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INTEGRATING REMOTE SENSING WITH GIS FOR URBAN FIRE RISK MODELLING: A MULTI-AGENT SYSTEM FOR DYNAMIC RESOURCE REDISTRIBUTION

***©Sunil BHASKARAN, *Bruce FORSTER, **Nandan PARAMESH, ***Trevor NEAL**

*School of surveying and spatial information systems, ** School of Computer Science and Engineering.
University of New South Wales, Sydney, 2052, NSW, Australia
*** Corporate Strategy Division, New South Wales Fire Brigades,
Sydney, 2000, NSW, Australia.

*©Tel: +61(2) 9385 4190/4182. Fax: +61(2) 9313 7493.
Email <z2240167@student.unsw.edu.au>

Abstract

Limited dynamic resources (fire fighting staff and fire equipment) have to be allocated on the basis of spatio-temporal factors, which may influence fire hazard and vulnerability (risk) in urban environments. On the one hand there is a need to develop a model that inputs spatio-temporal variables and enables spatial analysis of such variables for the assessment of composite fire hazard and vulnerability in a given place. On the other hand a major issue is to use such a model to develop algorithms, which will assist in the redistribution of available dynamic resources in order to accommodate increasing hazard levels (Bhaskaran et al, 2001). Such a model will not only enable the comparison of existing hazards, but may also provide a basis for the allocation of dynamic resources. This paper examines the active use of such a risk assessment model for deriving a more balanced distribution of dynamic resources employing a multiagent problem-solving model. By using mutli-sensor remote sensing data and integrating such datasets with the available cartographic data in a GIS environment, a methodology to develop a risk assessment model is demonstrated in near real time. By a system of assigning influences and biases the risk model may be modified to suit any geographical region. In this dynamic situation, agents in the proposed multiagent system respond to changes in the world by redistributing the resources after engaging in mutual negotiation. It is hoped that this model will lead to a more balanced utilization of resources thus minimizing the overall global risk in the world.

Key words: Dynamic Resources, Redistribution, Artificial Intelligence, Multi-Agent System.

1 Introduction

Urban fire hazards are influenced by an entirely different set of spatio-temporal factors, which are unique to other types of fire hazards such as bush fires, forest fires. The occurrence of fire or related hazards may cause different impacts in different areas due to the spatio-temporal variations of urban features. Furthermore, these urban features may undergo phenological changes, which must be recorded in near real time in order to provide up-to-date information and decision support tools for managing emergency operations. This information may be analysed with other available cartographic data on a GIS system for the assessment of risk in an urban environment (Bhaskaran, S). An understanding of fire hazard must encompass the threat posed by the physical structure, the geographical setting of the region, the community in the vicinity at risk (Bhaskaran et al, 2000). Such a model was developed for the city of Bathurst, NSW, Australia and applied to the central business district of Hornsby Shire in NSW, Australia. The methodology involved the integration of high spatial airborne remote sensor data in the form of ortho-rectified aerial photo images with cartographic GIS data to create semantic hazard and vulnerability model.

2 Objective

The main purpose of the present study is to propose a multi-agent system (MAS) for the redistribution of existing dynamic resources such as fire fighting staff and equipments within and between designated areas. The system will draw knowledge from the fire risk model to perform a resource redistribution algorithm, which will deal with resources at two major levels, *local* and *global*, which are discussed in this paper.

3.Study Area/s: Bathurst and Hornsby Shire

The study areas were chosen for their contrasting landscapes and spatial pattern of urban features, which determine the spatial pattern of hazard. Bathurst is a fast developing city approximately 210 kms to the west of Sydney, Australia. Hornsby Shire is a suburb more to the north of Sydney and has high population density and structural density when compared to Bathurst, which has a population of 30,000 people.

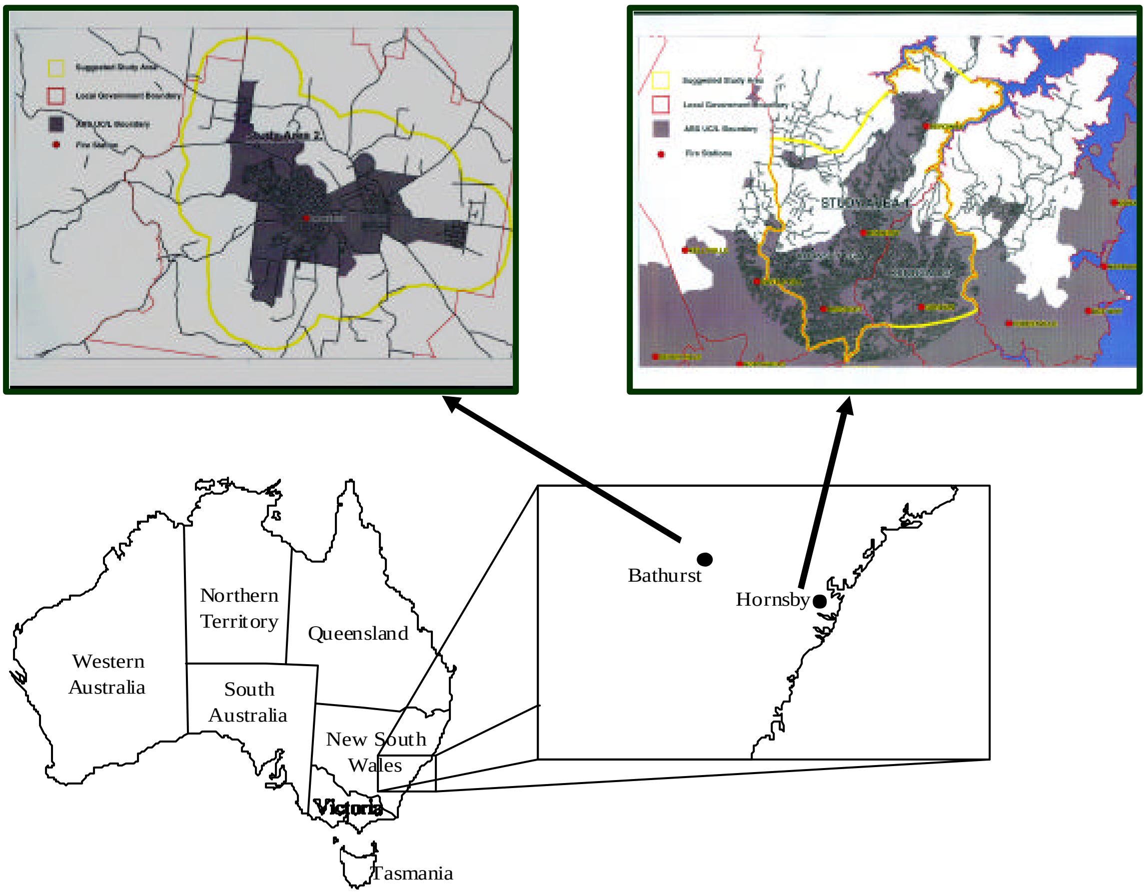


Fig 1 Study Areas of Bathurst and CBD Hornsby Shire, NSW.

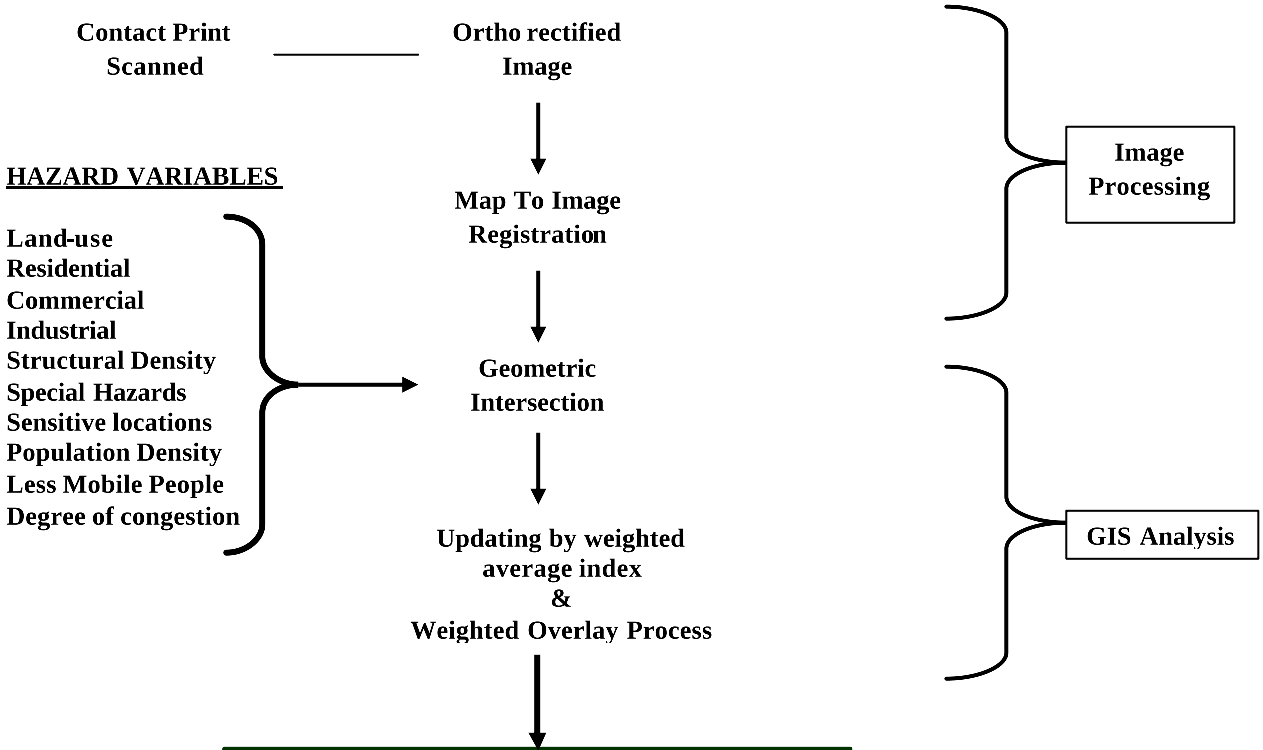
4. Methodology

The methodology uses a semantic fire risk model, which is developed by integrating fire hazard, and vulnerability related variables and high resolution airborne images (Fig 2). This model will be used for designing a multi-agent system (MAS) (Jennings, Adibi, 1999 Goyal, 2001) where a society of agents collectively negotiate to achieve the distribution of resources so that the over all risk is kept minimal. The given world is divided into a set of subregions where one agent A_i is assigned to monitor the resource requirements of the region R_i

Each agent A_i operates at two levels - the local level and the global level. At the local level, if any changes take place, the agent using a set of rules attempts to reassess the adequacy of the resources at hand. If additional resources are required it negotiates with the other agents and attempts to acquire new resources. However, if this agent receives requests from other agents for more some resources, then this agent negotiates with the other agents, assesses the global severity and decides to part with its resources or otherwise in order keep the global risk minimal level. In order to achieve this, each agent will use sets of rules in order to judge the severity of hazard levels amongst the agents. Once the severity levels are established, the flow of resources will be determined by the agent, which requires additional resources in the present time (Fig 3). Multi-agent interaction in the form of exchange of dynamic resources will be the dominant trend at the global level whereas at the local level agents (fire stations) will attempt to resolve the problems of dynamic resources in a self-sustaining manner. In essence the interaction between agents at these two levels will enable a proper and logical distribution of dynamic resources and answer equity issues.

4.1 Structure of Multi-Agent System: The proposed Multi-Agent system will consist of a) Fire risk model which has been developed by integrating high spatial resolution airborne remote sensor data and cartographic GIS data, and b) a network of multiagent system.

4.1.1 Fire risk model: This semantic model was developed over the city of Bathurst and applied over the central business district of Hornsby Shire in NSW, Australia. Available cartographic data such as land use, cadastral information, special hazard locations and attributes derived from the remote sensor data were combined and integrated to develop this model. A weighted overlay approach was adopted to assess the composite risk for individual spatial units measuring 250 by 250m. By a process of geometric intersection, new derived knowledge based layers were generated for each spatial units measuring 250 by 250m. (Bhaskaran et al, 2000). By assigning weights and biases this model can suit any geographical region. Further more, this model can input raster data from multiple resolution remote sensor data. (Fig 2) illustrates the methodology and model over the central business district of Hornsby Shire.



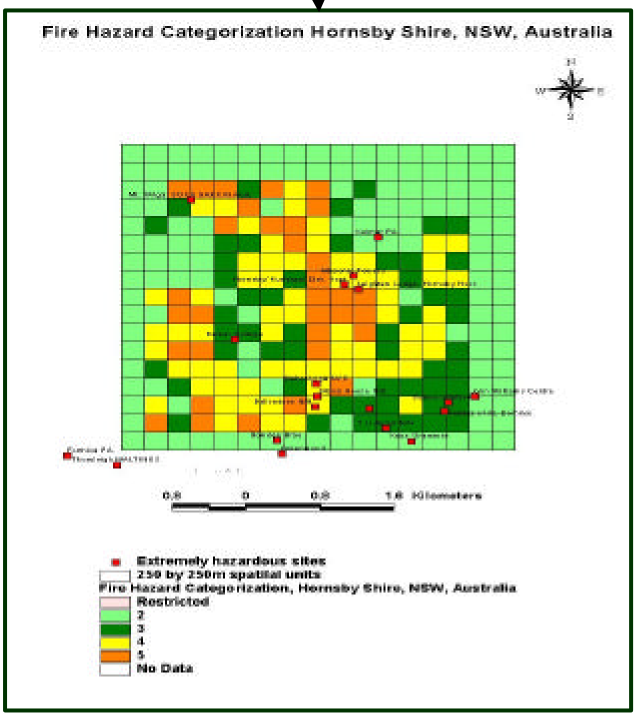


Fig 2. Methodology to develop Semantic Risk Model

4.1.2 Resource allocation using MAS: The risk model described earlier in this paper is used to aid in decision making, which involves the strategic allocation and redistribution of dynamic resources. The model approaches the concept of hazard holistically and therefore will assist in resolving fire resource management, protection and other related equity issues. The proposed MAS will draw its knowledge from this risk model. For instance, severity levels between different agents in varying landscapes may be calculated using this fire risk model.

4.1.3 Multi-Agent Network: Six agents are designed in a network for purposes of simulating the proposed Multi-Agent resource redistribution system (see Fig 3). Each agent is designated a geographical region over which it has the authority to provide fire protection. These agents operate at two levels the local level for which they are solely responsible and the global level where the dynamic resources will be supplied and secured from other agents.

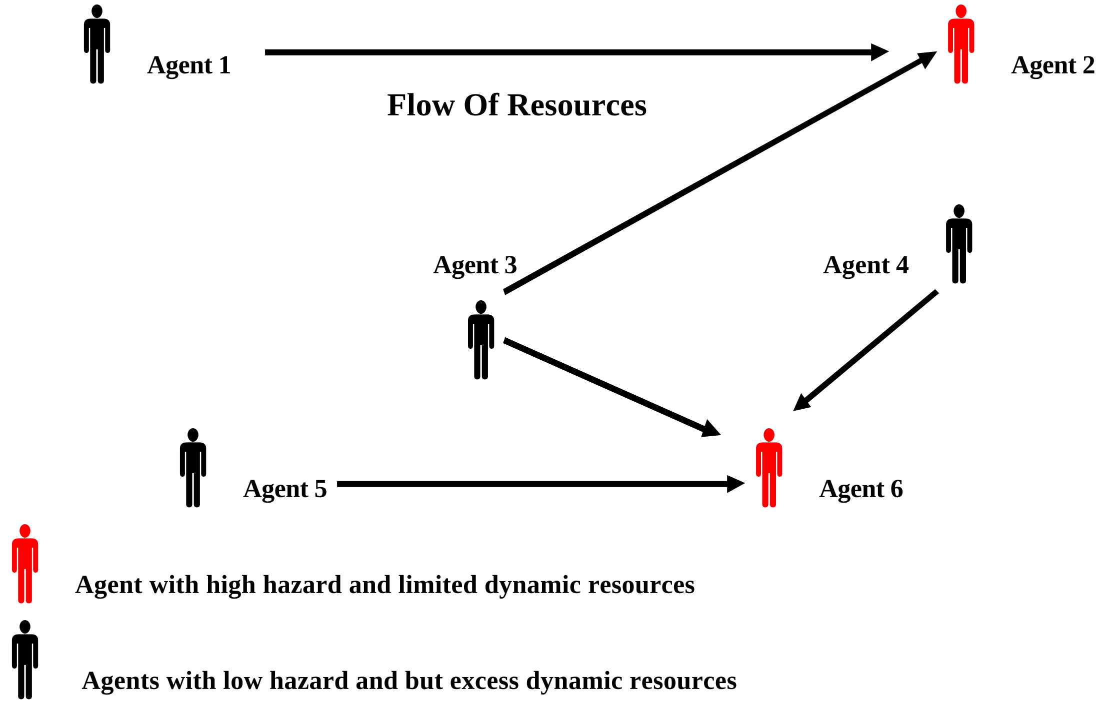


Fig 3 Simplified illustration of Multi Agent Network and proposed interaction & resource distribution

4.1.4 Set of Rules: If the population density {=dmax} + residential structures {=Rmax} + multi-storeyed structures {=Msmax}
Then allocate 2 Fire Engines (FE)
If multi-storeyed structures {=Msmax} + Height above mean sea level = 1000mts +Population density {=dmax} + less mobile people {= lmmax}
Then allocate 3 Fire Engines

5. Methodology: We now briefly describe the agent behaviours whenever the world undergoes a change. d
Assume: User inputs all changes that are taking place in the local region.
<u>Repeat the following steps forever:</u>
1. Read messages from other agents
2. Update world model taking the user input and the messages into account
3. Compute local severity
4. Compute global severity
5. If local severity > Global severity then send request to other agents;
6. Else /* NOTE: GLOBAL SEVERITY>LOCAL SEVERITY /*
7. Inform_others ("ready to share resources")'
8. Share resources through negotiation;

6. Negotiation Techniques: Negotiation is a process by which a joint decision is reached by two or more agents, each trying to reach an individual goal or objective. The agents first communicate their positions, which might conflict, and then try to move towards agreement by making concessions or searching for alternatives. (Wiess, G 1999). In the proposed model the fire risk model will form the main protocol for negotiation. The agent`s severity level calculated by the risk model will determine the existing degree of hazard giving rise to negotiations between them. Once the process of negotiation is started then each agent evaluates and compares their respective degree of severity, which will indicate the prevailing risk in their geographical region. Messages from one agent would be passed to another and the agent with a relatively acute risk will receive resources from other agents. However, the distribution mechanism will be balanced in such a manner that the agent who parts away with resources does not in the process endanger its own safety. All along it is assumed that no agent should have an incentive to deviate from the agreed-upon strategies.

7. Architecture of MAS and its components (see Fig 4): The architecture of the proposed MAS is described in the following paragraphs

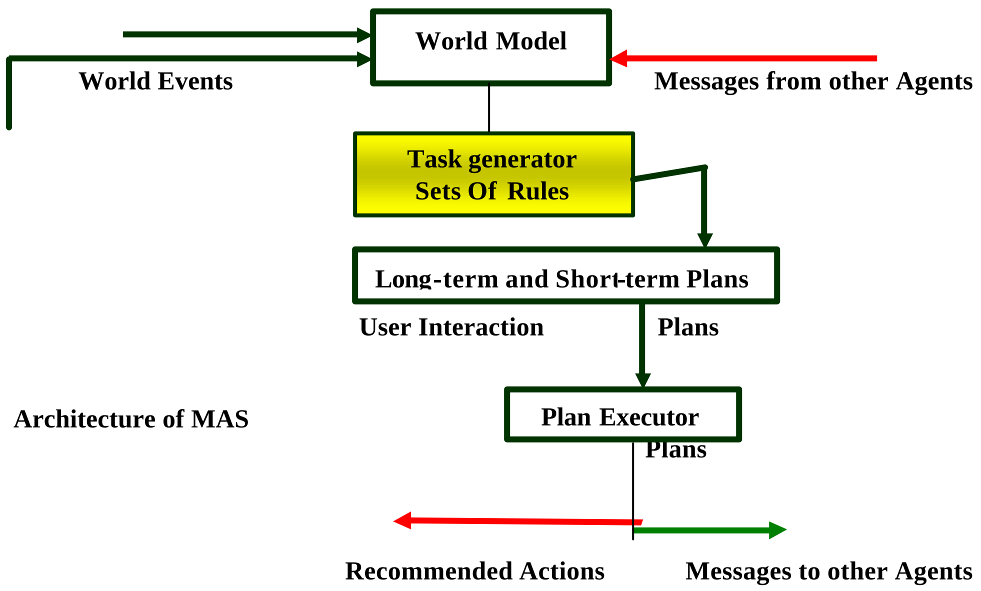


Fig 4. Architecture of MAS

7.1 The World Model: Each agent has its own world model. The world model consists of symbolic description about the world objects and the other agents in the world. The world object denotes descriptions about available resources such as fire equipments and human resource and a model of urban fire risk. The risk model has been developed by integrating high spatial resolution airborne remote sensor data and cartographic data, which influence hazard risk in an urban environment. The description about other agents includes the address of the location of these agents. As the spatio-temporal changes occur such as created by urban development indicated by new man-made structures the agent updates its world model. Thus the world model represents the current state of the prevalent risk for the respective agent who exists in a certain geographical region.

7.2 The Task Generator: This is a set of rules, which generates tasks whenever the world model undergoes a change. The task is represented by a set of goals, which are to be satisfied to achieve the tasks.

7.3 Plans are derived for the goals and stored on a time line. A long-term plan is a solution to a problem, which requires considerable amount of time and forward planning. A short-term plan is executed over a short period of time at the local level. The following relationships among the plans are possible. All plans may be associated with a time line.

7.3.1 Plans on priority basis- Before and After relation: Resources may be required by an agent immediately and sometimes after a span of time. For instance a major fire from a petrol station may demand immediate dynamic resources whereas the staging of a major event may require some additional resources after certain duration. In such cases, the corresponding plans bear the before or after relation between themselves.

7.3.2 Overlapping plans: Resources may also be required immediately as well as for a certain event which may also be staged at the same time. In such cases, plans overlap each other.

7.3.3 Equal Plans: Immediate requirements for additional resources may be coincided with the requirements for preparing for a major event or some future development. These two requirements may start and end at the same time, thus demanding plans such that they all start at the same time, and end at the same time.

7.3.4 Synchronised Plans: In this, when one plan ends, the other plan starts immediately after it.

8. Reasoning behaviour of Agents

We can decompose the reasoning behaviour into two components: local need based reasoning (LNBR) and global need based reasoning (GNBR). In the LNBR, the agent's goal is to acquire the minimum resources that will be necessary to meet any emergency situation. Thus, the reasoning behaviour will be mostly selfish in nature. In the GNBR, the agent's reasoning behaviour now is to aim at satisfying the global needs as well; thus, in this mode, the agent behaves like a social agent showing concern towards ensuring minimum resource availability for all agents across the entire society. Thus, each agent generates two types of goals: individual goals and social goals. Solving individual goals is the responsibility of the individual agent. In order to solve this goal, it reasons locally as well as negotiates with the other agents.

Social goals refer to the responsibility of the individual agent towards the society. Social goals are collectively solved. Typical rules for LNBR are described below:

If the population density {=dmax} + residential structures {=Rmax} + multi-storeyed structures {=Msmax}
Then demand 2 Fire Engines (FE).

If multi-storeyed structures {=Msmax} + Height above mean sea level = 1000mts +Population density {=dmax} + less mobile people {= lmmax}
Then demand 3 Fire Engines.

Some rules for GNBR are described below

If bushland + residential area = rbmax + elevation => 1000mts above seal level
Then allocate 2 fire engines….

If a major event has been scheduled + population density {=dmax} + traffic {= tmax} and Infrastructure {= imax}
Then demand additional resources from nearby station

9. Anticipated results, discussions and Future work

9.1 Results: The issue of allocating dynamic resources must be resolved by approaching the concept of risk holistically. Anticipated results would develop a methodology which will assess risk in near real time and create a multiagent system which may be used for redistributing dynamic resources. The risk model will provide the knowledge required to drive a multiagent system for solving problems related to fire risk protection by maximising resource distribution.

9.2 Discussions: Optimisation of dynamic resources is essential for the provision of fire protection and related emergency services. The distribution of such resources have to be determined by a composite understanding of hazard and vulnerability (risk) in an urban environment. The model we have proposed in this paper forms a basis for developing a multi-agent system, which may assist in the redistribution of dynamic resources. A multi-sensor and multi stage approach will be useful for automating and operationalising this model. This approach will assist in the automatic and semi-automatic detection of data related to risk and permits their subsequent analysis in near real time. This approach will lead to developing a database on a consistent and continuous coordinate system and may provide solutions for data sharing and redundancy issues which have influenced the application of remote sensing and GIS in recent times.

9.3 Future work: Future work will focus on developing interfaces and coding for simulating the real world resource distribution scenario. A MAS will be modelled which draws knowledge from the risk model woill be designed and tested by using a standalone programme such as Java. Severity levels would be worked out in real time and messages would be relayed back and forth from one agent to another agent with a final aim of providing maximum fire protection to areas with increasing risk. From the remote sensing approach a multi-sensor approach would be planned which will use currently available spaceborne and airborne remote sensor data in order to generate a near real time database.

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