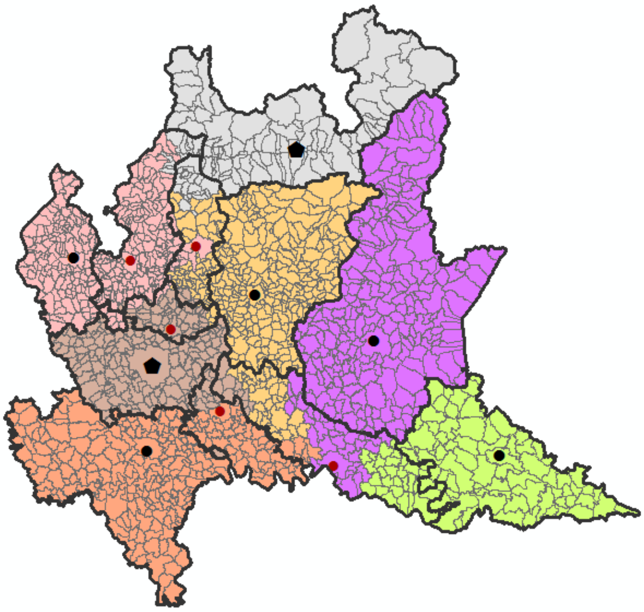

Figure 7 – Map of ORM solution (k=k_{min}=5)

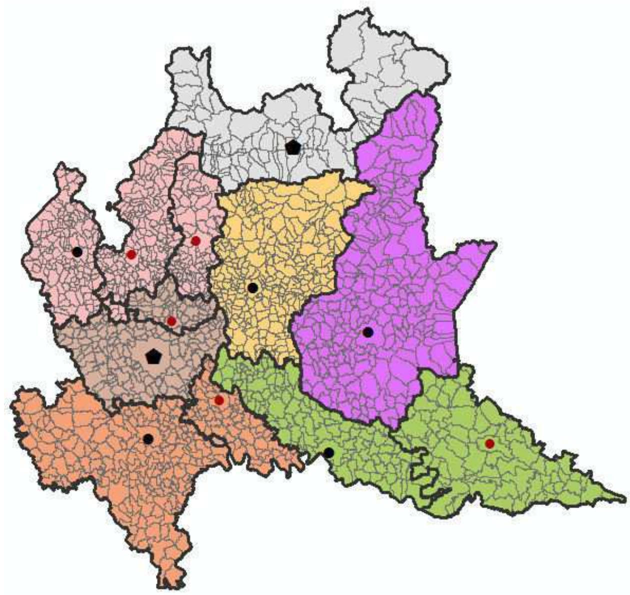

Figure 8 – Map of OMM solution (k=k_{min}=5)

	Districts	TUs	Pop.	Area (km^2)	R_{mj} (km)
	Milano	210	3.930.781	2.229,94	62,26
	Bergamo	344	1.427.265	3.657,61	65,63
	Brescia	238	1.366.144	5.378,33	114,68
	Pavia	242	729.441	3.718,09	76,39
	Mantova	100	459.659	2.850,18	64,48
	Sondrio	106	212.596	3.521,77	79,62
	Varese	304	1.578.265	2.507,74	85,42

Table 7 – Characteristics of ORM solution (k=k_{min}=5)

	Districts	TUs	Pop.	Area (km^2)	R_{mj} (km)
	Milano	189	3.878.549	1.981,07	59,23
	Bergamo	244	1.086.277	2.745,94	65,63
	Brescia	206	1.238.044	4.785,62	114,68
	Pavia	251	759.577	3.751,63	76,39
	Cremona	185	765.959	4.111,90	123,81
	Sondrio	78	180.814	3.195,76	79,61
	Varese	391	1.794.931	3.291,73	97,01

Table 8 – Characteristics of OMM solution (k=k_{min}=5)

- *Comparison with the governmental proposal*

As shown in Figure 3, Italian Government proposed a reorganization of the districts for each single region. Starting from the principle that infeasible provinces should be suppressed (apart the ones labeled as "special districts"), new provinces have been obtained by merging the current ones. This proposal has been obtained by performing, for each region, ad hoc considerations, also taking into account local political factors.

Figure 9 shows the governmental proposal for Lombardia. The following mergers are performed: Milano with Monza; Varese with Como and Lecco; Cremona with Mantova and Lodi. Sondrio, Bergamo, Brescia and Pavia remain unchanged.

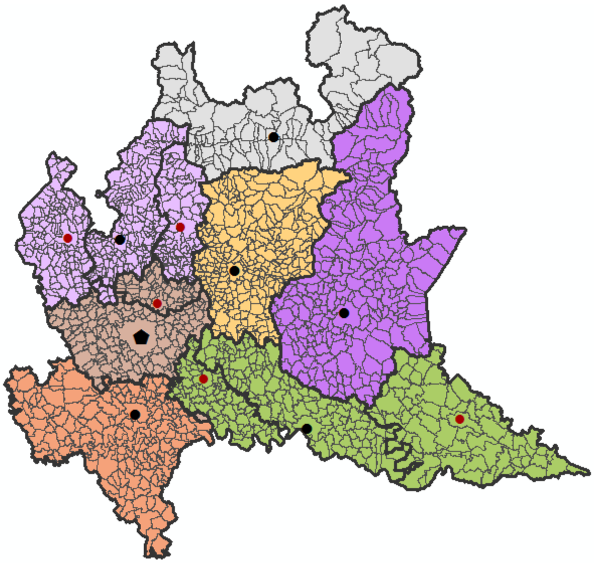

Figure 9 – Government Proposal (k= 5)

	Districts	TUs	Pop.	Area (km^2)	R_{mj} (km)
	Milano	189	3.878.549	1.981,07	59,23
	Bergamo	244	1.086.277	2.745,94	65,63
	Brescia	206	1.238.044	4.785,62	114,68
	Como	391	1.794.931	3.291,73	79,29
	Sondrio	78	180.814	3.195,80	79,62
	Cremona	246	989.714	4.894,89	123,81
	Pavia	190	535.822	2.968,60	71,23

Table 9 – Government Proposal (k= 5)

Comparing this solution to the ones provided by *optimal* models (Figures 7 and 8), many similarities can be noticed, especially with the one provided by the OMM. In this case, the main differences consist in the assignment of the province of Lodi (merged with Pavia instead of Mantova and Cremona) and in the choice of the chief town for the new province of Varese-Como-Lecco (located in Varese instead of Como). The choices of the model seem to be reasonable and produce more compact districts. Indeed, the centroid of the province of Lodi is closer to the chief town of Pavia than to the one of Cremona; moreover, the choice of Varese as chief town for the new Varese-Como-Lecco province guarantees a more compact solution in term of weighted distance.

On the other hand, the solution of the ORM (with $k = 5$) is the best one in terms of compactness (due to the possibility of reassigning single territorial units).

It has to be highlighted that the governmental proposal has not yet been implemented as, at this stage, implemented reforms have been concerned with administrative functions of provinces, without proceeding to amalgamation processes. As such, results from the models could inform policy-makers.

- *Decision making implications*

The proposed models can be used as useful decision support tool for policy makers, as they allow producing multiple scenarios (by varying calibration parameters) that may be compared across appropriate indicators.
An example of this possible usage of the models is shown in the following, where a scenario analysis is performed by varying the number k of districts to be suppressed. Results are compared across the following indicators:

- average, minimum and maximum values for Area, Population, Number of Territorial Units and Radius per district;
- the *Population* (*Area) Variance Index VAR_{pop} (VAR_{sup},)*, i.e. the mean square deviation of the population (area) of the new provinces from the average population (area) value. This index can be assumed as a proxy of the uniformity of the population (area) distribution across resulting provinces.
- the *Compactness index* (I_c), defined as the weighted average distance between a single user/citizen and its assigned chief town:

$$I_c = \frac{\sum_{j \in J}\sum_{i \in I} p_i d_{ic_j} x_{ij}}{\sum_{i \in I} p_i}$$

- the *Hoover Index* (I_H), defined as half of the sum of the differences between the percentages of population and area of each province:

$$I_H = \frac{1}{2} \cdot \sum_{j \in J} \left| \frac{P_j}{P} - \frac{S_j}{S} \right| * 100$$

  where P and S are the total population and area of the region. This index is generally used to evaluate population distribution across a set of districts (Long and Nucci, 1997); the population is considered to be fairly distributed if provinces account for similar shares of population and areas (for instance, a province accounting for 10% of the regional population should also account for 10% of the area). This way, I_H gets closer to 0; on the contrary, I_H gets closer to 100 as unbalances in population distribution grow.

Tables 10a and 10b report the values of the indicators provided by the proposed models, by varying the number k of provinces to be closed (from the minimum feasible value $k = 5$ to $k = 7$, i.e. the number of districts closed by the prescriptive models).

As expected, indicators generally worsen by increasing the number k of districts to be closed. In particular, for $k = 7$, the average value of province Radius increases almost of the 60%, as well as the Average Distance from the chief town, that passes from 17,28 km to almost 27 km.

	Active Districts	Population(inhabitants) 10^3			VAR_{pop} (10^6)	Area(km^2)			VAR_{area} (10^3)
		Avg	Min	Max		Avg	Min	Max	
Current Configuration	12	808	180	3.038	0,78	1.988	405	4.785	1,27
Governmental Proposal	7	1.386.	180	3.878	1,21	3409	1.981	4.894	1,07
ORM (k=5)	7	1.386	212	3.930	1,24	3.409	2.229	5.378	1,05
OMM (k=5)	7	1.386	180	3.878	1,21	3.409	1.981	4.785	0,92
ORM (k=6)	6	1.617	214	4.649	1,59	3.977	2.500	5.792	1,35
OMM (k=6)	6	1.617.	180	4.638	1,57	3.977	2.745	5.732	1,13
ORM (k=7)	5	1.940	241	6.080	2,38	4.772	2.850	7.704	1,88
PRM (k=7)	5	1.940.	241	5.364	2,02	4.772	3.728	8.228	1,94
OMM (k=7)	5	1.940	180	4.638	1,64	4.772	3.195	7.127	1,67
PMM (k=7)	5	1.940	180	5.337	2,01	4.772	3.195	7.127	1,54

	Active Districts	Number of territorial units			Average Distance I_c (*km*)	Radius (km)			*Hoover Index* I_H
		Avg	Min	Max		Avg	Min	Max	
Current Configuration	12	129	55	244	17,28	61	24	114	36,37
Governmental Proposal	7	221	78	391	24,34	84	59	123	36,37
ORM (k=5)	7	221	100	344	21,67	78	62	114	36,9
OMM (k=5)	7	221	78	391	23,93	88	59	123	36,4
ORM (k=6)	6	257	100	444	23,28	85	64	114	29,5
OMM (k=6)	6	257	78	440	25,46	98	65	123	28,5
ORM (k=7)	5	309	100	695	26,48	90	64	119	30,4
PRM (k=7)	5	309	129	462	27,73	97	66	137	38,0
OMM (k=7)	5	309	78	440	27,80	113	79	142	28,5
PMM (k=7)	5	309	78	490	28,86	111	76	142	36,3

Tables 10a (top) and 10b (bottom) – Comparison of the solutions provided by the models

As an example, scenarios with five active districts are discussed (see the last rows of Tables 10 - corresponding to $k = 7$ - and Figure 10) in order to compare results provided by the model.

In this case, solutions are characterized by large districts with an average population of almost 2 millions of inhabitants and an average area of about 5000 km^2. As expected, the reassigning models (ORM and PRM) produce better results than the corresponding merging ones (OMM and PMM) in terms of compactness, as testified by lower values of average distance and radius. However, this result is achieved by worsening the population and area balance among districts, as testified by higher values of the variances (area and population) and of the Hoover Index. In particular, ORM produces a very large district (Milano), composed of about 700 territorial units with a total population of more than 6 millions. This effect may be reduced including in the model balancing constraints (i.e. maximum value of population and/or area).

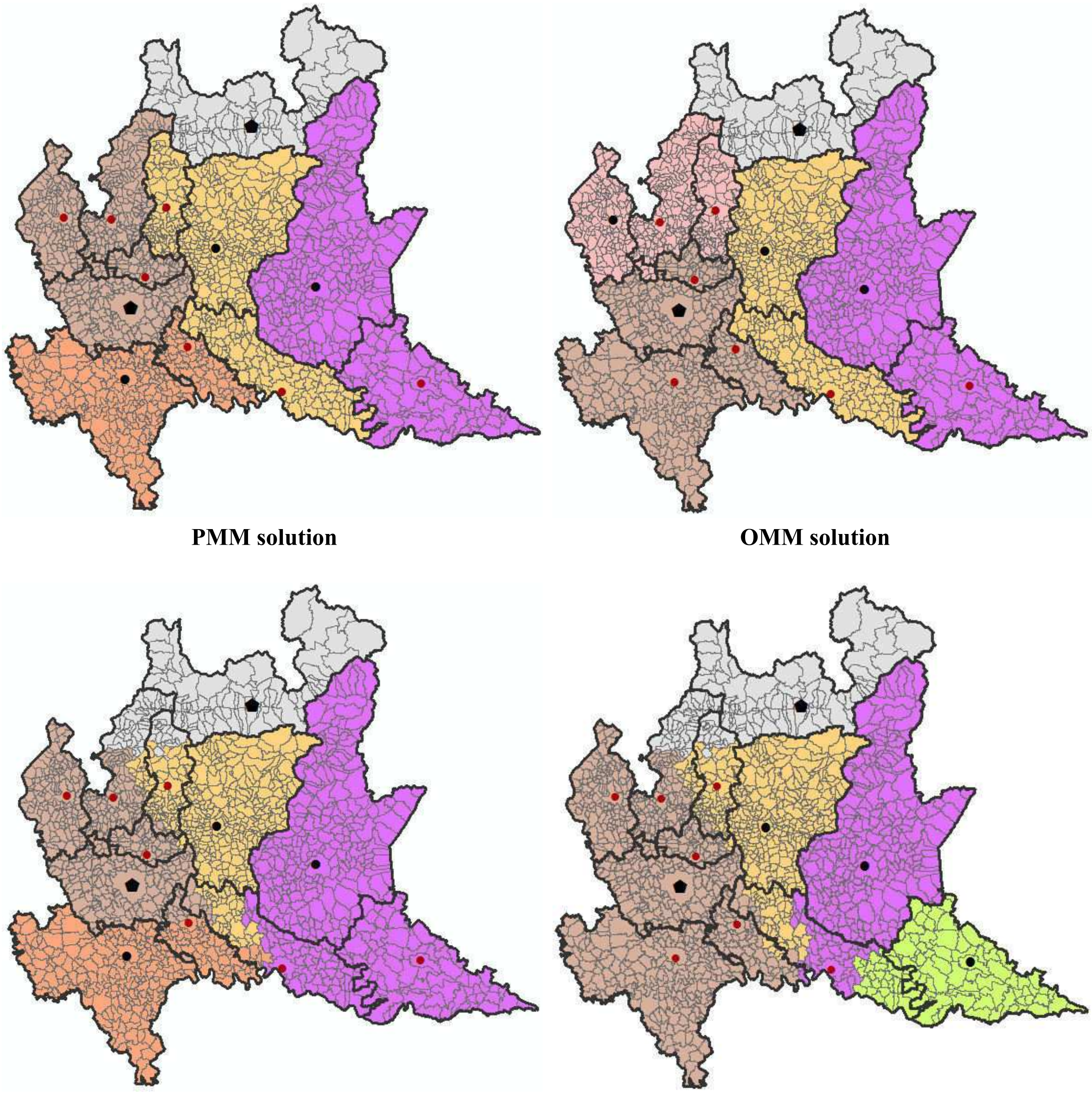

Figure 10 – Comparison of solutions provided by the models for k=7

6. Conclusions

In recent years, mainly due to austerity measures, central and local authorities in many countries have been involved in the rationalization and reorganization of systems providing essential public services. Consequently, due to the territorial organization of such services, many actions concerning the restructuring of local government administrative units have been undertaken, with the objective of reducing associated costs. Specifically, in Italy there have been several reform proposals aimed at merging and rearranging current territorial administrative units, such as provinces.

Starting from this real-world issue, this paper has proposed four mathematical programming models that can be used to perform amalgamation decisions in local government contexts. These models have been tested on the case of the largest Italian region; obtained results show

how models provide solutions with different characteristics and performances. In particular, by appropriately combining calibration parameters, models can provide a wide set of alternative territorial configurations to be analyzed and considered. Also, such configurations have been compared to governmental proposals, through the introduction of a set of appropriate indicators, highlighting how models can produce significantly better outcomes for the amalgamation process. Choices provided by the models are reasonable and produce more compact districts.

Further researches will be addressed at enhancing the models formulations in order to take into account further characteristics (such as balancing or political constraints) that may help in producing further attractive solutions for policy makers.

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