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ASSESSING VARIATIONS IN ACCESS TO SERVICES THROUGH TRAVEL TIME

OCENIANIE ZMIAN W DOSTĘPIE DO USŁUG PODCZAS PODRÓŻY

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Introduction

The time taken to travel between two locations is of importance in the delivery of services. In addition to delivery and collection services, the issue of accessibility is of great importance in locating fixed services, such as retail outlets and public services. In the location and accessibility of health care services the time taken to reach the service can literally be a matter of life or death. In the case of access to emergency health care there is the 'golden hour' where, if the patient receives appropriate specialist care within the first hour the chances of survival are significantly increased (Heled et al., 2004; UMMC, 2007). Advances in clinical expertise have led to the development of health care centres of specialisms, cardiology, oncology, etc. (Mungall, 2005; Maybin, 2007). Whilst the development of such specialist centres is advantageous to the clinicians, and those funding them, for many of the patients it means longer, and sometimes difficult, travel from home to the clinic. This study is driven by the needs of two projects, one studying access to a paediatric specialism and the other late or non-attendance at specialist out-patient clinics.

In both cases, data are available locating the source and destination for each journey, as is a detailed road network of Great Britain. In one case the source is defined in terms of a Postcode, giving a precision of approximately one hundred metres to the start of the journey, in the other it is defined by the census Lower Layer Super Output Area (LSOA) in which the patient resides. In rural areas a LSOA may contain several small settlements, so here the distance from each settlement is required, rather than a single value from the centroid of the LSOA.

This paper addresses the problem of determining travel times using a faster alternative (A*) to the standard Dijkstra (1959) approach.

Access to services

For any service to be viable it must have sufficient business, which means users, clients or customers, in order to justify the provision of the skills or stock required for the service. For a service to be accessible to these users, it must be within acceptable reach. What is 'acceptable' varies according to the nature of the service and the priority attached to that service by its clientele. Health care specialists need to see a minimum number of patients in order both to justify their salary and to maintain their skills. Any given clinic needs to have several specialists in order to provide continuity of care and sharing of experience: this leads to a trend towards fewer, larger units, inevitably located in metropolitan areas and requiring patients from rural areas to travel further for care (Mungall, 2005; Sedgwick, 2005; Maybin, 2007). From the perspective of patient referral to specialist services, a study of general practitioners (GPs) reported *the single most important equity issue was access and the constraints of geography and transport. This was felt most acutely by GPs in rural areas, but was present even for GPs in inner cities whose populations were deprived or elderly*. (Rosen et al., 2007). Christie and Fone (2003) note that *centralization of services reduces geographical access for all population subgroups*. They report that few studies had sought to study access by means of the road network the population would have to use and that their study fails to account for some of the critical time constraints of road travel, such as time for parking, rest breaks, traffic congestion, etc.

There has been considerable work on studying travel time to health provision, both in terms of general practitioner surgeries and hospitals, (Higgs, 2004; Damiana et al., 2004; Jordan et al., 2004; Haynes et al., 2006; Tanser, 2006). Haynes et al. (2006) and Fone et al. (2006) sought to validate the travel times estimated using the GIS methodologies against the times experienced by real patients. Both report a close relationship between the GIS methodology and actual experience, providing some confidence that the use of a GIS estimate of accessibility has some validity. Jordan et al. (2004) report that straight-line travel distances seemed to correlate well with actual drive distances where the source and destination were relatively close together, as in urban areas, and less well in more sparsely populated rural areas. They acknowledge that such measures only reflect those members of the population with access to a car (and driver). Damiana et al. (2004) also concentrate on access by independent road travel. Their concern was the time taken for travel to hospital for elective care but, rather than working with actual patient data, they calculated the distances between the hospitals and the centroids of the surrounding electoral wards. For rural areas, where electoral wards are large in area due to the more dispersed population, their calculated travel times varied considerably from those experienced by many of the patients.

The *accessibility* of services, in terms of how easy it is for those for whom the service is provided to get to the facility, has been another area of work. Termansen et al. (2007) used a statistical approach to assess the accessibility of forest-based recreation facilities. In addition to the distance travelled, they also incorporated the financial cost of travel. Given that many users of health care facilities are children, pensioners or others on a fixed or low income, the financial cost ought to be considered: we have not, however, seen any studies concerned with access to health care that take such a rigorous approach. Indeed, Lovett, Sünnenberg, et al. (2002) consider access to health care facilities by bus in terms of the routes taken and the frequency of service, important issues, but ignore cost.

Our study is concerned with two aspects of access: one in terms of the impact upon a patient through the location of a specialism relative to their home and the other being a part of a study into missed appointments. In the first case, the data relate to a paediatric specialism that is only available at one of three centres and having been restricted to a single centre until quite recently, where there is concern that the distances and time taken to travel may discriminate against some sectors of the community. The research hypothesis in the second case is that patients with the most difficult journeys are most likely to miss their appointments.

Wayfinding

It would appear that the ArcGIS tools for determining travel distance are widely used. Reneland (2002, 2006) studied integrated measures of accessibility by car, bus, cycle and on foot. Concerned with the safety of pedestrians, he used ArcGIS with datasets created to include the critical information required for each mode of transport, for example cycle lanes, bus stops, footpaths, pedestrian crossings, he modelled single and mixed modes of transport, initially within the Swedish town of Alingsĺs and later for other towns. Brabyn and Skelly (2002) studied access from 38 000 census enumeration district centroids to 63 hospitals, using the ArcGIS tools. They quote 8 hours just for computing the route paths and do not appear to have measured the computer time involved in obtaining the lengths of these routes.

Dijkstra's (1959) approach to finding the path of minimum total length between two given nodes, his "Problem 2", is widely known and implemented. The method tests all nodes in the network and can be slow for problems involving complex networks – such as the British road network. This is implemented by ESRI in ArcGIS (ESRI, 2002) and in most other GIS packages. For interactive searching for small numbers of routes, this approach has stood the test of time, but is less suitable for searches involving hundreds or thousands of source-destination pairs, because there is no optimisation and every possible node is evaluated at every step. The ESRI implementation yields a result which comprises the summed total 'cost' of the selected path and a route 'section' that comprises the various segments of the network that comprise the route. It is, using this tool, possible to select a route on the basis of a weighting, related to road type, and to determine the actual length of the route from the section table. This process, however, is relatively slow where many paths must be found: a test of some 600 source-destination pairs taking an average of 0.887 minutes to compute and report per path on a high powered computer. One of our study datasets requires determination of over 350000 source-destination pairs, requiring a faster method.

Car (1997) introduced the concept of Hierarchical Spatial Reasoning (HSR) for wayfinding, by which a route for road travel was determined by preferring roads of the highest class available. In her model, for example, a slightly longer route that used motorways is preferred to a shorter one using minor roads. For all but the shortest journeys, this methodology is demonstrated to generate routes with the shortest travel time. For the wayfinding, Car employed a modified form of Dijkstra's (1959) algorithm in which the road network was broken up into sub-networks by road classification. This approach generates a hierarchical set of networks and wayfinding computes a path that ascends the hierarchy as quickly as possible in order to reach as close as possible to the destination whilst remaining in the high level network and only descending the hierarchy on the final approach to the destination. Car et. al. (2001) were able to demonstrate that the use of an hierarchical preference had the impact of shortening the computing time normally required for the Dijkstra methodology by some 28%. O'Connor (2002) experimented with Car's methodology to model paths for football fans around a major stadium (Elland Road, Leeds). Following Dechter and Pearl (1985) and Korf (1995), she replaced Car's application of Dijkstra's algorithm with the more modern heuristic search strategy, the A* (A-Star) algorithm and simplified Car's hierarchical approach because of difficulties in extracting usable sub-networks from the British road network. When Jônsson (1997) implemented the A* algorithm, he found that he needed to take account of different road classifications and used the class as a multiplier for the edge length factor in A*. This has the effect of lengthening segments where the classification value is higher but, unless the road class related multipliers are quite large in value, a lower class edge may still be selected in preference to a shorter, higher class, edge because the lower class edge happens to end closer to the destination.

Our data

The data used in this study comprise a set of patient location and service location data, the Bartholomew 1:200000 digital road map and the National Statistics Postcode Data File (NSPD). The 602 patient and service locations are defined by Postcodes and the NSPD includes, amongst many other details, a point location for that Postcode in British National Grid coordinates (ONS, 2007). As a single Postcode represents an average of about eighteen delivery points/addresses, there remains a little uncertainty regarding the location, but this is minimal in terms of travel times and distances. The next phase of our study will use a patient dataset of some 350000 cases.

Our methodology

Korf (1995) noted that improvements in efficiency over Dijkstra's algorithm can be obtained by use of a heuristic *best-first* approach, citing the work of Dechter and Pearl (1985). A *best-first* search expands network graph nodes according to their suitability as determined by a heuristic function. Dechter and Pearl (1985) examined the concept of 'best-first' search strategies to see whether they are optimal in performance and chosen route. Whilst they detected a small number of pathological cases where they were able to prove A* to be non-optimal, they were able to show it to be optimal in the vast majority of cases. In this work, Car's (1997) hierarchical methodology has been adapted to use the A* heuristic approach to select the route, as prototyped by O'Connor (2002).

The HSR approach relies upon there being a proper hierarchical network: that it is possible to ascend the hierarchy at the start and only descend on approaching the destination. The British road network has developed in response to need, rather than being planned as a whole: unfortunately, it does not neatly decompose into the hierarchical layers, or sub-networks, required by HSR. This was noted by O'Connor (2002) and caused her to adopt a different approach. Efficient routes, however, require some measure of hierarchy: the better class, faster, roads are to be preferred over minor roads, along which travel is most often much slower. Our approach goes further than that of Jônsson (1997) by preferring those edges of equal or higher class to that of the edge by which the node has been reached. This comes closer to Car's HSR approach and is similar to the approach adopted by O'Connor: it is described in detail elsewhere (Halls). Running on the same computer as used for measuring the performance of the ArcGIS methodology, it takes just under seven CPU seconds to load the Bartholomew road network into the data structures. Tests to discover paths from one side of northern England to the other took less than one CPU second and the forward and backward paths, although slightly different in one area, were only two percent different in length and similar in estimated travel time. They were also similar to those chosen manually, from practical experience.

These tests did, however, demonstrate that the road classification alone is not enough. Although the Ordnance Survey Integrated Transport Network (ITN) layer includes a richer set of information, neither ITN nor the Bartholomew data contain information concerning speed restrictions. Timing at present is based upon the national speed limits for motorways, dual carriageway class 'A' roads and estimated lower speeds for the lower classes of roads, as shown in Table 1. However, this is clearly still not realistic, as restrictions on speed are commonly imposed in urban areas, for example, where overall speeds are also lower for many other reasons.

It was found that the A* algorithm will return slightly different results, depending upon the direction of the search. As the time taken for each search is minimal, we take the shorter route from computing the path from the start to the destination and from the destination to the start.

A similar analysis was performed in ArcGIS using an AML script running in ArcPlot that loaded the Bartholomew British road data as the *netcover* and then sought the locations of the start and destinations by means of looking up the Postcodes in the NSPD and using these values to define the start and end points for a single attempt at finding a route between the two locations using the *path* tool. The result was read back using the *show path* function and written into a table for later statistical analysis, to determine the minima, maxima, mean and standard deviation for access to each centre.

Table 1. Road speeds used in our analysis

Road class	Speed (mph)	Speed (kmph)	Speed (m per minute)
Motorways, Class A dual carriageways	70	112.6	1877.6
Class A single carriageways	60	96.5	1609.3
Class B	40	64.4	1072.3
Class C	30	48.3	804.7
Unclassified	20	32.2	536.4

Results

The data used for these results are the paediatric case data. These comprise the location of the three specialist centres for England, the location from which the patient normally accesses these services and the parental home, which may not be the location from which the service is accessed. As the basic question concerns the travel from the patients' locations to the specialism centres, it requires the analysis of the paths from both the patient location and the parental home to the centre at which the patient is registered. There are 602 cases in total, with all but four of the parental locations being on the mainland: the remaining locations are on the Isle of Wight or on one of the Channel Islands. As neither method currently has the ability to handle ferry data, no paths from the parental locations for these four cases were computed, although attempts to find paths were made.

Both methodologies used the same data, although in the case of the ArcGIS test, the NSPD data were held in an ArcGIS point coverage, whilst our program referred to an Oracle database table, loaded from the ArcGIS coverage using ArcGIS and ArcSDE; the Postcode attribute field was indexed in both instances. The ArcGIS method took took an elapsed time of twenty two hours, but failed to locate nearly a third of the Postcodes.

Running the same analysis through our methodology, with twice the number of path searches as performed in ArcGIS, took just two minutes fourteen seconds elapsed time, one hundred and eight CPU seconds. Unlike ArcGIS, there were no failures to find matching Postcodes in the NSPD and paths were found between all start-destination pairs, except for the four «island» cases already mentioned. As a result of the speed of the operation, the analysis using our program was extended to seek paths between the parents and the locations of the students, almost doubling the number of paths sought: the time taken by the program was commensurate with the number of additional paths sought, indicating a linear relationship between the number of cases and computation time.

Detailed study of the paths selected by the two methodologies showed minor differences: Table 2 illustrates the different values reported by the two approaches for a set of cases where ArcGIS 'found' all the relevant Postcode matches. As the ArcGIS methodology can only consider one constraint value and it was found necessary to use significant weighting values for the minor road classes in order to 'encourage' the ArcGIS methodology to prefer

Table 2. Travel from parental location to specialism centre

	Reported by ArcGIS	Reported by our program
Count of cases	68	68
Minimum distance (km)	2.177722	2.1934
Minimum cost / time (minutes)	104.478401	1.8838
Minimum access statistic	11.280576	na
Maximum distance (km)	266.763275	338.1268
Maximum cost / time (minutes)	4030.457520	239.0551
Maximum access statistic	161.460693	na
Mean distance (km)	41.521276	49.6487
Mean cost / time (minutes)	948.230456	32.6866
Mean access statistic	34.427341	na
Standard deviation distance	52.927329	102.7117
Standard deviation cost / time	812.335706	66.4118
Standard deviation access	28.208277	na

the major roads. This gave rise to the use of an 'access' statistic in the ArcGIS method that divided the 'cost' by the distance. Our methodology is able to consider distance and road classification simultaneously, with no need for that statistic, and the 'time' value provides an estimate of the time taken to traverse the selected route at the specified speeds (Table 1).

Examination of the complete results showed that the introduction of the additional specialist centres had halved the average distance from student location to specialist centre from 109 to 52 km, a significant improvement in accessibility.

Discussion

The principal driver for this work was to find a methodology that would facilitate the analysis of many thousand start-destination location pairs as, due to performance issues, the ArcGIS methodology was not practical for volumes of data (hundreds of cases). It is evident that the methodology developed is capable of computing these in an acceptable period of time, with performance significantly outstripping the conventional tools. Our program, based upon the A* algorithm and aspects of Car's HSR, has proven to generate valid and acceptable routes through the same network in significantly less time, making work with large datasets (hundreds of thousands of cases) a viable proposition. So far, we have only replicated the analysis undertaken with ArcGIS, but there are now opportunities to explore additional complexity. More work is needed on the matter of travel times generally, as there is at present no cost applied for junctions, for example. This will be addressed along with the work to load the Ordnance Survey ITN data, as the attributes contained within ITN include indicators for one way streets, no entry and turn restrictions, in addition to the motorway junction information in the Bartholomew data.

A secondary driver was to enable the addition of other modes of transport into the analysis. Lovett, Haynes, et. al. (2002) studied travel by car, bus and community transport services, obtaining their data for public transport by examining timetables, etc., and demonstrated the value of examining mixed-mode travel. It is already clear that ferry routes are needed; public transport routes, especially railways, are desirable. These additional route data form discrete networks of their own, so implementation will easily follow Car's (1997) HSR approach, with the option of treating such networks as being either higher or lower than roads in the hierarchy, as is appropriate for the analysis. de Palma and Picard (2005) investigated how people choose routes and modes of travel within economic constraints. They note that people demonstrate a level of risk-aversion, in making travel choices, related to the importance attached to the reason for travel. This is a consideration that may be important in modelling mixed mode access to health care facilities.

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Abstract

People accessing health care services start at their local practitioner but may then be referred on to specialist services elsewhere. Many such specialisms are provided at only a small number of centres, requiring the patient to travel a perhaps considerable distance. Such travel can also impact upon access to emergency care, the so called 'golden hour', but may also be reflected in the ability of patients to arrive on time, or at all, for consultations. A number of studies have explored access to services within relatively small bounded units, both rural and urban, but rarely has a mixed urban and rural environment been studied. Fewer studies have attempted to explore areas as large or diverse as England, for which this work contributes to studies of variability of access to services. This study builds on the standard Network Analysis tools of ArcGIS to look at the distance travelled by patients from their homes to their specialist units. ArcGIS uses the standard Dijkstra algorithm for finding the shortest path between two locations in a network of line segments. This can be modified by means of a turntable, which controls whether left or right turns may be made at a junction, and by an impedance value, which defines a cost of using a particular line segment, rather than using the segment length. The impedance value allows for the introduction of controls such as speed limits, etc., and for this study was set to reflect the length and type of road, with motorways and class 'A' dual carriageways having the lowest impedance value and unclassified the highest. Where impedances are used, the «length» of the path between two locations is reported in terms of the summed impedance 'cost'. To obtain actual lengths, the route section table must be examined, which provides pointers to the actual line segments comprising the path and from which the distance metric can be calculated. Whilst the ArcGIS approach performs at acceptable speeds for single route queries, with the route discovery and reporting taking a little under a minute per query, this is slow for bulk analyses of hundreds, or thousands, of records. This paper explores an alternative methodology for working with such quantities of data and introduces a possible enhancement for examining travel by public transport in addition to travel by road.

Streszczenie

Ludzie korzystający z usług opieki zdrowotnej pierwsze kroki kierują do lekarza pierwszego kontaktu, lecz mogą być następnie skierowani do specjalisty, świadczącego usługi w innym miejscu. Wiele specjalistycznych usług dostępnych jest tylko w niewielkiej liczbie placówek, co wymusza niejednokrotnie przebywanie znacznej odległości przez pacjenta. Takie przemieszczanie się pacjenta może wpłynąć na dostępność pogotowia ratunkowego (czynnik tzw. „złotej godziny"), lecz może również uniemożliwić dotarcie na czas, bądź niedotarcie w ogóle na konsultacje. Przeprowadzono szereg badań, polegających na rozpoznaniu dostępu do usług w obrębie względnie małych, ograniczonych jednostek, zarówno rolniczych jak i miejskich, rzadziej badano mieszane jednostki miejsko-rolnicze. W mniejszej liczbie badań usiłowano rozpoznać obszary tak duże, czy zróżnicowane jak Anglia, toteż praca ta wnosi wkład do stanu badań zmienności dostępu do usług. Niniejsze badanie opiera się na standardowym narzędziu Analizy Sieciowej środowiska ArcGIS do obserwacji odległości pokonywanych przez pacjantów z ich domów do specjalistycznych jednostek. ArcGIS do znajdowania najkrótszych połączeń pomiędzy dwoma lokalizacjami w sieci odcinków wykorzystuje standardowy algorytm Dijkstra. Modyfikacje mogą być wykonywane za pomocą zwrotnicy, kontrolującej na węźle skręt w lewo lub w prawo, i poprzez wartość impedancji definiującej koszt wykorzystania danego odcinka, a nie jego długość. Wartość impedancji pozwala na wprowadzenie regulacji, jak np. ograniczenia prędkości, itp. i dla niniejszego badania została ustalona by odzwierciedlić długość i typ drogi. Dla tego przypadku autostrada oraz droga dwupasmowa kategorii „A" mają najniższą impedancję, a drogi niesklasyfikowane najwyższą. Tam, gdzie wykorzystywana jest impedancja, „długość" połączenia pomiędzy dwiema lokalizacjami raportowana jest za pomocą sumarycznego „kosztu" impedancji. Aby uzyskać aktualne długości, zanalizowana zostać musi tabela odcinków trasy, która dostarcza wskaźniki dla aktualnych odcinków stanowiących ścieżkę i na podstawie których obliczona może zostać odległość metryczna. Podczas gdy podejście ArcGIS działa z akceptowalną prędkością dla pojedynczych zapytań o ścieżkę, której wyznaczanie i raportowanie dla jednego zapytania trwa niespełna minutę, jest wolne dla analiz masowych rzędu setek czy tysięcy rekordów. Niniejszy artykuł stanowi poszukiwanie alternatywnej metodyki pracy dla takiej ilości danych oraz przedstawia możliwe usprawnienie badania – obok podróży drogowych – procesu przemieszczania się za pomocą transportu publicznego.

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