

# SEEKER: A Web-Based Simulation Tool for Planning Community Evacuations

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## ABSTRACT

Bushfires cause widespread devastation in Australia, one of the most fire-prone countries on earth. Bushfire seasons are also becoming longer and outbreaks of severe bushfires are occurring more often. This creates the problem of having more people at risk in very diverse areas resulting in more difficult mass evacuations over time. The Barwon Otway region in Victoria's Surf Coast Shire is one such area with evacuation challenges due to its limited routes in and out of coastal areas and its massive population surges during the tourist season and holiday periods. The increasing gravity of the bushfire threat to the region has brought about the Great Ocean Road Decision Support System (GOR-DSS) project, and the subsequent development of a disaster evacuation tool to support emergency management organisations assess evacuation and risk mitigation options. This paper describes the design and development of SEEKER (Simulations of Emergency Evacuations for Knowledge, Education and Response). The SEEKER tool adds another level of intelligence to the evacuation response by incorporating agent-based modelling and allows emergency management agencies to design and run evacuation scenarios and analyse the risk posed by the fire to the population and road network. Furthermore, SEEKER can be used to develop multiple evacuation scenarios to investigate and compare the effectiveness of each emergency evacuation plan. This paper also discusses the application of SEEKER in a case study, community engagement, and training.

## Keywords

evacuation modelling, emergency management, decision support systems, agent-based simulation

## INTRODUCTION

Bushfires cause widespread devastation in Australia, one of the most fire-prone countries on earth. The 2009 Black Saturday bushfires in Victoria burnt 430,000 hectares of land and resulted in the death of 173 people. Deloitte estimates the tangible costs of the Black Saturday fires to be AUD3.1 billion in 2015 dollars and the intangible costs at around AUD3.9 billion resulting in a total cost of AUD7 billion (Read and Denniss, 2020). The 2019-2020 Australian Black Summer bushfires, designated as a megafire, burned an estimated 18.4 million

hectares, destroyed 9300 buildings and homes, and killed 34 people. During the ensuing firefighting operations, an air tanker, two helicopters and two fire trucks were involved in fatal incidents resulting in the death of three crew members and three firefighters. These fires, which burnt 25 times the corresponding area in the Black Saturday fires, is estimated to cost up to AUD88 billion making it Australia's costliest disaster. (Wikipedia, 2022).

Unfortunately, the bushfire risk for communities is increasing due to growing populations in high-risk, wildfire-urban interface (WUI) areas and a trend to higher daytime temperatures coupled with lower humidity and higher evaporation rates. Bushfire seasons are becoming longer, and outbreaks of severe bushfires are occurring more often (WFI, 2022). Studies have shown that natural disasters, in general, have been increasing in frequency and intensity over the past few years (Hooke, 2000; Newkirk, 2001). In addition, the increasing concentration of population in urban areas is exceeding the capacity of transport networks to move these people during times of disasters (Plowman, 2001; Barrett et al., 2000). The dynamic requirements of mass evacuation have caused research on evacuation and emergency management to receive more attention in recent years resulting in numerous evacuation models being developed (Xiongfei et al., 2010).

The Barwon Otway region in Victoria's Surf Coast Shire is one such area with evacuation challenges due to its limited routes in and out of coastal areas and its massive population surges during the tourist season and holiday periods. The increasing gravity of the bushfire threat to the region has brought about the Great Ocean Road Decision Support System (GOR-DSS) project to develop a disaster evacuation tool to support emergency management organisations assess evacuation and risk mitigation options. The delivery of this capability is expected to inform future policy and strategies on preparation and risk mitigation activities for emergencies in the entire state (Fairnie, 2017). This paper describes the design and development of the project's bushfire evacuation support tool SEEKER which stands for **S**imulations of **E**mergency **E**vacuations for **K**nowledge, **E**ducation and **R**esponse. This paper will also present and discuss results from the application of SEEKER in a case study, community events, and training.

## SEEKER STRUCTURE AND COMPONENTS

SEEKER is a decision support system or DSS designed to help key people in emergency management to make safer and more informed decisions regarding evacuations. The ability to model different scenarios will assist emergency management organisations to develop robust community evacuation plans and evaluate risk mitigation options. The DSS is expected to allow trained emergency management to:

- Carry out a preliminary analysis of the potential impact of a predicted wildfire on a road network
- Design an evacuation scenario to be simulated
- Run an evacuation simulation; and
- Visualize the outcome of the simulated evacuation and produce summary results.

## Transport and Behavioural Components

SEEKER uses an open-source transport simulation software called MATSim (Multi-Agent Transport Simulation) to simulate the evacuating traffic (Singh et al., 2019). In addition, a behavioural model called BDI (Belief-Desire-Intention) is used in conjunction with MATSim to provide the agents with a certain degree of "intelligence" intended to capture, in an idealised way, the complexity of human behaviour in an emergency situation and more specifically under the threat of a hazard. To implement this integration, each agent is split between two systems - the cognitive part in the BDI system, and a physical part in the agent-based modelling (ABM) system, as shown in Figure 1. The BDI component provides the "brain" where all decision making is performed while the ABM component provides the "body" where all actions are carried out. These two systems work synchronously as a single BDI-ABM engine passing information about actions, percepts and the status of actions (Singh et al., 2016).

The behavioural model for the individuals in the evacuating population is shown in Figure 2 and described in Singh et al. (2021). To represent and code these behaviours, we use the Belief-Desire-Intention (BDI) model of rational decision-making, underpinned in folk psychology, and for which several mature software implementations exist today (Bordini et al., 2020). A BDI agent is described by (a) its beliefs about its world, factual or assumed; (b) desires or goals, possibly even conflicting with one another, that it may care to achieve, and; (c) intentions, that are goals that it has committed to achieving using some plan of action.

Programmatically, for every conceivable goal (ovals in Figure 2), such as the high-level goal Response against bushfire threat, that an agent is designed to achieve, we supply one or more plan options (boxes), such as plan FullResponse. In this way, we say that a plan is *relevant* for achieving a goal by design, where each plan is a

recipe, or steps to achieve the goal prescribed by the programmer based on domain knowledge. For instance, the FullResponse plan of the agent consists of the step InitialResp(onse) followed by the step FinalResp(onse). The acute reader will note that these steps are in fact goals! Each with its own plan options, structured in a hierarchical fashion (a goal-plan tree).

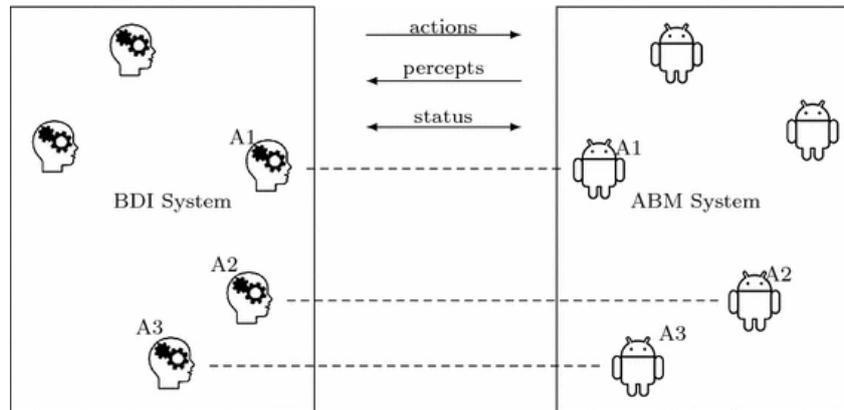


Figure 1. Conceptual BDI-ABM integration architecture

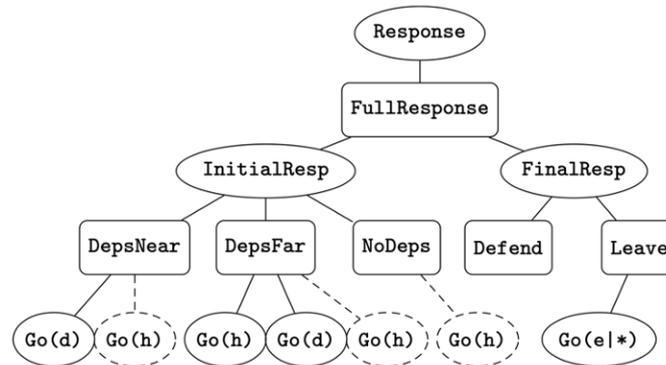


Figure 2. Sample goal-plan tree for evacuation response

To complete a plan, an agent must perform each step. In contrast, to achieve a goal, the agent need only select and complete one plan from the available plan options. Which of several relevant plans actually gets used by the agent to achieve the goal will depend on the run-time context at the moment of deliberation. Technically, relevant plans that can also be used in the moment are called *applicable*. For instance, to achieve its initial response (InitialResp), for an agent with dependents at a location (d) closer than its home (h) at the time of deliberation, the plan DepsNear (that requires going to that location (Go(d)) followed by possibly (dotted oval) going home (Go(h)) will apply, over plans DepsFar, that applies when home is closer than the dependent’s location, and NoDeps, that applies if the agent has no dependents to attend to at all.

The goal-plan tree of Figure 2 offers a compact visual representation of behaviour that is relatively intuitive and easy for domain experts to follow and critique, but can also be directly translated to software code, and can serve as a common language between domain experts and programmers, minimising risk in translation of behaviours from knowledge to code. The goal-plan tree captures the deliberation process of an agent and therefore, the eventual observed actions of agents (performed as steps in leaf-level plans) over time can be *explained* by tracing them back to the thought process and the context in which those decisions were made.

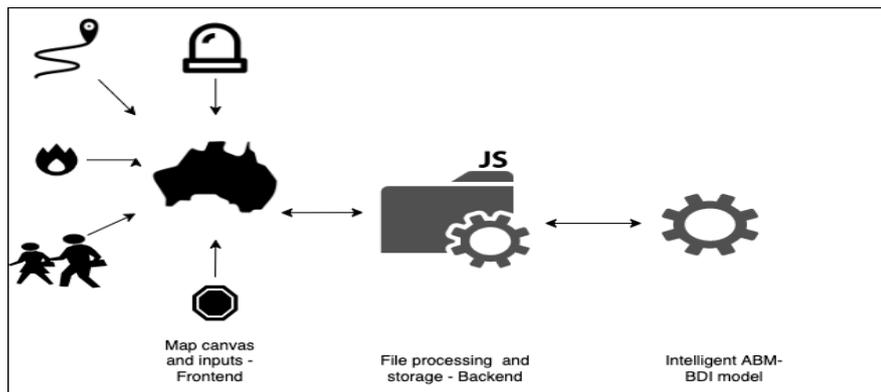
Finally, the goal-plan tree while compact, captures a richness of variability in behaviour, depending on what path the agent takes down the tree toward eventual action. For instance, an agent at work who has no dependents (beliefs) may decide to wait-and-see (path Response::FullResponse > InitialResp::NoDeps) or go home (Response::FullResponse > InitialResp::NoDeps > Go(h)::driveTo(h)), then eventually (based on other triggers, such as perception of the fire or reception of official emergency warnings) decide to leave to the evacuation place (e) (Response::FullResponse > InitialResp::NoDeps > Go(h)::driveTo(h) > FinalResp::Leave > Go(e)::driveTo(e)), where driveTo() is the leaf-level observed action of the agent driving to a given location. Different reasoning pathways will apply to agents that have dependents to attend to.

One final source of variation is BDI’s failure recovery reasoning. When, for instance, an agent that is driving to

an evacuation destination encounters an unforeseen situation, such as a road overrun by fire and no longer passable, its driving plan *fails*. In this case, the agent, following new deliberation, may choose a different plan to reach the goal destination via an alternative route, or, failing that, choose a different destination altogether. Overall, then, the same compact goal-plan tree can produce very different heterogenous behaviours scattered over time.

**Input Data**

SEEKER is being developed to plan for evacuations resulting from a host of natural and man-made hazards, including bushfires, flooding, cyclones, storm surges, and terrorist events. The front-end of the SEEKER software has the ability to load, store and manipulate the inputs required to run a simulation. As illustrated in Figure 3, SEEKER assembles the inputs to produce all the information needed to define an evacuation scenario, then calls on the integrated BDI-ABM engine to run the simulation and produce outputs, which are then loaded into a map canvas for visualisation and analysis.



**Figure 3. Map canvas and inputs used by SEEKER**

SEEKER uses a map-based canvas to load and visualise the input data as vector layers. These vector layers can be in the form of Mapbox tiles or GeoJSON files. SEEKER needs the following data to define an evacuation scenario:

- Region – zoning and transport network data on the evacuation region to be simulated. Three regions are currently available (Surf Coast Shire, Mount Alexander Shire, Yarra Ranges Shire).
- Fire – spread data (location, intensity, direction) on the fire event to be simulated
- Population – description (location, demographics, activities) of the population to be evacuated
- Ignition time – time when the fire event starts
- Evacuation plan – description of messaging and time management options selected

From the selected region, SEEKER will set up the pre-defined activity zones. Fire and population files available for the selected region will then be loaded to the interface for the user to select. Evacuation messages and traffic points can also be added to the scenario set up using the client interface. The following sub-sections provide detail on the input data and output produced.

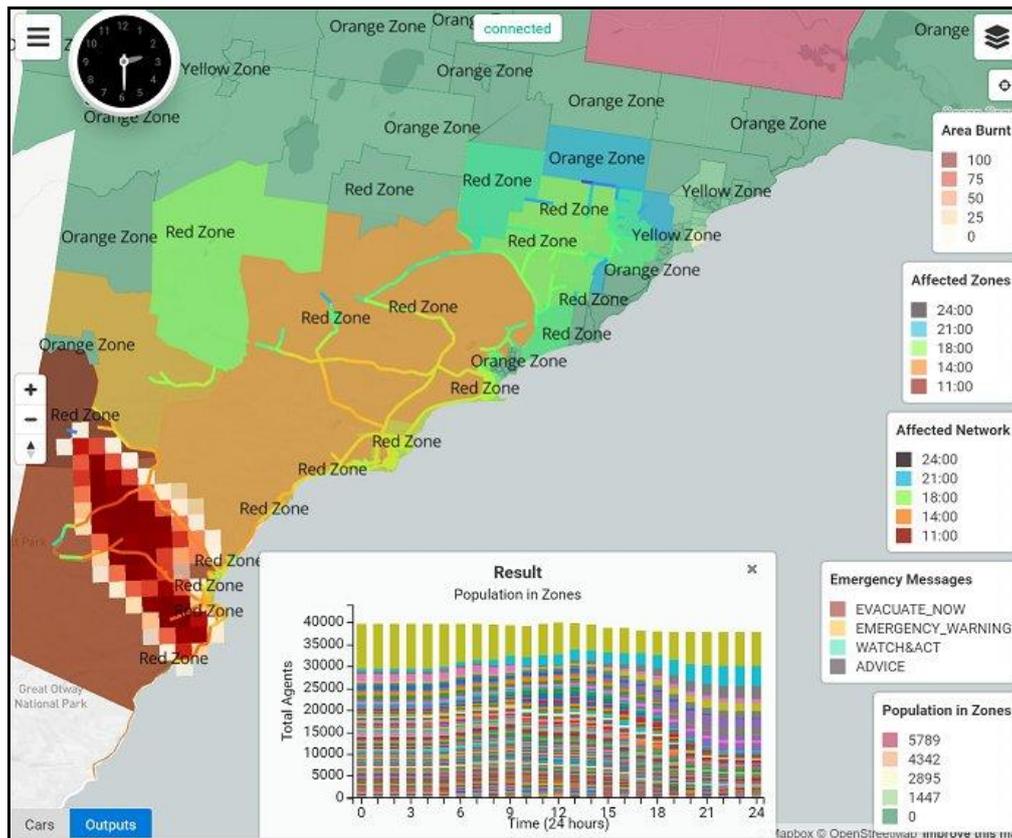


Figure 4. SEEKER window showing simulation status at 14:30

### Fire

SEEKER takes as input, simulated fire progression outputs from Phoenix RapidFire (provided as ESRI shapefiles and converted into GeoJSON format for consumption), for an ignition point in a region of interest, for chosen weather parameters, and under certain fuel load assumptions. The Phoenix fire file (GeoJSON) contains a collection of features, where each feature has a polygon-type geometry (square) defined by a set of latitude and longitude coordinates. One feature represents one fire cell. Each fire cell is 180 m<sup>2</sup> in area. Time is denoted using a 24-hour format where, for example, 13:45 or 1345 HRS is used to refer to 1:45 pm.

In the map canvas, the colour of the fire is dependent on the intensity of each fire cell. The fire will be animated based on the time each fire cell was burnt. As the fire progresses, the burnt fire cells will stay on the map canvas to demonstrate the extent of the fire. The lower left section of the map in Figure 4 shows the extent of a fire event at 14:30 after it ignited at 11:00. The colour of the pixels indicates the intensity of the fire as shown in the legend for Area Burnt.

### Road network

The road network is a graph representation of the roads, capturing the major and minor roads of interest for egress during evacuations. It is a connected graph, allowing agents in the simulation to find routes from any given location on the map to another, along the network links. Relevant road attributes like speed limits and number of lanes impact overall traffic flows, and contribute to estimates of traffic congestion in the network during mobility simulation performed using MATSim. The road network used by the SEEKER software is automatically extracted from Open Street Map, and adjusted based on local expert knowledge using JOSM (Java Open Street Map software). In the SEEKER web interface, the road network is presented using tiles, allowing the level of detail visible at different zoom settings to be automatically adjusted, giving an uncluttered and context aware experience to the end user. Figure 4 shows the major links in the road network displayed in the colour corresponding to the time of impact of the fire as shown in the legend for Affected Network.

### *Population*

A synthesis algorithm is used to generate an example population dataset for each region (Robertson et al., 2021). This algorithm uses CENSUS, VISTA and region-specific population data to build the example population. The population is categorised into sub-groups (full time residents, overnight visitors, etc.), with locations classified based on their suitability for certain activities (home, work, beach, shop, etc.). SEEKER renders this data into the map canvas as a point layer where the points on the map will be coloured based on the activity an agent is expected to perform at a certain location and time. The layer for the population in zones is at the bottom of the map in Figure 4 so the distribution of the population among the zones is not visible from the window. However, the SEEKER window provides a bar chart of the population in zones by hour.

### *Evacuation zones and messages*

SEEKER uses spatially defined zones to send out emergency messages to the synthetic population within each zone at specified times during the simulation. Such zones could represent population densities (e.g., Statistical Area Level 1 (SA1)), or represent administrative boundaries for the emergency services. SEEKER uses the unique zone ID to determine the spatial extent to send a given messages to. Agents within that extent at the time will receive the message. This aspect can also be configured, so that only a proportion of the agents in the area will actually become aware of the messaging, to more closely resemble real-world situations.

SEEKER identifies standard evacuation messages used by authorities in Victoria. These messages can be of type: ADVICE, WATCH AND ACT, EMERGENCY WARNING and EVACUATE NOW.

A single message must contain:

- A message type
- The time of the message
- Zone identification
- Message content (for EVACUATE NOW messages, this can include recommended evacuation destinations)

A single message can be sent to multiple zones. The zone identification can be a string or a number and will be defined in the model configuration file. These emergency messages will be saved as a JSON object and will be sent to the server at the time of the model execution. The scenario in Figure 4 includes the broadcast of the message EVACUATE NOW to all zones at 12:15. The thematic map of the messaging is not visible as it is under the other layers.

### *Traffic management points*

In an event of an emergency evacuation, authorities may activate manned traffic management points at key intersections to direct traffic in certain directions and/or away from other directions. These are effectively implemented in SEEKER as time-sensitive changes to road conditions impacting speeds or flow rates on specified road links. Specified changes must contain a start time, end time and an identification number of the impacted network link. Traffic management points can be added to the map canvas and are coloured in red. The user is presented with a dialog box to enter details of each traffic management point. Similar to the emergency messages, these traffic management points will be saved as a JSON and sent to the server at the time of the model execution along with other configuration files. No traffic management options were used in the scenario in Figure 4.

### **Outputs Produced**

The SEEKER backend outputs a file which contains details of activities performed by the agents from the start to the end of the simulation. The output files contain fields that describe the actions that were taken by agents, the time when each action was taken and where it was taken. SEEKER can process this data and produce a number of informative maps that can be used to evaluate the evacuation scenario. The thematic maps shown in Figure 4 illustrate some of these metrics. Furthermore, the model will output the routes taken by each agent along with their timestamps - SEEKER uses a third-party library called "DeckGL" to animate the agents on the map.

### *Car simulation*

Currently in the model, people and vehicles are not separate, and effectively each agent represents a vehicle

containing one person or household. In future work, we aim to add this separation using a pedestrian model, so that walking to/from vehicles as well as assignment of multiple persons to vehicles can be achieved.

As the main output, SEEKER demonstrates the routes taken by an agent during the evacuation. These agents will be rendered to the map canvas using the Trips layer provided by the DeckGL library. The output Trip files contain information of the path, the timestamps and traffic conditions that each agent faced during the evacuation. The Trip layer will render each agent on the map using their initial coordinates (in Latitude and Longitude format). Agents will be coloured in green, orange or red corresponding to the traffic conditions of go, slow or stop. A timer will be used to iterate the agents on the map whereby each agent will be moved to their next coordinate when the timer moves from the initial timestamp to the next timestamp. Figure 5 shows the animation window for viewing the simulated movement of vehicles along the road network for the selected evacuation scenario. The animation can be played, paused, moved forward or backward by using the controls at the bottom of the window.

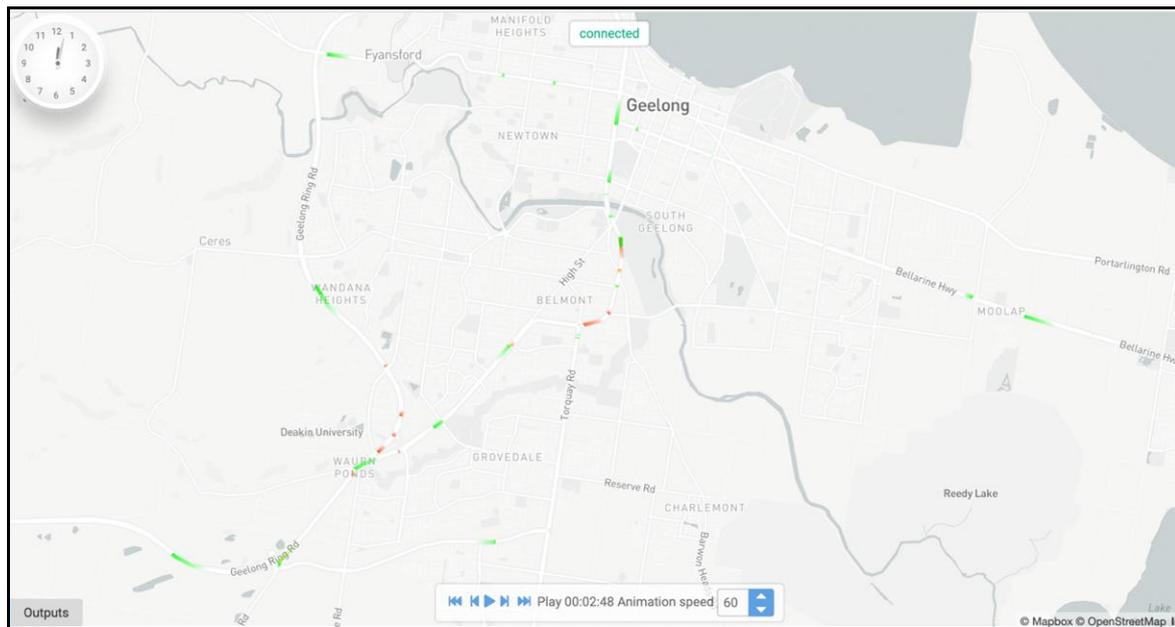


Figure 5. SEEKER car simulation example in Surf Coast Shire area

#### Affected Network

The main aim of this layer is to visualise the roads that were impacted by the fire. This is a basic intersection between Phoenix fire cells and the nodes of the road network. In addition, SEEKER provides further information about the affected network through this layer:

- The time that the road network gets overrun by the fire
- Total number of people on that road at the time of impact
- The number of people who received the emergency messages

#### Population in Zones

SEEKER software also has the ability to render geospatial data based on the user's selection of a time series. By default, the software will load the first timestamp data to the map canvas. Thereafter, the user is given control to change the time leading its respective data to change accordingly. Time will be displayed in both a digital and an analogue clock.

The population in a zone layer contains the number of people in each zone from the start of the evacuation to the end. This allows a user to investigate how the population of each zone reacts throughout the entire simulation. This data can be filtered based on aspects such as the total number of people in each zone, the number of people that were driving or the number of people engaging in other activities.

### Network Traffic

This layer visualises the same information as the population in a zone layer but using the road network links as the primary indicator. This layer can be used to observe the traffic in different parts of the road network.

Reduced speeds due to poor visibility is an important concern in evacuations. Smoke modelling however is a complex task and not often provided with the fire progression model. If it were, then the progressing smoke front could directly be used to determine road links where speed reductions should be assumed over time. We have had several conversations with emergency stakeholders on whether sensible assumptions about visibility can be derived purely from the fire front information when smoke modelling is not included. Consensus has been that too many variables impact smoke progression cannot be derived from the fire front. Therefore, determination of where visibility is reduced should be made, judiciously, by end user experts when constructing the evacuation scenario. This understanding should then be entered into SEEKER as a relative degradation to maximum speeds on all roads to account for widespread smoke effects.

### Area Burnt

This layer is similar to the input fire layer. The output area burnt by the fire is aggregated into grids of 1km<sup>2</sup> area to simplify the visualisation.

Moreover, all the outputs can be downloaded in JSON (JavaScript Object Notation) and CSV (Comma-separated values) format. These JSON files can be loaded to other available Geospatial data processing software and CSV files can be loaded to CSV viewers such as Microsoft Excel for further analysis and filtering.

## SURF COAST SHIRE CASE STUDY

The communities in the Barwon Otway Region face a huge challenge in planning and managing large scale evacuations due to the large populations involved and limited infrastructure available. The Great Ocean Road (GOR) provides the main route in and out of the region making the population particularly susceptible in the event of a bushfire. The Great Ocean Road is a 243 km stretch of highway along the south-eastern coast of Australia, connecting the Victorian towns of Torquay and Allansford on both ends. The road is important for the tourism industry, as it provides access to the most popular attractions of the Surf Coast and the Shipwreck Coast including the London Arch, Twelve Apostles, Loch Ard Gorge and the Grotto. The heaviest traffic occurs at the height of the tourist season which is also the height of the bushfire season. Much of the road runs through forest, creating risks for people who travel through the area. The Great Ocean Road is also the only main road connecting several of the highest-risk towns in Victoria such as Anglesea, Lorne, and Aireys Inlet.

### Evacuation Scenarios

The demographic, cultural and geographic characteristics of the Barwon Otway Region has made it one of the most visited areas of Australia featuring historic towns, popular festivals and events, and scenic attractions, while also remaining as one of the areas with the highest risk of bushfires in the country. In the Surf Coast Shire alone, the official population is 28,282 based on the 2016 census, but this swells to over 85,000 people during peak visitation periods. Adding to the complexity of evacuation planning, the location of people in the area varies depending on the time and day (i.e. weekend or weekday) and the bushfire threat may limit the availability of evacuation routes. The DELWP conducts fuel management activities enhanced by comprehensive traffic management plans for the area to reduce the risk of bushfires and other emergencies to road users. However, modelling by the Barwon Otway Risk Landscape Team shows that, in the Otway Fire District, the public land fuel management strategy (i.e. managed burns) can only mitigate risk by up to 40%, leaving a residual risk of 60% (DELWP, 2015). To mitigate this residual risk, it is crucial for emergency management organisations to possess the ability to model different scenarios for the Barwon Otway Region to develop robust community evacuation plans and to evaluate alternative risk mitigation options.

The scope of the GOR-DSS project provides for the application of SEEKER to explore different scenarios in order to investigate issues, such as:

- the impact on community evacuation times and options of different fire scenarios generated using third-party bushfire simulators;
- the impact of fire mitigation strategies on fire propagation and in turn community evacuations;
- the impact of infrastructure investments on improving evacuation performance; and,
- the potential impact of new developments or increases in population on evacuation preparedness.

The succeeding sections describe the results of a case study on the Barwon Otway Region where SEEKER simulation runs were completed for two evacuation scenarios described as follows:

1. S1 – A selected bushfire event is set to ignite at 11:00 on a representative summer weekday in the Barwon Otway Region. A synthetic population of 39500 people is generated for the 186 zones specified in the region. A representative road network is loaded for the Surf Coast Shire. The agents in the population are allowed to evacuate at their own discretion. There is no messaging or traffic management in place.
2. S2 – Identical to scenario S1 but with the “EVACUATE NOW” message sent to all regions at 12:15.

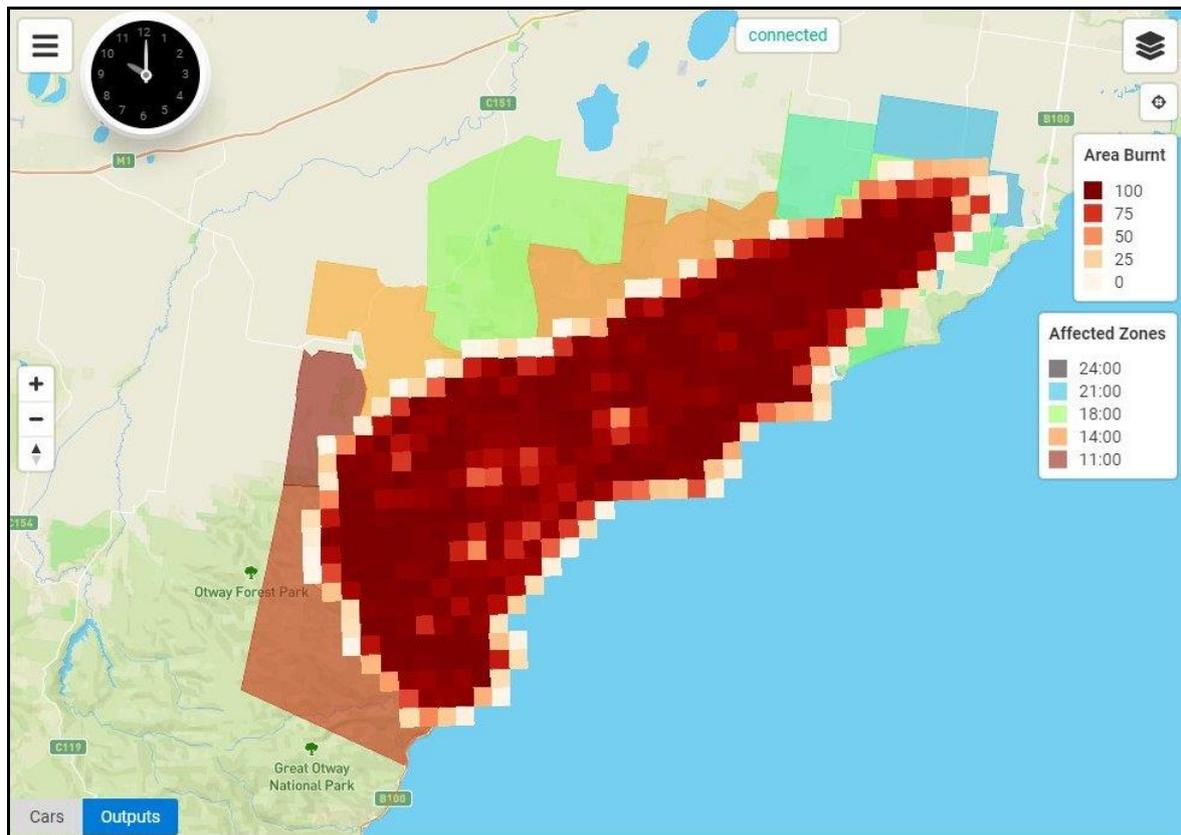


Figure 6. SEEKER window showing coverage of bushfire and time of impact on affected zones

### Fire Simulation

Figure 6 displays the SEEKER window showing the timing and extent of the bushfire event while Figure 7 shows the location of the major towns and cities along the coastline.

The simulated bushfire event is loaded using the file DSSrun2\_grid and starts at 11:00 from a point with coordinates longitude 143.881 and latitude -38.451. The bushfire burns for 12 hours and covers an area of around 366 sq. kms, as shown in Figure 6. The extent of the bushfire damage is mapped according to the percentage of the area burnt from no damage (0% burnt) to total damage (100% burnt)

Figure 6 also shows the time of impact of the bushfire on the different zones. The point of ignition is located in the zone impacted at 11:00 and the bushfire then moves south and then northeast. The town of Lorne is impacted at around 13:00 while Aireys Inlet and Anglesea are affected around 14:00. The towns of Bellbrae and Torquay are moderately affected by the bushfire at around 21:00.

### Population in Zones

Figure 7 shows a SEEKER window with a map of the simulated population in the zones at 12:00 on a representative summer weekday. The brown-shaded areas represent zones with populations of 500 or more while the green-shaded areas represent zones with populations below 250. Aireys Inlet and Anglesea are

surrounded by brown-shaded zones while Torquay and Bellbrae also have a number of high population zones close by. Note the large area of highly populated zones close to the ignition point of the bushfire. This ignition point, indicated by the burnt area on the map, is about 10 kms northwest of Lorne and less than 3 kms from the nearest brown-shaded zone.

Figure 7 also shows a map of the road network with the major links shaded according to the time when the link is cut off by the bushfire. Thus, the links close to the ignition point are mostly shaded brown (11:00) while those connecting Aireys Inlet and Anglesea are shaded close to orange (14:00). Links leading to Torquay and Bellbrae are shaded mostly in green (18:00) and blue (21:00).



Figure 7. Population in zones at 12:00 and time of bushfire impact on major road links

### Congestion in Links

The simulation of traffic movement for scenario S1 was performed for the entire day, from 00:00 to 11:00 with regular everyday traffic, and from 11:00 to 24:00 with traffic impacted by the bushfire event. Figure 8 shows the maximum volumes observed on the links of the road network for 30-minute periods occurring between 11:00 and 24:00. As the legend shows, the colour and width of the links indicate the range where the maximum number of vehicles was observed. The highest volumes occur along the Great Ocean Road which is the coastal highway connecting Torquay with Lorne. The most significant points of congestion on the Great Ocean Road occur on links near Lorne and Anglesea. This means that the Great Ocean Road remains the principal corridor of evacuation for populations in the Surf Coast Shire and that serious traffic management issues need to be addressed in order to keep traffic flowing along this corridor during a disaster event.

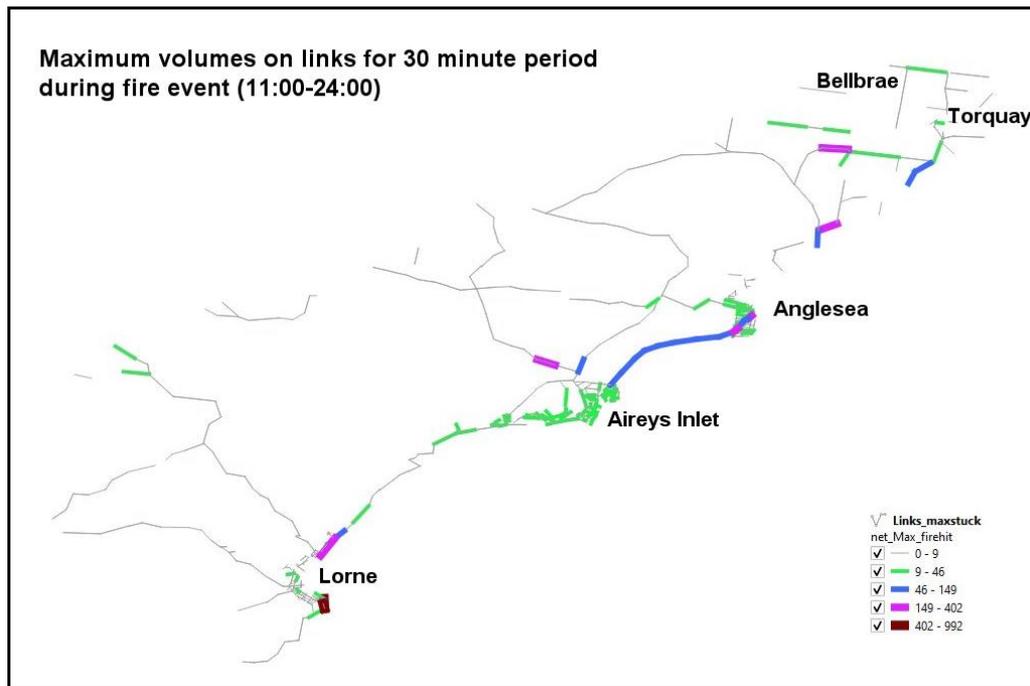


Figure 8. Potential points of congestion on the road network during the bushfire event

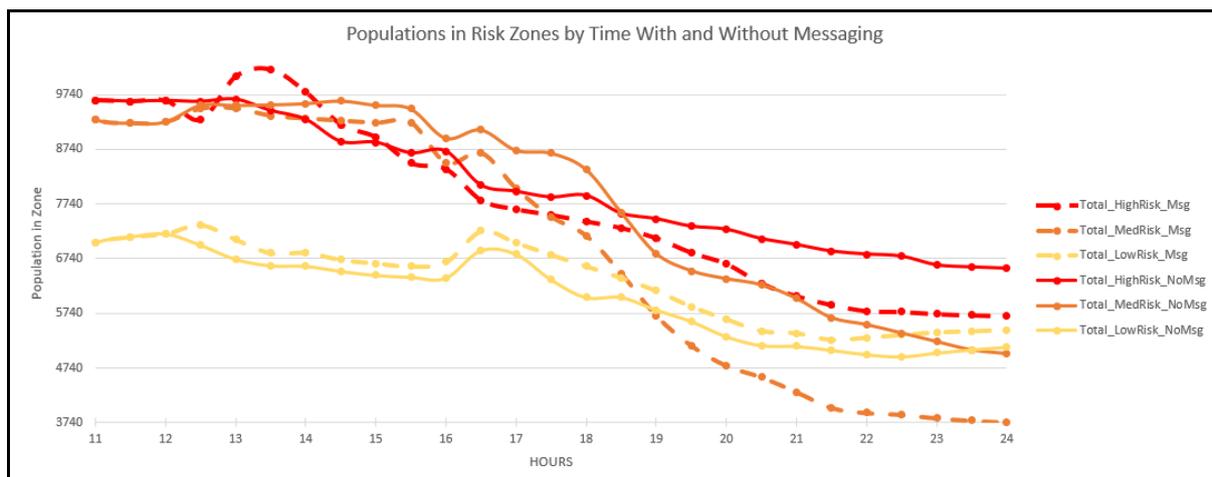


Figure 9. Total population in risk zones at each half hour during evacuation with and without messaging

### Population at Risk

The movement of the population during the bushfire event means that there is a continuous change in the size of the population at risk. The change in the population in a risk zone comes from the departures from the zone and from arrivals or transients from other zones. SEEKER tracks the population in zones at half hour intervals so the aggregate population within the three risk categories can be compared and analysed.

Figure 9 shows a chart of the total messaged and non-messaged population in each of the three risk categories at half-hour intervals from 11:00 to 24:00. For the high-risk (Red) zones, the population declined from 9639 to 5688 for the messaged group and 6559 for the non-messaged group. For the medium-risk (Orange) zones, the population went down from 9290 to 3744 for the messaged group and 4995 for the non-messaged group while for the low-risk (Yellow) zones, the population decreased from 7029 to 5437 for the messaged group and 5123 for the non-messaged group. This means that the non-messaged group had at least 16500 at some level of risk during the bushfire event while the messaged group only had 14700.

The reasons for staying within the risk zones during the bushfire event are many and varied, and can include staying to defend the property, having insufficient time to leave safely, or being unable to leave because of

transport or traffic problems. Whatever the reason for staying, there will be a significant portion of the population that will remain in the risk zones which means that emergency planning should include provisions for establishing and managing safety areas within the risk zones during a bushfire event. The results of scenario S1 shows that given an extremely large influx of visitors and transients to the Surf Coast Shire coupled with its unique geography and transport infrastructure, the complete evacuation of the population from risk zones during a bushfire event may be difficult to achieve which implies that alternative provisions for sheltering in place should be added to the emergency plan.

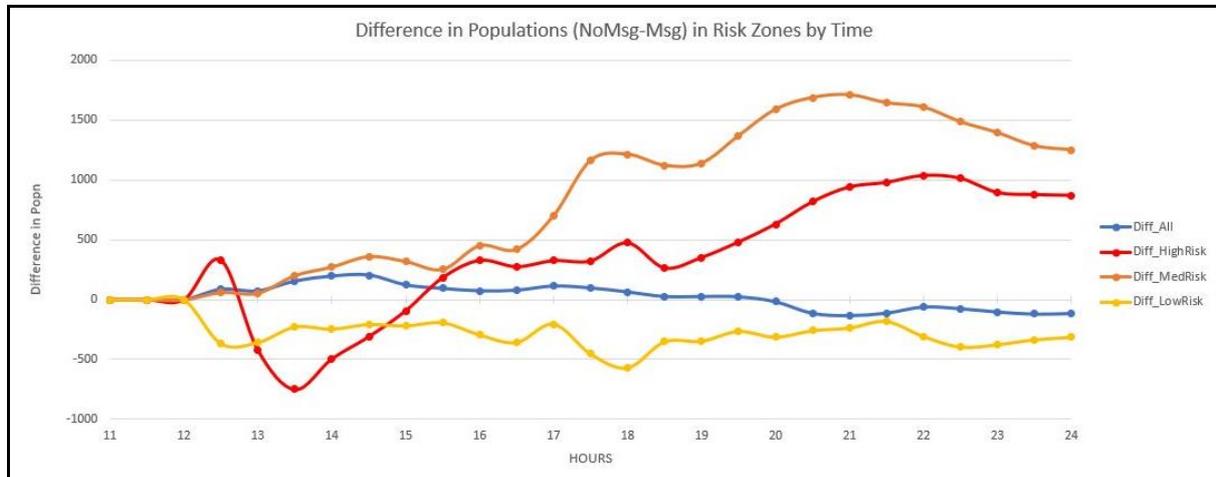


Figure 10. Differences in population in risk zones by time due to messaging

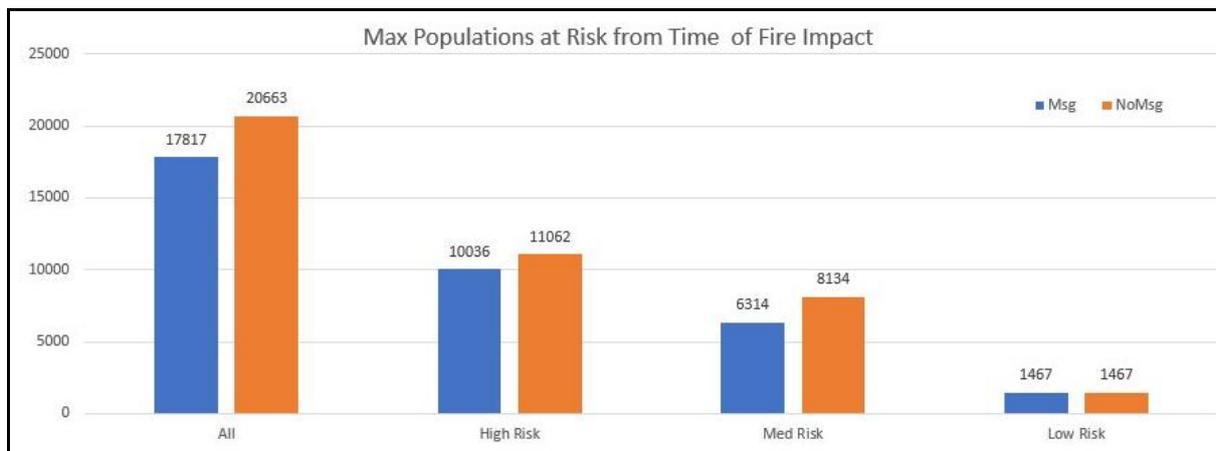


Figure 11. Comparison of total populations in risk zones after bushfire impact

**Evacuation with Messaging**

Scenario S2 is identical to scenario S1 except for the addition of messaging during the evacuation. Scenario S2 includes the sending out of the message “EVACUATE NOW” to all zones at 12:15, 75 minutes after the ignition of the bushfire. The distribution of the message can involve a number of technologies including SMS, social media, television and radio broadcast, as well as public and mobile address systems. The results from scenario S2 when compared to those from scenario S1 will show the impact of messaging on the level of population at risk during the bushfire event.

The flow of total populations within the risk zones in scenario S2 will follow similar curves for scenario S1 as shown in Figure 9. To evaluate the impact of messaging, Figure 10 charts the total difference (S1 minus S2) in population levels for each category of risk zone for each half-hour period from 11:00 to 24:00. Positive differences in the chart indicate times when no-messaging (S1) had a larger population at risk, while negative points indicate when messaging (S2) had a larger population at risk. Figure 10 shows that for the medium-risk (Orange) zones, messaging generally resulted in smaller populations at risk for the duration of the evacuation,

while the opposite was observed for the populations in the low-risk zones. For the high-risk (Red) zones, there was a noticeable spike in the difference (332) at 12:30 as immediate response to the messaging at 12:15. The difference then favours no-messaging from 13:00 to 15:00 after which messaging produced less populations at high-risk for the remainder of the evacuation. Messaging put more people in high-risk zones between 13:00 and 15:00 since people started evacuating from all zones reached by the broadcast, resulting in some transiting through high-risk areas. In the no-messaging scenario, only the people who can see the fire front, who are already in high-risk areas, started the evacuation.

Figure 11 compares populations from the two scenarios that were actually impacted by the bushfire. The bars in the chart indicate the total of the maximum population in the risk zones after the zone has been overrun by the bushfire. For the low-risk regions, the population directly impacted by the bushfire was the same for S1 and S2. For the medium-risk zones, 29% more people were impacted in S1 compared to S2 while at the high-risk zones, 10% more people were impacted in S1 as compared to S2. Overall, the messaging scenario resulted in 16% less people being directly impacted by the bushfire.

The results from scenario S2 demonstrate the potential of messaging in improving the performance of an evacuation plan and in lowering the risk faced by a population during a disaster event. Messaging can be used to provide effective warnings and information, help the affected population understand risk, increase compliance with recommended actions, and establish order within an uncertain and chaotic environment. The framing and wording of a message, the timing and the sequencing of the messages, and the selection of recipients all contribute to an effective emergency response and in the mitigation of misinformation. More scenarios will be added to the case study in order to investigate various strategies in messaging, traffic management and evacuation planning.

## COMMUNITY ENGAGEMENT, PLANNING, PREPAREDNESS AND TRAINING

SEEKER's development to date has followed an iterative improvement approach, in a process of co-production with emergency sector stakeholders. Through this process, SEEKER has been trialled for different use cases, towards improving understanding of risks to communities from bushfires, and informing planning, preparedness, community engagement, and training.<sup>1</sup> Feedback from uses has directly contributed to prioritisation of development of SEEKER features, refinement of its user interface to suit end user needs, and development of evacuation related metrics. The two regional areas where SEEKER has been trialled are Mount Alexander Shire and Surf Coast Shire in Victoria, Australia.

### Emergency Response Training in Surf Coast Shire

As mentioned earlier, the Surf Coast Shire (SCS) is renowned for the picturesque Great Ocean Road and its quaint coastal townships but is also a high bushfire danger region. During summer months, the seasonal population in the Shire can swell to several times its full-time resident population, with many visitors often unaware of the risks and unprepared, posing a unique challenge for the emergency services in ensuring community safety. An important factor, therefore, in modelling evacuation was to first build a detailed representation of the population in the area on a typical summer (week)day, capturing the different subgroups (full and part-time residents, and regular, overnight, and daily visitors), their locations at different times of the day (home, work, shop, beach, etc.), and their commutes (background traffic on the roads). Established methods of building such activity-based synthetic populations rely on travel surveys to build a representative population (Both et al., 2021), however, these are not readily applicable due to the paucity of samples in regional areas such as SCS. Novel techniques were therefore developed (Robertson, 2019; Robertson et al., 2021; Singh et al., 2022), to allow such understanding of population behaviour to be elicited from local emergency experts in the form of tubular data on aggregated distributions of activities of sub-population at different times of the day. Robertson et al. (2021) presents the approach used to automatically output detailed synthetic populations, consisting of individuals, each with their individual daily travel itinerary that collectively represented the activities and travels of the real population on such a day.

In December 2021, SEEKER was used in a multi-agency training exercise to test live emergency response decision making in a rapid-onset bushfire event in SCS (Singh et al., 2022). The typical summer weekday population for the Shire was used as the population on the day, along with a simulated fire on a severe weather

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<sup>1</sup> We note that SEEKER is the new name for the cloud-based evacuation modelling application as of 2022 and encompasses both the web-based user interface, as well as the underlying agent-based evacuation behaviour and traffic model. Previous iterations of the tool have been referred to as the Decision Support System. The underlying model is also known as Emergency Evacuation Simulator (EES) in earlier documents.

day. The Incident Management Team (IMT) responsible for evacuation decisions was briefed with SEEKER modelling results from a set of evacuation scenarios, including (a) evacuating the entire region as early as possible, (b) with or without activation of the traffic management points with manned emergency personnel directing traffic flow at key intersections, and (c) restricting evacuation to high fire risk areas only, or (d) staging the evacuation of high-risk areas over time, against (e) a base case of no response from the emergency services. In each scenario, synthetic persons self-evacuate based on their perception of the situation (sight of fire, embers), emergency messages received, and their behaviour persona as per Strahan's self-evacuation archetypes (Singh et al., 2021). While each managed evacuation scenario improved on the base case of no intervention, overall, the results showed that none of the managed evacuation scenarios were viable options in such a rapid-onset event, and that "too late to leave" messaging and related responses should be considered by the IMT. Post event debriefing on the day allowed participants to give feedback on SEEKER use in the training exercise. Overall, SEEKER was seen as a valuable tool to help with decision making. Participants also expressed a need for modelling to be re-run in real time to reflect IMT decisions, such as activation of traffic management points. As well, "ground-truthing" the typical population to match the actual population at the time, was highlighted as an important next step for SEEKER use during live events.

### Planning and Preparedness in Mount Alexander Shire

The Mount Alexander Shire Municipal Fire Management Planning Committee has supported development of the evacuation modelling capability underlying SEEKER for several years. Through 2015-16, the committee, through a working group, contributed to the development of the first web-based version of SEEKER (Singh and Padgham, 2017). The tool was used to model the evacuation of the township of Maldon during the Twilight Dinner event that is held in the peak of summer and when the population in the town increases significantly from visitors attending the event. The modelling showed significant challenges to evacuation due to risk to major roads from the progressing fire and prompted considerations of improving traffic management and egress planning for these events. Evacuation modelling was similarly used to identify evacuation risk during an annual antique fair that was held in the township of Fryerstown during summer. The simulations showed a high level of risk to visitors in the event of a bushfire, due to the very limited egress options and high volumes of vehicles expected. Evacuation risk contributed to planning changes and the final decision to relocate the fair permanently to a new safer location.

In 2022, SEEKER is being used for modelling community response and possible consequences for the Chewton Bushlands region in the Shire. Through meetings and workshops, involving community members and local emergency agency personnel, inputs will be collected around a specific bushfire scenario. Assumptions about the population, its whereabouts, and behaviour will be recorded. The scenario will then be modelled in SEEKER, and results of the "what-if" scenario presented back to the community. This project is being undertaken under the Country Fire Authority's Community Based Bushfire Management initiative helping communities to become risk aware and more resilient against bushfire threats.

### REVIEW OF LITERATURE

SEEKER is part of an emerging group of emergency management support tools whose main feature is the integration of the three important components of wildlife-urban interface (WUI) evacuation - fire spread, pedestrian behaviour, and traffic movement. Given the complexity of the issues involved in managing extreme events and the multitude of information required in the decision making, traffic simulation models have become indispensable in the analysis and planning of emergency evacuations (Barrett et al., 2000; Hardy et al., 2010). The current generation of traffic simulation models provide structure and integration to various layers of information from different sources, helping emergency management to obtain a better understanding of the disaster conditions and the effect of response strategies and control measures (Pel et al., 2012). These models enable authorities make better estimates or predictions of evacuation travel times, average speeds at different locations, traffic flow rates, congestion points and departure and arrival patterns. These models also help management to make evidence-based decisions on the latest possible time to start an evacuation, the best destination locations for each group of evacuees, the best travel routes to take and the most effective traffic management measures.

Before SEEKER, there have been four notable applications that demonstrated the coupling between bushfire and traffic models through case studies. The WUIVAC (Wildland Urban Interface Evacuation) model by Dennison et al. (2007) linked a simplified traffic modelling approach with the FLAMMAP fire model to establish trigger points around communities and transport links to initiate evacuations. The dynamic factors framework by Beloglazov et al. (2016), uses a workflow consisting of a wildfire simulator, warning generator, behaviour modeller, traffic simulator and an analytics engine to predict the outcome of wildfire evacuation scenarios, and

calculate the exposure count, a new risk metric that quantifies the threat to a population. The approach has been implemented in a Software as a Service (SaaS) called IBM Evacuation Planner and applied to three independent evacuation scenarios in the Dandenong Ranges, a wildfire-prone area of Victoria in Australia.

The third application, GEO-SAFE (Veeraswamy et al., 2020), combines two established simulation tools, urbanEXODUS (Veeraswamy et al., 2018) for pedestrian modelling based on the well-known EXODUS software, and the agent-based traffic simulation model SUMO (SUMO, 2018). The integrated software tool estimates the impact of wildfire development on pedestrian and vehicle movement by linking to data produced by various wildfire simulation tools such as PHOENIX (Tolhurst et al., 2010), Prometheus (Tymstra, et al., 2010) or Wildfire Analyst (Monedero et al., 2019).

Finally, WUI-NITY (Ronchi et al., 2020) is a modelling platform that integrates different modelling layers (fire, pedestrian and traffic) to generate dynamic projections of the evacuation situation to enable responders and residents to generate similarly integrated and dynamic vulnerability assessment. WUI-NITY is built on the Unity game engine [<https://unity.com/>] which allows the application to be developed modularly with separate sub-models for key modelling components and the required data exchange with external components such as FARSITE (Finney 1998) for wildfire modelling and PERIL for trigger buffer generation.

Compared to previous evacuation models, the SEEKER tool adds another level of intelligence to the evacuation response by combining agent-based modelling with a BDI behavioural model specifically capturing human responses to bushfire disasters, and it allows emergency management agencies to design and run evacuation scenarios and analyse the risk posed by the fire to the population and road network. Furthermore, the SEEKER workflow was designed in close collaboration with emergency services and can be used to develop multiple evacuation scenarios to investigate the relative effectiveness of each emergency evacuation plan considered by emergency coordinators.

## CONCLUSION

The increasing number of people choosing to live and work along the wildfire-urban interface, and the increasing frequency and intensity of natural disasters is making the task of evacuating mass populations during disaster events more complex. Emergency management organisations are turning to computer-based decision support tools to investigate potential disaster scenarios, develop robust evacuation plans and evaluate risk mitigation options. The GOR-DSS project has developed SEEKER as an evacuation support tool to assist communities faced with the challenge of evacuating large, diverse and highly variable populations from areas with the highest risk of bushfire using limited transport infrastructure. The application of SEEKER in a number of reality-based case studies and its engagement in live training exercises showed that it can provide valuable support to local emergency personnel.

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