The evolution of geographical information systems for fire prevention support

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Abstract

Geographical information systems (GIS) provide visual map based analysis and reporting of information implemented in map layers. Geographical information systems evolve by incorporating new and enhanced means of analyzing and presenting location based information. In this paper we examine the evolution of a geographical information system for fire prevention support that evolved through transitions of the underlying approach to analysis of dwelling fire risk over a six year period 2007 to 2013. The novel theoretical contribution of this paper is the examination of the evolution of GIS analysis and modelling approaches, and in the specific context of fire and rescue services, the examination of the evolution of a fire prevention support GIS.

Key words: geographical information system evolution dwelling fire risk

1. Introduction

Information systems evolve in response to a change in the environment in which they operate. The geographical information system for fire prevention support studied in the research reported in this paper underwent a rapid evolution over a relatively short time period due to two main reasons. Firstly, significant budget reductions experienced by the fire and rescue service studied necessitated a significant change in the operation of the fire and rescue service, and secondly, the existing system for fire prevention support which was based upon spatial analysis of previous fire incidents was viewed as being unable to support required improvements in fire prevention.

Historically fire prevention support systems were based upon spatial analysis of fire incidence within a region (FSEC, 2014). In this paper we examine the evolution of a geographical information system for fire prevention support over a six year period, 2007 to 2013 in a fire and rescue service in the North West of England. The existing geographical information system for fire prevention support in use within the fire and rescue service studied was based upon spatial analysis of historical fire incidence combined with the level of deprivation in the different areas within the region covered.

In order to respond to increased efficiency requirements necessitated by significantly reduced fire and rescue service budgets, the geographical information system for fire prevention support needed to evolve to be more predictive in nature. Multiple linear regression modeling was utilized within the geographical information system to model the probability of fire incidence based upon socio-economic causal factors associated with fire incidence. The more predictive multiple linear regression model formed the basis of the first evolution of the geographical information systems for fire prevention support within the fire and rescue service studied (Taylor et al, 2011).

In order to respond to further reductions in fire and rescue service budgets, and to further enhance targeting of fire prevention activities, it was necessary for the geographical information system for fire prevention support to further evolve to move from a coarse grained geographic area based predictive approach, to a finer grained socio-economic group based model. The approach utilized k-means cluster analysis of socio-economic indicators within the region studied to provide analysis of the different population segments within the region via the geographical information system (Higgins et al, 2013).

The population segmentation based model underlying the second evolution of the geographical information system for fire prevention support supported inter-agency working between a variety of partner public sector agencies including: the fire and rescue service studied, an NHS primary care trust, a local council and a police service. Inter-agency collaborative working was necessary in order to address not only the incidence of unintentional dwelling fire, but also the lifestyle and individual socio-economic causal factors underlying such fires that could not be changed by the fire and rescue service, but could however be changed by partner agencies through advocacy and referral services (Taylor et al, 2014). For example smoking cessation (NHS SC, 2014) services (offered by the NHS primary care trust) and support services for elderly and disabled individuals (provided by the local council) were utilized in order to attempt to change the lifestyle factors associated with fire risk of individuals and communities within the region studied.

The population segmentation (community profile) based model underlying the second evolution of the geographical information systems for fire prevention support also supported more targeted fire prevention by fire type analysis. For example, three of the social groups (middle income residents living in privately owned properties, young families with high benefit need, and younger urban population with high levels of deprivation) were identified as being at greater risk of dwelling fire instance.

The novel theoretical contribution of the research reported in this paper is the examination of the evolution of GIS analysis and modelling approaches, and in the specific context of fire and rescue services, the examination of the evolution of a GIS for fire prevention support over a six year period.

2. Literature review

The literature review was undertaken by the authors of the paper who work for a university, and the fire and rescue service studied.

Systems evolution

During their lifetime, information systems are subject to a process of evolution, mainly caused by changes in the business processes of the organization (Salvaneschi, 2011). Jarke et al (2011) commented upon the dynamic evolution of information systems over time that includes both incremental and evolutionary changes. Lyytinen and Newman, (2008) identified both incremental and evolutionary socio-technical change in the context of information systems at multiple levels: the work system level, the building system level, and the organizational environment. Lyytinen and Newman, (2008) advocated the use of socio-technical event sequences and their properties to explain how a change outcome emerged. The critical events in these sequences correspond to gaps in socio-technical systems. By considering information system change as a multi-level and punctuated sequence of socio-technical events (evolutionary stages), it is possible to analyze the evolution of an information system. Cook et al (2006) discussed a classification scheme for evolution in software systems that considered the aspects of: continuing change, increasing complexity, self-regulation, conservation of organizational stability, conservation of familiarity, continuing growth, declining quality and feedback systems in systems evolution.

The majority of studies of software development processes explore initial development rather than ongoing software maintenance, yet the majority of the systems development budget in many organizations is devoted to maintenance. Software maintenance projects differ significantly from original development projects, indicating a need for more research specifically concerning evolutionary processes (Edberg et al, 2012). However, there appears to have been little if any research concerning the evolutionary development of geographical information systems, and in particular concerning the evolution of geographical information systems for fire prevention support.

Fire prevention

Fire prevention strategies (Shai, 2006; Parmer et al, 2006) have played an increasing part in efforts reduce fire incidence in many countries. Crawford (2005) commented that continual reassessment and adjustment of fire prevention activities is necessary in order to attempt to provide a long term solution for reducing fire deaths, injuries and property damage. Fire and rescue services typically target fire prevention initiatives at those individuals, and social groups estimated to have a higher risk of fire incidence (Diekman, 2010).

Previous research identified that dwelling fires are not uniformly spread amongst the population, but are more likely to occur in communities with a high proportion of individuals from at risk groups such as the elderly, the disabled, and the deprived (Chien and Wu, 2008; Zhang et al, 2006; Holborn et al, 2003). A more detailed understanding of the relationships between population characteristics and the risk of dwelling fire would enable fire and rescue services to make informed decisions regarding fire prevention activities.

Current fire risk models adopted by UK fire and rescue services as part of their integrated risk management planning (IRMP, 2014) approach typically involve the analysis of previous incidence of fires, combined with indices of multiple deprivation (IMD, 2014). The Fire Services Emergency Cover (FSEC) model of fire risk used by some UK fire and rescue services (FSEC, 2014) covers dwelling fire risk, as well as other types of risk. The dwelling risk approach uses previous dwelling fire incident data, resource locations and time taken to travel to dwelling fire incidents, and analyses the relationship between response time and dwelling fire fatality rates.

Geographical information systems for fire prevention support

Geographical information systems (GIS) form a research and development area that involves diverse academic fields including geography, mathematical modelling and computer science (Church, 2002). The analytical capabilities of geographical information systems are evolving, and range from visual to exploratory and modelling methods (Pfeiffer and Hugh-Jones, 2002). Obermeyer (2007) commented that the field of geographic information systems is maturing as a profession. Geographical information systems provide spatial and themed queries (relating to bands of values of a given set of variables across a geographical area) that are not typically provided by other forms of information systems. The map based nature of geographical information systems provides information and analyses in a highly visual manner, which cannot typically be clearly and easily provided by other means. Geographic information systems have been commonly used in local government for some time (Petch and Reeve, 1999).

Geographical information systems are evolving to model increasingly complex social simulations and ease of management of the updating of their underlying datasets (Kadri-Dahmani et al, 2008). Tomlinson (2007) commented that although individual geographic information systems themselves tend to evolve over time, geographic information systems also have value as a facilitator for organizational evolution. Nedovic-Budic et al (2004) stated that the sharing of geographic data between organizations remains largely resisted despite the obvious benefits that could be derived. Geographical information systems have been used by fire and rescue services for functions including identifying suitable locations or boundaries for fire stations (Corcoran et al, 2007a) and for fire vehicle dispatch. Geographical information systems have been used for modelling forest fires (Corcoran et al, 2007b; Black et al, 2007) however, there appears to have been little use of geographical information systems for modelling dwelling fires (Corcoran et al, 2007a).

3. Research method

The research reported in this paper concerned the examination of the evolution of a geographical information system for fire prevention support over a six year period (2007 to 2013). The case study research method (Gillham, 2010) was adopted. The case study research method was an appropriate choice of research method, as it allowed an in-depth qualitative examination of the evolution of a geographical information system for fire prevention support in actual practice.

A six year case study of the evolution of a geographical information system for fire prevention support was undertaken between 2007 and 2013. The qualitative research techniques adopted were meetings and discussions with relevant staff such as community fire prevention officers, and project managers. Quantitative data analysis was undertaken by the Strategic Planning department within the fire and rescue service using multiple linear regression and k-means cluster analysis within the SPSS statistical package (SPSS, 2014).

The development of the GIS was instigated by the information management team within the fire and rescue service studied. The two university based authors worked with the fire and rescue service staff to develop the fire risk models and GIS. The evolution of the GIS was guided by the need of the fire and rescue service studied to improve fire prevention in order to support reduction of the number of accidental dwelling fires and accidental dwelling fire fatalities, and in the wider context by significant reductions in fire and rescue service budgets. The research undertaken by the authors was used to support the process of evolution of the GIS. The fire and rescue service staff perceived that the evolution of the GIS would not have been as rapid without the research carried out by the authors. The pattern of evolution of the GIS in terms of the development of the underlying statistical modelling of risk would be relevant to other fire and rescue services and more generally to other public service providers.

The research reported in this paper concerned the following research questions:

- What is involved in the evolution of a geographical information system?
- How does a geographical information system evolve in actual practice?
- How can the evolution of geographical information systems support improvements in fire prevention in actual practice?

These are important research questions since ongoing public sector budgets reductions necessitate fire and rescue services operating more efficiently and more effectively, and improvements in geographical information systems for fire prevention support are one mechanism for supporting such improvements. The evolution of the GIS within the fire and rescue service studied was driven by the need for more targeted fire prevention, due to significantly reduced fire and rescue service budgets.

3.1 Data collection

The evolution of the geographical information system for fire prevention support was discussed in meetings with staff involved with fire prevention and community safety. These included two IT managers, two project managers, two data protection officers and two community fire safety officers within the fire and rescue service studied who were all involved in the on-going development of the GIS and its operational use. The same interviewees were interviewed at different times throughout the whole duration of the GIS implementation and evolution. The meetings typically lasted for approximately one hour. The meeting notes were recorded and then analyzed. These meetings facilitated discussions around the use of geographical information systems for fire prevention activities. Topics discussed in these meetings included the rationale for fire prevention, the mechanisms for fire prevention, and the use of the geographical information systems for fire prevention activities. The question asked covered:

What does fire prevention involve?
How is fire prevention undertaken?
Why is fire prevention undertaken?
When is fire prevention undertaken?
Who is involved in fire prevention?
Where do fire prevention activities take place?
What are the information requirements for fire prevention activities?
How can fire risk be modelled?
How can communities be modelled?
What causal factors are associated with dwelling fires?
How can geographic fire risk data be displayed?
How can geographic community data be displayed?

3.2 Data analysis

The case study method enabled a critical analysis of the evolution of the GIS for fire prevention support by providing a means for examining the rationale for the development of each of the versions of the fire prevention support GIS, and the rationale for why the newer versions were required.

The data collected was content analyzed by identifying themes within the meeting texts. For example, what potential benefits were envisaged from the use of the geographical information system for fire prevention. This allowed an understanding of the issues associated with the use of a geographical information system for fire prevention, and how the system needed to evolve to support changing fire prevention strategies.

The themes were derived from the interviews by content analysis of the text of the interview notes. The research into the evolution of the GIS was based upon the need for the evolution, which derived from the need to more effectively target fire prevention activities in order to further support the reduction of dwelling fire incidence and fire fatalities, and also in order to cope with reducing fire and rescue service budgets.

The multiple linear regression model combined weighted causal factor variables to predict the level of unintentional dwelling fires within the different Lower Super Output Areas (LSOA, 2014) within the region studied. The existing geographical information system for fire prevention was enhanced to present the areas of different levels of fire risk (fire risk bands) based upon the multiple linear regression model, and the different levels of the individual causal factors present in each area.

The k-means cluster analysis identified population segments within the region studied. Data available at the more detailed Output Area (OA, 2014) of geographical granularity was used to create customer insight profile groups for each output area within the region studied and was used to enhance the geographical information system for fire prevention support to show the geographical distribution of the different population segments within the region.

Analysis of fire incidence across the socio-economic groups (community profiles) via the geographical information system was then used to further target fire prevention activities, for example, fire fatalities were found to mainly occur within just three of the ten community profile groups.

An important aspect of fire prevention support that was ascertained during the analysis of the evolution or the geographical information system was that it was insufficient for the fire and rescue service to act in isolation. Unintentional dwelling fires caused by smoking could be identified via the geographical information system, but could only realistically be reduced if smoking rates could be reduced within the region. Partnership with NHS primary care trusts supported referral to smoking cessation services, in order to attempt to assist in the reduction of smoking rates within the region. The fire officer conducting a home fire safety check visit would provide smoking cessation leaflets to households that included smokers during the visit. Unfortunately records were not kept by the NHS primary care trust to indicate which individuals undertaking smoking cessation sessions were prompted to do so via the fire and rescue service. However, a significant proportion of fire fatalities had included smoking materials prior to 2009/10. After this period the proportion of fire fatalities within the region involving smokers materials had fallen.

Unintentional dwelling fires associated with elderly and disabled individuals, especially those living alone could also be identified via the geographical information system, but could only realistically be reduced by appropriate social care interventions. Partnership with local council social services supported referral to a variety of housing and social services to address care issues that could assist in reducing unintentional dwelling fires.

The actual geographical information system was developed and enhanced using the MAPINFO (Mapinfo, 2014) geographical information system software development tool and the MAPBASIC programming language.

4. Results

Research results

The evolution of the geographical information system to support fire prevention utilized by the fire and rescue service studied stemmed from the need to understand the nature of dwelling fires, the causes of such fires, and their distribution across the population in the geographical area concerned.

Initially the understanding of the pattern of fire incidence via the geographical information system arose from a spatial analysis of fire incidence. Dwelling fires occurred more frequently in some geographical areas than others. In the main this appeared to be linked to the level of deprivation, since areas with a higher level of deprivation appeared to have higher levels of fire incidence (Corcoran et al, 2007a).

A literature survey of research into causal factors associated with dwelling fires revealed that there were common causal factors associated with dwelling fires irrespective of nationality or level of urbanization. Population data relating to these causal factors was analyzed to develop a statistical understanding of how these related to patterns of fire incidence within the geographical area concerned. This enabled a predictive causal factor model to be included within the geographical information system that provided an insight into those population characteristics that indicated that an individual or household would be statistically more at risk of dwelling fire.

The next step in the evolution of the geographical information system for fire prevention support concerned the conceptual leap that although individual risk factors such as being elderly, living alone, and being a smoker could assist in identifying those at risk of dwelling fire, it was the *combination* of characteristics, that is the nature of at-risk social groups, that needed to be analyzed. A customer segmentation approach using k-means cluster analysis was then used to create a set of ten customer profiles that differentiated social groups present in the local population. The customer profiles were:

Wealthy over 50s in semi-rural locations
Older retirees
Middle income residents in privately owned properties
Average income older residents
Students in city centre locations
Young families
High benefit need young families
Social housing and high benefit need residents
Transient populations in poor housing
Younger urban population with high levels of deprivation

Analysis of the number of dwelling fires, fire related injuries and fire fatalities within each group (as a proportion of the population within each group) via the geographical information system informed identification of the level and nature of fire risk for each of the ten customer profile groups.

The next development in the understanding of the nature of dwelling fires and their distribution amongst the local population concerned a deeper understanding of the nature of the fire instances themselves. Each dwelling fire incidence involves one or more combustible materials and an ignition source. Common types of dwelling fires include kitchen fires, electrical equipment fires, and smokers' materials. Analysis of the different types of dwelling fires across the customer profile groups via the geographical information system identified that, for example, three groups: middle income residents in privately owned properties, young families with high benefit need, and younger urban population in high levels of deprivation accounted for nearly fifty percent of accidental dwelling fires.

Original geographical information system for fire prevention support

The original state of the geographical information system for fire prevention support was that of a computer based map of risk banded areas, where fire risk was calculated by weighted number of fires and indices of multiple deprivation (IMD, 2014). There had been a steady decline in the number of accidental dwelling fires within the region, however, this had begun to level off, and there were anomalous fires present in lower risk areas. For example, fire fatalities were less likely to occur in low risk areas, yet did still occur in such areas. The geographic granularity of the original geographical information system for fire prevention support was the Lower Super Output Area level (LSOA, 2014).

Enhanced fire risk model geographical information system for fire prevention support

The enhanced fire risk model state of the geographical information system for fire prevention started from a literature review of unintentional dwelling fire research that identified a set of causal socio-economic factors associated with unintentional dwelling fires for which data was obtained for the region studied. An enhanced dwelling fire risk model was developed using multiple linear regression modelling to more accurately and more predictively model dwelling fire risk in the different areas within the region. The fire prevention support geographical information system was enhanced to include more accurate fire risk banded areas within the region, and to show the individual risk factor levels within the different areas in the region (Taylor et al, 2011). The actual linear regression model developed was:

Fire risk level = 0.035 x number of mental benefit claimants
+ 0.012 x number of smoke alarms
- 0.116 x number of severe disability claimants
+ 0.209 x percentage of binge drinkers
- 0.155 x number of lone parents
+ 0.113 x number living alone
- 0.016 x number of disability living allowance claimants
- 6.532

(Higgins et al, 2012)

The geographic granularity of the geographical information system was the Lower Super Output area level (LSOA, 2014). A Lower Super Output Area has an average of roughly

1500 residents and 650 households. Figure 1 shows an example fire risk map from the GIS.

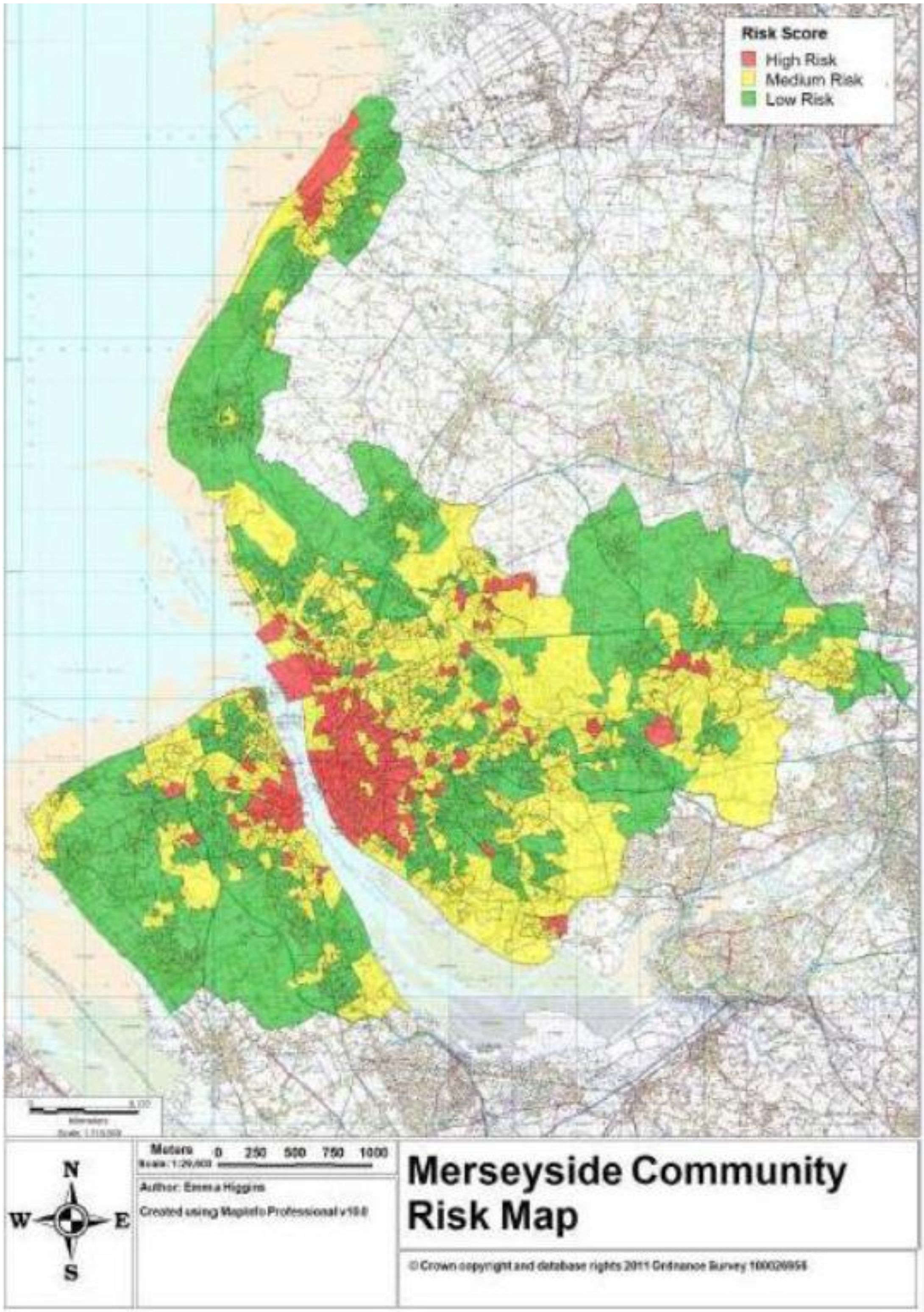

Figure 1 Example fire risk map from the GIS (Higgins et al, 2012).

Enhanced community profile geographical information system for fire prevention support

The enhanced community profiling state of the geographical information system for fire prevention supported further targeting of fire prevention, not just to geographical areas, but to specific communities within geographical areas. K-means clustering was used to identify a set of community profiles from the population within the region (Higgins et al, 2013) Each of the ten identified community profiles had differing levels of dwelling fire incidence, fire related injuries and fire fatalities. Ten population segments were created since, from an operational perspective, this number of population segments was viewed as providing an appropriate level of granularity for fire prevention activities. This supported analysis of fire risk at a more detailed level of geography (output area) (OA, 2014). Each output area within the region covered by the fire and rescue service was associated with one of the ten community profiles. This also supported analysis of fire types across the region studied, for example, kitchen fires occurred mainly within just three of the ten community profiles: younger urban population with high level of deprivation, young families with high benefit need, and middle income residents in privately owned properties. Figure 2 shows an example community profile map from the GIS.

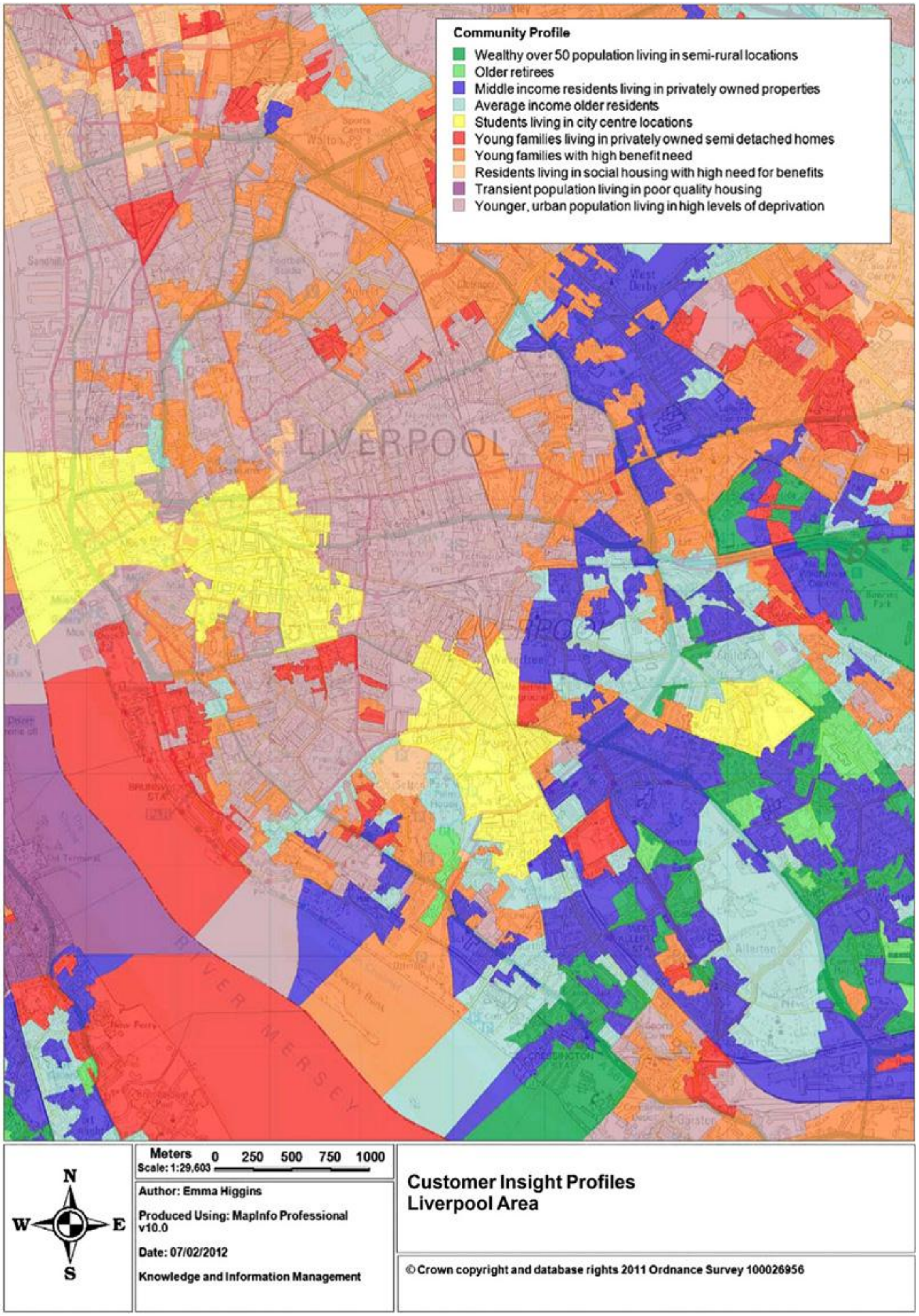

Figure 2 Example community profile map (Higgins et al, 2013)

The process of evolution of the geographical information systems for fire prevention support

An important aspect of any decision to commit funds to fire prevention activities was to attempt to ensure that the most benefit possible was gained from the funds committed. The fire and rescue service studied had identified that over time the reduction in fire incidence and fire fatalities within the region had started to ‘flatten out’. In particular it had been identified that fire fatalities were occurring in areas that were not classified as high risk by the existing model of risk based upon the number of previous fire incidences and indices of multiple deprivation. Since the number of fire fatalities in the region each year was small, typically less than ten, such anomalies were not particularly statistically significant, but were of concern since some fatalities occurred in low risk areas. To address this issue an evolved version of the geographical information systems for fire prevention support was developed based upon a new more predictive model of fire risk that incorporated previously identified causal factors concerning socio-economic population characteristics (funded by the fire and rescue service concerned and the UK Technology Strategy Board). Previous studies had indicated that fire incidence and fire fatalities were more likely amongst the elderly, the disabled, smokers and binge drinkers amongst other factors. The enhanced geographical information systems for fire prevention support based upon the new model of fire risk enabled targeting of areas of higher risk associated with the known causal factors. This could potentially assist in reducing fire incidence and fire fatalities in areas that were previously considered to be lower risk areas. In order to manage the provision of fire prevention services, the fire and rescue service studied created new risk bands equating to low, medium and high risk levels based upon the fire risk model. The classification of the fire risk bands was based upon the resources available within the fire and rescue service and the number of dwellings already visited within the region as part of the home fire safety check scheme (HFSC, 2014). Typically the fire and rescue service studied had visited approximately 100,000 dwellings per year, however due to budget restrictions this was later reduced to approximately 40,000 dwellings per year.

The second evolution of the geographical information systems for fire prevention support utilized cluster analysis (k-means cluster analysis) to perform customer segmentation to identify specific social groups to support further refined targeting not only for fire prevention, but also for associated health and social care interventions (funded by the fire and rescue service concerned and the UK Department of Communities and Local Government). This was based upon customer insight modelling as part of a partnership between the fire and rescue service studied and the local council, the local National Health Service primary care trust and the local police force. The customer insight (community profile) modelling also appeared to indicate that with regard to the ‘level of service’ provided for fire prevention activities, that a higher level of service (that included a home fire safety check, free installation of smoke detector and advocacy services for other agencies) targeted at identified high risk groups would overall be more beneficial and cost effective than a lesser level of service provided for a wider customer base within the region. This was because lower income households might be less likely to purchase or maintain smoke detectors.

Overall the geographical information system for fire prevention support evolved from a spatial analysis of previous fire incidents, to a predictive linear regression model of fire risk based upon causal socio-economic factors, and then to a population segmentation model based upon k-means cluster analysis that supported the analysis of the overall level of fire risk by population segments, and also by the level of risk of different types of dwelling fire across the population segments.

The impact of a change in procedures due to more external collaboration resulted in the database underlying the GIS being updated more regularly with data from the partner organizations. The evolution of the GIS was impacted by expertise from the two authors who were university staff and who provided external expertise in GIS development and statistical modelling.

The actual GIS software development tool used was MAPINFO (MAPINFO, 2014). The MAPBASIC programmes used in the GIS were developed by one of the authors who worked in the information management department of the fire and rescue service studied. The more complex predictive model was relatively easily implemented in MAPINFO through the use of the MAPBASIC programming language. The MAPINFO GIS software tool provided a similar level of functionality compared to other GIS tools such as ARCGIS and GEOMEDIA.

The community safety model was supported by the GIS, without which it would have been difficult to analyse the geographical distribution of the different community profiles. Figure 3 shows how the statistical modelling underlying the geographical information system for fire prevention system evolved over the period studied.

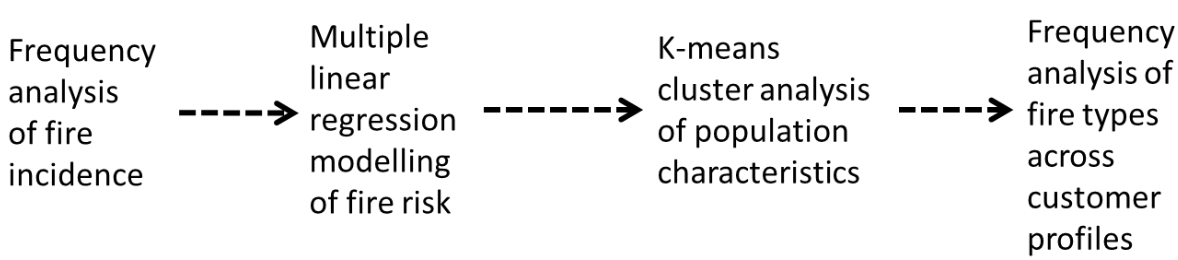

Figure 3 Evolution of statistical modelling of fire risk used in the geographical information system.

Overall the geographical information system for fire prevention support system needed to evolve rapidly in order to accommodate a number of rapidly changing requirements concerning:

- Reduction of the number of accidental dwelling fires and related injuries
- Improved signposting to early intervention services enabling people to live independently in their own homes.

The evolutionary process was driven by rapidly changing organizational needs, resulting from significant budget reductions. The evolutionary process was determined by:

- The need for more predictive modelling of fire risk.
- The need for more targeted fire prevention activities.
- The need to work collaboratively with partner agencies in order to attempt to reduce the underlying causal factors associated with fire risk.
- The need to provide more efficient and effective fire prevention with less resources

Figure 4 shows how the measure used for area classification (that is level of fire risk) evolved within the geographical information system for fire prevention support over the period studied.

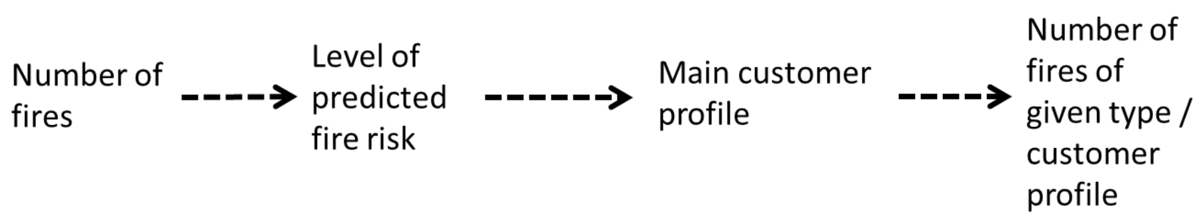

Figure 4 Evolution of measure used for area classification within the geographical information system

Evaluation of the evolution of geographical information systems for fire prevention support

Previously between 2005/06 and 2008/09 there was a reduction in accidental dwelling fires by approximately 10% (154 incidents). Between 2009/10 and 2012/13, there was a reduction in accidental dwelling fires by approximately 12% (163 incidents) across the region concerned. This reduction in accidental dwelling fires was associated with improved delivery of fire prevention activities. Based upon the knowledge gained from causal factor analysis, the enhanced community safety model enabled more accurate identification of vulnerable groups and individuals within the community. However, the reduction in dwelling fire incidence and dwelling fire fatalities has not only flattened out, but had actually reversed in 2013/14. One possible explanation for this was the recent substantial reduction in fire and rescue service budgets. Table 1 shows accidental fires and accidental dwelling fire fatalities between 2005/06 and 2013/14.

Year	Number of dwelling fires	Number of dwelling fire fatalities	
2005/06	1456	11	
2006/07	1369	8	
2007/08	1314	9	
2008/09	1302	9	
2009/10	1299	8	
2010/11	1315	5	(Introduction of causal risk factor methodology)
2011/12	1196	5	
2012/13	1135	6	(Introduction of customer insight methodology)
2013/14	1153	9	

Table 1 Accidental dwelling fires and accidental dwelling fire fatalities between 2005/06 and 2013/14

The fire and rescue service concerned was able to more effectively identify groups of individuals at increased risk of experiencing an accidental dwelling fire. This allowed greater understanding why groups of individuals are at risk for better tailoring and targeting of services to the community. The adoption in 2010 of the approach as best practice for improved delivery of fire prevention activities is associated with an observed reduction in accidental dwelling fires between 2009/10 and 2012/13. The financial impact was measured by the reduced cost of responding to accidental dwelling fires. Response to fire is estimated at £3,100 per incident, therefore reducing the number of incidents amounted to an estimated saving of over £500,000 over the period 2009/10 to 2012/13.

The evolution of the geographical information system assisted with further reductions in dwelling fire instances by better targeting of fire prevention activities using a spatial analysis of known accidental dwelling fire risk factors. As this methodology is based on risk factors that are also of relevance to other partners, it enhanced collaboration with other public service agencies to the most vulnerable communities. This will have significant economic value in the region but most importantly in reducing human suffering. The system has the potential to be adopted by Fire & Rescue Services across the UK and possibly beyond.

The approach to fire safety was extended to other aspects of assessing risk to the community through a customer insight project funded by the UK Department of Communities and Local Government and the fire and rescue service concerned. This extended the analysis of fire risk to incorporate associated health, social care and crime risks that used the previous analysis of fire risk as a basis for further analysis of causal factors. The research provided an objective means to identify households most at risk in the community in order to support more targeted use of fire prevention. The approach has been disseminated as a model good practice approach by the UK Department of Communities and Local Government. This supports the joined-up public sector provision approach advocated by the UK Government. The results of a pilot of customer insight found that over 70% of residents visited during the customer insight pilot had some factors present that could result in them becoming at risk from fire. In addition, 50% of residents visited were signposted or referred onto another agency because additional risks or needs were identified. This evidences the value of more accurate targeting of fire prevention activities as part of a multi-agency preventative approach, by allowing officers to signpost, or refer on to other agencies if additional risks are identified. Potential problems with adopting a multi-agency approach relate to the sharing of information, data protection issues, and the frequency of information updates.

The methodology has the potential to significantly reduce costs for the fire and rescue service and its partners involved. For example, due to more accurate identification of vulnerable individuals through the customer insight project, elderly falls, and problems related to excess cold will be reduced. An elderly person falling at home will cost the NHS approximately £2,500, whereas preventative remedial work carried out at the home of an elderly person would result in a potential avoided cost of approximately £2,000 per person (there are approximately 5000 elderly falls in the region each year). Another currently important concern is that of problems relating to excess cold, which cost £3.2m per local authority, whereas remedial work is estimated to cost less than £1m, giving a significant saving if the vulnerable people can be identified through the customer insight approach.

The local community has benefited from more co-ordinated community safety which supports elderly, disabled and other at-risk individuals to live independently via co-ordinated support from the fire and rescue service, National Health Service, local council and police service. The community profiles developed are used by the six Service District Prevention Teams and the Home Safety Coordinator at headquarters when developing new fire safety campaigns. The Community Profiles allow for a greater understanding of communities. For example, an analysis of kitchen fires identified that over 80% occurred in three out of ten Community Profile groups. This enabled greater targeting of safer cooking messages towards those most at risk. The number of accidental kitchen fires fell from in 249 in 2012/13 to 219 in 2013/14. Typically, some of these vulnerable individuals may not have been identified using previous methodologies as they live within ‘low risk’ areas. Utilising this methodology has resulted in 5% increase of Home Fire Safety Check visits within areas previously defined as ‘low risk’. In addition, over 70% of these individuals were found to have some fire risks present that could lead to death or injury.

Conclusions

Geographical information systems provide visual map based analysis and reporting of information implemented in map layers. Such systems evolve by incorporating new and enhanced means of analyzing and presenting information. In this paper we have examined the stages of evolution of a fire prevention support system that evolved via transitions in the underlying approach to analysis of fire risk by the fire and rescue service studied. The findings were derived from the interviews conducted by the authors, as well as their involvement in the development of the evolution of the GIS that was supported by research and development grants from the fire and rescue service studied, the UK Technology Strategy Board, and the UK Department of Communities and Local Government. Two of the authors were academics and three of the authors were employed by the fire and rescue service studied.

The first stage of evolution of the geographical information system for fire prevention support concerned a transition of fire risk modelling from a model that involved just the number of previous fires and the deprivation level of an area, to a more complex predictive model that concerned a much larger set of interrelated socio-economic causal factors. The second stage in the evolution of the geographical information system for fire prevention support concerned a change in fire risk modelling perspective, in that fire risk relates to ‘communities’, that is not just how many individuals in an area may present risk factors (e.g. a disability, living alone, high smoking rates etc.), but rather what ‘communities’ are present in terms of ‘shared’ socio-economic characteristics within an area.

The first evolution of the geographical information systems for fire prevention support allowed targeting of fire prevention activities to specific geographical areas, the second evolution allowed further targeted fire prevention activities to communities within those geographical areas.

The modelling of fire risk underlying the evolved geographical information system could be conceptualized as a function that maps the multi-dimensional data space of individuals’ attributes (socio-economic characteristics) onto the space of fire incidents. The first stage of the evolution of the geographical information system for fire prevention support ‘reduced’ the dimensions of the data space to the attributes of individuals within the region to those dimensions (attributes) most strongly associated with unintentional dwelling fires (causal factors from previous research) via all subsets multiple linear regression modelling of data for the region in order to identify the ‘most predictive’ set of socio-economic characteristics. The second stage of the evolution of the geographical information system for fire prevention support identified the ‘regions’ or clusters within the data space of individuals’ attributes that identified different social groups or community profiles that had different levels of fire risk.

The evolution of the GIS for fire prevention support ran smoothly mainly due to the high level of user involvement of operational fire and rescue service staff in the project. Two of the authors worked in the information management department of the fire and rescue service, one in the community safety department, and the other two authors were university academics. The high level of user involvement in the prototyping approach used for the development of the GIS meant that operational users within the fire and rescue service were involved in every stage of the development process, which helped to ensure that the GIS met with user expectations.

Overall the modelling underlying the geographical information system for fire prevention support evolved from a ‘chaotic’ distribution of fire incidences (from simple spatial analysis of fire incidence within the region) to a 'chaordic' distribution that had identified patterns of fire incidence in terms of specific attributes (causal factor dimensions) of the data space and specific groupings (clusters) within the data space (community profiles). The 'chaordic' modelling focused upon the analysis of 'initial states' (that is the individual socio-economic characteristics, and combinations and clusters of such) associated with a higher probability of fire, rather than modelling the dynamics of actual individual fire incidences, which are currently too complex to model.

References

Black, J., Arrowsmith, C., Black, M., Cartwright, W. (2007) Comparisons of techniques for visualising fire behaviour, Transactions in GIS, 11, 4, 621-635.

Chien, S., Wu, G. (2008) The strategies of fire prevention on residential fire in Taipei, Fire Safety Journal, 43, 71-76.

Church, R. (2002) Geographic information systems and location science, Computers and Operations Research, 29, 541-562.

Cook, S., Harrison, R., Lehman, M., Wernick, P. (2006) Evolution in software systems: foundations of the SPE classification scheme, Journal of Software Maintenance and Evolution: Research and Practice, 18, 1, 1-35.

Corcoran, J., Higgs, G., Brunsdon, C., Ware, A., Norman, P. (2007a) The use of spatial analytical techniques to explore patterns of fire incidence: A South Wales case study, Computers, Environment and Urban Systems, 31, 623-647.

Corcoran, J., Higgs, G., Brunsdon, C., Ware, A., (2007b) The use of comaps to explore the spatial and temporal dynamics of fire incidents: A case study in South Wales, United Kingdom, The Professional Geographer, 59, 4, 521-536.

Crawford, B. (2005) Reducing fire risk for the poor, Fire Engineering, 58, 1, 83-88.

Diekman, S. (2010) A qualitative evaluation of fire safety education programs for older adults, Health Promotion Practice, 11, 2, 216-225.

Edberg, D., Ivanova, P., Kuechler, W. (2012) Methodology Mashups: An Exploration of Processes Used to Maintain Software, Journal of Management Information Systems, 28, 4, 271-304.

FSEC (2014) Fire Service Emergency Cover (FSEC) Toolkit, https://www.gov.uk/government/publications/fsec-toolkit-review-manual

Gillham, B. (2010) Case Study Research Methods, Continuum, London, UK.

E. Higgins, E., Taylor, M., Francis, H. (2012) A systemic approach to fire prevention support, Systems Practice and Action Research, 25, 5, 393–406.

Higgins, E., Taylor, M., Jones, M., Lisboa, P. (2013) Understanding community fire risk – a spatial model for targeting fire prevention activities, Fire Safety Journal, 62, 20–29.

Holborn, P., Nolan, P., Golt, J. (2003) An analysis of fatal unintentional dwelling fires investigated by London Fire Brigade between 1996 and 2000, Fire Safety Journal, 38, 1-42.

HFSC (2014) Home fire safety check, London Fire Brigade, https://www.londonfire/gov.uk/homefiresafetyvisit.asp

IMD (2014) Indices of Multiple Deprivation, UK Communities and Local Government, http://www.communities.gov.uk

IRMP (2014) Integrated Risk Management Planning, Fire and Resilience, UK Communities and Local Government, http://www.communities.gov.uk

Jarke, M., Loucopoulos, P. Lyytinen, K., Myopoulos, J., Robinson, W. (2011) The brave new world of design requirements, Information Systems, 36, 7, 992-1008.

Kadri-Dahmani, H., Bertell, C., Duchamp, G, Osmani, A. (2008) Emergent property of consistent updated geographical database, International Journal of Modelling, Identification and Control, 3, 1, 58-68.

LSOA (2014) Lower Super Output Area classification, UK Office for National Statistics, http://www.neighbourhood.statistics.gov.uk

Lyytinen, K., Newman, M. (2008) Explaining information systems change: a punctuated socio-technical change model, European Journal of Information Systems, 17, 589-613.

Mapinfo (2014) Mapinfo, http://www.mapinfo.com/

Nedovic-Budic, Z., Pinto, J., Warneche, L. (2004) GIS database development and exchange: Interaction mechanisms and motivations, ORISA Journal, 16, 1, 15-29.

NHS SC (2014) Stop smoking with the NHS, http://www.smokefree.nhs.uk

OA (2014) Output Area classification, UK Office for National Statistics, http://www.neighbourhood.statistics.gov.uk

Obermeyer, N. (2007) GIS: The maturation of a profession, Cartography and Geographic Information Science, 34, 2, 129-132.

Parmer, J., Corso, P., Ballesteros, M. (2006) A cost analysis of smoke alarm installation and fire safety education program, Journal of Safety Research, 37, 367-373.

Petch, J., Reeve, D. (1999) GIS organisations and people: A socio-technical approach, Taylor and Francis, London, UK, pp 6.

Pfeiffer, D., Hugh-Jones, M. (2002) Geographical information systems as a tool in epidemiological assessment of wildlife disease management, Revue Scientifique et Technique, 2, 1, 91-102.

Salvaneschi, P. (2011) The evolution of information systems, a case study on document management, in Proceedings of IEEE International Conference on Software Maintenance, 25-30 September, 2011, Williamsburg, Virgina, USA, pp 428-437

Shai, D. (2006) Income, housing and fire injuries: a census tract analysis, Public Health Reports, 121, 2, 149-154.

SPSS (2014) Statistical Package for the Social Sciences, http://www.ibm.com/software/uk/analytics/spss/

Taylor, M., Higgins, E., Francis, M., Lisboa, P. (2011), Managing unintentional dwelling fire risk, Journal of Risk Research,14, 10, 1207–1218.

Taylor, M., Higgins, E. Lisboa, P., Arshad, F. (2014) Developing a data sharing framework: a case study, Transforming Government, People, Process, and Policy, 8, 1, 151–164.

Tomlinson, R. (2007) Thinking about GIS: geographic information system planning for managers, ESRI Press, Redlands, CA, USA, pp15.

Zhang, G., Lee A., Lee, H., Clinton, M. (2006) Fire safety among the elderly in Western Australia, Fire Safety Journal, 41, 57-61.