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A methodological framework for geographic information systems development

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Keywords: methodology geographic information system

Abstract

Geographic Information Systems (GIS) provide map based spatial analyses of geo-coded data. In this paper we examine a methodological framework for geographic information systems development that was developed and refined over a six year period based upon a fire prevention support geographic information system for a UK fire and rescue service. The methodological framework involves the use of a multi-methodology approach that incorporates social and organisational analysis, spatial modelling, and functional design.

Key words: methodology geographic information system

1. Introduction

Geographic information systems (GIS) are different from other types of information system since they incorporate spatial analyses of geo-coded data, and present map based output. One of the first documented applications of spatial analysis was a study by Picquet in 1832 in Paris of cholera epidemiology. In 1854 John Snow analysed the spatial distribution of cholera cases in London which helped to identify the source of the disease. The term "GIS" was initially used by Tomlinson in the 1960s who developed a digital natural resources inventory system (Bruno and Giannikos, 2015).

When developing a GIS it is important to establish the overall purpose of the GIS, what information it will actually provide for an organisation, and how it will be used by the organisation to support operational activities. In this paper we examine a methodological framework for GIS development that incorporates social and organisational analysis to address the purpose of a GIS, spatial analysis to address what information the GIS will actually provide for the organisation, and functional design to address how the geographic information system will be physically implemented. Georgiou (2012) and Small and Wainwright (2014) stated that operational research supports the development of the theory and practice of multi-methodology. A 'soft' requirements analysis approach (Checkland, 1972; Checkland, 1990) can support a wide ranging analysis of the purpose of a GIS that takes into account the perspectives (including the concerns and potential conflicts) of the stakeholders in order to identity the requirements for the GIS. Mingers and White (2010) and Paucer-Caceres (2011) commented that systems thinking approaches are intimately connected with the development of the practice of operational research. Spatial analysis supports the 'logical' design of a GIS in terms of modelling the information requirements identified by the 'soft' requirements analysis via appropriate statistical analysis techniques. Spatial analysis involves the determination of an appropriate mathematical and statistical basis for analysis of geo-coded data variables to provide the required information. A 'hard' systems design approach (Clarke and Lehaney, 2000) can support the detailed 'physical' design of the GIS in terms of the geo-coded data variables, their groupings and associations, the logic of the program code required to manipulate the geo-coded data and transform such into the information required, and the design of map layers and report formats that can be physically implemented using appropriate GIS software development tools (Mapinfo, 2015; Arcgis, 2015; Geomedia, 2015), and database management software tools. O'Keefe (2014) stated that there is a need to better understand how operational research can contribute to the design of systems.

The development of the methodological framework for GIS development examined in this paper took place over a six year period from 2007 to 2013 based upon a GIS for fire prevention support in a UK fire and rescue service.

The originality of the research reported in this paper concerns the development of a multi-methodology approach to GIS development that provides support for spatial analysis, and integrates 'soft' requirements analysis, spatial analysis and 'hard' systems design, thus making a substantive theoretical contribution to the field of information systems development methodologies in the area of GIS development. This research also makes a contribution to knowledge in terms of demonstrating how the approach was used in practice within a UK fire and rescue service.

2. Literature review

2.1 Geographic Information Systems

A GIS provides map based information involving spatial analysis operations on geo-coded data (Laefer and Pradhan, 2006). Rayed (2012) stated that GISs have become an effective tool for decision support within organisations. Manase, Heesom, Oloke, Proverbs, Young, and Luckhurst (2011) stated that GISs can bring together fragmented information, and provide ease of communication and ease of storage and analysis of varied information. Tucci, Giordmo, and Ronza (2010) argued that geovisualization via a GIS can help to provide the contextual reference information to support interdisciplinary activities. Nielsen, Oberle and Sugumaran (2011) stated that numerous industry sectors now at least partially depend on geospatial technology, including fields as diverse as civil engineering, public health, environmental science, urban and regional planning, and the geosciences.

Mukherjee and Ghose (2011) stated that GIS adoption is shaped by the interaction between the technology and potential users within particular political, cultural, and organisational contexts. Moon and Norris (2005) discussed eight human factors concerned with the adoption of GISs in organisations: perceived relative advantage of GISs, personal values and beliefs regarding GIS technology, level of computer experience, perceived complexity of the GIS, exposure to GISs, computer and GIS anxiety, attitude towards work related changes, and communication behaviour. Das and Choudhury (2014) commented that although GIS technologies have existed for several decades, research is required into the development, implementation and use of this technology in business settings.

2.2 Spatial analysis

Spatial analysis involves examining the geographic patterns in data and observing the relationships between geo-coded data variables (Robinson, Wyatt, Hickson, Gwinn, Faruque, Sims, Sarpong and Taylor, 2009; Laefer and Pradhan, 2006). Grabowski, Curriero, Baker and Guohua (2002) stated that exploratory spatial analysis can be used to describe the geographic characteristics of geo-coded data. Marble (2000) commented that spatial analysis incorporates statistical techniques to address large-scale real-world problems in many different types of organisations.

Rosenberger, Sneh, Phipps and Gurvitch (2005) stated that an important aspect in spatial analysis is the quantification of location in terms of co-ordinates of entities in Cartesian space, and contiguity, that is the relative positions of entities with regard to each other in space. Kotavaara et al (2014) discussed the need to identify appropriate statistical modelling techniques for the purpose of spatial analysis within a GIS. Currently there does not appear to be any commonly used information systems development methodologies that specifically address spatial analysis.

2.3 Information systems development methodologies

Avison and Fitzgerald (1995) defined an information systems development methodology as a system of procedures, techniques, tools and documentation aids, which assist systems developers with implementing a new information system. Siau and Rossi (2007) commented upon the importance of understanding the systems development process in order to develop better modelling methods. Paivarinta, Sein and Peltola (2007) stated that systems development methodologies undergo a great extent of adaption as they are used in practice. Karlsson and Wistrand (2006) commented that standardised systems development methods may need tailoring for unique projects. Clarke and Lehaney (2000) and Sharif (2003) expressed the view that both interpretivist and functionalist elements are required in an information systems methodology in order to address the variety of information systems problem contexts that may be encountered during information systems development projects. Baskarada (2011) discussed how a lack of use of information systems development methodologies may affect information quality within organisations. Although current commonly used information systems development methodologies address a wide variety of the different aspects of systems development activities, there appears to be little if any support for spatial analysis.

2.4 Multi-methodology approaches to information systems development

Operational research has been undertaken into the use of a combination of ‘soft’ and ‘hard’ information systems development approaches (Georgiou, 2012; Pollack, 2009; Wood-Harper and Wood, 2005; Clarke and Lehaney, 2000). Typically ‘soft’ approaches to information systems development (Checkland, 1981) assist with understanding and modelling the ‘problem situation’ (Franco, 2013), that is the social and organisational aspects of the requirements for an information system. This process then informs the use of ‘hard’ information systems design approaches (Clarke and Lehaney, 2000) that then take the outputs from the ‘soft’ requirements analysis phase and then utilise such to develop detailed designs for physical implementation of an information system. The transition between ‘soft’ requirements analysis and ‘hard’ systems design approaches has been examined by previous research (Clarke and Lehaney, 2000; Wood-Harper and Wood, 2005). Clegg and Shaw (2008) stated that there has been previous academic attention on multi-methodology approaches that integrate harder and softer modelling approaches. However, in GIS development a multi-methodology approach to information systems development would also need to include an additional dimension of the transition between ‘soft’ requirements analysis and spatial analysis, and between spatial analysis and ‘hard’ systems design.

2.5 Geographic information systems development approaches

The GIS development process involves acquiring geo-coded data, developing database structures to store and retrieve such data, developing appropriate approaches to manipulate and analyse the geo-coded data, and generating tabular reports and maps to present the spatial information (Benhart, 2000). Although there are guides available that cover the activities involved in the GIS development process (UNESCO, 2015; Clarke, 1991) there do not appear to be commonly available methodological frameworks that cover the information systems development techniques to be used to undertake the different activities within GIS development, and how such techniques are integrated (Das and Choudhury, 2014). Overall, although multi-methodology approaches to information systems development that combine both ‘soft’ information requirements analysis and ‘hard’ systems design could potentially be used for GIS development, such approaches currently lack support for spatial analysis, which is a key element of GIS development.

Previous research had examined aspects of the use of “soft” and “hard” approaches for GIS development, as well as the statistical modelling involved in GIS development (Higgins et al, 2012, Taylor et al, 2011). However, in this paper we examine a more detailed and comprehensive methodological framework for GIS development that details a methodological approach to the statistical modelling that underpins the spatial analysis involved in GIS development, and also details the integration of “soft” and “hard” information systems development methodology techniques with spatial analysis for the development of GISs.

3. Research method

The methodological framework for GIS development examined in this paper was developed and refined during a six year project in a UK fire and rescue service between 2007 and 2013. A GIS for fire prevention support was developed and enhanced by the authors and other staff within the fire and rescue service concerned. A case study (Yin 2012) based upon a facilitated operational research approach (Franco and Montibeller, 2010) whereby the researchers worked with the organisation not only as analysts but also as facilitators was chosen as this provided the means of undertaking an in-depth study of the development process for a GIS in a professional environment.

The GIS developed for fire prevention support within the UK fire and rescue service studied initially aimed to predict the risk of occurrence of unintentional dwelling fires based upon socio-economic causal factor data for each of the Lower Super Output Areas (LSOA, 2015) within the region covered by the fire and rescue service studied. A Lower Super Output Area (LSOA, 2015) forms part of a geographical area hierarchy developed by the UK Office for National Statistics. A Lower Super Output Area typically contains an average population of 1500 and a minimum population of 1000. The GIS for fire prevention support proved useful in terms of identifying the geographical areas of greatest unintentional dwelling fire risk within the region covered by the fire and rescue service studied. However, the spatial analysis approach embodied in the geographic information system identified only coarse-grained geographical areas and could not identify social groups at greatest risk of fires, other than in terms of causal factors such as being a smoker, elderly, living alone, or being disabled. The GIS for fire prevention support within the fire and rescue service studied was then enhanced by modelling the different social groups present within the region (based upon socio-economic data) using k-means cluster analysis to support identification of the distribution of such social groups at the more detailed Output Area level (OA, 2015) within the region concerned, and the rates of incidence of different types of unintentional dwelling fires (e.g. kitchen fires, alcohol related fires) across these social groups. In this manner, the enhanced GIS for fire prevention support allowed for finer-grained identification of geographical areas, as well as social groups at risk of different types of unintentional dwelling fires within the region covered by the fire and rescue service. Output Areas form part of a geographical area hierarchy developed by the UK Office for National Statistics and have a minimum size of 40 resident households and 100 residents.

The GIS for fire prevention was developed by utilising a rich picture, CATWOE analysis, root definition and conceptual model to develop an understanding of the GIS requirements (Checkland, 1972; Checkland, 1981). The rich picture helped to identify the geo-coded data required, and the root definition, CATWOE analysis and conceptual model helped to identify the type of spatial analysis required (multiple linear regression modelling and k-means cluster analysis respectively). The rich picture, CATWOE analysis, root definition and conceptual model were also used to develop the class diagram and use case diagram for the GIS, which were used to design the database schema and user interface for the GIS.

The research questions posed by this research were:

- What is involved in GIS development?
- How can GIS development be undertaken?
- How can spatial analysis be addressed within an information systems development methodology?
- How can a multi-methodology approach to GIS development incorporate support for spatial analysis?

These are important research questions since GISs are increasingly being used for decision support in a wide range of industries (Rayed, 2012; Nielsen et al, 2011) and therefore it is important that such systems are developed in a thorough and professional manner. An appropriate methodological framework for geographic information systems development can assist in the development process for such systems by providing a set of integrated systems development techniques.

3.1 Data collection

The development of a methodological framework for GIS development was discussed in meetings with fire and rescue service staff involved in the development of a GIS for fire prevention support through a process of participatory enquiry and joint learning supported by the use of SSM rich picture and CATWOE analysis techniques (Checkland, 1981) during which the different viewpoints of the stakeholders concerned were used to develop an overall view of the nature of GIS development. The fire and rescue staff involved in the project over the six year period of study included one project manager, two IT managers, two GIS developers, and two community fire safety officers. The meetings typically lasted for around one hour and typically occurred on a monthly or more frequent basis.

The process of GIS development for the fire prevention support system within the fire and rescue service studied developed in an on-going manner, since new fire prevention support requirements appeared during the period of the case study, and fire prevention activities changed due to more collaborative working practices between public sector agencies including partnerships with a local council, an NHS trust and a local police service. In particular, data sharing and referral services between the partner agencies developed which affected the development of the GIS for fire prevention support in terms of the data available, and the operational use of the fire prevention support system.

The meeting notes regarding GIS development were recorded on paper and then content analyzed. The meetings facilitated discussions regarding the process of GIS development and in particular the methodological approaches and techniques to be used for GIS development.

A potential difficulty regarding the use of a case study approach can be the access required to staff within the organisation studied.

3.2 Data analysis

The case study based upon a facilitated operational research approach (Franco and Montibeller, 2010) supported an examination of the development of a methodological framework for GIS development applied to the development of a GIS for fire prevention support. The data collected was content analyzed by the identification of themes within the meeting texts. For example, what systems development techniques are appropriate for GIS development activities, and in particular how spatial analysis could be supported by an information systems development methodology, and how spatial analysis techniques could be incorporated into a multi-methodology approach to GIS development. This allowed an understanding of the issues associated with the development of a methodological framework for GIS development in the context of a GIS for fire prevention support. A possible limitation of case study research concerns the generalizability of the results obtained for other organisations. The actual GIS for fire prevention support was developed and enhanced using the MAPINFO (Mapinfo, 2015) GIS software development tool, the MAPBASIC programming language, and the Microsoft SQL Server database management system software tool.

4. A Proposed multi-methodology geographic information systems development framework

In GIS development there is an added "dimension" to the systems development process that involves spatial analysis of geo-coded data, which makes GIS development different to other forms of information systems development (Taylor et al, 2012). The methodological framework for geographic information systems development developed by the authors built upon previous research into the combination of 'soft' requirements analysis and 'hard' systems design approaches (Wood-Harper and Wood, 2012; Clarke and Lehaney, 2000) by catering for the additional dimension of spatial analysis that is unique to GIS development (Higgins et al, 2012; Taylor et al, 2011), as shown in Figure 1.

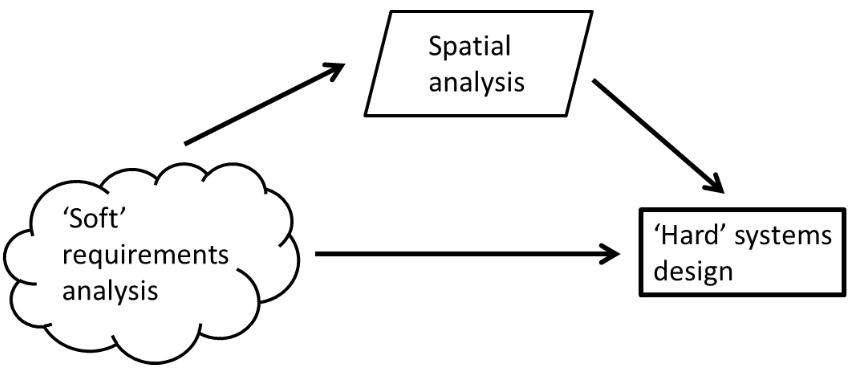

Figure 1. Main elements of the geographic information systems development methodological framework

Spatial analysis is an activity that involves the application of mathematical / statistical analysis to geo-coded data. 'Soft' requirements analysis and traditional 'hard' systems design approaches do not cater well for spatial analysis since they lack the techniques to address the mathematical / statistical modelling of geo-coded data (Higgins et al, 2012).

In a GIS development project there is a need to understand the requirements for the GIS, and a need to implement a physical design that incorporates the manipulation of geo-coded data stored in database tables and files to produce map layers and reports. However, in between, we need to understand, model and design an appropriate spatial analysis approach that defines the required manipulation of the geo-coded data.

A 'soft' requirements analysis approach (Checkland, 1972; Checkland, 1981; Checkland, 1990) can inform spatial analysis by developing an understanding of the required basis for the spatial analysis through a process of participatory enquiry and joint learning. For example, will the spatial analysis simply involve identification of instances of particular entities at particular geographical locations, or show averages of some particular measure in each geographical area, or involve more complex statistical processes based upon variables associated with points or geographical areas. The spatial analysis phase also involves the use of mathematical and statistical logic in order to ensure that the analyses undertaken are mathematically and statistically rigorous. For example, if parametric statistical methods (Newton and Rudestam, 1999) are used for spatial analysis, is the geo-coded data used at least measured on an interval scale and normal in distribution.

The spatial analysis then informs the 'hard' systems design (Clarke and Lehaney, 2000) (along with the original 'soft' requirements analysis) in terms of describing how the spatial analyses will be performed using the geo-coded data stored in the database tables, and the logic of the calculations required on the geo-coded data in order to implement the spatial analysis in program code.

Spatial analysis requires an understanding of the information needs of the organisation, in terms of what the statistical analysis is attempting to measure or compare or rank, and also how the measuring, comparison, or ranking can be achieved via appropriate mathematical or statistical techniques applied to the geo-coded data variables. For example, in terms of fire prevention support, spatial analysis in the fire and rescue service studied initially modelled purely the geographic distribution of dwelling fires, then modelled the fire risk level of different geographic areas based upon causal risk factor data, and then modelled the geographic distribution of different socio-economic groups in terms of different types of fires associated with such groups.

Spatial analysis adds an additional dimension to the systems development process for GISs because it involves a modelling stage that is fundamentally a mathematical or statistical abstraction concerning manipulation of geo-coded data. Spatial analysis involves taking an information requirement, then identifying the geo-coded data variables that can be manipulated to provide such information, and then identifying an appropriate mathematical or statistical method to produce such information. For example, to provide a fire risk spatial analysis, possible data variables might include geo-coded variables representing causal factors in fire risk such as binge drinking, smoking, and being elderly or disabled, and possible statistical approaches might include multiple linear regression or logistic regression modelling of fire risk using such ‘predictor’ geo-coded variables.

5. Research results

5.1 Requirements elicitation for a geographic information system via ‘soft’ requirements analysis

In the case study fire and rescue service, ‘soft’ requirements analysis supported the examination of the perspectives of the different stakeholders associated with the GIS for fire prevention support through a process of participatory enquiry and joint learning. For example, in the first version of the GIS for fire prevention support, the stakeholders included the different types of staff within the fire and rescue service, the residents of the region concerned, and also agencies supplying the required socio-economic causal factor data that included the UK Department of Work and Pensions, the UK Office for National Statistics and the UK NHS. In the second version of the GIS for fire prevention support, the ‘soft’ requirements analysis approach also involved further stakeholders including the local council, the local NHS Primary Care Trust, and the local Police Force. The ‘soft’ requirements analysis approach identified the need for the GIS to provide support for collaboration between the partner agencies to address the underlying causal factors associated with unintentional dwelling fires such as high smoking rates, old age, disability and living alone, through appropriate early interventions (for example referral to smoking cessation services, or social services). It is important in any GIS development project to understand what organisational processes the GIS will support.

The ‘soft’ analysis of requirements for a GIS informs the basis for the spatial analysis required. For example, for the fire prevention support GIS, the following ‘soft’ information requirements informed the following spatial analysis approaches (in brackets):

- Where do most unintentional dwelling fires occur (fires per unit area)
- Where do most unintentional dwelling fire fatalities occur (fire fatalities per unit area)
- Which areas are at highest risk of unintentional dwelling fire (multiple linear regression model of fire risk per unit area)
- Which communities are at highest risk of a given type of unintentional dwelling fire (k-means cluster analysis of socio-economic characteristics data to identity community type per unit area, combined with analysis of fires of a given type per unit area)

Overall the ‘soft’ requirements analysis approach provided a richer understanding of the purpose of the fire prevention support GIS from the perspectives of the different stakeholders involved compared to other types of approaches. This then informed a more detailed understanding of what type of spatial analysis would be appropriate to meet the information needs of the stakeholders. For example, for the fire prevention support GIS, the needs of the stakeholders concerned identifying patterns of unintentional dwelling fire occurrence, the probability of unintentional dwelling fires occurring, and the communities most at risk of different types of unintentional dwelling fires. Each of these different types of information needs requires a different form of spatial analysis that can be most effectively identified by appreciating the nature of the information needs of the stakeholders involved. In statistical terms, the basis of the spatial analysis required for a GIS will typically concern the comparison of groups (identified by the categories of one or more discrete geo-coded variables) or the relationship between continuous or orderable discrete geo-coded variables (Newton and Rudestam, 1999). In the case study GIS for fire prevention support, the 'soft' requirements analysis approach identified the need to spatially analyse historical fire incidents, to calculate the fire risk for each geographical area, and to identify community profiles for each geographical area within the region covered by the fire and rescue service.

5.2 Information systems development methodology support for spatial analysis

Spatial analysis involves identifying appropriate mathematical / statistical techniques that can be applied to the geo-coded data available to provide the information required by the project stakeholders. By appropriate statistical technique is meant one that can provide the information required and that is suitable for use with the geo-coded data available, in other words that the geo-coded data meets the assumptions of the statistical test (Newton and Rudestam, 1999). Typical assumptions of statistical tests include normality (that the frequency distribution of a geo-coded variable approximates a bell shaped curve), the level of measurement of the geo-coded variable (nominal = categories of values, ordinal = ordered categories of value, or continuous = values that are at least on an interval scale), and homoscedasticity (equality of variances, or 'variability' of values of two or more groups) (Newton and Rudestam, 1999).

The 'soft' requirements analysis phase can inform the spatial analysis approach to be adopted for the development of a GIS in terms of informing what type of spatial analysis may be required:

Summative (number of a geo-coded entity per unit area)

Comparative (rank or percentage of a geo-coded entity per unit area)

Predictive (linear model combining one or more 'predictor' geo-coded entity variables per unit area)

Classification (assigning a category to a geo-coded entity or a geographical area)

Proximity (identifying the geographical area 'centred' on a geo-coded entity or entities)

Clustering (identifying cluster centres based upon the distribution of geo-coded entities, or identifying distinct groups and their distribution by geographical areas based upon clusters of geo-coded variable values)

The first aspect of addressing spatial analysis within an information systems development methodology is to classify what type of spatial analysis is required, as per the above categories. The next step is to assess what statistical techniques might support the required type of spatial analysis.

In order for the spatial analysis used within a GIS to be mathematically and statistically rigorous, it will be necessary to examine the distributions and nature of the geo-coded variables concerned to check that such are suitable for the potential statistical techniques that could be used to support the information needs of the stakeholders.

The choice of statistical techniques to be used for spatial analysis is informed by the 'soft' analysis of stakeholder needs in the following terms (Newton and Rudestam, 1999):

- The degree or strength of relationship between geo-coded variables.
- The difference between groups associated with the discrete categories of one or more geo-coded variables.
- The differences in the frequency of occurrence of one or more geo-coded variables.
- The differences between the cross-classifications of groups associated with the discrete categories of different geo-coded variables.

Figure 2 outlines the spatial modelling approach that was developed.

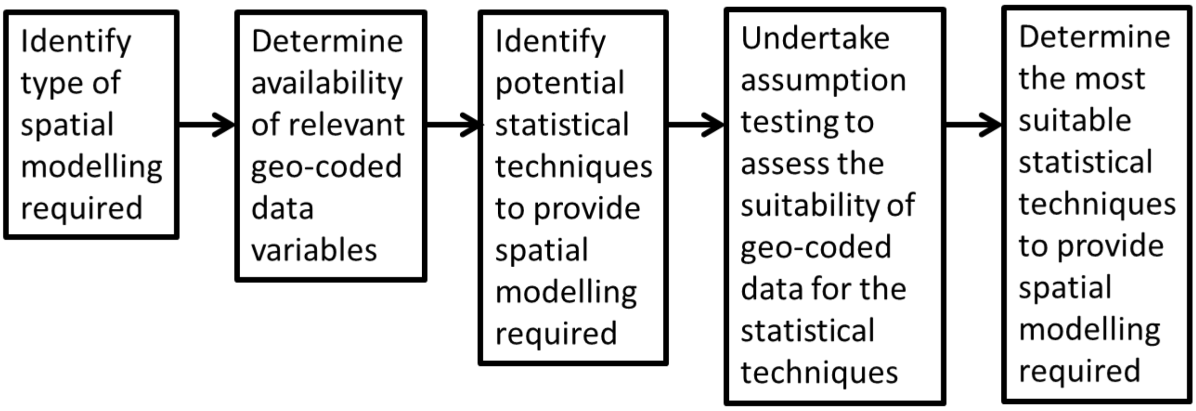

Figure 2 Spatial modelling approach for GIS development

In the example of the fire prevention support GIS, the 'soft' requirements analysis informed the required statistical basis for the spatial analysis to be used within the GIS e.g. average numbers of unintentional dwelling fire incidents per geographical area, multiple linear regression modelling of fire risk across geographical areas, and cluster analysis of residents' socio-economic data across geographical areas.

The first version of the GIS for fire prevention support required the use of an appropriate statistical approach to support spatial analysis of unintentional dwelling fire risk modelling. Multiple linear regression and logistic regression were examined, and a multiple linear regression approach was found to yield a more predictive model.

The fire risk multiple linear regression model was:

Fire risk level = 0.035 * number of mental benefit claimants
\+ 0.012 * number of smoke alarms
\- 0.116 * number of severe disability claimants
\+ 0.209 * percentage of binge drinkers

- 0.155 * number of lone parents
+ 0.113 * number living alone
- 0.016 * number of disability living claimants
- 6.532

A full investigation of the assumptions underlying the statistical techniques was undertaken, that included a linear relationship, multivariate normality and homoscedasticity of the geo-coded variables concerned.

Figure 3 illustrates the nature of the spatial analysis adopted in the first version of the GIS for fire prevention support that used a linear combination of ‘predictor’ variables to predict unintentional dwelling fire risk

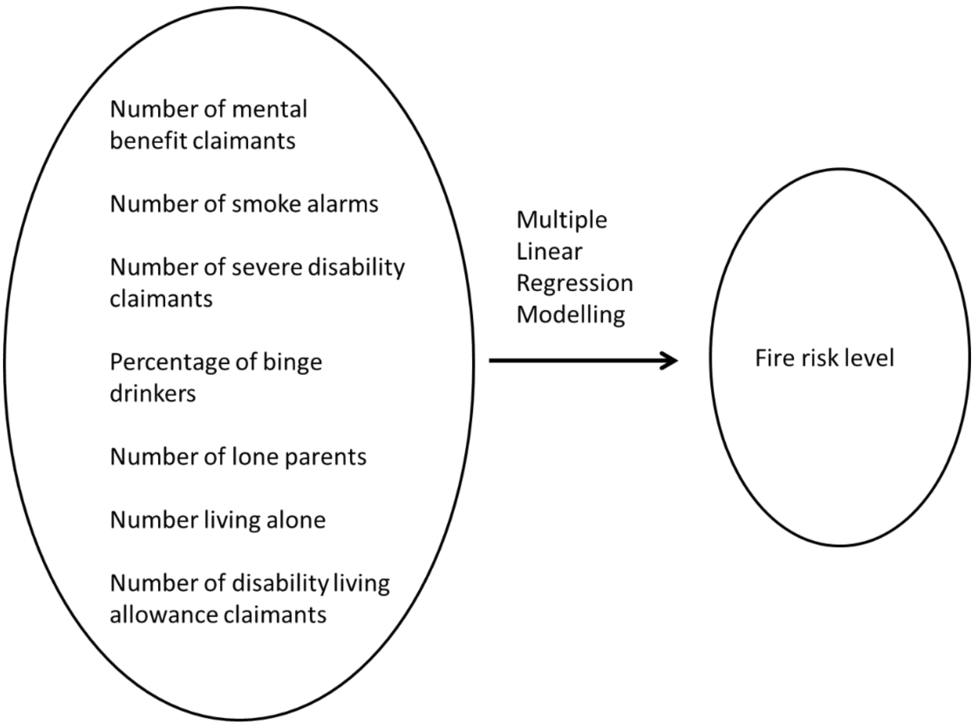

Figure 3 Multiple linear regression spatial analysis use in the first version of the fire prevention support geographic information system

The second version of the GIS for fire prevention support required the use of an appropriate statistical approach for cluster analysis of the socio-economic characteristics of residents within the region in order to identify distinct social groups within the region. K-means cluster analysis was examined for this purpose. The fire and rescue service required that an appropriate number of social group clusters were identified for operational purposes. Too few groups would result in too coarse-grained a set of social groups, and too many groups would have resulted in an unwieldy set of social groups. Ten social groups were identified by the community safety officers within the fire and rescue service studied as being an operationally appropriate number of social groups for the purposes of fire prevention activities (UKDCLG, 2016). The main assumption underlying k-means cluster analysis is that the data variables have similar ranges of values. In order to meet this assumption a z-transformation (Newton and Rudestam, 1999) was applied to the variables used for the k-means cluster analysis.

Figure 4 illustrates the nature of the spatial analysis adopted in the second version of the GIS for fire prevention support that used a cluster analysis approach to identify distinct 'community profiles' within the area covered by the fire and rescue service studied.

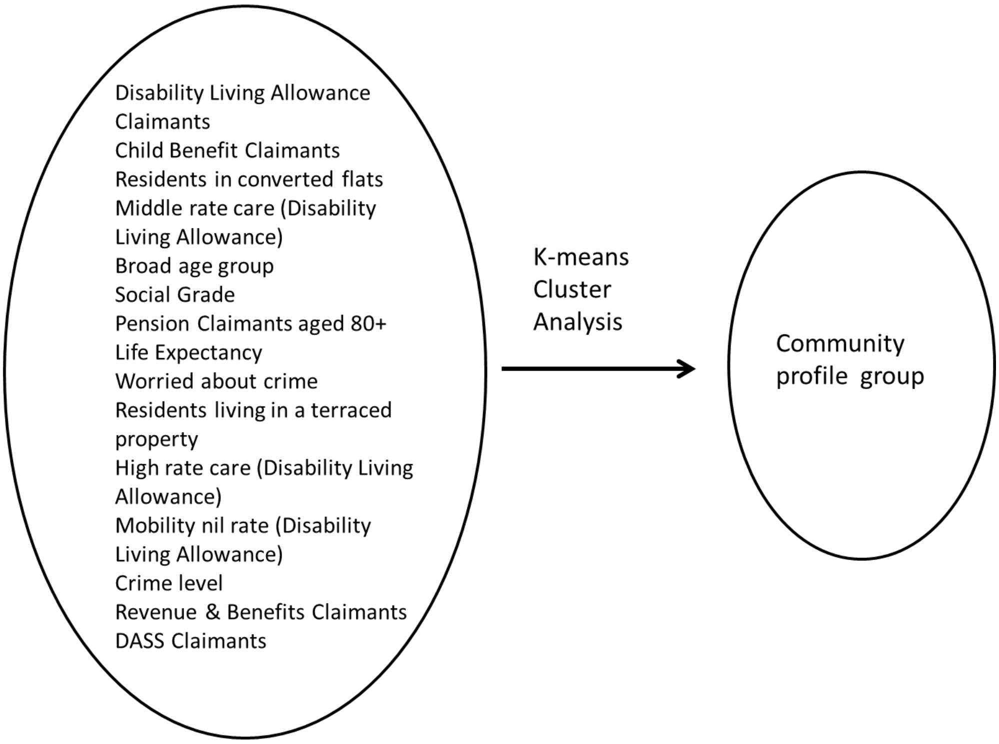

Figure 4 K-means cluster spatial analysis use in the second version of the fire prevention support geographic information system

5.3 Functional design for a geographic information system via 'hard' systems design

In terms of the transition between spatial analysis and 'hard' systems design, the spatial analysis phase (along with the 'soft' requirements analysis phase) informs what geo-coded data variables will be required to be stored and manipulated and the nature of the mathematical and statistical operations to be carried out upon such geo-coded data and implemented in program code.

In terms of the transition between 'soft' requirements analysis and 'hard' systems design, the perspectives of the different stakeholders informs the 'hard' systems design of a GIS in terms of:

- The scales of the map based information required
- The required presentation of geo-coded entities and areas on the map layers
- The breakdown of map layers required

- The required presentation of different categorical values of geo-coded entities and areas on the map layers
- The menu structures required for selecting given sets of map-based information
- The report format required for summaries and analyses of geo-coded data

For example, in the case study fire prevention support GIS, different fire risk levels and different community profile group area were represented by colour coding of the different geographic areas. For fire risk levels, red indicated high dwelling fire risk areas, yellow indicated medium dwelling fire risk areas, and green indicated low dwelling fire risk areas.

'Hard' systems design approaches include techniques such as use case diagrams (UML, 2015) (which can be used to identify the use of map-based outputs and reports required by the different types of GIS user) and class diagrams (UML, 2015) (which can be used to identify the data structures, and operations required on geo-coded data) (Taylor et al, 2011) to physically implement the GIS using a GIS software development tool such as Mapinfo (Mapinfo, 2015) or Arcgis (Arcgis, 2015), or Geomedia (Geomedia, 2015) and an appropriate database management system software tool.

In the case study GIS for fire prevention support, the 'hard' systems design approach supported the detailed design of the required unintentional dwelling fire hotspot maps, unintentional dwelling fire risk level maps, community profile maps, and lists of properties for home fire safety check visits within the region covered by the fire and rescue service.

5.4 Integration of 'soft' requirements analysis, spatial analysis and 'hard' systems design into a multi-methodology approach for geographic information systems development

Overall the 'soft' requirements analysis assisted in identifying who will use the GIS, what information the system will need to provide, and what geo-coded data will be required for the GIS. The spatial analysis models how the geo-coded data will be mathematically / statistically manipulated to provide the required information. The 'hard' systems design models how the mathematical / statistical manipulation of the geo-coded data will be implemented in program code, and the database tables, map layers and report layouts needed to fulfil the information requirements identified in the 'soft' requirements analysis.

In terms of the actual systems development techniques used within the methodological framework for GIS development, Figure 5 illustrates how the different systems development techniques are integrated. Figure 5 shows the overall GIS methodological framework, and expands on the conceptual level framework shown in Figure 1. Figures 2, 3, and 4 show further detail and examples of the spatial analysis aspects of the framework.

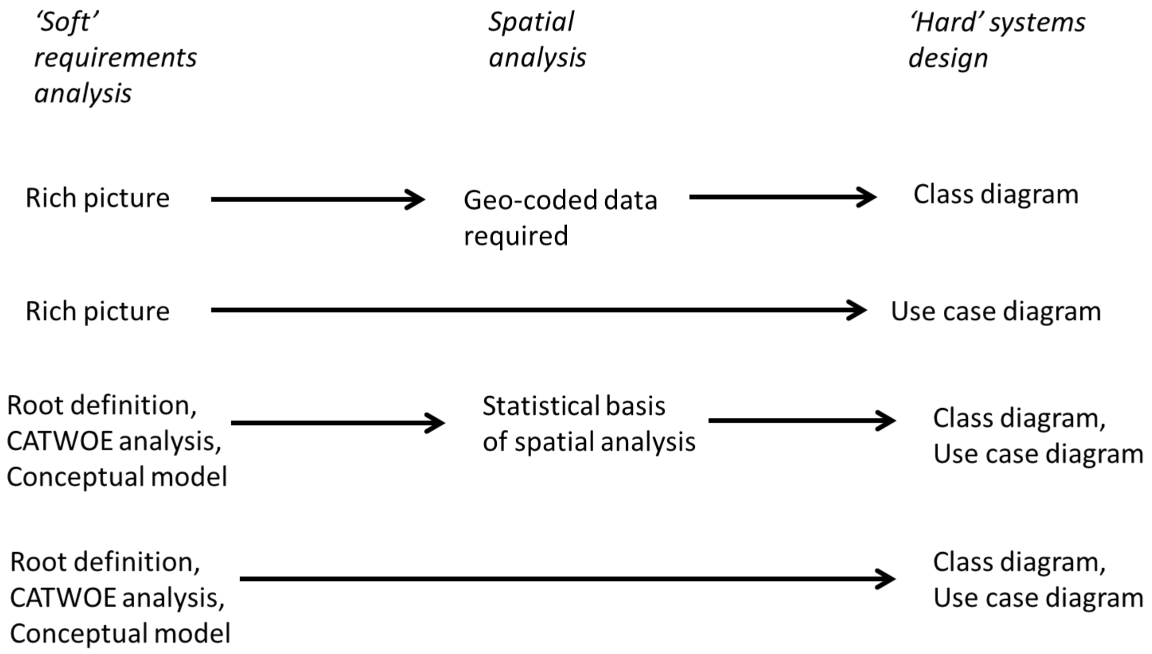

Figure 5. Overall GIS methodological framework showing the integration of the systems development techniques used in the methodological framework

The rich picture (Checkland, 1972) identifies possible sources and recipients of geo-coded data, and the types of geo-coded data required to satisfy stakeholder information needs. The rich picture also identifies possible actors in a use case diagram (UML, 2015) (and the use cases associated with such actors).

The root definition, CATWOE analysis and conceptual model (Checkland, 1972) support the determination of the possible mathematical / statistical basis for spatial analysis via the described transformation of operational activities. These techniques also identify possible use cases, and methods in the class diagram (UML, 2015).

The spatial analysis identifies the detail of the use cases and the methods in the class diagram, in terms of the required manipulation of geo-coded data variables, and the geo-coded data required in the class diagram.

Overall, the multi-methodology approach to GIS development discussed in this paper makes a substantive theoretical contribution in terms of addressing how an information systems methodology can support spatial analysis, and how 'soft' requirements analysis, spatial analysis, and 'hard' systems design can be integrated into a methodological framework for GIS development.

5. Conclusions

Geographic information systems are different to other types of information systems because of the spatial analysis involved, and the presentation of information in a map-based format. Although there are guides available regarding the activities involved in the GIS development process, there do not appear to be commonly available methodological frameworks that describe the systems development techniques to be used for the activities with GIS development, and how these would be integrated.

The methodological framework was developed and used over a six year period to develop a GIS for fire prevention support. This involved using a rich picture, CATWOE analysis, root definition and a conceptual model to identify the requirements for the fire prevention support GIS and in particular to identify the geo-coded data required and the statistical basis for the spatial analysis required. Initially a multiple linear regression model was used to model the fire risk level. This was then enhanced via k-means cluster analysis to model the different at-risk communities. The rich picture, CATWOE analysis, root definition and a conceptual model were used to develop use case and class diagrams which were used to design the GIS user interface and database schema.

The methodological framework for GIS development that was developed provided an approach to GIS development that catered well for the analysis of complex information requirements, the identification of an appropriate type of spatial modelling (and appropriate statistical techniques to support the spatial modelling) to provide the information required, and the physical design of a GIS to provide the information required in a format appropriate for operational fire and rescue service staff use. In particular, the ‘soft’ requirements analysis proved useful for understanding stakeholder information needs, and the types of geo-coded data that might be required. Also, the ‘soft’ requirements analysis, through a process of participatory enquiry and joint learning, supported understanding of the nature and purpose of the information required which informed the type of spatial analysis required. Both the ‘soft’ requirements analysis, and the statistical modelling involved in spatial analysis informed the ‘hard’ systems design in terms of the geo-coded variable characteristics, their associations and groupings for database table design, as well as the design of program code required to implement the statistical manipulations on the geo-coded data.

The originality of the research reported in this paper concerns the development of a multi-methodology approach to GIS development that provides support for spatial analysis and integrates ‘soft’ requirements analysis, spatial analysis, and ‘hard’ systems design, and thus extends theoretical knowledge of information systems development methodologies into the realm of GIS development.

Since GISs are increasingly being used for decision support by organisations in a variety of industries, it is important that methodological frameworks are available to those developing such systems to enable a thorough and professional approach to the systems development process. It is hoped that the methodological framework for GIS development examined in this paper may be useful for other organisations undertaking GIS development.

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