PoleSat, health planning modelling for decision support. Application to a reorganization of the vascular catheterization provision, at the geographic level of “territorial hospital grouping”.

PoleSat, modélisation de la planification sanitaire pour l’aide à la décision. Application à la réorganisation de l’offre de cathétérisme vasculaire au niveau géographique des « groupements hospitaliers de territoire ».

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ABSTRACT. Three factors are essential to the annual optimization objectives of public hospitals: the rapid evolution of medical technologies, budgetary balance, and human attraction. Finding the right territorial analysis tools to achieve the efficiency of the care chains of the territorial hospital groupings is an important lever for the General directorate for healthcare provision, which tested the PoleSat tool in this context. Method: Three planning scenarios for "vascular catheterization" for seven hospital hubs in New Aquitaine were developed: the initial state of supply, the elimination/suppression of the activity of the Rochefort hub and the transfer of the activity of the Rochefort hub to the Saintes hub. The analyses of the modelled zones of influence, i.e., the modelled catchment areas and the modelled distributions of "populations and activities" were compared. Results: The consequences and impacts for the hospital hubs, following the pre- and post-scenario comparisons of the areas covered and the population statistics concerned, are expressed in terms of "risks of loss" and "chances of gain" of activity and patient base. Conclusion: PoleSat meets a need in view of its initial tests and the repeatability of the modelled results. It will be enriched and reused for other databases of care chains/sectors, geographical areas, and territories.

RESUME. Trois facteurs s'imposent aux objectifs d'optimisation annuelle de l'Hôpital Public : l'évolution rapide des technologies médicales, l'équilibre budgétaire et l’attractivité humaine. Trouver les bons outils d'analyse territoriale, permettant d'atteindre l'efficience des filières de soins des groupements hospitaliers de territoires est un levier important de la direction générale de l’offre de soins qui dans ce cadre a testé l’outil PoleSat. Méthode : trois scénarios de planification des "cathétérismes vasculaires" pour sept pôles hospitaliers en Nouvelle Aquitaine ont été élaborés : l'état de l'offre initiale, la suppression de l’activité du pôle de Rochefort et le transfert d'activité de Rochefort vers le pôle de Saintes. les analyses des zones d'influence et des répartitions modélisées des "populations et activités" ont été comparées. Résultats : Les conséquences et impacts pour les pôles, à l'issue des comparaisons pré et post scénarios des aires couvertes et des statistiques, s'expriment en "risques de pertes" et en "chances de gains" d'activité et de patientèle. Conclusion : PoleSat répond à un besoin au vu de ses premiers tests et de la répétabilité des résultats. Il sera enrichi et réutilisé pour d'autres filières de soins, espaces géographiques et territoires.

KEYWORDS. Adapted Newton gravity model, Prospective Studies, Health planning, Decision Making, Geographic Mapping, Management Information Systems, Hospital Restructuring, Delivery of Health Care.

MOTS-CLÉS. Modèle de gravité de Newton appliqué, Études prospectives, Planification sanitaire, Prise de décision, Carte géographique, Systèmes d'information de gestion, Restructuration d'hôpitaux, Prestation de soins de santé.

1. Introduction

Public hospitals in France must constantly adapt and the current objective of decision-makers is an annual optimization of their performance in a context where (1) hospitals are constantly reorganizing, (2) medical technologies are advancing rapidly, and (3) financial constraints are weighing on the establishments. Taking these three factors into account is essential in order to achieve the main objective of optimization, which is to "find a better territorial healthcare distribution, by heath care networks[1] (ressources.anap.fr. 2016b; a) and by Territorial hospital grouping (THG, ***GHT groupement hospitalier de territoire)***". The optimized planning of health territories (Quesnel-Barbet *et al*. 2016 pp. 10-11) now targets each medical and surgical specialty at the level of the THG, ***GHT*** network. Given the objective of improving the efficiency of care networks/chains at the territorial level, the Regional health agencies (RHAs, ***ARSs agences régionales de santé)*** and the General directorate for healthcare provision (GDHP, ***DGOS direction générale de l'offre de soins***) are facing the following problems: how is territorial reorganization to be assessed a priori? What are the existing tools for simulating and providing decision support? Over time, three "business tools" have been tested without fully meeting the need: 1st- "Health territories tool", 2nd- "Territory of health needs tool"[2] (THN, ***TBS territoires des besoins de santé***) (Patrick 2011, Lorthiois 2013) and 3rd- "Metric/Simplexe tool". (I.N.S.E.E. progedo-adisp.fr. 2019). Consequently, the GDHP, ***DGOS*** works and wants to define relevant modelling and simulation tools for regional planning of public hospitals.

We first present the context of hospital reorganization, its stakes and the scientific problematic which results from it, then PoleSat[3] as a new modelling and prospective and strategic (gravity) simulation tool with variable geometry dedicated to health planning. In a second step, we present the PoleSat modelling applied to the neurology activity: "vascular catheterization" of the Atlantic 17 THG, ***GHT*** territory (solidarites-sante.gouv.fr. 2017). This part includes the context and objectives (issues and hypotheses) of the PoleSat custom (commercial) version, the materials and methods sections, the results of the modelling and simulations with a summary table of the scenarios presenting the statistical analyses (modelled flows of both activity and population). We conclude by discussing the results of several supply reconfiguration scenarios, **the perspectives,** and conclusions.

2. Context of hospital reorganization, challenges, scientific issue

2.1. *French health organization, public hospitals, and territorial hospital grouping*

Under the Hospital, Patients, Health and Territories (HPHT, ***HPST hôpital, patients, santé et territoires***) law of 2009 and until 2016, French health territories were managed by the Regional health organization plan (RHOP, ***SROS schéma régional d'organisation sanitaire***) for medical care and by the Regional health socio-medical organization plan (RHSMOP, ***SROMS schéma régional d'organisation médico-sociale***) for medico-social assistance, (Quesnel-Barbet *et al.* 2016 pp. 7-8, 10-11, 23, 28, 30, Patrick 2011). In 2016, a national modernization law was enacted involving the merger of the two regional plans into a single Regional health plan (RHP, ***SRS schema regional sanitaire***) (2016d). Since then, the Public hospital has been organized into THG, ***GHT***. Each

[1] The Hubert-Martineau report defines the sector based on three criteria. Thus, "each pathway corresponds to: A course or succession of care episodes involving different modes of care (consultations and outpatient procedures, short-stay hospitalizations, follow-up and rehabilitation care, etc.); For similar indications of care (diagnosis and level of severity); May involve a homogeneous patient profile (population criteria).

[2] "The Territory of health needs" (THN, ***TBS territoires des besoins de santé***) business tool is accessible from a professional environment, the "DIAMANT" portal.

[3] POLESAT is an acronym for "Sanitary hubs".

hospital in a THG, ***GHT*** is required to organize and share its Hospital information system (HIS, ***SIH système d'information hospitalier***) (2016b). It can also open and share its technical platforms (medical imaging, biology, telemedicine, etc.) with the other establishments in the THG, ***GHT***, (Arnaud *et al.* 2011). Transversal and coordinated medical organizations are managed by inter-institutional hospital hubs/centers. The Territorial hospital grouping THG, ***GHT*** is generally associated with a university hospital or a large hospital center identified as the THG, ***GHT*** support establishment (Fédération Hospitalière de France (FHF) 2017). Finally, the establishments in the same THG, ***GHT*** must work together, apply a specific 'medical project' and share medical information and statistical-economic indicators such as the Rate of use (RU, ***TR taux de recours***) of medical services (Scansanté. 2021). This indicator is defined as "the measurement of the consumption of hospital care by the inhabitants of a given geographical area (regardless of where the care is provided), in relation to the resident population of this area". (2017, Scansanté. 2021). The resulting geographical area defines the THG, ***GHT*** (2016a).

2.2. *Shared medical and care projects in territorial hospital grouping THG, GHT*

Each THG, ***GHT*** is obliged to implement a common and graded patient care strategy resulting in the guaranteeing of 'a local offer also called **proximity offer'** on the one hand and "a reference and recourse offer" on the other (Quesnel-Barbet *et al.* 2016 pp. 7-8). The THG, ***GHT*** then builds a Shared medical project (SMP, ***PMP projet medical partagé***) and a Shared care project (SCP, ***PSP projet de soins partagé***). The SMP, ***PMP*** describes the organization of care-by-care channels. The care networks are the linchpins/**pivot points** of the THG, ***GHT*** (solidarites-sante.gouv.fr. 2018) (ressources.anap.fr. 2016b; a). Their description specifies the organization of all the activities implemented in the care of a patient for a given pathology in a "health territory", cf. example of Cerebral vascular accident (CVA, ***AVC accident vasculaire cérébral***) (Quesnel-Barbet *et al.* 2016 pp. 13-14, 34). For each care sector/chain, the SMP, ***PMP*** therefore defines the bases for the organization of care activities, broken down by establishment and by care modality[4] according to the gradation of the activity (proximity or recourse activity) and its technicality (Quesnel-Barbet *et al.* 2016 p. 8). At the THG, ***GHT*** level, service supply and activities that are not proximity/local can be better distributed among the various establishments (solidarites-sante.gouv.fr. 2018).

2.3. *Intra- territorial hospital grouping THG, GHT cooperation*

Cooperation is a key concept for achieving efficiency, the aim of which is to adapt supply distribution responses as closely as possible to the needs of the population. In 2011, to encourage cooperation and the sharing of "scarce" human resources between establishments, a guide to territorial cooperation was co-published by the National performance support agency (NPSA, ***ANAP agence nationale d'appui à la performance***) and the General directorate for healthcare provision (GDHP, ***DGOS Direction Générale de l'Offre de Soins***). The aim of this guide is to help health and medico-social establishments and the Regional health agencies (RHAs, ***ARSs agences régionales de santé)*** in the choice and implementation of cooperation structures at the level of "health territories", (Quesnel-Barbet *et al.* 2016 pp. 30,31). It also provides the keys to understanding territorial cooperation, which are: (1) to understand the history of cooperation; (2) to identify each form of cooperation and to understand how it can contribute to the opening up of healthcare provision and the creation of territorial medical projects; (3) to determine the phases prior to territorial cooperation; (4) to define a methodology for conducting a cooperation project (Arnaud *et al.* 2011).

[4] The methods of care are the permanence and continuity of care; outpatient and advanced consultations; outpatient care; partial and conventional hospitalization; technical platforms; emergencies and unscheduled care; hospitalization at home; medico-social activity and exceptional health crisis activity. In addition, the Shared medical project (SMP, ***PMP projet medical partagé)*** can specify the medical organization and associate the university hospitals with the coordination of hospital-university missions.

2.4. *Territorial planning in health - challenges, scientific issue/problem*

2.4.1. *Challenges, scientific issue/ problem*

The main objective of the decision-makers is to optimize the territorial distribution of the care provision, by care chain/ pathway, building on organizations that can be led by the Territorial hospital groupings (THGs, ***GHTs groupements hospitaliers de territoire).*** In addition, decision-makers must target the actors (both public and private) concerned by territorial reorganization and encourage them to work together. Several approaches addressing the subject from different angles: "health territories", "Territory of health needs (THN, ***TBS, territoires des besoins de santé***)" (Patrick 2011, Lorthiois 2013) and "Metric/Simplexe" (I.N.S.E.E. progedo-adisp.fr. 2019), available as specific tools to decision-makers, are described below. Even if these approaches seem to be scientifically hugely different, they are in fact competing procedures, because guaranteeing that all care offers can be found in each territory means securing the consequences of reorganizations so that they do not harm the health care access for the population. In the following, we will therefore compare the 'Health Territories' and 'Territory of health needs' (THN, ***TBS territoires des besoins de santé***) tools for the 'definition of relevant territories' with the tools for the 'prospective modelling/simulation of territories' or in other words, for simulating the consequences of reorganizations, a category in which Metric/Simplexe and PoleSat tools are included.

1. The tool "health territories" constitutes an administrative grid empirically defined by the Regional health agencies (RHAs, ***ARS agences régionales de santé***) which is central to the territorial diagnosis of the Regional health organization plan (RHOP, ***SROS schéma régional d'organisation sanitaire)***. This territorial grid is common to all care sectors, whether their objective is to provide local/proximity care or exceptional recourse (ressources.anap.fr. 2016a). These territories have the advantage of being simple, stable**,** and shared. They are generally suitable for standard medical activities but lack flexibility and adaptability for more specific and technical recourse cares because they do not take into account the actual consumption of care and mobility of patient base in a given territory, (Quesnel-Barbet *et al.* 2016 pp. 7-8, 11, 23 , C.R.E.D.E.S. solidarites-sante.gouv.fr. 2003 pp. 31-34) (Lorthiois 2013);

2. The "Territory of health needs" (THN, ***TBS territoires des besoins de santé***) tool [5]was developed on the basis of the French National institute of statistics and economic studies (NISES, ***INSEE Institut National de la Statistique et des Études Économiques***) algorithm (I.N.S.E.E. progedo-adisp.fr. 2019) to meet the need to identify a "playing field" for a specific activity, in which health establishments could better allocate their care supply to optimize the efficiency of their organizations. The territories are re-calculated on the fly for each care sector based on patient flows identified in the French National Hospital discharge database (HDDB, ***PMSI, Programme de Médicalisation des Systèmes d'Information)***, used for Diagnosis-related group-based billing (DRG). The "Territory of health needs, THN, ***TBS***", also known as "territories of autarky", is calculated in relation to the consumption of health care services (Mace 2015) in such a way that the majority of patients seek treatment there. The principle is based on an algorithm for each patient's postal code[6] which assigns the postal code of the site of his or her care consumption. Elementary territories are thus identified, corresponding to zones/areas where the patient postal code and consumption postal code are identical. Then the algorithm aggregates (on successive occasions, iteratively) the finest geographical units of the communes under

[5] "The territories of health needs (THB) designate local spaces structured by the daily activities of the inhabitants who live there" according to the definition of J Lorthiois.

[6] The patient postal code at the DRG/***PMSI*** level is assimilated to the Postal office DRG (PO-DRG, ***BP-PMSI Bureau Postal PMSI***) which is an alphanumeric code.

autarky constraint. At each cycle, the autarky obtained per zone/area is either higher than 50%, which means that 50% of the patients are treated in the territory considered as stable, or lower than 50%, which characterizes the zone considered as unstable. The algorithm stops naturally when all the territories become stable, defining the network/territorial grid of Territory of health needs THN, ***TBS*** or "territories of autarky". Indicators of leakage (loss of patients) or over-attraction (gain of patients) can be associated, as in the example of La Rochelle’s Territory of health needs (THN**, *TBS territoires des besoins de santé*)** (Figure 1), and they characterize the movements in and out of the THN, ***TBS***. In a self-sufficient THN**, *TBS***, 80% of the territory's activity is centered in La Rochelle and consequently the sum of leakages is equal to 20%. The analysis of the THN**, *TBS*** territories makes it possible to draw up a multi-criteria diagnosis on coherent territories, to bring together the actors of these territories to work on what would make it possible to improve the efficiency of the adequacy of health care supply/need and to evaluate the investments needed. The tool is used by the National performance support agency (NPSA, ***ANAP agence nationale d’appui à la performance***) and by the General directorate for healthcare provision (GDHP, ***DGOS direction générale de l’offre de soins***) with a view to its gradual deployment to the RHAs, ***ARSs*** from September 2021. It is accessible from the private platform "DIAMANT[7]", (Quesnel-Barbet *et al.* 2016 pp. 8, 11, 18, 31, 34) (Patrick 2011) to which only the RHAs, ***ARSs*** and the "THG, ***GHT*** support public institutions” have access. However, a transfer to the Technical agency for information on hospitalization (TAIH, ***ATIH agence technique de l'information sur l'hospitalisation***) is underway.

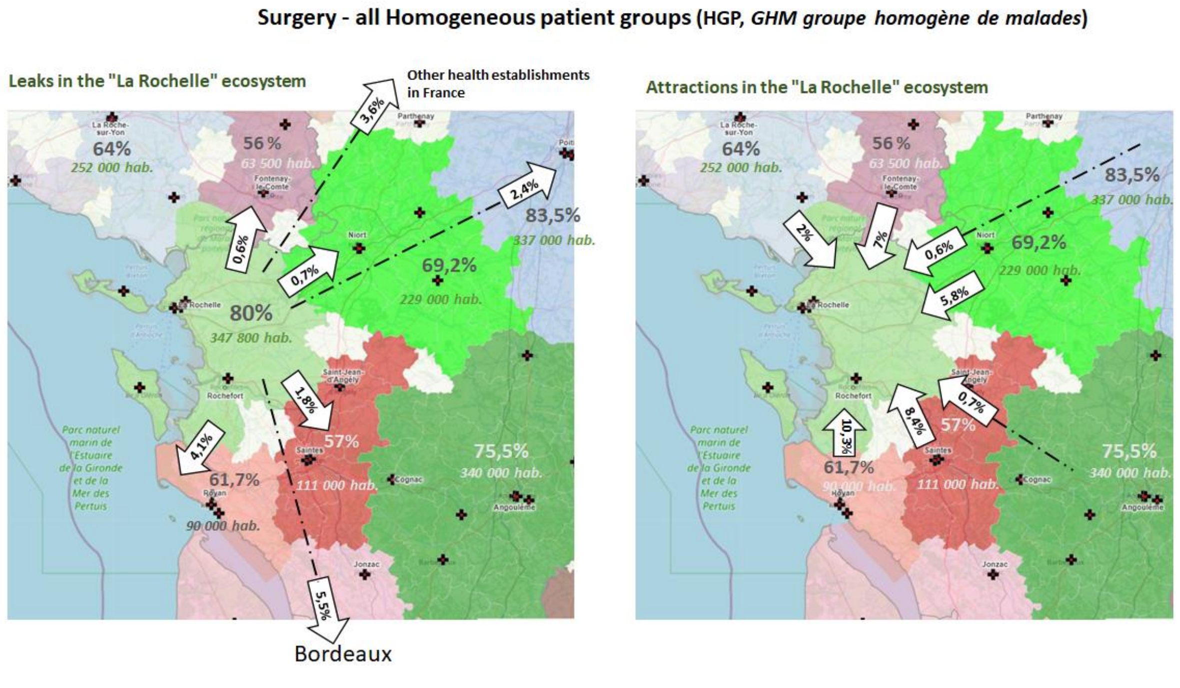

Figure 1. *Territory of health needs (THN, TBS territoires des besoins de santé) of the La Rochelle ecosystem - with outward leakage and inward attraction. The map (left), the THN, TBS of La Rochelle hospital (light green) shows 80% of the surgery supply (all Homogeneous group of patients (HGP, GHM groupe homogène de malades)) and the outward movement of patients (arrows going outside the THN, TBS); the map (right) shows the opposite movement of patients inwards (arrows coming into the THN, TBS from outside, more or less close).*

[7] DIAMANT is a decision-making and performance support software package: "it is a portal consisting of a common space for all the Regional health agencies (RHA, ***ARS agence régionale de santé***) presenting common indicators and management charts (from nine different sources) and a private space for each RHA, ***ARS*** allowing regional distribution of documents and data management. It is intended for experts and Diamond referents; in addition, there are Online analytical processing (OLAP) cubes allowing referents and experts from each RHA, *ARS* to create cross-tabulations according to their needs.

3. The Simplexe tool (based on the Metric distancer, i.e., route calculation module) is a method of prospective modelling/simulation of territories. This method relating to the “production of health care" developed by the Directorate of research, studies, evaluation and statistics (DRSES, ***DREES direction de la recherche, des études, de l'évaluation et des statistiques***) is based on modelling and simulations of the process of territorial recomposition or so called territorial reorganization (I.N.S.E.E. progedo-adisp.fr. 2019). The deriving issues are of the following type: "what would be the potential consequences for health care producers in the context of simulations of opening, closing or reorganization scenarios for hospital services, by health care sector/chain in a given territory? For example: if a service in a specific care pathway/chain is opened or closed, what will be the impact on the production and consumption of care and on the spatial mobility of patients? The only possible actions for decision-makers facing the simulations carried out and the results obtained are reallocations of the territories according to the "proximity accessibility observed for patients" (proximity zones) (C.R.E.D.E.S. solidarites-sante.gouv.fr. 2003) (Quesnel-Barbet *et al.* 2016 pp. 7-8). Those reallocations are calculated based on a distance chart, based either on a distance in km by road or on a distance in access time (isochrone) (I.N.S.E.E. progedo-adisp.fr. 2019 , geoportail.gouv.fr. 2016).

Until recently, the Directorate of research, studies, evaluation**,** and statistics (DRSES, ***DREES direction de la recherche, des études, de l'évaluation et des statistiques***) Simplexe tool combined with the Metric distancer tool of the French National institute of statistics and economic studies (NISES, ***INSEE Institut National de la Statistique et des Études Économiques***) could have been a relevant approach. But this insightful proximity approach to similar activities (homogeneous numbers of activity) of the 'maternity type' proved insufficient when the territories included establishments of very heterogeneous sizes (masses of activity). Indeed, *Métric/Simplexe* systematically reallocates territories to all the nearest establishments (so-called proximity establishments), without considering their importance via the "mass of activity" that can be evaluated by their number of beds or similar criteria calculated. As a result, at the end of this assignment, the Metric/Simplexe model concluded that local/proximity hospitals had zones of influence identical to regional hospitals (so-called recourse hospitals/ referral health institution) that would have been placed under the same conditions, which was very different from the reality of the Diagnosis-related group-based billing (DRG, ***PMSI Programme de Médicalisation des Systèmes d'Information***) flows analyzed. Because of these failings, the decision-makers gave up on "Metric/Simplexe" and are still looking for suitable "modelling and simulation tools to optimize territorial efficiency by care pathway (distribution of the care offer)".

4. PoleSat, which is a prospective modelling/simulation tool for territories (see sections 0 and 0 below), but also for definition of territories (in its phase one of the thesis (Quesnel-Barbet 2002, Quesnel-Barbet *et al.* 2020a)), would be a potential candidate to complete tools like THB (cf. section 0 section, above point 2). The National performance support agency (NPSA, ***ANAP agence nationale d’appui à la performance***) and the GDHP**,** ***DGOS*** working group is currently piloting the deployment of THB tool; PoleSat would come after this stage of territorial recomposition of supply and would allow us to simulate the consequences of reorganizations foreseen by the decision-makers to secure the choices. As Métric/Simplexe has been abandoned, PoleSat is one potential successor at present to support these simulations.

3. Existing modelling approaches

In the 2000s, the needs of health care decision-makers led researchers in economics and geography to propose new methods for dividing up territories. Within the framework of the first generation of the Regional health organization plan (RHOP, ***SROS schéma régional d'organisation***

sanitaire), these territories had to be representative of a homogeneous distribution of the overall hospital care offer based on the specialty group of Medicine, surgery, obstetrics (MSO, ***MCO médecine, chirurgie, obstétrique***) and the offer of heavy equipment (Magnetic Resonance Imaging, Scanner etc.). Thus, Reilly's gravity model was adopted and proposed in France as a method of division (Quesnel-Barbet 2002, Quesnel-Barbet *et al.* 2020a). In a thesis on quantitative geography in 2002 (Quesnel-Barbet 2002), we improved it by weighting, partially automated it and applied it to two medical specialties in a "non-mountainous" region where the density of road infrastructure justified the use of Euclidean distance in the model. Thus, our research on hospital systems was based on an analysis of the spatial practices of patients in the Nord **-** Pas-de-Calais region and on the development of a reference model to target the organizational structure. This refined Reilly model is the core of the PoleSat tool in its currently accessible, optimized, and automated version. The complete modelling process of the thesis consisted of four phases: PoleSat in its current development involves only two of these four phases (Quesnel-Barbet 2002, Quesnel-Barbet *et al.* 2020a).

4. PoleSat_2019 private-access custom (commercial) version – French name *PoleSat-métier*

4.1. *Evolution towards PoleSat_métier private-access custom (commercial) version*

PoleSat is a tool for immediate prospective and strategic modelling of health territories[8]. Its optimized and automated version has been validated for the whole of France excluding Corsica. The business version dedicated to commercial customers (PoleSat_2019 private-access custom version, ***PoleSat-métier***) was developed in 2019 and includes in its outputs, the analysis of automated scenarios (see Table 1 of our applied case). The thesis' phases two and four integrated into PoleSat meet the objectives of "modelling Hospital catchment areas (HCAs, ***AAHs aires d'attractions hospitalières***) and of simulating HCA***, AAH*** by opening, closing, and grouping establishments, hospital units or hospital hubs with or without transferring activities with constraints. Using a Graphical user interface (GUI, ***IU interface utilisateur***), simulations are carried out according to the constraint values "P5: mass of activity" and "P8: consolidation perimeter". This meets the objective of "simulating the deletion and regrouping of establishments based on constraints". In addition, specific simulations can be carried out outside GUI, ***IU*** by modifying the inputs of the scenarios considered. This meets the objective of "simulating and targeting specific hospital units/hospital hubs". On the other hand, ***PoleSat-métier*** does not currently integrate phases one and three. Consequently, it does not meet yet the "objective of phase one modelling of the observed" of validating the hypothesis of contiguous proximity attraction around a hospital hub - with calculations of indicators of over-attraction and leakage (essential before continuing with modelling with ***PoleSat-métier***). However, we have an external program to ***PoleSat-métier***, which performs phase one from more detailed chained data, and outputs its maps and statistics (see section 1 above). On the other hand, it does not meet yet the "phase three modelling **objectives**" of comparing observed and modelled areas and calculating the attraction coefficient indicator.

PoleSat-métier can be considered to be an interesting modelling algorithm, thanks to the distance, but above all to its two other key factors/criteria: "the mass" linked to the importance of the activity of the hospital hub, which is similar to a number of stays, and "the population per hospital hub", which is essential for the natural distribution calculations (the population is the weighting parameter refining the gravity model (Quesnel-Barbet *et al.* 2020a p. 5)). The observed repeatability of the results is validated: i.e., there is no difference in results after repeating the same scenario. The scientific interest and the objective help of PoleSat are thus approved by the experts in health land use planning/spatial planning, especially as the main competing prospective modelling tool "Metric @ linked to the Simplexe algorithm" only integrates the distance factor out of the three mentioned

[8] The planning of health territories, this term does not refer to the territorial grid defined by the RHOP, ***SROS***- RHA, ***ARS*** of "health territories". It refers to the development of any geographical space in the context of health planning.

above in the PoleSat algorithm (I.N.S.E.E. progedo-adisp.fr. 2019). PoleSat is clearly positioned as a complementary tool to THN, ***TBS*** through its prospective modelling/simulations and calculations of natural distribution indicators and robustness tests (see Table 1). It is a tool for planning health territories, with variable geometry and by care pathway, which has attracted the attention and support of health decision-makers.

The reader can access PoleSat-demo online[9], which now includes four data sets. The last one concerns the "vascular catheterization" activity, our applied case presented in section 0, p. 9.

4.2. *PoleSat_2019 custom (commercial) version – PoleSat-métier: diagram of the modelling and simulation process*

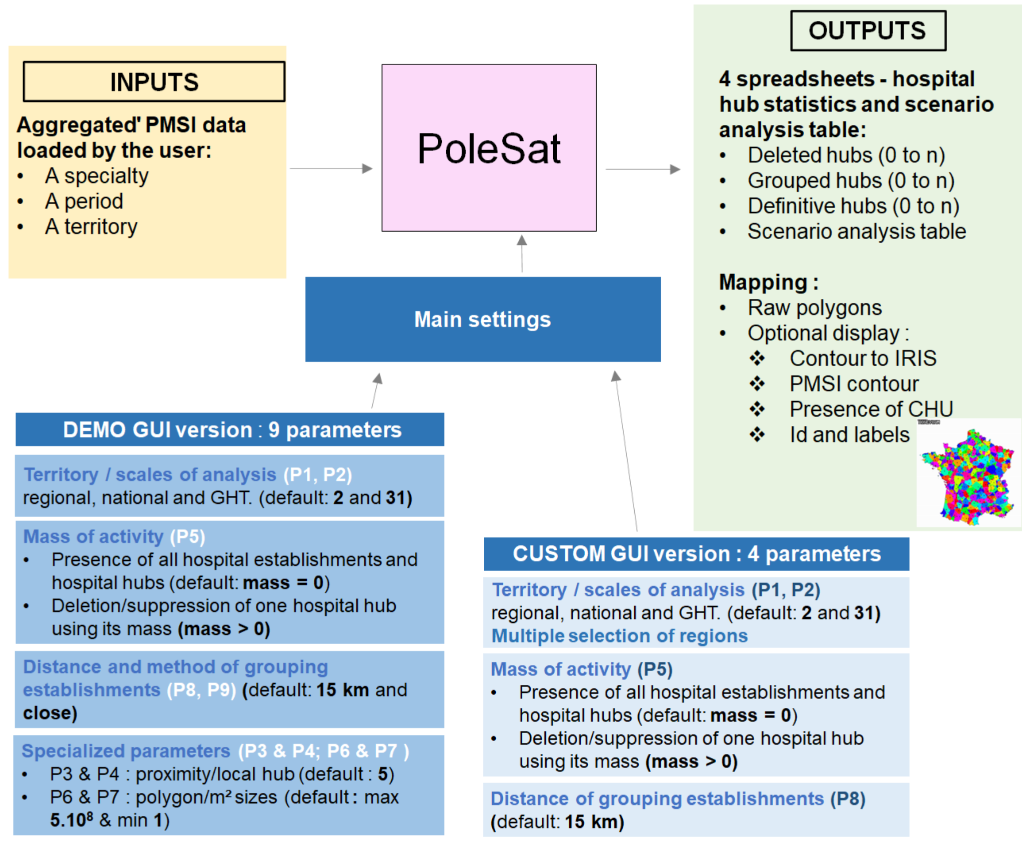

Figure 2. *PoleSat_2019 custom version – PoleSat-métier: diagram of the modelling and simulation process*

Figure 2 presents an overview diagram of the modelling and simulation process. The recent update of ***PoleSat-métier*** allows us, on the one hand, to load simultaneously more than one input file (up to 3 through a grouped request). Each input is dedicated to a specific scenario, for example: 1- initial situation; 2- deletion of the health hub/service; 3- deletion of the health hub/service and transfer of its activity to another hospital hub/service. On the other hand, the user can retrieve the automated analysis of the scenarios in the form of a spreadsheet corresponding to the results presented (in section 0 below section, in Table) on the statistical analyses of the flows of activity and population of the applied case.

[9] "PoleSat-demo", the version updated in July 2020 is accessible via the url: https://thymine.univ-lille.fr/polesat2018/, login: demo3 and password: polesat4.

5. PoleSat-métier: the custom 2019 version, application to the case of "vascular catheterization" in the Atlantic territory 17

5.1. *Context - issue and proposed response from Atlantique 17's territorial hospital grouping THG, GHT*

In the context of their medical project, the Atlantique 17's decision-makers (solidarites-sante.gouv.fr. 2017 , réseau-hôpital-G.H.T.fr. 2016) noted that one of their establishments, the Rochefort hospital, had a low activity of "vascular catheterization" relating to the diagnoses made, a *very specialized activity in neurology* (2016c, AideAuCodage.fr 2021). The Territorial hospital grouping (THG, ***GHT groupement hospitalier de territoire***)" wishes to withdraw the vascular catheterization activities from the Rochefort hospital, which are qualified on the one hand as risky and on the other hand, as economically unviable in view of the *highly specialized/advanced technical platform to be mobilized* in terms of neuro-vascular imaging and medical staff.

The THG, ***GHT*** has therefore imagined in its multi-annual program to transfer the activity of the Rochefort hospital to the Saintes hospital belonging to the Saintonge THG, ***GHT*** and has issued as a Null hypothesis (H0) of recruitment, "a complete gain of 100% in favor of the Saintes hospital with recovery of the Rochefort hospital's patient base". It thus hopes to better distribute the vascular catheterization activity offers on the targeted territory of the Saintes hospital, which would see its vascular catheterization activity increase as well as its modelled Hospital attraction area (HAA, ***AAH aire d'attraction hospitalière***) also called by the decision-makers "influence zone", thus foreseeing a strong impact in terms of territorial reorganization.

This field of application was selected to test the PoleSat custom version ***(PoleSat-métier)***. Through this test, we hope to provide elements of prospective analysis to answer the above-mentioned questions: business issues, decision-makers' hypotheses and territorial recomposition objectives for the "vascular catheterization" activity.

5.2. *PoleSat's business and technical usage objectives*

The 1st objective is to evaluate to which establishments and in what quantity patients from Rochefort hospital would naturally go for treatment. The analyses of the scenarios (cf. Table 1, section 5.3) lead to estimates of the "chance of gain" and "risk of loss" of activity. They provide something to consider and help in decision making on the territorial reorganization of the THG, ***GHT*** Atlantique 17 and other THGs, ***GHTs*** potentially affected.

The 2nd objective is to enable the health teams of the surrounding establishments/hubs to evaluate their capacity in terms of human resources and imaging equipment to distribute this vascular catheterization activity based on the scenario analyses (Table 1). To do this, the health professionals would use operational indicators of the following types: time taken to obtain an appointment, occupancy rate of the scheduled slots, number of professionals taking turns on duty and on-call slots, current profitability of the service through its charges and revenue per activity.

Finally, the two technical usage objectives of **PoleSat_2019 custom (commercial) version** are to identify the natural flows of activity distribution of the hospital service to be closed and to know whether this redistribution of activity seems stable or unstable (see section 5.3.2 below).

5.3. *Materials and Methods*

5.3.1. *Setting up the three scenarios to confirm or deny H0 of the Atlantic territorial hospital grouping seventeen*

We have developed three scenarios to confirm or refute the H0 hypothesis of THG, ***GHT*** Atlantique 17. *Scenario one* aims to roughly estimate the zones of influence of the establishments according to their vascular catheterization activity. *Scenario two* enables us to estimate the variations in the Hospital catchment areas (HCAs, ***AAHs aires d'attractions hospitalières***) if the activity of the Rochefort hospital is eliminated. The objectives of *scenario three* are (1) to estimate the variations in the HCAs/***AAHs*** if 100% of the activity of the Rochefort hospital is transferred to the Saintes hospital and (2) to evaluate whether the increase in the activity of the Saintes hospital will be sufficient to impact the increase in its Hospital catchment area HCA/***AAH***.

The input file is obtained after extraction from the French National Hospital discharge database HDDB, ***PMSI*** [DIAMANT, p. 4] and a pre-processing of the file structure (Quesnel-Barbet *et al.* 2019, Quesnel-Barbet *et al.* 2020b, Quesnel-Barbet *et al.* 2020a, p.11) (cf. Figure 2).

The four parameters (cf. Figure 2) have the following values or constraints: *P1=2* which selects the former regions, *P2= 54* which corresponds to the "Poitou-Charentes" region; *P5=2,* which corresponds to a mass value > 0 and allows the deletion of institutions with a mass of less than 2; and *P8 = 15000*, which corresponds to a grouping radius of no more than 15km of "child institutions" to the "parent (or referent) institution". In addition, *five parameters are pre-checked* (cf. Figure 2) (Quesnel-Barbet *et al.* 2020a) and represent the following outputs: "the presence of a University hospital (UH, ***CHU centre hospitalier universitaire***)", "the health hub ID", "the health hub name", "the map with The DRG Postal office (DRG-PO, ***BP-PMSI bureau postal PMSI***) contours" and the map with Administrative census area boundaries (ACABs, ***IRIS îlôts regroupés pour l'information statistique***) contours, the infra-communal grid of the population census (I.N.S.E.E. 2016) (Quesnel-Barbet *et al.* 2020a).

5.3.1.1. Scenario one: modelled Hospital catchment areas include all hospitals after grouping at 15km

To model the Hospital catchment areas (HCAs, ***AAHs aires d'attractions hospitalières***) of all hospitals after grouping at 15 km, the initial input is loaded directly using the Graphical user interface (GUI, ***IU interface utilisateur***). The values of the four parameters to be entered to simulate **scenario one**, are *P1 = 2, P2 = 54, P5 = 2 and P8 = 15,000* and *all five parameters are pre-checked for presence*. For reasons for the tool's threshold effect, the initial input is modified with an activity in number of days multiplied by **2** for all establishments[10]. The output file of hubs "*poles*.csv" shows in this case for the Rochefort hospital a mass greater than **2.** It is because this mass is greater than **2** that the Rochefort hospital appears in the results of **scenario one** (cf. Figure 3: map (a)), since in this case, it cannot be deleted according to the parameter setting *P5=2.*

The settings adjustment is also based on the analysis of the modelling outputs and particularly on the two other spreadsheets with French names: "***supprime_masse_petite*.csv**" and "***regroupement*.csv**".

5.3.1.2. Scenario two: deletion of the Rochefort hospital followed by the modelling of the Hospital catchment areas HCAs, AAHs for the remaining hospitals after regrouping at 15 kms

To simulate the suppression of the Rochefort hospital and to estimate the geographical (based on the Hospital catchment areas (HCAs, ***AAHs aires d'attractions hospitalières***) and statistical (population flows and hospital activity) variations in relation to the initial results obtained since scenario one, the expert modifies the input and the parameterization of the GUI, ***IU.***

1. The line corresponding to the mass of activity of the Rochefort hospital is deleted manually from the input which is then loaded on the remote server of the GUI, ***IU***, (see the GUI, ***IU*** line D5).

2. The setting of the four parameters remains the same as in scenario one.

[10] However, the best solution found is to use the values 1 or a decimal figure of 1.34 for the parameter P5, thus avoiding the threshold effect and the multiplication by 2 of the activity of all establishments.

Scenario two set by the expert via the **GUI,** ***IU***: *P1=2, P2=54, P5=2 and P8=15,000*. The initial input is modified by the "vascular catheterization" activity *2 for all establishments and by the deletion of the Rochefort hospital line.

5.3.1.3. Scenario three: transfer of the activity of the Rochefort hospital to the Saintes hospital, followed by the suppression of the Rochefort hospital and the modelling of the Hospital catchment areas of the remaining hospital hubs, after regrouping at 15 km

To simulate the "transfer of activity from Rochefort hospital to Saintes hospital" followed by the "suppression of Rochefort hospital", and to estimate the geographical (from the Hospital catchment areas (HCAs, ***AAHs aires d'attractions hospitalières***) and statistical (of population flows and hospital activity) variations compared to the initial results obtained since scenario two, the expert modifies the "input" and keeps the same GUI, ***IU*** parameterization as for scenario two.

1. The activity observed at Rochefort hospital is transferred by addition to that of Saintes hospital.

2. The line corresponding to the mass of activity of the Rochefort hospital is deleted.

3. The input is then uploaded to the remote server using the D5 online GUI, ***IU.***

Scenario three set by the expert via the GUI, ***IU***: *P1=2, P2=54, P5=2 and P8=15,000*. The initial input is modified by the "vascular catheterization" activity ***2** for all the establishments, by the deletion of the Rochefort hospital line and by the addition of the activity recovered after the transfer to the Saintes hospital.

5.3.2. *Activity and population distribution methodology – new recalculations based on the outputs of the three scenarios*

Principle: knowing that the modelled HCA/***AAH*** (for each structure called hub) does not take into account the real patient flows (cf. 0, not chained BD), we base our simulations of the "evolution of the activity of the hubs" on the "evolution of the population covered for each hub" before and after simulation of the reorganization. We make the hypothesis that the reorganization (through scenarios two and three) does not modify the rate of recourse of the populations in each initial hospital hub territory (scenario one). As the number of inhabitants does not change between our simulations on the whole analyzed territory, the effect for scenarios two and three is that the number of stays gained or the evolution of the activity estimated by hospital hub remains and will remain constant in scenario two, (cols 5 and 6) and scenario three (col 2) cf**.** Table, en page 13, see the PoleSat hospital hubs' "*poles.csv*" processed output file.

The method for using ***PoleSat-métier*** consists of three steps:

1. Initial: modelling of the initial situation (scenario one) of the zones of influence known as Hospital catchment areas (HCAs/***AAHs Aires d'attractions hospitalières***) based on the actual activity of the hospital hubs without any specific reorganization (i.e., neither specific hub abolition, nor abolition with prior transfer of activity to a specific hospital hub).

2. Target 1**:** deletion without prior transfer of (closed) activity to a specific hub: simulation of the situation (scenario two) after reorganization of the HCA/***AAH*** by deletion of a specific hospital hub: this makes it possible to estimate the distribution of inhabitants (columns 2 and 3) and the distribution of activity (columns 4, 5 and 6) between the hubs which are both calculated in 3 sub-stages a, b, and c.

    a. For each hub/pole with a change in its area of influence, the "number of inhabitants" in addition to and minus (the change in the number of inhabitants) is calculated, which is expressed in gross values in col 2 by the difference between the

HCA/***AAH*** populations of the hubs/poles in scenarios one and two (output: *hubs: "poles.csv"*) and in percentages in col 3.

b. Then for each unit, we express (displayed in column 4) a "change in activity, in number of stays, proportional" to the percentages of "change in population" (column 3). Then we calculate in col 5 (from col 4) "the evolution of activity brought back to a stable rate of use of the population". To obtain the gross numbers in (col 5) and percentages in (col 6), the value of (col 4) is divided by "the sum of positive changes in activity (col 4)", the whole is multiplied by the number of people in the activity of the hospital hub deleted.

c. The percentages in column 6 are obtained by dividing the gross value (column 5) by the number of activities in the deleted hospital hub/hospital department (displayed in column 1 of scenario one), all of which is multiplied by 100, and we can see that the total of each percentage per hospital hub is 0% (with an identical Rate of recourse (ROR, ***TR taux de recours hospitalier***)), there is conservation of the activity and each sum of the positive and negative percentages is respectively +100% and -100%). This percentage speaks for itself and shows us towards which hub the activity of the closed structure(s) is redirected.

3. Target 2: deletion with prior transfer of activity to a specific hospital hub/department: simulation of the situation (scenario three) after reorganization considering the opposite of the results calculated in step 2 above. Based on the observation of scenario two, the following question is asked: knowing that the activity evolves mainly for the benefit of hub B and therefore less for of the **hub** C**,** what would have been the natural balance of population distribution if the transfer of activity to the specific hub C was forced? Would the zones of influence / Hospital catchment areas (HCAs, ***AAHs aires d'attractions hospitalières***) of the hospital hubs have been sufficiently different to significantly modify the distribution of activity compared to the results of scenario two? Scenario three of transferring activity to a specific hub tries to answer this question.

Assessment of the robustness of scenario two: if the simulations of scenarios two and three result in the same HCA/***AAH*** (at the municipality level), then the simulation of scenario two suppression without transfer is considered robust. Conversely, in some cases depending on where the patients are distributed after the reorganization scenarios two and three, the HCAs/***AAHs*** have varied considerably (between scenarios two and three), which indicates the 'unstable' nature of the (scenario two -deletion without transfer) solution compared to the (scenario three -deletion with transfer). For example, if the hospital hub to be closed has a high level of activity (in terms of volume) like that of contiguous hospital hubs, this could lead to an 'unstable' reorganization solution. It should be remembered that 'stable' is synonymous with: "We can rely on the simulated redistribution" and "unstable" is synonymous with: "we cannot conclude without risk of misinterpretation".

5.4. *Results on the application to the case of vascular catheterization in the THG, GHT Atlantic 17*

5.4.1. *Results of the scenarii analysis*

The Table, which will henceforth be found at the output under the name "*analyse_scenarii*", displays the results of statistical analyses of the activity and population flows of the following three scenarios: "scenario one - initial state"; "scenario two - suppression of the Rochefort hospital and natural distribution" and "scenario three - suppression with transfer of activity from the Rochefort hospital to the Saintes hospital and testing the robustness of the solution".

Table is separated into three parts, each corresponding to a scenario, and displays seven hospital hubs (obtained at the end of the query after the grouping of establishments within a radius of 15km).

Each scenario has a column representing the "initial" or "modified input for scenarios two and three". For each scenario, the calculated values of activity and population flows are ventilated by establishment/hospital hub according to the weights of each in the modelling. The simulation results are based on the geography of the former Poitou-Charentes region, which has been part of the "New Aquitaine" region since 2016.

	Scenario 1. initial state			**Scenario 2. natural distribution**						**Scenario 3. testing the robustness of the solution**	
Social reasons	**Input :** Activity in days	Initial population of zones of influence **(simulation1)**	Initial population of zones of influence / regional population **%**	**Input:** Activity in days **with suppression of days in Rochefort**	Evolution of the population of each zone when Rochefort disappears **(simulation 2)**	Evolution of the population of each zone when Rochefort disappeared **%**	Evolution of the activity proportional to the population growth of each zone of influence	Evolution if the activity is proportional to the evolution of the population with stability of the use rate	Evolution if the activity is proportional to the evolution of the population with stability of the recourse rate **%**	**Input:** Activity in number of days **with transfer of days to Saintes**	Population change when Rochefort disappears **(simulation 3)**
Angoulême H	7332	331 179	18,6%	7332	0	0%	0	0	0%	7332	0
Clinique Pasteur	1022	90 623	5,1%	1022	21 036	23%	237	38	6%	1022	21 036
La Rochelle H	8256	212 235	11,9%	8256	70 461	33%	2741	437	71%	8256	70 461
Saintes H	5588	205 051	11,5%	5588	28 873	14%	787	126	20%	**6205**	28 873
Rochefort H	617	124 448	7,0%		-124 448	-100%	-617	-617	-100%		-124 448
Niort H	8167	329 404	18,5%	8167	4 078	1%	101	16	3%	8167	4 078
Poitiers Univ Hospital	17591	484 833	27,3%	17591	0	0%	0	0	0%	17591	0

Table1. *Distribution of "vascular catheterization" activity and population, according to the three scenarios*

Table 1 - Scenario one - initial situation of health care supply

Scenario one, the results of the Rochefort hospital can be read in columns 1, 2 and 3 which correspond to the initial situation of scenario one. The initial vascular catheterization activity is positive (+617) (col 1) and the modelled Hospital catchment areas (HCAs, ***AAHs aires d'attractions hospitalières***) population is expressed in raw values and as percentages (cols 2 and 3).

Table 1 - Scenario two - suppression of activity at Rochefort hospital and natural distribution

For scenario two of the suppression of the Rochefort hospital, we simply remove its activity from the input (col 1 of scenario two). The variations in the natural distribution for the 'population' are indicated (columns 2 and 3 of scenario two) in gross values (-124,448) and as percentages (-100%). The variations of the "vascular catheterization" activity in number of days according to two calculation modes are displayed (cols 4 to 6 of scenario two); mode 1, "the evolution of the activity is proportional to the increase of the population of each zone of influence", the negative activity value (-617) is displayed (col 4 of scenario two); mode 2, "evolution if the activity is proportional to the evolution of the population with stability of the Rate of recourse (ROR, ***TR taux de recours hospitalier***)", the negative activity values : Gross (-617) and percentage (-100%) are displayed (cols 5 and 6 of scenario two).

Table 1 - Scenario three - deletion with transfer of activity from Rochefort hospital to Saintes hospital – robustness test

If we look at the Rochefort and Saintes hospitals, for the "3rd scenario – deletion with transfer of activity – Test of the robustness of the solution", the activity is increased for the benefit of the Saintes hospital (**6,205** stays compared to **5,588** in scenario two). On the other hand, scenario three does not show any variation in population for the Saintes hospital, the value **28,873** remaining identical between scenarios two and three (column 2 of scenario three).

5.4.2. *Results of the mapping analysis*

The cartographic results (ACAB, ***IRIS*** contours in black and DRG-PO, ***BP-PMSI bureau postal PMSI*** in white) of the three scenarios are shown in Figure 3. On map (a) we can see particularly the modelled Hospital catchment areas (HCAs, ***AAHs aires d'attractions hospitalières***) of the Saintes hospital (yellow), the Rochefort hospital (light green) and the La Rochelle hospital (fuchsia). On map (b), it can only be seen that the modelled HCA/***AAH*** of the Saintes hospital remains, practically identical to that on map (a), the modelled HCA/***AAH*** of the La Rochelle hospital is much larger and there is no longer any modelled HCA/***AAH*** in the vicinity of the Rochefort hospital after theoretical removal. Between map b (suppression) and map c (suppression and transfer) there is little or no actual visual difference. Each map was modelled with the parameters of the GUI, ***IU***: *P8: grouping at 15 km and P5: mass set at 2*, excluding from the modelling results the establishments/hospital hubs with *a mass lower than* ***2.***

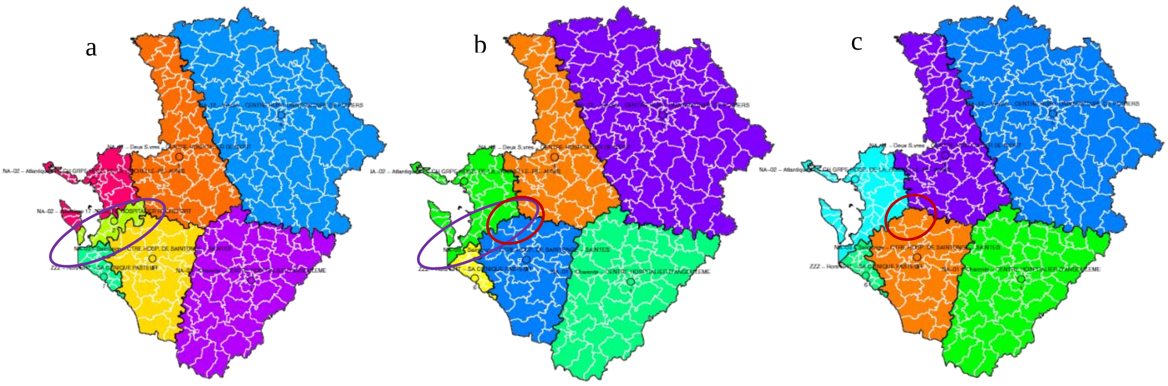

Figure 3. *Hospital catchment areas modelled by scenario: Map a: scenario one, map b: scenario two, map c: scenario three.*

5.4.3. *Summary of analyzed results*

According to this cartographic and statistical analysis of the scenarios of (Table), the results, which are both the most likely and the most accepted by the local players, are circled in red (columns 5 and 6 of scenario two). They reflect the mode 2 of calculation of the evolution of the "vascular catheterization" activity, which is proportional to the population growth with a stable rate of use. In column 6, the 71% growth value (437 out of 617), observed for the La Rochelle hospital, shows that this hospital will capture three times more of the gain in activity than the Saintes hospital, which will only capture 20% of the procedures (126 out of 617).

The results show the rejection of the null hypothesis (see section 0 above, p. 9) and the acceptance of the alternative hypothesis which is very favorable to the La Rochelle hospital and to the detriment of the Saintes hospital; "H0: 100% expected gain for the Sainte hospital" and "H1: 71% expected gain for the La Rochelle hospital and only 20% gain for the Saintes hospital".

6. Discussions

6.1. *Discussions of the results - what the expert takes away from his analysis*

6.1.1. *Discussion of the mapping analysis results*

In Figure 3, through the purple ellipse and the red circle, the map b (scenario two) shows the suppression of the Rochefort hospital and the map c (scenario three) shows the transfer of activity; we observe that the modelled Hospital catchment areas (HCAs, ***AAHs aires d'attractions hospitalières)*** of the La Rochelle hospital have absorbed almost all of the initial HCA/***AAH*** of the Rochefort hospital (Figure 3, scenario one, map a) to the detriment of the Saintes hospital and that suggests that the geographical attraction will be greater in terms of patients and activity to the benefit of the La Rochelle hospital of the THG, ***GHT*** Atlantique 17.

6.1.2. *Discussion of the statistical results of the scenarios*

In Table (cols 5 and 6 of scenario two), the results surrounded by a red ellipse show around the Rochefort hospital the increase in the activity of each hospital hub, proportional to the evolution of the population covered; thus the La Rochelle hospital is likely to capture many more patients (33% - col 3 of scenario two) than what is observed for the Saintes hospital (14% - col 3 of scenario two); on the other hand, it should increase its "vascular catheterization" activity very strongly in proportion to the evolution of the population with a stabilized rate of recourse, since we observe (col 6 of scenario two) a much higher (71%) growth in comparison with the hospital of Saintes (20%).

In Table (column 2 of scenario three), the results of the population evolution lead us to estimate that the transfer of activity from the Rochefort hospital to the Saintes hospital does not generate a decrease in the use of care by the population in the zone initially served by the Rochefort hospital (cf. Figure 3, map a), as there is no variation in the population (the value 28,873 remains identical to scenario two). The transfer of 100% of the activity to Saintes Hospital has not impacted the attraction of Saintes hospital in terms of "population gain" and "significant expansion of its modelled HCA/***AAH*** "; in parallel, only a slight recovery in terms of surface area is to be noted in the red circle of (Figure 3, map c) to the benefit of Saintes hospital.

6.1.3. *Discussion of the robustness test against scenario two*

Scenario three is a robustness test against scenario two. It consists of unbalancing the "simulation of the suppression of the Rochefort hospital" by evaluating the result of the artificial transfer of all the activity of the Rochefort hospital to the Saintes hospital (the establishment indirectly (to a lesser extent) benefiting from the closure of the Rochefort hospital). The activity of Saintes hospital would increase from 5,588 days for scenario two to 6,205 days for scenario three (Table), i.e., an increase of 11%.

At the cartographic level, there is a slight increase in area of influence of the Saintes hospital (Figure 3, map c, scenario three), but this does not change the coverage of the communes in scenario two (Figure 3, map b) and therefore does not change the population balances between the modelled areas of influence of each establishment. In other words, the scenario two simulation is robust because the population breakdown in the scenario three simulation remains the same as in simulation two.

On the other hand, if this transfer test showed (Figure 3, scenario three, map c) that one or more significantly populated communes (representing, for example, more than 30% of the population of the zone initially covered by the Rochefort hospital on (Figure 3, map b of scenario two)) were 'out of balance' when moving from the zone of influence of the La Rochelle hospital to that of the Saintes hospital between simulations 2 and 3, this would indicate a fragility in the conclusions derived from the simulations.

6.1.4. *Experts' estimates - what the expert has learned from his or her business analysis*

The experts estimate that 1-The activity of each hospital hub around Rochefort hospital increases proportionally to the evolution of the population covered. 2-The transfer of activity does not lead to a decrease in the use of "vascular catheterization" care in the vicinity of Rochefort hospital. 3-The La Rochelle hospital could attract two to three times as many patients as the Saintes hospital and increase its activity accordingly. Here it can reasonably be expected that 71% of Rochefort's activity will go to the La Rochelle hospital as opposed to only 20% for the Saintes hospital, in accordance with the natural behavior expected from current Rochefort patients. In the context of supply planning, if this time we position ourselves in relation to Saintes, we must not forget that it is always possible to reduce the "leakage of activity", with the implementation of "advanced consultations and prior agreements" with local doctors in the Rochefort hospital's zone of influence to balance or counterbalance the flows between Saintes and La Rochelle. We would thus move from a natural distribution of activity to a distribution regulated by planning.

Finally, it appears that the project of territorial recomposition of the "vascular catheterization" activity envisaged by the decision-makers of the "THG, ***GHT*** Atlantique 17" regarding their establishment, the Rochefort hospital, must absolutely be negotiated in consultation with the THG, ***GHT*** Saintonge representing the Saintes hospital to verify that the latter can absorb the additional activity.

6.2. *How did PoleSat meet the objectives of the territorial hospital grouping Atlantique 17 decision-makers?*

6.2.1. *Development of the 4-point argument below.*

The cartographic analysis completed by a business analysis (expert opinion) by comparing the modelled areas with the observed areas is essential. Statistical calculations of the distribution of population and activities made it possible to overcome the limits of the gravity model. In the interest of improvement, the integration of an isochronous distance within the algorithm is a new challenge in the short to medium term.

1. Analysis on the modelled maps alone seems delicate, as the geometric shapes of the polygons (raw, Administrative census area boundaries (ACAB, ***IRIS îlôts regroupés pour l'information statistique)*** and PO-HDDB, ***BP-PMSI))*** could mislead the 'human eye' by under or over-evaluating the modelled HCAs/***AAHs*** with low numbers of 'vascular catheterization' activity. Fortunately, PoleSat associates statistical tables by scenario to avoid wrong conclusions.

2. If an establishment produces only "imaging", the risk of seeing the establishment appear in the modelled map for a vascular catheterization procedure that it does not actually produce must be eliminated. Therefore, a business expertise of the modelled offer compared to the real offer is essential to adapt the thresholds. Phase one of the observation (cf. section 4.1, p 6), once integrated into PoleSat, will allow expertise directly from a single application environment.

3. PoleSat, as a gravity model, does not appear to be optimal in mountainous or coastal areas (the edge effect cannot represent the HCA/***AAH*** in the sea), which may be a disadvantage without adjustment (Quesnel-Barbet *et al.* 2020a). This limitation has been mitigated for scenarios two and three (deletion and deletion with transfer) thanks to the population and activity distributions expressed in gross and relative values (%) which reduce subjective errors in the interpretation of the modelled HCA/***AAH*** (related to topology and transport types). These population breakdowns/redistributions (indexed on the initial activity-scenario one) of each hub produce an observed difference between scenarios two and three (Figure 3, maps b and c) centered on the Rochefort hospital, which appears to be a realistic division, despite the geographical irregularities of the "west coast" and the "geometry errors" modelled on the west coast. From now on, the outputs of the PoleSat custom (commercial) version or the French ***PoleSat-métier*** integrate the "scenario analysis" spreadsheet, which is equivalent to (Table 1, p. 11), thus saving time for the user.

4. Our calculations based on Euclidean distance (the alternative would be a travel time distance via the road network) may currently bias certain simulations in the event of asymmetry in the road network distributing the establishments concerned by the renovation of the territorial organization. However, in view of the motorway network (A837) linking the cities of Saintes, Rochefort, and La Rochelle in a quasi-rectilinear manner, this confirms our use of the Euclidean distance in our applied case. Nevertheless, we are aware that this limit could be penalizing in case of asymmetry of road access (road

typology) (Quesnel-Barbet *et al.* 2020a). Henceforth, several options based on (Open-source routine machine (OSRM)), the National institute of geographic and Forest information (NIG-FI, ***IGN institut géographique national et forestier***) and possibly heliport algorithms, coupled with traffic constraints, traffic load of road-network) are considered to integrate the travel time distance – the length of time called an isochrone.

7. Perspectives

7.1. *Potential generalizations of PoleSat to other situations*

To generalize the approach to other sectors of activity (specialties, branches), it is necessary to be able to test whether patient referrals do indeed follow a law of attraction based on the size of the establishment (law of gravity, see section 3, p. 6). In this perspective, we propose to distinguish the areas of experimentation according to the existence of activity databases, i.e., those with chaining (link node between the patient's place of residence and the place of care), and those without chaining[11] (see details below).

From a methodological point of view, this descriptive exercise on the observed (cf. section 4, phase one, p. 6) is much more constraining and time-consuming. On the other hand, once the applicability of the gravity model to a field of activity has been proven, the strength of PoleSat-business is that it only needs simple activity data of non-chained structures to function. This places de facto PoleSat as " a promising solution" to simulate reorganizations in such contexts. Indeed, "Metric/**Simplexe** and Territory of health needs" (THN, ***TBS territoires des besoins de santé***) only work on "chained data" and therefore cannot compete with PoleSat on the niche of reference activities (unchained data).

7.1.1. *If chaining is possible – there exits a link node between the patient's place of residence and the place of care*

As we have been able to do with the French National Hospital discharge database HDDB/***PMSI***, the tests will be easy and quick to carry out. This will require systematic data analysis from "big data", experimental design or optimization, (Quesnel-Barbet *et al.* 2016 p. 35), experimental design or optimization to check the proximity behavior of patients **to** use the gravity model (see Section 1 above). A thematic extension using databases other than the HDDB/***PMSI*** is envisaged, and we mention it in (sections 0 below).

7.1.2. *If chaining is not possible – there does not exist a link node between the patient's place of residence and the place of care*

As for the activity databases for which we only have the activity of medico-social structures or those responding to missions outside the Activity-based payment/Funding system (ABP/FS, ***T2A*** tarification à l'activité) (reference to activities financed via the Missions of general interest (MGI, ***MIG Missions d'Intérêt Général***) and Contractualisation Assistance (CA/***AC*** aides à la contractualisation) (solidarites-sante.gouv.fr. 2021, 2020) to be able to carry out a systematic test on a large scale, it will be necessary to test the applicability of the gravity model on a few control territories[12].

[11] The unchained databases concern few care sectors representing operating budgets of hundreds of millions of euros. We find, for example, health centres for the treatment of cystic fibrosis, multiple sclerosis, chronic pain and, in general, structures responding to Missions of general interest (MGI, ***MIG missions d'intérêt général***) which must also respond to a population coverage.

[12] This operation would require (1) mobilising the establishments in an area that has undergone a reorganisation of supply in the past; (2) recovering their respective activities by place of origin over several years before and after the reorganisation. Finally, this operation would make it possible to reposition oneself within a framework of chained data.

7.2. *PoleSat, its upcoming features*

Mainly, it seems important to us to see how to integrate in the simulations the distances in inter-municipal access time so that the tool can work on all types of territories (see section 6.2, p. 16). Then, as a complement, this tool should be integrated into a "Territorial hospital grouping ***(***THG, ***GHT groupement hospitalier de territoire)"*** support approach" to confront the tool with a greater number of operational situations in the field. At the same time, beyond the calculations, decision-makers need to secure the mathematical approach by means of a more traditional "organizational diagnosis of the business" based on interviews with the players and a concerted approach; this is complementary, since to apply a model, up-to-date knowledge of the field is required.

On a more technical level, minor improvements (in the short and medium term) may be added to PoleSat, by acting: (1) directly on the algorithm and on the Graphical User Interface (GUI, ***IU*** **interface utilisateur**); for example, options for the use of distances in access time (or isochronous) will be added (see section 6.2) (2) Upstream, for the pre-processing of other inputs potentially usable in PoleSat; adapting the current *"program in R-code or moulinette"* for the French National Hospital discharge database HDDB/***PMSI,*** and other aggregated and anonymized health databases such as the Emergency room summaries (ERSs / ***RPUs Résumés de Passage aux Urgences***) and the National health data system (NHDS, ***SNDS système national des données de santé***) inherited from the National information system inter regimes-Health insurance (NISIR-HI, ***SNIIR-AM système national d'information inter-régimes de l'assurance maladie***) managed by the National health insurance fund of Salaried workers (NHIF-SW, ***CNAMTS caisse nationale de l'assurance maladie des travailleurs salariés***) (S.N.D.S.gouv.fr. 2021) (Quesnel-Barbet *et al.* 2016 pp. 4, 8, 18, 24-26, 28,33-34, 38) (3) by planning and automating queries by sector over different periods, or applied to other fields such as health logistics.

In the medium term, further developments related to the four phases of the thesis on which PoleSat was based are envisaged:

(1) Verification of phase one indicators and addition of new classical/bayesian statistical indicators and integration of our "R program" into the PoleSat environment. Coupling of the real maps of care production to those modelled by PoleSat and building phase three of comparison and calculation of attraction coefficients; (2) extending the phase three analysis over a five-year period to observe the evolution of the attraction coefficients of establishments; (3) implementation of other methods of calculating the mass, such as cost or other units (for the outpatient hospital sector), as well as the calculation of weights to further weight by factors of "disease severity" and "awareness of a facility"; (4) reduction of the calculation time of the algorithm and carrying out additional tests of parameterization and debugging of the algorithm.

In the medium and long term, further developments based on multidisciplinary research are envisaged:

(1) Facilitating the use of the UI by decision-makers in order to test the most favorable scenarios for recomposing the offer and to reduce the time needed to set up the system; (2) Implementation of Artificial Intelligence techniques (Machine Learning) and Operational research (OR, ***RO recherche opérationnelle***) methods to optimize the masses of hubs per THG, ***GHT*** sector; (3) an introduction and refinement of economic indicators for evaluating quality: hospital hub operating threshold, activity maintenance criteria (profitability, quality, care, etc.); (4) finally, a redevelopment of the PoleSat application towards a professional, ergonomic, secure solution that is adapted to healthcare partners, with the aim of making PoleSat transposable to a real-life context.

7.3. *Prospects for use with the regional health agencies and general directorate for healthcare provision in 2022-2023*

The "future functionalities" (section 0 above) of development and continuation of tests would make it possible (on a temporal axis, before and after territorial recomposition) on the one hand, to validate or invalidate the scenarios and hypotheses envisaged on analyzing the evolution of hospital activity at different scales, and on the other hand, to compare the behavior of spatial practices of consumption of care following the local closures of certain sectors and to confront those outcomes with the result of PoleSat with the same evolution in activity (ressources.anap.fr. 2016a).

As mentioned in section 0, p.17 the generalization of the gravity approach will be more time consuming, the difficulty lying in the realization of the proof of the spatial practices of proximity of the patients. It is even likely that limits to the gravity model can be found, empirical thresholds could vary differently (Quesnel-Barbet 2002, Quesnel-Barbet *et al.* 2020a) (cf. section 3, p. 6) if factors of notoriety and medical professional networks are strong. In any case, the financial stakes are such that it is worth persevering and extending the uses of proximity checks in phase one of the study (Quesnel-Barbet 2002, Quesnel-Barbet *et al.* 2020a) (cf. section 4, p. 6). We draw the attention of future users wishing to test our approach on new sectors of activity to the fact that it will be necessary to verify and validate the proximity and exception indicators, (Quesnel-Barbet 2002 p. 192).

The development of new PoleSat-business services at the request of decision-makers involves establishing the structural framework of PoleSat and its economic model.

7.4. *Perspectives at academic level*

Partnerships with student training courses are envisaged to extend PoleSat's applications to other issues (in health and outside health). The applications could be opened, on the one hand, to health data other than that of the French National Hospital discharge database HDDB/***PMSI*** and, on the other hand, to geographical areas in countries with different medico-economic management systems (USA, Canada).

8. Conclusions

In this article, we proposed to use a prospective tool of spatial analysis and territorial reorganization, to answer the problematic of a group of decision makers of the Territorial hospital grouping (THG, ***GHT groupement hospitalier de territoire***)"Atlantique-17. The initial hypotheses formulated by the THG, ***GHT*** Atlantique 17 were that the transfer of "617 acts of vascular catheterization" from the Rochefort hospital to the Saintes hospital (of the THG, ***GHT***-Saintonge) would lead to a complete gain in attractiveness of 100% of the activity of the Rochefort hospital in favor of the Saintes hospital with recovery of the Rochefort hospital's patient base. As a result, Saintes hospital would see its activity increase and its Hospital catchment areas (HCAs, ***AAHs aires d'attractions hospitalières***) widen.

The simulation of such a scenario in PoleSat finally showed that only 20% of the 617 procedures would be transferred (in terms of gains in activity) to the Saintes hospital and that **most of the** gains (71% of the 617 procedures) would be transferred to the La Rochelle hospital. It is therefore recommended that decision-makers plan to increase the treatment capacity of La Rochelle Hospital. The robustness test carried out in scenario 3 against scenario 2 shows the robustness of scenario 2, allowing us to consider that the simulated redistribution of the "vascular catheterization" activity between the reorganized hospital hubs can be trusted.

The expertise provided by the analysis of the results of the scenarios would thus enable decision-makers to be actors in a regulated distribution of planning rather than simply observing the natural distribution of activity following the suppression of activity in a specific establishment. Finally, technical developments are planned for the PoleSat tool, **to** make it more easily transposable to real life, or even to extend it to other application areas than health.

9. Acknowledgements

The authors would like to thank Patrick Staelen (Altense Consulting, Landas, France); Xavier Vitry (Geographer of Health, Ministry of Solidarity and Health, Paris, France); Professor Régis Beuscart, former Head of Department (CERIM, Faculty of Medicine - University of Lille and UH, ***CHU*** of Lille) and Professor Pascal Staccini, (RETINES, Faculty of Medicine, University of Côte d'Azur and CHRU of Nice) for their support of the POLESAT project.

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