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Planning health services with explicit geographical considerations: a stochastic location–allocation approach

P.R. Harper[a,*], A.K. Shahani[a], J.E. Gallagher[b], C. Bowie[c]

[a]School of Mathematics, University of Southampton, Southampton S017 IBJ, UK
[b]Oral Health Services Research & Dental Public Health, GKT School of Dentistry, King's College London, UK
[c]Department of Community Health, College of Medicine, Malawi

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Abstract

This paper is concerned with modeling for planning health services when geographical considerations in the location of services and in the locations of patients who need services are important. Examples of geographical distribution and organization of health services are the location of hospital outpatient departments within a city, and the provision of hospital-based specialist services, such as cardiac and dental surgery, across a region. Important issues in the provision of services include the location of the service centers, service capacities, geographical distribution of patients, and ease of access to the health services. This paper describes the development of a discrete-event geographical location–allocation simulation model for evaluating various options for the provision of services. Real-life case studies will illustrate the practical importance of the modeling approach.

Keywords: Health services; Location; Geographical modeling; Simulation

1. Introduction

Health-care services operate in an environment of continuous change, extreme uncertainty and variability, where detailed information for decision-making is highly desirable [1]. A need often arises to examine the geographical distribution and organization of health-care service capacities, from the local hospital level to services provided throughout a region or a nation as a whole. For example, planning issues might include the location of hospital outpatient departments within a city, and the facilities offered at each center, or re-configuration of specialist health services across the country. In order to plan for the provision of health services, various geographical distributions of service providers, together with the organization of each provider, must be examined. Predictions on patient numbers, traveling times and traveling distances are important for helping to answer questions on the number of health centers to provide, the services they offer, and the geographical location of these centers. Quantitative information greatly aids the decision-making process by local district, regional, and national health service planners.

The role of location–allocation models for quantitative analysis in planning health services is well documented [2–4]. This approach provides a framework for evaluating service accessibility under different location options, helping to generate more efficient geographical distributions. Various sophisticated mathematical location–allocation techniques have been formulated and proposed, primarily adopting deterministic models such as the location set covering problem (LSCP) [5] and the p-median problem [6]. These algorithms are attractive since they have a clear objective function such as to minimize total weighted travel distance. However, they assume deterministic conditions, such as fixed traveling distances for all individuals traveling from one region to another, and often make simplifying assumptions in order to formulate the problem. Solutions that aim to minimize total travel distance alone, such as

* Corresponding author.
E-mail address: p.r.harper@maths.soton.ac.uk (P.R. Harper).

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p-median, may be inequitable forcing some users to travel far [2]. Set covering methods, such as LCSP, that find the minimum number of centers so that everyone travels less than a defined maximum distance, can lead to more centers being required than is feasible [3]. Furthermore, the practical usefulness of mathematical sophisticated tools has not been addressed.

This paper discusses the issues surrounding the distribution and organization of geographical health service capacities and the needs of those who must plan for these services. Organizations collaborating in this research included The United Kingdom (UK) Department of Health (Cardiac provision and Cleft Lip and Palate services across health authorities), Oral Health Services Research & Dental Public Health, King's College London (Facial, Oral, and Dental services across London), and Portsmouth Hospital (outpatient and post-acute services in the Portsmouth region). To meet this need, a flexible practical stochastic geographical simulation model was developed, a description of which is presented here. It was possible to build a generic model capturing the underlying process of patients traveling to providers, whilst accounting for and monitoring necessary resource capacities, variability in patient needs, and travel considerations.

The model includes a geographical front-end, showing on a map of the area the user-defined service providers and information on the population they serve. The model provides the necessary information for answering a variety of "what if…?" questions such as the effect of changing the location of the providers, opening or closing providers, and changing the facilities offered at each provider. Patient traveling times and distances are captured, incorporating different modes of transport. The consequence of new distributions and organization of capacities may be readily examined. This approach is demonstrated in more detail through real-life case studies with Oral Health Services Research & Dental Public Health, King's College London.

This paper is divided into five sections. In Section 2, the use of location–allocation models for geographical organization of health services is reviewed. In Section 3, the elements of a geographical model are discussed, as based on findings from discussions with the participating organizations. Section 4 describes the simulation model development and two case studies of the model in use are provided in Section 5. Section 6 concludes the paper and discusses the benefits and drawbacks of the adopted stochastic approach taken for the health service planning location–allocation problem.

2. Health service location–allocation models

The UK National Health Service (NHS) has over the last decade undergone major changes in its organization and delivery, and this experience has to a large degree been mirrored in most major western nations [7,8]. Increasingly large amounts of resources are being directed to support a service that is strained sometimes to its limit under growing demands. Changes in technology and medical practice generally have led to shifting patterns of care, that are often difficult to predict. In addition, demographic shifts, for example an increasingly aging population, also impact on healthcare demand [8]. In this context, there is a growing need to tightly manage healthcare resources, including efficient and effective use of resources such as hospital beds, workforce planning, and location of services.

Given the increasing pressures on health service providers, the potential benefit of modeling for health service capacities is substantial and has found considerable application, including bed capacities [1,9,10], operating theatres [11,12], workforce planning [13,14], intensive care [15,16], and outpatient services [17,18]. For geographical considerations, location–allocation models are typically employed for finding optimal geographical sites, locating optimal sites in a new area, or improving existing location patterns [2]. A number of mathematical formulations for solving location–allocation problems have been proposed, and include the p-median problem [6], the pq-median problem [19], the location set covering problem (LSCP) [5], and the maximal covering location problem (MCLP) [20]. Descriptions of these techniques are well documented and will not be discussed here. Some concerns however have been raised about the appropriateness for capturing the complexities of real-life location issues by adopting these deterministic tools. Inadequacies include the inability to capture the variability in patient traveling modes, times and distances, uncertainty over patient preferences for traveling to different center locations, and complexities over consideration of healthcare services involving multiple services rather than a single theme. Furthermore, the practical usefulness of sophisticated mathematical tools has not been addressed, although health service planners, who can expect to have little understanding and trust in black-box methods, will likely want to use these tools themselves.

Given the needs of the participating health service organizations, it was the authors' intention to consider the elements of a geographical model and develop a user-friendly flexible scenario planning tool. The aim was not to build a single image of the future provision of services but rather to allow participating organizations to explore a number of possible futures. Such a model needed to quantify the effect of changes to the location of the providers, opening or closing providers, and changes to the services offered at each provider. Detailed information on patient numbers and patient traveling times and distances should be made available to aid the decision-making process. Given real-world variability, uncertainty and complexity, a stochastic model seems appropriate.

3. Elements of a geographical model

Health service planners must consider a range of issues when evaluating different geographical distributions and organization of their services. From the provider (organizational) viewpoint, a desired configuration of care should ensure efficient and effective use of available resources. This will involve the range of services that they offer, and deciding on a good distribution of locations for these services within the region they serve. Re-organization of care typically involves consolidation of providers whilst ensuring that each center treats a minimum number of patients (critical mass) to make it financially viable. As an example, the UK Government has committed to expand cardiac services in the NHS in England and Wales through rationalization of existing capacities in a coherent way [21]. Providers will need to predict future population needs accounting for demographic changes, advances in treatments, and resulting resource requirements. From a patient's viewpoint, quality of care and access to services are key concerns. In particular, patients would like to minimize traveling distances and times in accessing desired health services. Under consolidation plans, a patient might be expected to find that a local provider closes and that a larger regional center is situated further from home. The provider, whilst potentially wanting to minimize the number of centers open, must also consider the consequence of new distributions and organization of capacities on patient access. This is a complex issue for planners to evaluate.

In order to develop a geographical modeling tool for the planning of health services, it was first necessary to consider the elements of the model. Based on discussion with, and the needs of, participating health service organizations, the following elements were apparent.

3.1. Services (specialties)

Information on the service provision offered to patients. For example, within an outpatient department there might be separate services for different hospital specialties (Surgical, Medical, Oncology, Blood testing, X-ray services, etc.).

3.2. Centers (provider locations)

The number and location of centers offering patient care within the geographical region. Information on which services are available at each location.

3.3. Distribution of population

A spatial knowledge of the population which is served by the providers. This may be captured through defining suitable population areas, such as existing boroughs within a city, health authorities across a region, or towns and cities in a nation.

3.4. Demand for services

Estimates of patient demand for the different services across the defined population areas. For example, number of patients requiring specialist dental surgery within a city. Forecast of demand will need to account for demographic and migrational change. Demand is also a function of time and this may be important when planning for services. For example, demand for some services may be seasonal, such as elderly care during the winter months or pediatric services during the school vacations.

3.5. Mode of transport

Patients use different modes of transport to complete the return journey from home to provider. A patient will usually travel by bus, train, car, bicycle, or on foot. Travel considerations are typically influenced by location of the patient (across the defined population areas describing the population distribution). A patient living in a rural area, with limited public transport might, for example, travel by car, whereas a city dwelling patient might make use of an extensive public transport network thus avoiding traffic congestion.

When exploring future scenarios of patient care, and corresponding location of centers, health planners will need to consider the following options:

3.6. Number of centers and organization of services

The purpose of the modeling exercise for planners is usually to evaluate changes to the current provision of care through consolidation of services. Thus the total number and distribution of provider centers may change, usually through closing existing centers and expanding others. Planners should have in mind what combination of center locations and services offered at each center might be feasible. The developed geographical planning tool should permit any center/service combination to be either opened or closed. There should also be the possibility to open new centers in new locations.

3.7. Patient preferences

A useful feature of a geographical planning tool would be to capture preferences of patients and providers when evaluating which available center patients should travel to. For instance, if a local center closes, then in future patients might be able to choose between different centers across the region, or alternatively health service planners may insist that the affected population use a particular center (based on catchment areas). An expressed need from the participating organizations was for the possibility to evaluate user-chosen preferences (expressed as a percentage of a population area traveling to each center) plus an alternative option for the model to send patients to the closest available center offering the required services (nearest center option).

In order to provide helpful quantitative information for each patient care scenario, the following information is desirable:

3.8. Patient access

Traveling times (in minutes) and distances (in miles) for all patients traveling to a given center for each service. Summaries for travel *to* each center and *from* each of the defined population areas.

3.9. Patient demand

Information on numbers of patients traveling to each center by service. Where appropriate, this should be captured over time to show daily and monthly variations.

3.10. Critical mass

The decision on the number of centers to provide across a geographical region, and the services that they each offer, will in practice depend on both patient access information and patient numbers at each center. A critical mass, i.e. a minimum number of patients being treated for each available service at each center within a defined time period, will help to decide whether a center–service combination is viable.

With all of the above elements in mind, a flexible practical detailed geographical simulation model was developed, a description of which is presented in the next section. By addressing the above elements, it was found to be possible to build a generic simulation model capturing the underlying process of patients traveling to providers, whilst accounting for and monitoring necessary resource capacities, variability in patient needs, and travel considerations. Suitable changes to the model parameters and selection of a map of the study region permits the use of the tool for a number of different applications and service planners, as demonstrated by the diverse range of collaborating organizations.

4. Development of a geographical simulation

From a practical viewpoint, a model in which centers may be readily opened and closed on a map depicting the geographical region has great appeal. Information on population densities, traveling and provider preferences, and center–service combinations must be easily changed. Furthermore, demand is often a function of time, and stochastic traveling times and distances vary from patient to patient, thus a deterministic approach may be expected to underestimate resource capacities [1,22].

With these concerns in mind, together with the needs of the participating organizations, a discrete-event simulation has been developed. The simulation model was developed in a Delphi environment using a three-phase simulation shell TOCHSIM [23], developed at the University of Southampton, UK, and named after Professor Tocher, founder of the three-phase simulation approach [24]. The use of Delphi results in the familiarity of a Windows environment that aids ease of use. The three-phase simulation shell can reflect the experiences of the providers very rapidly. For example, thousands of patients traveling around the region from home to provider corresponds to a few seconds of TOCHSIM time. This approach has been successfully used in many other University of Southampton health-care research projects [1,15,25,26].

The simulation includes a geographical front-end, showing on a map of the area the user-defined center locations and information on the population they serve. Any image file may be used for loading a map of the region. Centers may be placed on to the map using the tool bar and clicking directly on the map in the desired location. Population areas are drawn on the map using rectangles or circles to capture the area. For example, depending on the detail of the map and the region being studied, these areas may correspond to a part of city, an entire city, or a number of cities and surrounding area. Using the above tool-bar facilities, a benchmark model of existing population and provider distributions may be created, such as the example of cleft lip and palate services across Southern England shown in Fig. 1.

The screen pixels are used to measure distances on the map. To do this, the user must define the benchmark scale in miles per bit, together with a benchmark speed of travel (mph) that is used in calculating travel times (more detail is given under population parameters below). To check distances, the user may drag the mouse from one point to another on the front-end map, and the distance between the two points is automatically displayed. Service information must be defined in the model. This is simply a list of all possible services. For example, working with dental services across London, 36 different types of service admissions were identified, including specialties such as ENT (Otorhinolaryngology), OMFS (Oral and Maxillofacial Surgery), and Plastic Surgery (PS), each further split by sub-specialist categories of surgery such as trauma, removal of wisdom teeth, and orthognathic work. Provider and population parameters are more complex and are described below.

4.1. Center parameters

Provider information may be accessed via the menu-bar or by double-clicking the provider directly on the map. Each center is given a name, such as the hospital or specialist center it represents. A list of user-defined services is presented and the user can open (select) or close (deselect) each service offered at the center. For example, the list of dental services offered at The Royal Free Hospital, London, is shown in Fig. 2. The user may easily change the organization of care by clicking on each of the services listed to either select or deselect. Furthermore, the entire center may be open or closed, as opposed to selected services being open or closed. This is a useful feature in readily allowing different scenarios to be evaluated, such as closing an entire center or changes to the types of care offered within each center.

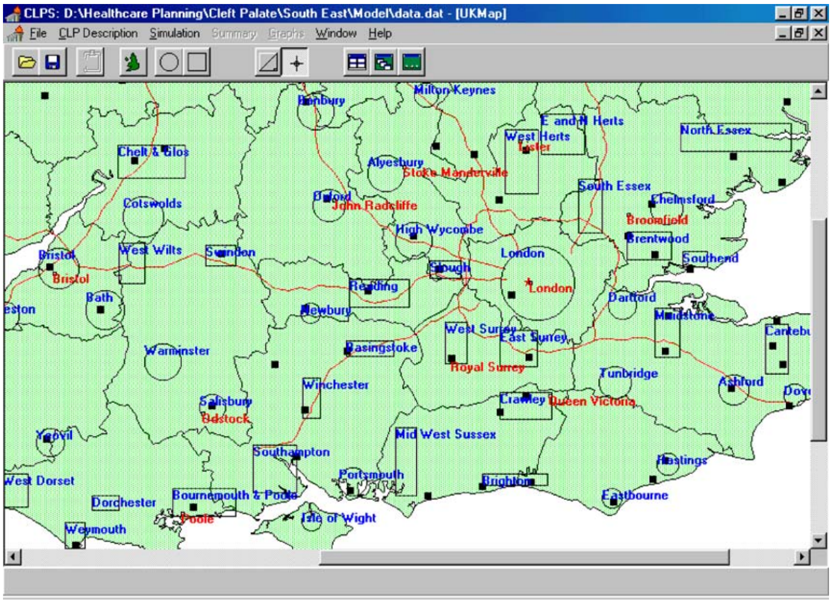

Fig. 1. Model front-end map indicating provider center and population distributions.

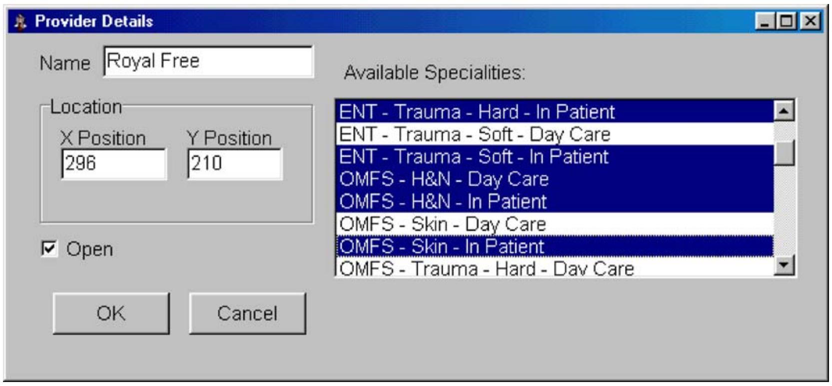

Fig. 2. Center and service information.

4.2. Population parameters

Population information may be accessed via the menu-bar or by double-clicking anywhere within in the population area on the map. Each population area is given a name, for example the name of the city or district to uniquely identify it. Information is also provided concerning (Fig. 3):

Number of patients (*incidence*) *that require access to services*: This may be a yearly number of arrivals (with patients equally likely to require access to services throughout the year, as sampled using exponential inter-arrival times) or the distribution of monthly arrivals to capture demand as a function of time (the simulation clock generates daily demand based on the monthly arrival profile). Furthermore, a facility to define follow-up visits, expressed as a follow-up ratio, is made available. Thus for example, for every new outpatient, on average two further follow-up visits may be necessary (a user-defined ratio of 2:1). The model will generate any necessary further journeys for each patient based on this ratio.

Travel preferences of the population within the area. This is captured with up to three different modes, with user-defined proportions of the population using each mode, and distance and time factors for each mode. The factors alter the straight-line distance that is calculated in the model. For example, with respect to the user-defined benchmark speed of travel (baseline factor of 1), if traveling by bus then the speed of travel might be faster because of dedicated

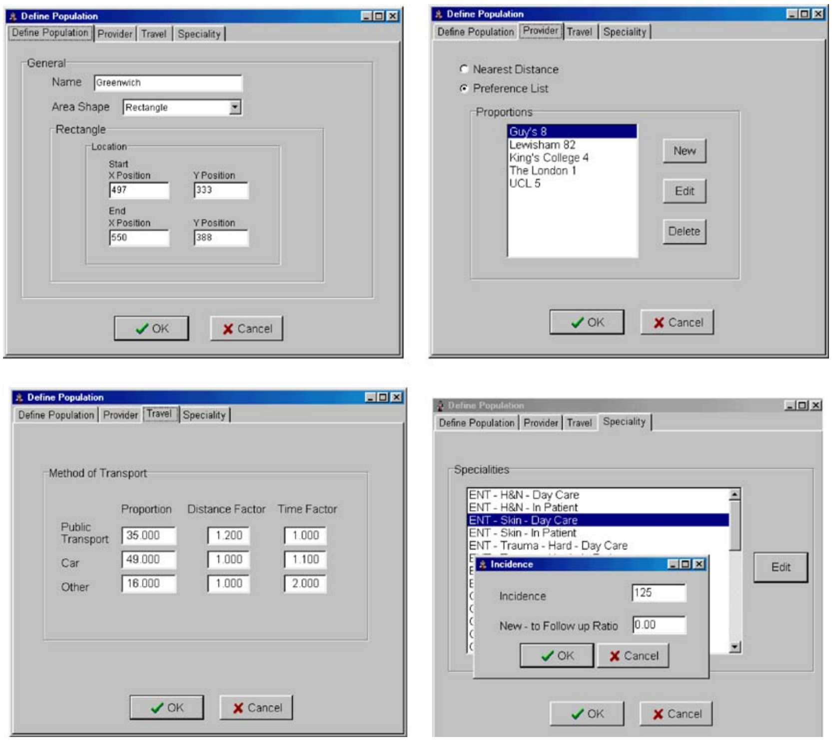

Fig. 3. Illustrative population data screen-shots.

bus lanes (time factor less than 1), but longer because buses will typically not travel along the most direct route, instead diverting to serve a larger region (distance factor greater than 1).

Center preferences. Travel may be made to any of the defined list of centers. Preferences are expressed as a percentage of the population traveling to each center. This may mimic current travel patterns or be changed for scenario purposes. Alternatively, the user may select the "nearest center" option, in which case the model will automatically send the patient to the nearest available (open) provider offering the desired service.

Based on incidence statistics and demand profiles from each population area, the simulation model generates patients at random points from within the area, and then decides which center they must travel to, and by which mode of transport. This is dependent upon user-selected preferences as described above. The journey is then simulated on the map, measuring the distance and calculating the resulting time of each individual patient journey. Thus, the simulation is necessarily detailed to capture individual journeys. Statistics are recorded on each journey. A user-chosen number of simulation runs are conducted. Summary statistics are made available at a number of different levels, from overall statistics at the center level, to detailed service information at the population area level. Resulting summaries of patient numbers, and traveling times to centers and from populations, help health service planners to evaluate the effects of different scenarios and their impact from both the provider and patient points of view.

The developed generic model has been adopted for a number of projects with the participating organizations. In the next section, two such projects are described and help illustrate the practical importance of the geographical modeling approach.

5. Applications

5.1. Local district level planning—provision of dental services across London

In 1996, the Gelbier Report [27] undertook a major review of Oral and Dental specialities within London. It highlighted the overlap of Oral and Maxillofacial Surgery with other medical specialties of Plastic Surgery and ENT [27,28]. Further work on this issue revealed complex overlap between these specialties and a pattern of service provision which is unnecessarily complex and inefficient [29,30]. The modeling work, in partnership with Dental Public Health colleagues at King's College London, explored scenarios for rationalization of services across London, and the impact on volumes of care and patient access. This modeling formed one element of a wider Health Futures study which sought

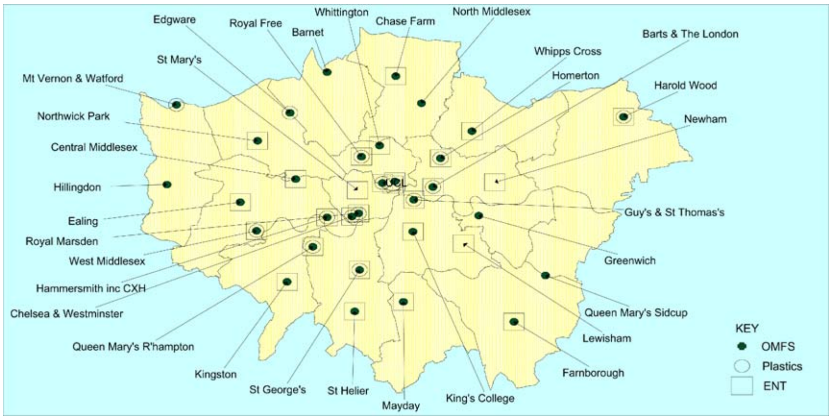

Fig. 4. Provision of OMFS, ENT and Plastic Surgery Services in London, 1997/1998.

Table 1
Scenarios for future OMFS clinical networks in London

Scenario	Sector				
	NW	N	NE	SE	SW
Scenario 1					
Largest in-patient center	Mt Vernon	UCH	London	GKT Guy's	St George's
Scenario 2					
Gelbier using Guy's in SE	Northwick Pk	UCH	London	GKT (Guy's)	St George's
Scenario 3					
Gelbier using King's in SE	Northwick Pk	UCH	London	GKT (King's)	St George's
Scenario 4					
Co-terminus with cancer and trauma centers	Charing Cross	UCH	London	GKT (King's and KCH trauma)	St George's
Cancer center	Charing Cross	UCH	London	GKT (Guy's)	St George's
Trauma center	Charing Cross	UCH	London	GKT (King's)	St George's

to provide foresight to planners and providers of the above specialist services at regional level [31].

The current service provision of OMFS, PS and ENT was captured for London based on hospital activity data (Fig. 4). This task was complex, since the facilities offered at each center not only varied by specialty (OMFS, PS and ENT) but furthermore by sub-specialty including Head and Neck Cancer, Facial Trauma, and Surgical Dentistry. In total, 36 services were defined for 42 different centers (hospitals) across 33 London Boroughs. Patient traveling preferences and traveling speeds for different modes of transport were based on the latest London Transport statistics [32].

Modeling of OMFS services was undertaken on a hub and spoke arrangement in a simulation of London's hospital services and patient flow at sector level (London has been divided into five medical sectors each of population 1–1.5 million—North-West, North, North-East, South-East, and South-West). Episodes of care for each specialty (surgical admissions) and aspects of care were modelled as coming from their borough of residence. Four main themes of scenario for OMFS were explored based on the hubs listed in Table 1. Thus, Scenario 1 modelled the largest existing in-patient center as the hub, as they have the largest capacity. Scenarios 2 and 3 utilized the recommendations of the Gelbier report (1996), which arose out of professional consensus for Inner London. Scenario 4 designated the hubs in line with evolving policy in relation to cancer and trauma centers [33,34]. Model validation was achieved by comparing the observed data with model results for the baseline (current) configuration, and performing statistical tests to ensure that the model was capturing reality.

The modeling process demonstrated the impact that changes in one sector may have on patient flows and volume of care at individual hospitals which remained hubs across all four scenarios. Baseline data for London, presented in Table 2, demonstrate variation in average patient traveling distances between sectors. In-patient traveling distances and times to providers increase significantly as a result of OMFS service rationalization across all scenarios for London. The average increase for all patients traveling to London

Table 2
Distances traveled by OMFS in-patients to main London provider by sector of treatment for 1 year

Distance traveled to hub by sector of treatment (miles)						
Scenario[a]	NW	NC	NE	SE	SW	London
Baseline	**8.5**	**3.7**	**4.3**	**5.5**	**3.4**	**5.4**
(95% Cl)	+/ − 0.45	+/ − 0.10	+/ − 0.21	+/ − 0.16	+/ − 0.11	+/ − 0.15
Scenario 1	Mt Vernon	UCH	London	GKT (Guy's)	St George's	1 total
Largest in-patient center	**13.3**[*,b]	**5.4**	**6.1**	**7.5**	**5.1**	**7.4**[*,c]
Change	+4.8	+1.7	+1.8	+2.0	+1.7	+2
% change	+ 57%	+ 46%	+ 42%	+ 36%	+ 50%	+ 37%
95% Cl	+/ − 0.5	+/ − 0.15	+/ − 0.2	+/ − 0.25	+/ − 0.15	+/ − 0.21
	[12.8; 13.8]	[5.25; 5.55]	[5.9; 6.3]	[7.25; 7.75]	[4.95; 5.25]	[7.19; 7.61]
Scenario 2	Northwick					
Gelbier (Guy's)	Pk	UCH	London	GKT (Guy's)	St George's	2 total
	5.9	**5.5**	**6.1**	**6.9**	**5.2**	**6.2**
Change	−2.6	+1.8	+1.8	+1.4	+1.8	+0.8
% change	−31%	+49%	+42%	+26%	+53%	+ 15%
95% Cl	+/ − 0.5	+/ − 0.15	+/ − 0.2	+/ − 0.25	+/ − 0.15	+/ − 0.15
	[5.4; 6.4]	[5.35; 5.65]	[5.9; 6.3]	[6.65; 7.15]	[5.05; 5.35]	[6.05; 6.35]
Scenario 3	Northwick					
Gelbier (KCH)	Pk	UCH	London	GKT (King's)	St George's	3 total
	5.9	**5.9**	**6.2**	**6.2**[*,d]	**5.5**	**6**
Change	−2.6	+2.2	+1.9	+0.7	+2.1	+0.6
% change	−31%	+60%	+44%	+13%	+62%	+11%
95% Cl	+/ − 0.3	+/ − 0.35	+/ − 0.4	+/ − 0.35	+/ − 0.15	+/ − 0.13
	[5.6; 6.2]	[5.55; 6.25]	[5.8; 6.6]	[5.85; 6.55]	[5.35; 5.65]	[5.87; 6.13]
Scenario 4	Charing Cross	UCH	London	GKT (King's)	St George's	4 total
Co-terminus cancer/trauma	**6.4**	**6.6**[*,e]	**6.3**	**6.3**[*,d]	**5.4**	**6.3**
Change	−2.1	2.9	2	0.8	2	0.9
% change	−25%	+78%	+47%	+15%	+59%	+17%
95% Cl	+/ − 0.35	+/ − 0.3	+/ − 0.25	+/ − 0.2	+/ − 0.2	+/ − 0.18
	[6.05; 6.75]	[6.3; 7.2]	[6.05; 6.55]	[6.1; 6.5]	[5.2; 5.6]	[6.02; 6.48]

[*] Significance is taken at 95% level.
[a] Scenarios are modelled on actual patient activity (episodes of care) for 1997/1998 in London.
[b] Mt Vernon for the NW sector in Scenario 1 had a significantly higher average traveling distance than any other scenario.
[c] Scenario 1 had the highest overall average traveling distance to hospital for London.
[d] Traveling for King's in Scenarios 3 and 4 was significantly lower than Guy's in Scenarios 1 and 2.
[e] UCH in Scenario 4 has a significantly higher average traveling distance for this Sector in conjunction with lower volume as Charing Cross has preferentially absorbed more central London patients for the NW hub.

hospitals ranges from 11 to 37% by scenario. At the sector level, traveling distances and times are significantly higher for the North-West sector in Scenario 1. Looking across scenarios, the North-West sector demonstrates wide variation in traveling. This relates to the fact that this part of London had no natural 'focus' such as a dental hospital and thus there are several centers competing for this position, one of which was located on the outer border of London and had a high proportion of non-Londoners utilizing its services.

The research demonstrated the need for a systems approach to service reconfiguration in London, whereby changes in one sector have a significant impact on patient flow to other hospitals, particularly in relation to the North-West sector. It demonstrates that rationalization of care involves a significant increase in traveling times and distances for London residents, for in-patient care, over the baseline scenarios. Based on the modeling process and discussions with oral and dental providers across London, a rational plan for London has now been formed and involves co-location of OMFS hubs with cancer and trauma services as demonstrated in Scenario 4. It provides the most equitable spread of care, based on historical commissioning and

Table 3
New center at Chelmsford with patients going to their most accessible center

To service provider: from health authority:	St. Mary's	Barts & London	UCLH	A'brookes	Chelmsford	Total patients	Av. travel time (min)
Bedfordshire	267	0	0	238	0	505	72.7
Cambridgeshire	0	0	0	584	0	584	38.3
Hertfordshire	211	66	238	260	0	775	50.8
Norfolk	0	0	0	766	0	766	121.0
Essex—North	0	61	0	65	688	814	48.5
Essex—South	0	0	0	0	642	642	52.2
Suffolk	0	0	0	155	476	631	85.1
Total patients	478	127	238	2,068	1,806	4,717	—
Av. travel time (min)	57.0	54.5	47.5	78.5	60.9	—	67.4

referral patterns as well as the opportunity for multidisciplinary head and neck cancer surgery and enables OMFS to be on site to retain their monopoly on trauma care, whilst acknowledging the multidisciplinary nature of future care. The geographical model has been seen to play a major role in providing a quantified basis for rational decision-making in the complex provision of dental services across London.

5.2. *Regional level planning—provision of CABG services within Eastern England*

The UK Government has committed to expand revascularisation services in the NHS in England and Wales [21]. The national plan is to increase coronary artery bypass graft (CABG) operations and coronary angioplasties (PTCA) by 50% to 750 of each procedure per million population. The authors were asked to help find ways of planning this expansion in the eastern region of the UK in a coherent manner. The Department of Health had already undertaken a study to predict future incidence and prevalence of coronary heart disease for each of the 48 local authority districts within the eastern region (downloadable from www.cam.bowie.btinternet.co.uk). This study used the most recent national general practice morbidity survey [35], 2005 national population forecasts [36], and adjusted for the known differences and anticipated reductions in incidence of heart disease in each district [37].

The southern part of the eastern region has until now relied on London hospitals for tertiary services. Waiting times are poor and the networks of local intervention cardiology based on district general hospitals are rudimentary. Modeling work was needed to help decide where the new cardiac services should be located. A scattering of small cardiac surgery units would be expensive and small units are known to have less favorable outcomes than large ones [38]. The key issue was the importance of center locations for patient access whilst assuring a critical mass at each center.

Assumptions were made about the mode of transport based on discussions with health authorities. The majority of travel to London hospitals is assumed to be by train. The majority of travel in the northern quadrants of the region is assumed to be by car, although the percentage splits between modes changes by district. A number of scenarios were explored. Two choices for traveling by individual patients needing cardiac surgery were considered for each of the scenarios. The choices are:

- People travel according to a defined catchment for each center based on expected flows around cardiac networks of district general hospitals and their cardiac surgery center.
- People travel to their nearest center.

Whilst no theoretical upper limit to the size of a cardiac surgery center exists, there probably are potential diseconomies for units with throughputs greater than 2300 operative cases per year. A consensus is forming around a minimum size to allow economies of scale and critical mass for duty rotas and training [21]. It is 1200 operative cases per year provided by a team of six cardiac surgeons.

A benchmark model was constructed showing current provision of services. In total 42 scenarios were evaluated, examining four core centers with combinations of one, two, or three new additional centers. An illustrative scenario table is presented (Table 3) and access times for all scenarios are shown in Fig. 5. Here, the first bar for each option represents the traveling time under a nearest center scenario, where appropriate, and the second bar represents existing General Practitioner referral areas, acting as a proxy for patient preferences.

The Department of Health was able to use the quantitative information in their discussions with providers and patients across the region. The study showed that a center in Norfolk (at Norwich) makes the most impact on access, whilst Essex and Hertfordshire centers make little impact. The benefits of three new centers as opposed to two could be calculated. The bottom-up approach to planning has encouraged patients and clinicians to contribute to the

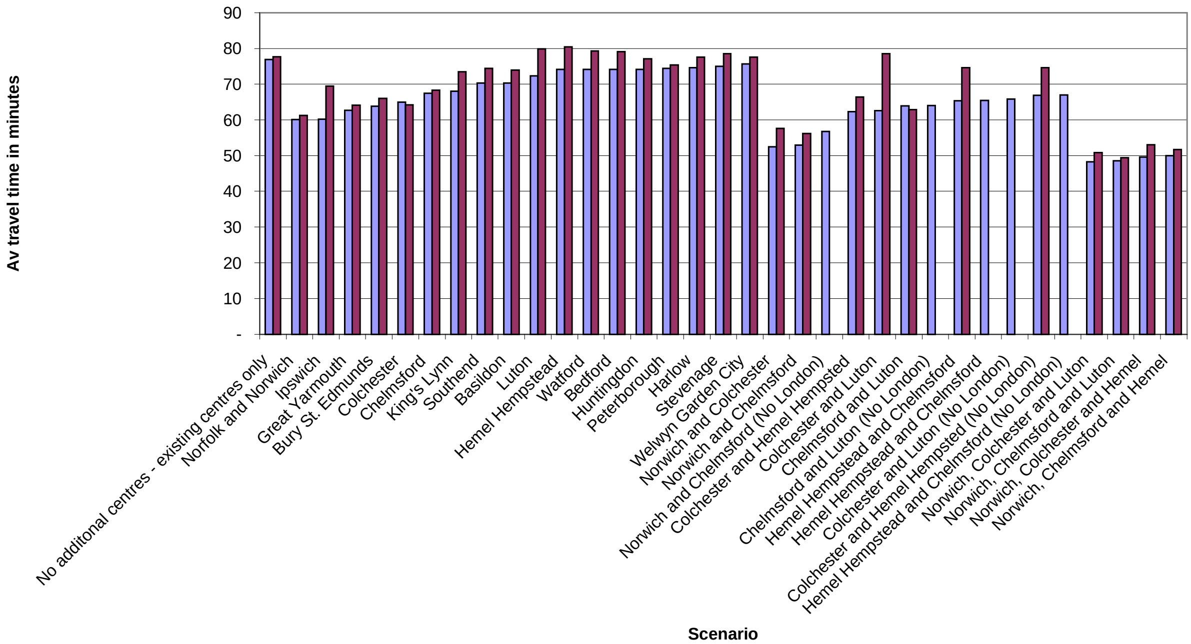

Fig. 5. Access study for cardiac surgery based on projected need—Eastern Region. Nearest center scenario—first bar, clinical network preferences—second bar.

process using their experiences of existing practice and their expectations for the future. The model has helped identify scenarios that make significant differences in access times and distances, and suggests suitable center locations of new services in a rational way based on best evidence. It has enabled the Regional Office of the Department of Health to recommend sites plus the creation of an additional cardiac centre, the plans and justification of which are currently being presented to the Government Secretary of State for approval. The Department of Health have also used the model to plan for Cleft Lip and Palate services and used the model in the forming policy on the rationalization of services to enhance the quality of care [39].

6. Conclusions

Location–allocation models historically have played a major role in geographical modeling of health-care services. This paper has presented a stochastic approach to the problem through the development of a geographical simulation model. The benefits of the stochastic approach include the recognition and incorporation of variable patient flows, traveling times, and transport preferences, as well as providing a single generic user-friendly model in which to undertake such work. Ease of use of location–allocation models has been largely ignored in the literature and was a major consideration in the research. Consequently it has allowed the model to be used by the participating organizations, without the need to understand sophisticated mathematical equations, as employed by traditional deterministic approaches to the location–allocation problem.

By simulating individual patient movements, the model avoids the potential pitfall of the deterministic approach to health service planning by underestimating resource requirements and traveling distances, thus providing false assurances about the levels of expected service and disruption to patients [1,22]. In addressing this problem, we simulate individual patient movements by generating patients at random points within defined geographical population areas, and sampling center preferences and mode of travel. By generating demand at points across a population area, we more closely reflect reality of geographical distributions of patients, which are particularly relevant when evaluating travel to the nearest center. In such a scenario, some patients may find that traveling to a center in a neighboring area is actually nearer than to a center in their own catchment area. A simulation approach is necessary to reflect these patient movements, whereas a traditional location–allocation model in which demand is assumed to originate from a central point within each population area would not capture this.

The simulation tool gives rise to an easy-to-use model. Centers may be readily opened, closed and re-located on a geographical map of the area in the front-end of the model, and the services they offer defined. Patient population sectors may be easily drawn on the map and the relevant information captured. Various scenarios can be rapidly explored by simple changes to population and provider parameters captured on user-friendly screens.

A drawback to the simulation approach is that an optimal solution is not necessarily found. However, real-life location planning is subject to various constraints and other drivers, such as political considerations, and the primary purpose of the model was to permit any possible scenario of service configuration to be rapidly explored. Often in practice, a single objective may not be feasible, as for example to minimize the total weighted travel distance (p-median problem). There may be many reasons why such solutions may not be acceptable from a service point of view [2]. The benefit of the simulation approach is that an objective function is not necessary. Instead detailed results, from both provider and patient viewpoints, permit discussions between key players and help move towards a suitable geographical distribution and organization of services. Furthermore, the user-friendly interface of the simulation builds confidence in the end-user, thus avoiding a black-box approach.

Use of the model has been demonstrated through two case studies, one at a local planning level and the second at a wider regional level. This helps to demonstrate the generic nature of the model and its use for geographical health service planning at different levels. A number of quantitative model outputs help health planners to evaluate the consequences of different geographical distributions and organization of their services, both from the provider (organizational) and patient viewpoints. This paper has demonstrated the benefits of a stochastic approach to complex real-life location–allocation problems.

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References

[1] Harper PR, Shahani AK. Modelling for the planning and management of bed capacities in hospitals. Journal of the Operational Research Society 2002;53:11–8.
[2] Rahman S, Smith DK. Use of location–allocation models in health service development planning in developing nations. European Journal of Operational Research 2000;123:437–52.
[3] Mohan J. Location–allocation models, social science and health service planning: an example from North West England. Social Science and Medicine 1983;8:493–9.
[4] Fortney J. A cost–benefit location–allocation model for public facilities: an econometric approach. Geographical Analysis 1996;28:67–92.
[5] Toregas C, Swain R, ReVelle CS, Bergman L. The location of emergency service facilities. Operations Research 1971;19:1363–73.
[6] ReVelle CS, Marks D, Liebman LC. An analysis of private and public sector location models. Management Science 1970;16:692–707.
[7] World Bank. Investing in health. World Development Report 2001. Oxford University Press, Oxford, 2001.
[8] Saltman RD, Von Otter C. Planned markets and public competition: strategic reform in Northern European health systems. Buckingham: Open University Press; 1992.
[9] Bagust A, Place M, Posnett JW. Dynamics of bed use in accommodating emergency admissions: stochastic simulation model. British Medical Journal 1999;319:155–8.
[10] Lane DC, Monefeldt C, Rosenhead JV. Looking in the wrong place for healthcare improvements: a system dynamics study of an accident and emergency department. Journal of the Operational Research Society 2000;51:518–31.
[11] Gibson. A model way to plan for surgical needs, Health Service Journal 1998;98:5085–6.
[12] Rose MB, Davies DC. Scheduling in the operating theatre. Annals of the Royal College of Surgeons of England 1984;66:372–4.
[13] Dowsland KA, Thompson JM. Solving a nurse scheduling problem with knapsacks, networks and tabu search. Journal of the Operational Research Society 2000;51:825–33.
[14] Silfred SP, Benton WC. A decision model for shift scheduling of nurses. European Journal of Operational Research 1994;74:519–27.
[15] Ridge JC, Jones SK, Nielsen MS, Shahani AK. Capacity planning for intensive care units. European Journal of the Operational Research Society 1998;105:346–55.
[16] Knighton J, Will SJ, Brampton WJ. A statistical model to predict intensive care unit bed availability. Clinical Intensive Care 1994;5:146.
[17] Taylor S, Kuljis J. Simulation in health care management: modelling an outpatient clinic. OR Insight 1998;11:7–11.
[18] Paul RJ. Outpatient clinics—The CLINSIM simulation package. OR Insight 1995;8:24–7.
[19] Serra D, ReVelle CS. The pq-median problem: location and districting of hierarchical facilities. Location Services 1993;1:299–312.
[20] Church RL, ReVelle CS. The maximal covering location problem papers. Regional Science Association 1974;32: 101–8.
[21] Department of Health. National service framework for coronary heart disease. http://www.doh.gov.uk/nsf/coronary.htm
[22] Shahani AK. Reasonable averages that give wrong answers. Teaching Statistics 1981;3:50–4.
[23] Hawkins JD. TOCHSIM manual. Southampton Centre for Operational Research, Faculty of Mathematical Studies, University of Southampton, 1993.
[24] Tocher KD. The art of simulation. London: English Universities Press; 1963.
[25] Gove D, Hewett D, Shahani AK. Towards a model for hospital case-load decision support. IMA Journal of Mathematics Applied in Medicine and Biology 1995;12:329–38.
[26] Shahani AK. Towards an operational model for the prevention and treatment of asthma attacks. Journal of the Operational Research Society 1994;45:916–26.
[27] Gelbier S. Oral and dental specialties: a review for the chief executives of inner London health authorities. London, UK: King's College London; 1996.
[28] Gallagher JE. Oral and dental specialties serving inner London health authorities: hospital directory, 1994–96. London, UK: King's College London; 1996.

[29] Gallagher JE. A health futures study of facial, oral and dental surgery in London. Ph.D. thesis, University of London, 2002.
[30] Gallagher J. Specialties in transition. In: Davies C, editor. The future health workforce: nuffield trust & University of Cambridge. Basingstoke, UK: Palgrave, McMillan; 2003. p. 104–23.
[31] Garrett MJ. WHO health futures handbook. Geneva: World Health Organisation; 1999.
[32] Focus on London. Office of National Statistics. London Research Centre and Government Office for London. London: HSMO, 2000.
[33] Lecky F, Woodford M, Yates DW. UK trauma audit and research network—trends in trauma care in England & Wales, 1989–97. Lancet 2000;358:1717–22.
[34] Gallagher JE. Hospital dental services for London: an update for inner London purchasing chief executives. London, UK: King's College London; 1998.
[35] OPCS Morbidity Statistics from General Practice—Fourth national study 1991–92. Office of National Statistics.
[36] 2005 national population forecasts, Office of National Statistics. http://www.statistics.gov.uk/themes/population/default.asp
[37] Department of Health. Saving lives: our healthier nation. London: Stationary Office; 1999.
[38] Sowden AJ, Deeks JJ, Sheldon TA. Volume and outcome in coronary artery bypass graft surgery: true association or artefact? British Medical Journal 1995;311:151–5.
[39] NHS Publications. Modernising NHS dentistry— implementing the NHS plan. http://www.doh.gov.uk/dental/strategy