Using modular simulation and agent based modelling to explore emergency management scenarios

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ABSTRACT

Computer simulation is a powerful technology which could be used by the emergency management sector to improve an understanding of complex scenarios. We present two emerging simulation technologies, Agent Based Modelling and Modular simulation development, and describe how they could aid with communication, collaboration and understanding of complex emergency management scenarios. Ⓡ

Introduction

Viewed across the planning, preparedness, response and recovery (PPRR) spectrum, emergency management has multiple factors including land use planning, building regulations, community development, tourism, health, the education sector, and major infrastructure management including electricity, water, roads and rail. Consequently, emergency management involves a vast range of stakeholders, each with often independent responsibilities. It is the need to consider and address this multitude and often dynamic range of responsibilities and issues that makes emergency management increasingly complex and complicated.

This paper will discuss the potential of combining two emerging computer simulation technologies for emergency management planning and preparedness. The project was funded by the National Climate Change Adaptation Research Facility (NCCARF), and our project partners were Victoria's Country Fire Authority (CFA) and Department of Sustainability and Environment (DSE). We worked with these agencies to identify that bushfire evacuation was an area of concern for the state's fire agencies and then to build a prototype simulation for exploring bushfire evacuation scenarios.

The technologies the project brought together to explore complex emergency management scenarios were modular simulation and Agent Based Modelling and Simulation. Modular simulation allows the building of complex simulations by integrating multiple models, where each model can capture a different aspect of the scenario, and be based on different stakeholder expertise and perspectives. This can involve combining existing tools and data (that were not necessarily originally designed to interact), as well as creating new models, to build a complex scenario whilst maintaining the integrity of each model or program. Agent based modelling and Simulation is a computer-based technology that allows individual 'agents' to be programmed with unique behaviours in a way that is intuitive and natural. It allows for complex group behaviour to emerge from relatively simple behaviours of individual agents. Bringing these technologies together can capture many different aspects of an emergency management scenario in one common computer simulation, while allowing for a focus on human behaviour and the modelling of individuals. Importantly, this allows users to explore an array of interactions between the multiple aspects of an emergency scenario, under non-emergency conditions.

In this paper we first outline a prototype simulation that was developed for this project, which explored bushfire evacuation scenarios. Using this example prototype we then describe the potential relevance of modular simulation and agent based modelling to EM planning and preparedness, as well as training and community engagement. We consider how visualisation and manipulation of complex emergency management scenarios, and the ability to define, examine and control individual agents, can aid collaboration and communication between different stakeholders.

Bushfire response evacuation prototype

The prototype simulation developed in this project aimed to capture the movement of people during a bushfire evacuation. It incorporates key aspects of the scenario, including fire spread, traffic flow, and the decision making of citizens surrounding when they choose to leave and which roads they might take. The simulation can be configured for different scenarios using different road maps, fire profiles, evacuation point(s), and information about the characteristics and behaviours of people such as their starting address, how long they take to respond to 'evacuation stimuli[1]', and whether they go directly to an evacuation point or take more circuitous routes.

The prototype incorporates a number of existing and purpose-designed models. As it is widely accepted in the industry and trusted by the project's partners, the fire spread model uses outputs from the Phoenix Fire Simulator[2]. The traffic model utilises an existing agent-based model developed by traffic researchers in Germany known as the Multi-Agent Transport Simulation (MATSIM) (Balmer, Rieser *et al*. 2009). Each vehicle on the road is modelled individually, and the driver plans their own route for reaching the evacuation area. Driving behaviour such as acceleration and deceleration speeds can also be unique to each vehicle. When the vehicles move on the road, they interact with other vehicles by attempting to maintain safe distances from those around them. This allows realistic traffic movement to be modelled, with bottlenecks able to appear at high traffic areas and traffic jams emerging from the dynamics of cars stopping and starting. The behaviour of people in response to the bushfire threat is an agent-based model developed specifically for this prototype. It is based on a fairly simple analysis of the academic and grey literature (Perry 1979; Sorensen 1991; Alsnih and Stopher 2004), and has fairly basic behavioural characteristics.

Modular simulation

Modular simulation supports modelling a complex scenario as a set of largely independent parts, and their interactions (Scerri, Drogoul *et al*.). This is particularly suited to various emergency management scenarios that typically involve a multitude of stakeholders, infrastructure, and environmental impacts, each of which are complex in themselves. For example, a simulation scenario may comprise a weather model, a communication network model, a transport network model, an EM sector response model, a disease spread model, etc, and the interactions between these models. Modular simulation allows for each of these parts to be defined and developed independently, subject to its own modeling requirements, data needs, and stakeholder responsibilities and expertise. It allows organisations with specialised expertise to develop, validate and understand their part of the scenario, and the way it interacts with the bigger picture, without having to delve into the details of other parts of that picture. For example, the traffic model allows drivers to be affected by aspects of the fire model, such as the current location of the fire, but the intricacies of how the fire spreads are able to be confined to the fire model. This approach readily supports the incorporation of existing models and data that have established credibility within different stakeholder groups.

The modular simulation approach also supports exploration of a multitude of scenarios by expanding on the current scenario, re-orienting the scenario, or interchanging models in the scenario. For example the fire evacuation simulation could be expanded to include a model capturing police control of traffic; it could be re-oriented to look at spread of information by including a communication network model; or it could be converted to a flood evacuation simulation by swapping the fire spread for a flood model and including the interactions between vehicles and water levels.

Agent-based modelling

Agent-based modelling is a particular modelling paradigm that is increasingly popular for examining scenarios where individual behaviours and interactions between individuals are considered important (Bonabeau 2002). While the agents in an ABM may represent any real world entity, such as animals, plants or biological cells, we focus on humans or groups of humans as the 'agents'. An agent-based model is based on particular descriptions of individual agent behaviours, including decision processes that might be considered to influence actions. This is distinct from modelling a presumed average behaviour of a group or from simplifying behaviours down to mathematical formulae. Attributing each individual agent unique behavioural characteristics allows for modelling of a heterogeneous population, which is closer to a real-world scenario than one which assumes homogeneous behaviour.

An agent-based model is then used in a computer-based simulation. A simulation uses the model along with some other input parameters and produces some form of output. Because a simulation can be configured in a multitude of ways, it allows users to explore a range of different scenarios. The outputs from any one simulation can also take a range of forms. Sometimes, system level values such as total survivors or total infrastructure damage are considered sufficient information. Other times, it is more interesting to look at agent-level values such as the time it took an agent to evacuate from a danger area or the path which the agent took. It is possible to record a history of the actions and interactions of each agent, so that later these can be analysed to identify why and how an agent reached a particular state. ABM simulations also usually have some form of visualisation, which can allow the user to understand the scenario from a unique perspective, and to observe parts of the simulation which cannot be captured as individual components because the outcomes (the simulated 'behaviour') depend upon the interactions of a number of factors.

The appeal of ABM over other modelling paradigms for exploring some of the aspects of an emergency management scenario depends on many factors that are discussed below.

1 'Evacuation stimuli' might include official and unofficial warnings and information, including comments from neighbours, responses to weather conditions etc

2 Developed as part of the Bushfire CRC by Tolhurst, Chong and Strangard

Spatially explicit

Emergency management scenarios typically have a significant geographical element to them, with the physical location of people, hazards and infrastructure playing a vital role in how a scenario unfolds. This is well supported by the agent-based modelling technique, where agents, and other objects can be made spatially explicit, and relationships or interactions between them can be dependent on their geographic location. For example, it is possible to have agents that are close to a hazard be aware of its existence directly, while other agents are dependent on warnings, or may be totally oblivious to any indication of threat.

Availability of individual data

Agent-based modelling requires information at the individual agent level and thus is not based on necessarily simplified aggregated information. This type of information might be obtained via various research methods, particularly those from the social sciences. Information from some of Australia's worst disasters can provide an initial starting point (CRC 2010). This also allows for a mapping of certain social science data into an agent-based model. The strength of using individual level data was discussed above.

Emergence

There are some phenomena present in emergency management scenarios which are simply not well understood at a high level, and it is therefore difficult to model them from that level. The phenomena of 'a traffic jam from nowhere', where a small, temporary disruption to traffic flow is magnified and eventually results in cars being brought to a standstill, is best explained through the behaviour of individual cars, with each car slightly overreacting to the braking of the car in front. Agent based modelling allows for this type of phenomena, which would otherwise be missed, to emerge from the interactions of the agents. (Cariani 1992).

Heterogeneity

The ability of Agent Based models to include heterogeneous populations has a number of benefits for emergency management planning. The assumption of homogeneous populations in other forms of modelling often fails to capture variances that are inevitably present in any scenario. Therefore, while it may be possible to identify a theoretically best or worst result, it isn't possible to capture more complex subtleties that might be expected from a model based on heterogeneous characteristics. Using agent-based modelling allows a closer representation of a population to be modelled. For example, a combination approach to a warning system which uses SMS messages, community phone trees, and visual warnings, could be modelled on a heterogeneous population, and the specific parts of the community which have characteristics which mean they are missed by the warnings could be identified and more robust policies identified.

Capturing behaviours and decision processes

There is also a clear difference in the way the behaviour of an agent can be defined in ABM, compared to other modelling paradigms, which is better suited to attempts to capture human behaviour. Agents may be described using simple rules: how they will react to another agent's actions, which actions they will perform regularly independently of others, and simple decision making about what actions to perform under which conditions. There are also more complex ways of describing agents which attempt to map some psychological understandings of human decision making, and allow the modeller to work at a higher level of abstraction using the concepts of the agents beliefs, desires and intentions (Bratman 1999). This intuitive way of modelling behaviour both makes modelling easier and the resulting model easier to understand. While still limited in its actual ability to represent the actual complexities of human behaviour, the ability of ABM to allow for programming of individual agents allows for model outputs that may be somewhat more indicative of complex human behaviour and social scenarios than potentially oversimplified mathematical models based on homogeneous model inputs.

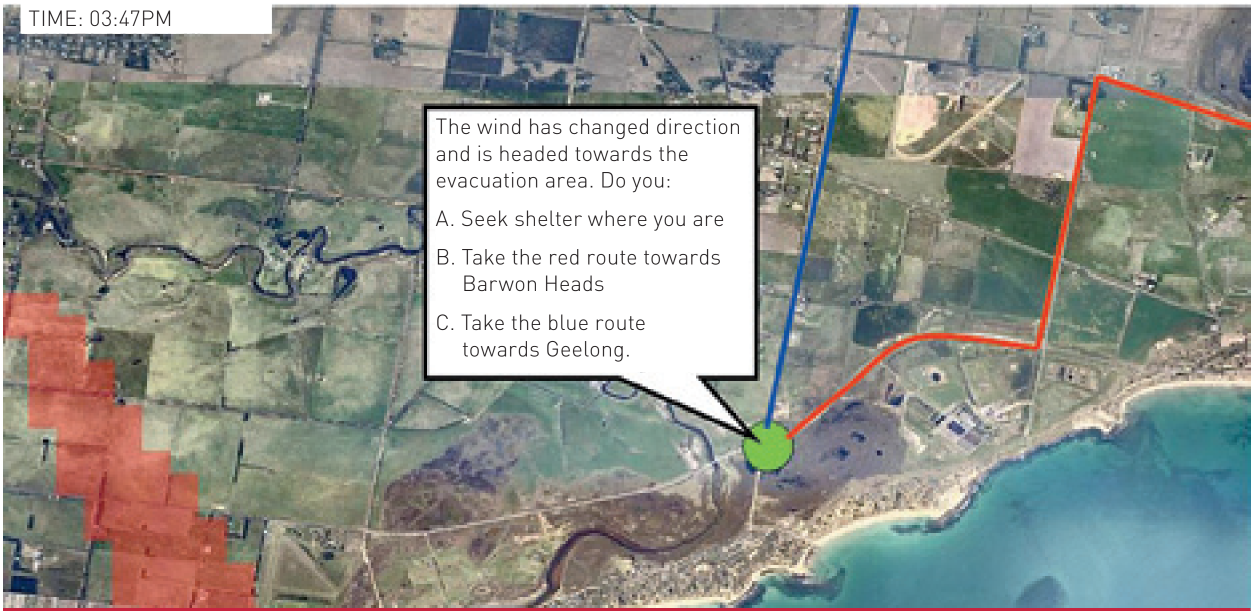
How might modular, agent-based simulation be used in emergency management planning?

We have identified three key areas where we believe modular, agent-based simulation might be useful for the emergency management community, each with a different level of control over the simulations progression. However, the flexible nature of these types of simulation mean they can be used for many other purposes beyond the examples presented here.

Community awareness

The simulation platform can be a powerful tool for sharing information with the community and raising community awareness of specific issues. A key advantage of having an agent based model that includes some basic human behavioural factors, is that people can relate better to individual behaviour in the simulation, particularly when it is localised to their community or even them specifically. For example, in the current prototype it is possible to visually follow the movement of a single agent, giving the participant sense of being immersed in the scenario. This visual engagement can be a very powerful way of communicating information, particularly across language or cultural borders. By developing scenarios for specific communities people can understand the specific issues in their area, and explore the advantages and disadvantages of their planned response to a threat.

In these types of simulations, it is possible to strictly control the progression of the simulation so that specific messages can be portrayed. For example, users who select risky responses to a threat can be



Screenshot of a community awareness tool, where the user has to choose between two alternative routes to safety.

shown how these can result in negative outcomes, rather than occasionally being successful which could result in a false understanding of the associated risks.

Training

Interactive simulations, or 'serious games', can be used for the training of emergency management staff. An interactive simulation could also allow the user to perform the same actions as they would be expected to perform during an actual emergency event. For example the evacuation prototype could be used by incident controllers to explore the possible timing of evacuations. Simulations can be developed to allow users access only to the information they would likely have access to in a real scenario, or alternatively can allow the user access to different perspectives to allow them to better understand the effects of their actions.

It is possible in these interactive simulations to maintain a balance between directing the simulation towards a goal, so that the purpose of the training is achieved, and allowing the user to feel in control and that they are having an actual affect on the simulation's progression. The exact progression of the simulation will vary based on the actions of the users, but specific desired effects may always be present. This allows simulations to be set up to train users about specific hazards or common mistakes while allowing them to practice as realistically as possible in non-emergency conditions.

Research

Using the simulation platform, with the input of stakeholders from different emergency management agencies, communities and organisations can support the generation of new insights or understandings for research. Some examples include exploring different warning delivery methods and their effectiveness; exploring different evacuation plans in under different circumstances; exploring potential congestion locations even under best-case scenarios.

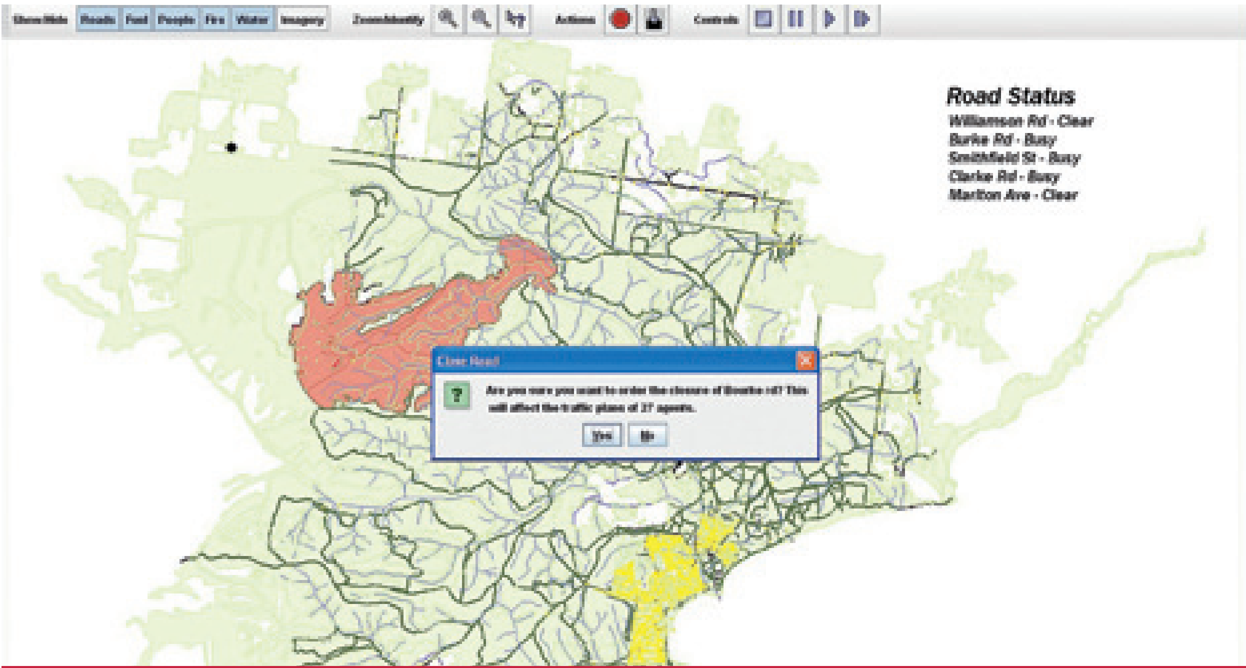
Different simulations could explore scenarios in the same town using differing weather conditions, householder and tourist reaction times and movements, emergency service vehicle movements and a range of evacuation points. In this way, an exploration of the sensitivity of an outcome to the variables examined can be made, including some consideration of the influence of various planning and response activities on those outcomes and can support policy makers in identifying robust[3] management options.

In simulations for the purpose of research, there is less control needed over the progression of the simulation, and instead outcomes are allowed to emerge. This allows new phenomena and insights to be generated without the modellers having to explicitly model them, and often results in more exploratory, thought-provoking type simulations rather than strictly predictive ones.

Conclusion

Agent-based modelling and modular simulation development are two technologies that could be used by the emergency management sector to improve an understanding of complex scenarios. It allows groups with separate expertise to model specific parts of a scenario using tools and data that they consider suitable and that are available. Complex simulations can be built from these parts which are still easy to understand and change. Utilising an agent-based

3 Here robust is taken to mean a management or policy option that has positive outcomes under a broad range of conditions



Screenshot of a possible training simulator, with the user able to make decisions about which roads to close, but also have access to extra information such as how many people a closure will affect.

approach to model parts of the simulation that involve people can allow for a more natural and intuitive inclusion of human behaviour, albeit simplified in the simulation, and can allow for outputs to emerge from interactions between agents.

We believe that computer simulation can play a vital role in Emergency Management planning and preparedness, and that these two technologies can allow more complex simulations to be developed, understood and used.

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