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GIS AND CHAOS MODELLING IN THE PREDICTION OF DWELLING FIRES IN MERSEYSIDE AND TRABZON: A PIONEERING APPROACH TO PREDICTIVE MODELLING

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BACKGROUND TO THE PROJECT

More than 3,000 dwelling fires have occurred each year over the past 10 years in the Merseyside region in north-west England. On average, 9 deaths have occurred in dwelling fires each year in the region throughout the same period of time. Most fire-related deaths in Merseyside have occurred in out-of-context, unexpected dwelling fires.

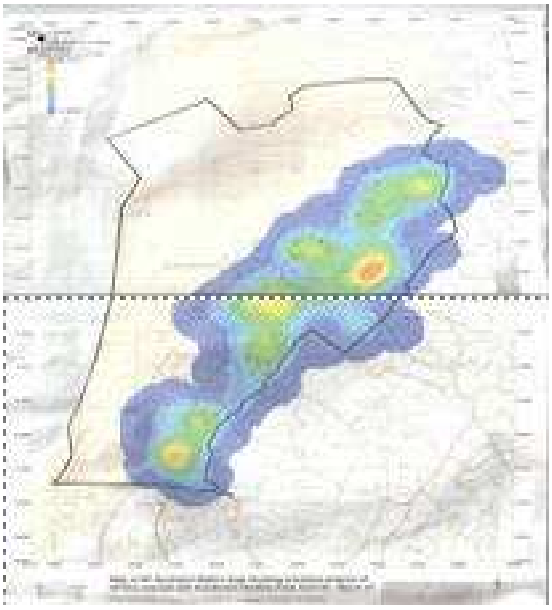

Figure 1. Dwelling Fire Occurrences in Merseyside April 2006 – March 2007

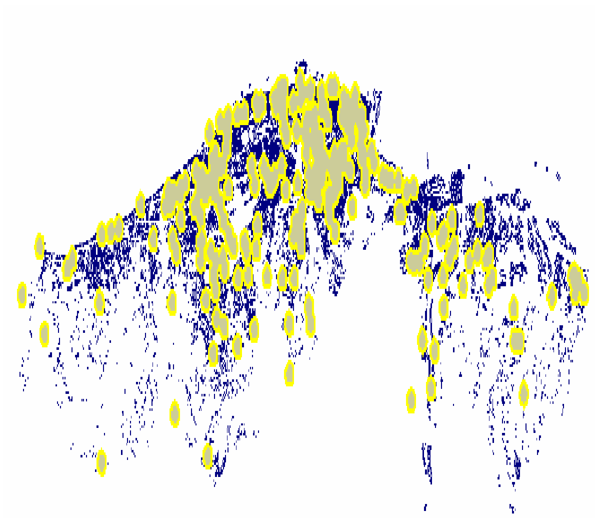

Figure 2 Dwelling Fire Occurrences in Trabzon 2006 to 2007

Dwelling fires occur when a set of pre-existing rules are satisfied.

There is a need to identify the rules that lead up to the occurrence of a dwelling fire. If we understand the rules that are an integral part of the process that leads up to the likelihood of a dwelling fire developing then, it will be possible to identify when a rule has been satisfied and to forecast with some accuracy which type of dwellings are at risk from fires.

THE RESEARCH AND DEVELOPMENT TEAM

In Liverpool, we have a team of researchers at the GISLab and, we are working closely with a team of operational fire service managers from the Merseyside Fire and Rescue Service.

THE CHALLENGE

Conventional prediction modelling based on linear techniques fails to provide accurate forecasts of dwelling fire occurrences. Anomalous, out-of-context, unexpected dwelling fires occur that often result in fatalities.
Given the failure of conventional modelling techniques in forecasting dwelling fires, there is a need to develop new methodology.

In a new GISLab (UK) research project, pioneering methodology is being developed to investigate the circumstances of all sudden, unexpected or unusual dwelling fires in the Merseyside (north UK) and Trabzon (north Turkey) regions. The main purpose of the research study is to identify the rules that exist in the process leading up to the occurrence of dwelling fires. The aim is to develop a new methodology for predicting dwelling fires. The framework developed will help prevent the development of the process that may lead to a dwelling fire taking place.
Although, using legacy data gathered at the time of fire incident investigation, a great deal is known about the causes and effects of dwelling fires, little is known about the rules that exist in the process leading up to the occurrence of a dwelling fire.

THE PROBLEMS

Current modelling technologies assume linearity. This is to say they anticipate future events to occur based on what happens today. This approach ignores the diversities and dynamism of human life and assumes that what happens today will happen tomorrow given the exact same circumstances.

Given legacy data describing dwelling fires, can it be assumed that if the same circumstances were to be replicated, would then a dwelling fire occur? It is unlikely we can answer with any certainty that a dwelling fire will occur. An example of this in an operational sense is to note the real existence of anomalous, unexpected dwelling fires in both case study areas.

Most data are currently stored using paper-based information systems. This often means that data is not readily accessible for modelling purposes.

All fire and rescue services have an obligation to deliver the best possible service to the communities they serve. To achieve this, often with the constraints of budget limitations, resource allocation is a vital component. If the possibility of hazard and risk associated with dwelling fires is known then, this information can be used to augment the resource allocation system used by the fire and rescue services.

OBJECTIVES OF THE PROJECT

The broad objectives of the research study are to:

1. Enable the system to forecast potential dwelling fires.
2. Ensure that this project has the potential to impact positively on current approaches to planning fire and rescue service response to dwelling fires.
3. Improve resource allocation and reduce overheads whilst increasing prevention of death and injury from dwelling fires.
4. Provide a more flexible and responsive planning model that can be commercialised.
5. Provide potential to integrate with other Fire and Rescue Services both in the UK and internationally.
6. Enable improvements to be made in fire response planning.

EXPECTED BENEFITS OF THE PROJECT

The project is expected to generate the following benefits:

1. Less fatalities, injuries and damage.

2. Greater efficiency.
3. Effective management of fire and rescue resources.
4. Improved service to the community.
5. Ability to learn from the planning process to improve the planning process in the future.

WHAT IS THE PROJECT

Broadly, the project includes the development of:

1. A **F**ire and **R**escue **P**lanning **T**ool (FRPT).
    1. A completely newly designed web-based Geographical Information System.
    2. A set of completely new models that forecast likely occurrences of house fires and their possible future impact.
2. An improved set of digital data that, as far as possible, accurately models the region.
3. The design and development of a software application that operates via the World Wide Web that integrates the elements described above.

INITIAL ANALYSIS OF THE MERSEYSIDE DATA

When did the fires occur?

The late evening and early hours of the morning were the periods when most fire deaths occurred, with 70 per cent of fires starting between 9pm and 6am. Only one fire death occurred from a fire started between 6am and 6pm.

The days of the week when the fires occurred were:

Monday	4
Tuesday	0
Wednesday	0
Thursday	1
Friday	1
Saturday	3
Sunday	0

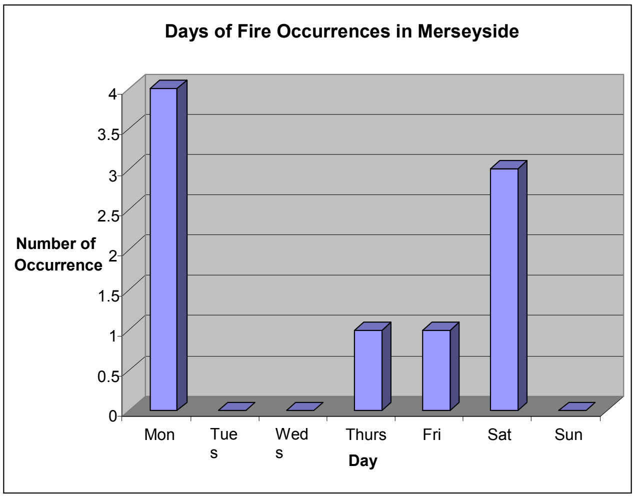

Fig 3. Days of the week when fire occurred, 2007

February was the worst month, with 3 fatalities, but there were no other significant factors regarding the time of the year when the fires occurred.

What were the causes of the fires?

Four of the fires were the result of careless use of smoking materials or matches, a figure consistent with previous year's causes of accidental fire deaths. Two of the fires were the direct result of misuse, or careless use of cooking facilities. One was caused by radiated heat, one by an open fire setting fire to nearby combustible item and one by careless use of candles.

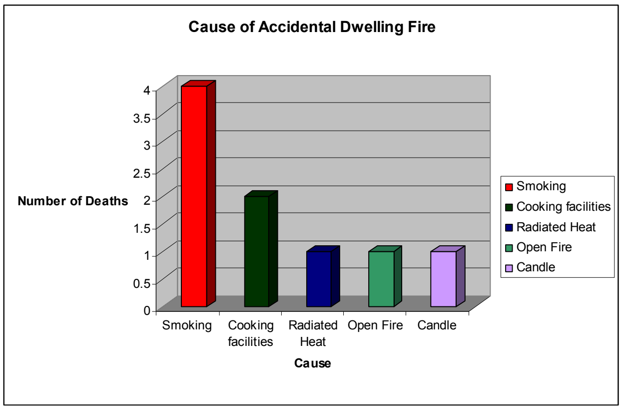

Fig 4. Graph showing causes of accidental dwelling fires in Merseyside.

Who died in the fires?

Of the nine accidental fire deaths, six were female and the ages of the victims ranged from 25 to 97. Older people were more vulnerable with 6 of the victims over the age of 60.

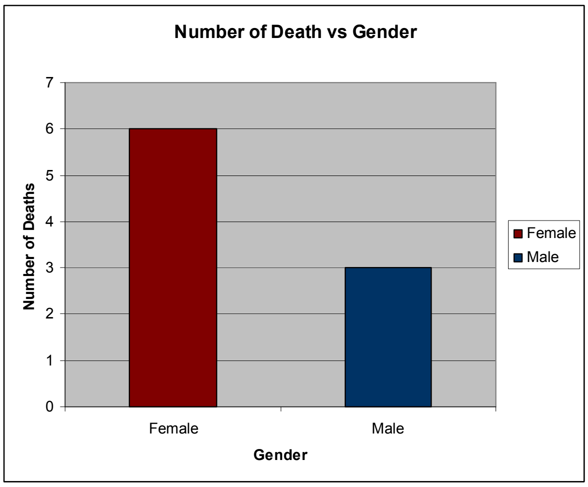

Fig 5. Graph showing 6 out of 9 victims were female.

Where are people dying?

In Merseyside, initial investigation into legacy data revealed a distinct clustering of dwelling fires (Fig. 1).
All of the victims died in their own homes and the majority occurred in terraced houses:

Type of property
5: Terraced houses
1: Semi-detached house
3: Flats/multi-occupied houses

Of the nine victims, only four were in the room where the fire started at the time that it started and five were elsewhere in the property.

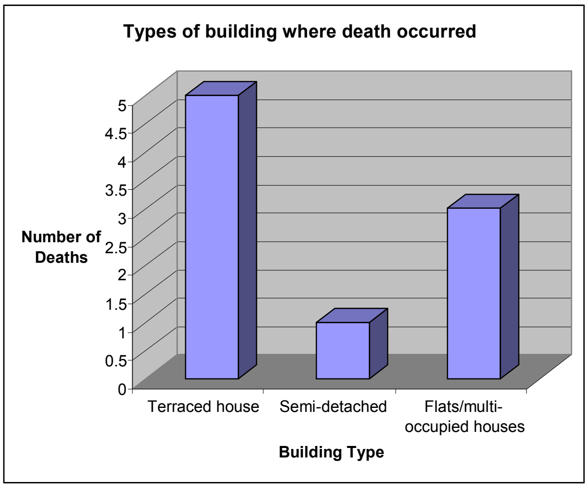

Fig 6. Building types where people died.

People factors

The most common underlying factor of these fires was alcohol. In six of the nine cases the deceased had been drinking alcohol before the fire started. Alcohol not only contributed to the fire starting in the six cases, but also the inability of the casualties to become aware of the fire and escape. In five of the six cases where alcohol was an issue, the casualties were believed to have been in an alcohol-induced sleep as the fire developed.

The three casualties for whom alcohol was not a factor were the oldest fire victims, a male aged 70 and two females aged 92 and 97. The three incidents involved a poorly maintained electric fire, clothing being set on fire while cooking on an open flame and the careless use of candles.

DEVELOPING THE BEAST

The software system design is based in state-of-the-art object oriented technology.

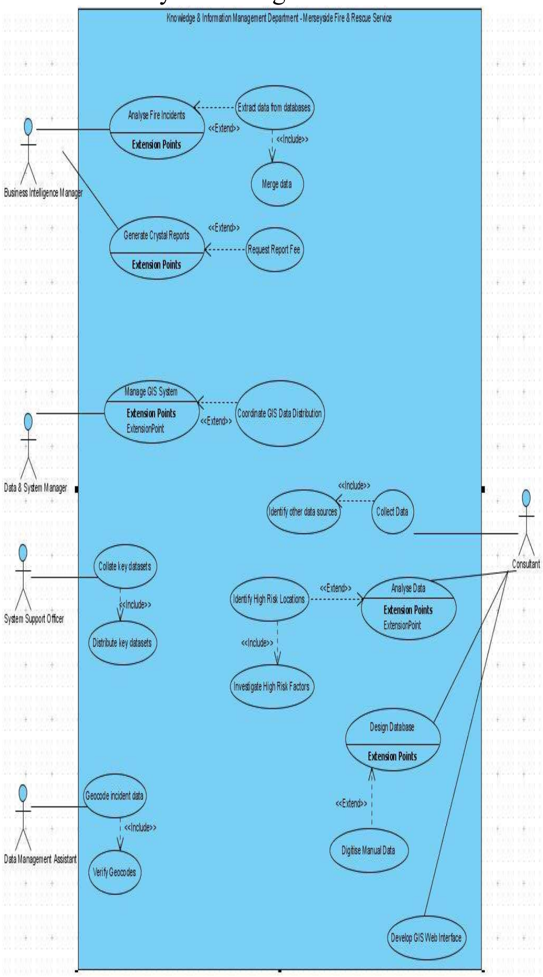

Fig 7. Use Case Model of the system

THE PROBLEM

Merseyside Fire and Rescue Service has recorded its lowest ever number of accidental fire deaths. The Service set demanding five-year targets in 2007 to reduce fire deaths in the region and called upon GISLab to assist with deriving new methodology to help achieve the targets.

In Trabzon the number of dwelling fires is similar to Merseyside and, the number of unexpected fires occurring in out-of-context locations matches that found in Merseyside.

The primary purpose of this research study is to identify those people in Merseyside and in Trabzon, in the community, that are the highest 'at risk' groups.

OUR APPROACH TO A NEW METHODOLOGY

Geographical Information Systems (GIS) are used to store, retrieve, manipulate and analyse data that are spatially and, often temporally, referenced (Kent et al, 1993i). Geographical Information Systems can be used to model complex systems that would be difficult to represent using other types of existing software systems or by pure mathematical models (Forcht, 2000ii).

Systems that can exhibit chaotic behaviour can be the most difficult to model in geographic terms. In mathematical terms such systems can include a multitude of variables and such a variety of possible outcomes that providing formal mathematical formulae to describe their behaviour or to model future activity is extremely difficult.

Chaos Theory (Kapitaniak, 2000iii) can be used to model systems that are apparently disordered. Chaos theory identifies the underlying order in what appear to be random data. In a scenario where events occur in a turbulent, complex and unpredictable environment, the tenets of chaos theory can be extremely useful to model the system.

Many people believe that twentieth century science will be remembered for three main theories: quantum mechanics, relativity, and chaos. It is safe to say that where the classical sciences end, chaos is only beginning.

Prior to the development of chaos theory, the majority of scientific investigation involved attempting to understand the world using linear modelling approaches. The mathematics associated with this approach has been linear in nature.

Chaos theory adopts a contra approach and is the study of unstable, aperiodic behaviour in deterministic, nonlinear dynamical systems in the world.

An innovative research project in the North-West GIS Research Laboratory (NWGISRL)iv is for the first time, integrating, chaos theory with GIS. Legacy data for the Merseyside (UK) region is being examined against this backdrop. Early indications in the research study are that a number of house fires occurred between 2003 and 2006, that were not expected. Such anomalous activity, sometimes leading to deaths or serious injuries, clearly needs to be better understood. Chaos theory integrated with a GIS is being used to identify answers.

The goal of the ongoing research study in GISLab (UK) is to address the problem outlined above by designing and developing a new modelling framework to identify potential hazard and risk to properties from dwelling fires.
Linear quantitative modelling fails to take into account anomalous data about possible fire hazard and risk. As a result, forecasts based on linear modelling provide an adequate but incomplete picture of possible future dwelling fire hazard and risk.

Our aim in the study is to pioneer new methodology to identify the 'rules' most likely to lead to the development of a dwelling fire. If we know the rules that underpin the existence of a dwelling fire we are then in a position to target the groups affected to reduce the hazard and risk of dwelling fires occurring.

Our approach is to step back from examining the post-impact of a dwelling fire and, we will be looking at the system as a whole to identify what the causal factors (rules) are in dwelling fires. These might be long-term causal factors that are neither readily apparent nor obvious from an examination of the fire ground.

If we know and understand the rules that eventually can lead to the development of dwelling fire we can then see that a situation is developing and do something to help avert disaster. In other words, knowledge about the process leading to a catastrophic outcome can be used to avert the same outcome.

The new information model based on the tenets of chaos theory and the powerful query and spatial analysis capability of GIS that is being developed takes into account anomalous data. Early indications from the research study are that this approach provides a clearer picture of possible hazard and risk associated with house fires in the region. As a result the research study indicates a possible way of augmenting the decision making process underlying emergency services resource allocation in the Merseyside region. The UK National Fire Service is considering the model for future planning of resources across the country.

Trabzonv is a heavily compacted coastal urban area backed by a high mountainous region. The road network is characterised by narrow streets with heavy, congested vehicular and pedestrian traffic flows. A similar research study has been implemented to the one used in Merseyside. New area-specific quantitative and qualitative models in a chaos theory and GIS modelling approach are being developed for the study. Using legacy data about fire events in Trabzon, the models will be calibrated. Early results from the study indicate this approach will be useful for augmenting the delivery of emergency services in Trabzon.

Given the international dimension in this research study it has been possible to draw comparisons and to form early indications from the study. The new, innovative information framework being developed based on the integration of chaos theory and GIS, appear to offer positive improvements to emergency services resource allocation planning both in Trabzon and in Merseyside. The early results from this innovative research are reported to the conference in this paper.

COPING WITH HUGE SPATIALLY-REFERENCED DATASETS

The approach we are adopting to cope with the huge datasets necessary in Chaos Modelling is to employ Principal Component Analysis. PCA is a technique used to reduce multi-dimensional data sets to lower dimensions for analysis. In our case we have a large number of entity tables containing a variety of variables – both qualitative and quantitative – that may be relevant to incidents of dwelling fires (based upon legacy data from the fire service and other agencies such as Health, Police, and Social Services). PCA is being used for dimensionality reduction in a data set by retaining those characteristics of the data set that contribute most to its variance, by keeping lower-order principal components and ignoring higher-order ones.

Basically, PCA is an orthogonal linear transformation that transforms the data to a new coordinate system such that the greatest variance along any projection (or axis) comes to lie on the first coordinate (first axis), and the second greatest variance on the second coordinate (second axis) and so on.

What we are aiming to identify in the data are the attractors (i.e. what ranges of what variables in combination give us the highest probability of a dwelling fire incident). A simplistic approach can just identify point attractors (for example, faulty wiring (yes or no)).

However, we need to find more complex attractors and these can be identified by examining the variables related with dwelling fires that show the greatest degree of variability (for example, age of 'main' occupant, age of dwelling, etc.).

By applying PCA we will be able to explore a vast set of data in order to be able us to 'see' the attractors and the rules that underpin their development, and thus form a predictive model.
To accomplish the modelling, we are using the SPSS statistical package to perform PCA. This is because the complex algorithms used would have to be 'grafted' into the GIS or written from scratch which would be messy and time consuming.

CONCLUSION

The FRPT will provide more accurate and readily accessible forecasts of dwelling fire occurrences. This will help improve service to the community in Trabzon and in Merseyside by:

1. Accurately forecasting likely occurrences of house fires;
2. Reducing irrelevant forecasts;
3. Avoiding proposing resource allocation with a low chance of success;
4. Reducing time required to interpret and check forecasts of likely house fires;
5. Improving the efficiency of preventive work.

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[iv] North West GIS Research Laboratory, School of Computing and Mathematical Sciences, Liverpool John Moores University
[v] Trabzon a heavily compacted coastal city in the North-East of Turkey.

Appendix 1
Merseyside Fire and Rescue Service Operational Area

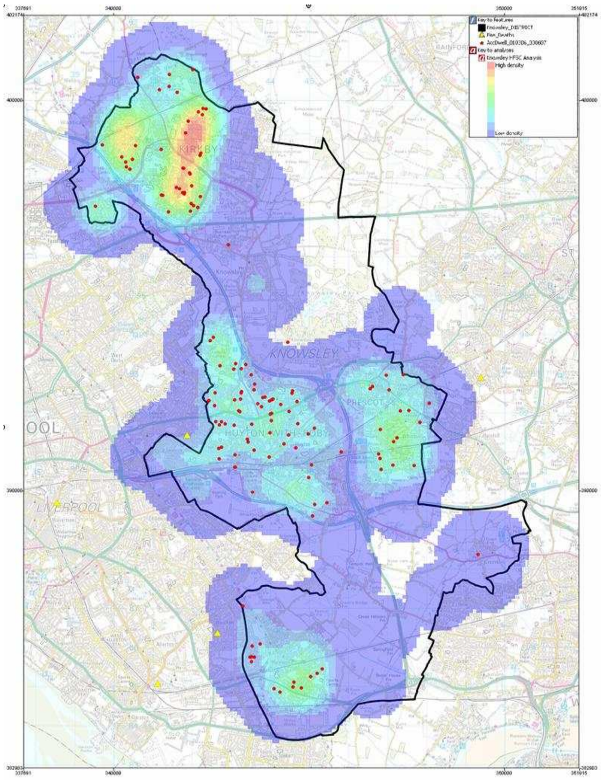

Fig 8. Map of Knowsley showing a hotspot analysis of HFSCs overlaid with Accidental Dwelling Fires and Fire Deaths (01/03/06 – 30/06/07)

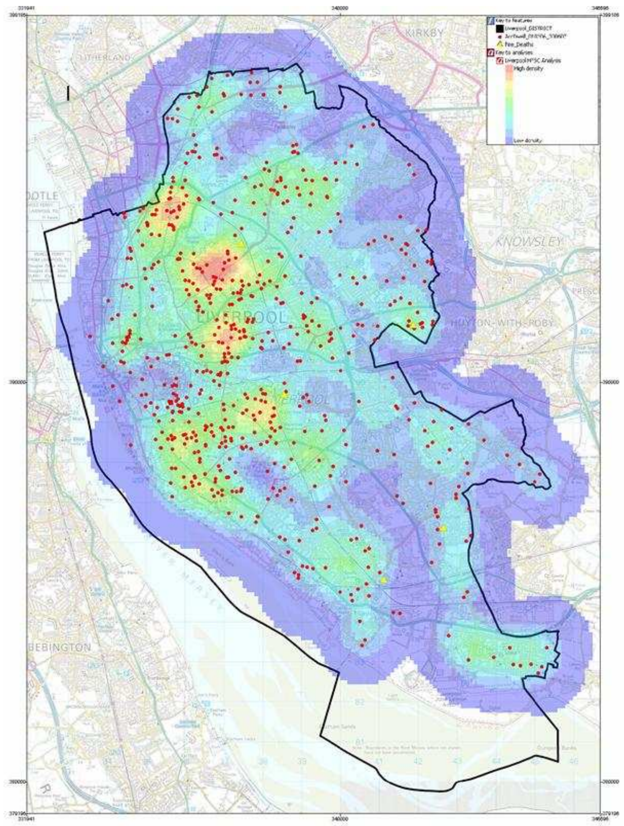

Fig 9. Map of Liverpool showing a hotspot analysis of HFSCs overlaid with Accidental Dwelling Fires and Fire Deaths (01/03/06 – 30/06/07)

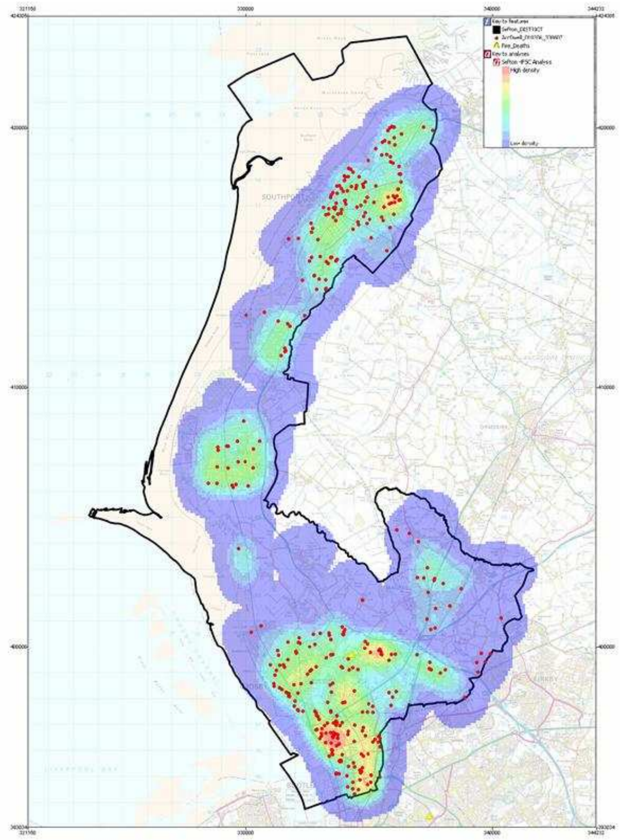

Fig 10. Map of Sefton showing a hotspot analysis of HFSCs overlaid with Accidental Dwelling Fires and Fire Deaths (01/03/06 – 30/06/07)

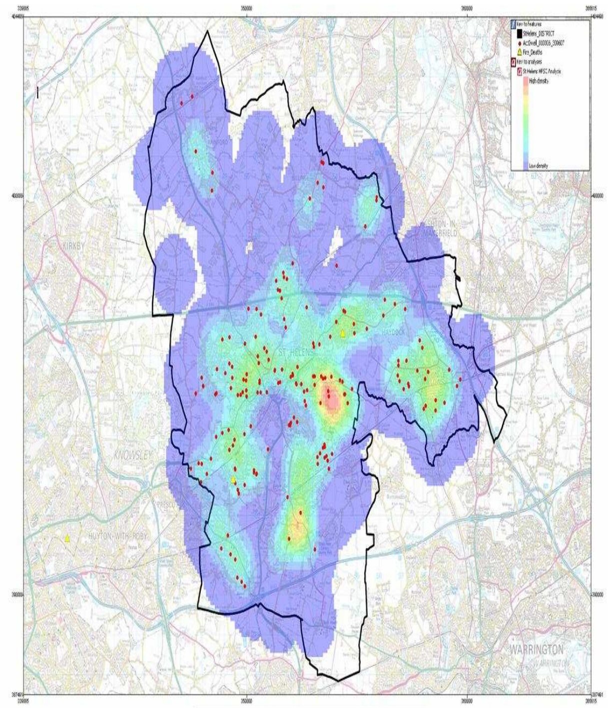

Fig 11. Map of St. Helens showing a hotspot analysis of HFSCs overlaid with Accidental Dwelling Fires and Fire Deaths (01/03/06 – 30/06/07)

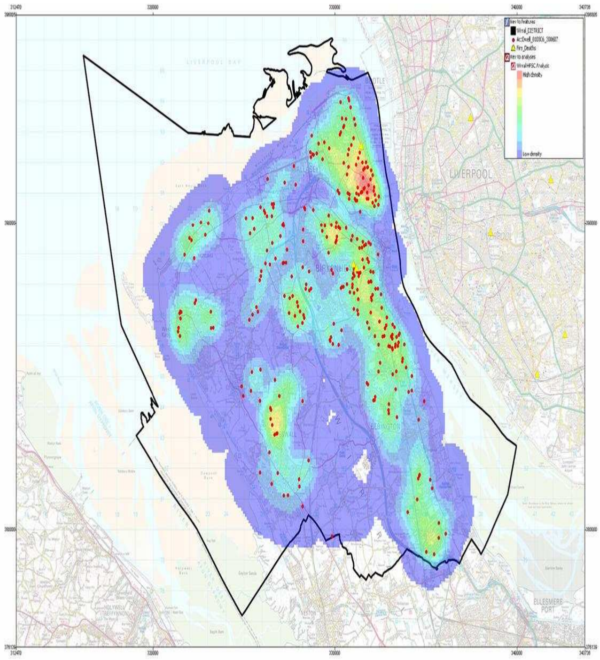

Fig 12. Map of Wirral showing a hotspot analysis of HFSCs overlaid with Accidental Dwelling Fires and Fire Deaths (01/03/06 – 30/06/07)