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Abstract:	This document represents Deliverable 2.4 for Task 2.4 and is concerned with identifying the key requirements for evacuation modelling tools as perceived by the authorities involved in planning and real-time management of urban-scale evacuation resulting from wildfires. The document first describes the methodology (interview questionnaire and on-line survey) for collecting the data from fire authorities and disaster management organisations that have experience of managing large-scale evacuations associated with wildfires. The secondments implemented to achieve the objectives of Task 2.4 are described next which is followed by a detailed analysis of the data. Finally, a set of conclusions are presented which includes 22 key evacuation modelling requirements as perceived by end-users from 18 organisations in six countries.
Keywords:	Large scale evacuation, wildfire evacuation, end-user requirements

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V1.0	15/04/2019	Modified the abstract	Prof Ed Galea

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Common abbreviations

Abbreviation	Meaning
ER	Experienced Researcher
ESR	Early Stage Researcher
FSEG	Fire Safety Engineering Group
GEO-SAFE	Geospatial based Environment for Optimisation Systems Addressing Fire Emergencies
PM	Person Months
UoG	University of Greenwich
WG	Work Group
WP	Work Package
WUI	Wildland-Urban Interface

Executive Summary

This deliverable provides an overview of the process of identifying the key requirements for evacuation modelling tools as perceived by the authorities involved in planning and real-time management of urban-scale evacuation resulting from wildfires. The process involves identifying organisations (13 in total) involved in the management of wildfire evacuation in six countries (Australia, Ireland, Italy, Netherlands, Spain, and the UK) and then approaching key staff in those organisations (18 in total) that are involved in incident management with specially designed interview questionnaires and on-line surveys. The methodology used to prepare the interview questionnaires and surveys is described followed by a description of the interview protocols and each section of the questionnaire. This is followed by a description of the secondments that were carried out to collect the data, which forms part of Geo-Safe Task 2.4. The results are then presented with a detailed analysis of the data collected from the interviews and on-line surveys. Finally, the analysis of the interview/survey responses are distilled down into 22 key factors within 10 broad categories that identify the perceived needs and desires of the emergency management end-user community in relation to the use of urban-scale evacuation models for planning, real-time applications and community training.

1. INTRODUCTION

GEO-SAFE stands for **G**eospatial based **E**nvironment for **O**ptimisation **S**ystems **A**ddressing **F**ire **E**mergencies. Forest fires are an annual occurrence in many parts of the world causing evacuation of nearby residential and industrial facilities. In EU and Australia, every year thousands of square miles of forests and other lands burn due to wildfires. These fires affect the population and environment of the adjacent areas causing important economic and ecological losses, and often, human causalities. Both EU and Australian governments are aware of how crucial it is to improve wildfires management and containment. Scientists from different specialties, both in EU and Australia, have already developed methods and models in order to improve the management and decision process pertaining to preparedness and response phases in case of bushfire. The GEO-SAFE project, aims at creating a network enabling the two regions to exchange knowledge, ideas and experience, thus boosting the progress of wildfires knowledge and the related development of innovative methods for dealing efficiently with such fires. More precisely, the GEO-SAFE project will focus on developing the tools enabling to set up an integrated decision support system optimizing the resources during the response phase, through:

- Developing a dynamic risk cartography of a region with regard to the possibility of a wildfire. The task will involve data collection (satellite and remote sensors), risk analysis and development of a tool enabling to forecast fire extension and in particular to predict fire and risk evolution during the response phase
- Designing and testing a resource allocation tool for the response phase using the dynamic risk cartography. One of the problems to consider will be the resource allocation for securing key places (such as schools and hospitals) given time dependent constraints. Problems will be identified through connections with final users, and the proposed solutions will be tested on simulated data.
- Developing analyses of relevant management processes as well as training tools in order to facilitate the implementation of such solution to be completed

The overall aim of the GEO-SAFE project is to push forward the development of innovative tools for fire management and to develop and assess global or semi-global dynamic tools for: fire suppression, lives/goods protection and implementation and training. This will be realised through an active RISE knowledge exchange scheme that will foster a shared culture of research and innovation and will accelerate the transformation of creative ideas into innovative products, services or processes. The objective is challenging as it includes several multidisciplinary domains, involving complex problems. The most important strength of GEO-SAFE is the nature and the quality of the exchanges and interactions between researchers and domain-based experts from very different and complementary fields and cultures. The state-of-the-art has highlighted severe limitations in the actual methods that explain why these methods essentially fail to fit end-users needs and why they are marginally used in practice. These limitations will be addressed in the GEO-SAFE project through four key elements:

1. The project has partners with a high level of multi-disciplinarity and expertise ensuring that the most up-to-date methods and approaches are considered,
2. The project is divided into seven Working Groups focusing on different aspects of wildfire research,
3. The project has a mix of academics and end-users in every Working Group that ensures the relevance of proposed solutions and
4. An implementation scheme that maximises cross-knowledge and interactions and put the basis of sustainable and productive collaborations.

1.1 Objectives of D2.4

This deliverable describes the work performed in Task 2.4: Explore requirements of Large-scale evacuations resulting from wildfire. The main aim of this task is to identify end-user requirements for large-scale evacuation modelling applied to wildfires. The objectives of D2.4 are

- Review the capabilities of the current large-scale evacuation and wildfire models.
- Gain an understanding of the current methodology and tools used to manage large-scale evacuations.
- Develop a list of end-user requirements from large-scale evacuation models and prioritise these requirements.

1.2 Work Methodology

Undertake a detailed literature review of: urban-scale evacuation models, wildfire simulation tools and past wildfire events. The literature review helped identify key end-user requirements that would be beneficial to manage large-scale evacuations. A questionnaire was designed to be used during a semi-structured interview consisting of a combination of specific questions as well as open-ended questions related to end-user requirements. An online survey was also prepared to reach a wider audience. The results from the interviews and survey was analysed to prepare the end-user requirements that would guide further model developments for large scale evacuation models.

1.3 Structure of the deliverable

A description of the interview, questionnaire and survey design is first provided in this document. This is followed by a detailed description of the secondments that were implemented with a focus on the Task 2.4 activities relevant to this deliverable. The meetings and work done during secondments is explained. The results of the interviews and a list of end-user requirements is then presented in Section 4.

2. INTERVIEWING END-USERS OF EVACUATION MODELLING TOOLS

This section provides the general design that was utilised to prepare the interview questions to gather end-user requirements for large-scale evacuation models.

Interviews were conducted amongst an array of emergency authorities who are responsible for planning large-scale evacuations, such as incident commanders/controllers, civil protection authorities, and police officers. As potential end-users of the evacuation models, they need to have at their disposal a reliable simulation system adapted to their actual needs. Having such a tool would certainly become an asset when it comes to making quick decisions that affect people's life. Thus, documenting their contribution helped to identify key requirements towards the development of a system appropriately embedded to assist in decision making and operational needs.

The opinions of authorities involved in emergency management were collected through the use of an **interview questionnaire,** which was completed face-to-face, and/or **online surveys**. General objectives of both the **interview questionnaire** and the online survey were:

- Establish an understanding of how evacuation is currently managed in the face of wildfire emergency scenarios, and what tools are used to support risk-informed decision making across planning and live emergency contexts.
- Identify potential training and operational applications of evacuation modelling tools in the management of wildfire emergency scenarios.
- Document large-scale evacuation model requirements (i.e. features to be incorporated into these models) that will assist incident commanders to make informed decisions across planning and live emergency contexts.

2.1 Selection of participants

The sample of participants was rather selective and targeted disaster management authorities with past experience in large-scale evacuation resulting e from major disasters, in particular wildfires. Notably, the profile of the participant's matches with rescue authorities and evacuation managers that during and prior to disaster events are responsible for assessing, planning and advising safe and efficient evacuation practices to the population in danger. As potential users of evacuation computational tools such as ***urbanEXODUS***, they are believed to be the best persons to identify key modelling features that would assist with operational decision-making. Thus, the objective was not get as many interview participants as possible but to identify key authorities (and organisations) that may contribute to actual solutions for the research. Valuable insights expected from the participants likewise included their experiences, lessons learned, and perspectives from former emergency evacuation situations.

2.2 Design of the interview questionnaire

This section provides the general design that was utilised to prepare the interview questions to gather end-user requirements for large-scale evacuation models. The interview questionnaire is composed of three parts with each part consisting of a number of sections. Please see "This deliverable provided a detailed analysis of the end-user requirements from large-scale evacuations due to wildfires. A total of 18 staff from 13 organisations in 6 countries (Australia, Ireland, Italy, Netherlands, Spain, and the UK) involved with wildfire evacuation/management were either interviewed or participated in an online survey to provide answers to open ended and specific questions designed for the purpose of collecting end-user requirements that will enhance current large scale evacuation models.

Analysis of these interviews/surveys suggest that there are four main contextual factors that could influence the end-user requirements, namely: management policies and strategies, mode of evacuation (vehicle versus foot), and wildfire hazard context.

Management policies and strategies varies across jurisdictions at local, regional, and national levels. In some jurisdictions, evacuation warnings are mandatory whereas in others it is advisory. In some jurisdictions, evacuation managers are generally supportive of evacuation, and in others, they are supportive of shelter-in-place. These factors are bound to result in varied evacuation dynamics and it is vital for evacuation models to consider these factors.

The mode of evacuation, notably pedestrian or vehicle-based evacuation, is a major contextual factor that influenced the prioritisation of the requirements. It was established that vehicle-based evacuation is the most common mode of evacuation during wildfire incidents, and as a result, most of the participants showed more interest in vehicle-related features than in pedestrian-based features. The few participants who showed high interest in pedestrian-based features were from jurisdictions where pedestrian evacuation is more common. Furthermore, modelling the evacuation of large urban areas needs to incorporate public transport as an additional form of mobility.

The wildfire hazard context, which refers to the characteristics of the fire regime (i.e. frequency, intensity, seasonality, type) also, had an influence on evacuation requirements. The responses of the participants from countries where large wildfires are recurrent and pose social and environmental calamities —group 1— were compared against the responses of the participants from countries where large wildfires are rather sporadic and rarely pose social or environmental calamities —group 2. The group 1 merged the responses of the participants from Australia, Italy and Spain, whereas the group 2 merged the responses of the participants from Ireland, the Netherlands and the UK. The nature of the fire hazard regime, determined the participants' desire for certain modelling requirements, notably for those related to real-time incident management (i.e. Ability to adjust the evacuation procedures or to compare model inputs/outputs of multiple scenarios), as well as for the performance factors that characterises the evacuation (slower/higher results combined with lower/higher accuracy).

Finally, the analysis of the interview/survey responses were distilled down into 22 key factors within 10 broad categories that identify the perceived needs and desires of the emergency management end-user community in relation to the use of urban-scale evacuation models for planning, real-time applications and community training. If urban-scale evacuation models are to be readily adopted by the emergency management community, it is suggested that they should address as many of these key factors as possible.

Task/Deliverable 2.4 has been accomplished through three staff secondments comprising two Experienced Researchers and one Early Stage Researcher performing six person months of secondments in RMIT, Australia. There were more than 15 meetings that took place between the UoG seconded staff and staff from Australian organisations.

Annex I: Interview questionnaire" for the actual interview questions document. The overall design of the interview – the parts, sections and the questions in each section is presented next.

2.2.1 PART 1: PRESENTATIONS

Part 1 involves presentations from the interviewer and the interviewee. Firstly, the interviewer gives a short introductory presentation aimed to provide the participants with an overview of the Fire Safety Engineering Group (FSEG), the GEO-SAFE project, and the development of evacuation modelling capabilities as part of the GEO-SAFE. Finally, it will lay emphasis on the EXODUS current capabilities and the plans for development of future capabilities. Then, it is the interviewee's turn to provide a brief overview of the work, roles and responsibilities of her/his organisation as part of the emergency management structure. The objective of this part is twofold:

- The interviewer (member of Fire Safety Engineering Group (FSEG)) provides the participants with an overview of the current capabilities of EXODUS and the plans for development of future capabilities, in particular associated with urbanEXODUS.
- The interviewee provides the interviewer with an understanding of work, roles and responsibilities of their organisation as part of the emergency management structure, with a particular focus on their roles and responsibilities concerning large-scale evacuation.

2.2.2 PART 2: UNDERSTANDING CURRENT POLICIES/PROCEDURES/TOOLS RELATED TO EVACUATION MANAGEMENT

Part 2 poses a set of predefined open-ended questions related to the performance of evacuation management tasks. Notably, the interviewee is asked to describe her/his organisation's policy, procedures and protocols to deal with evacuation under a variety of scenarios, and whether or not they use any tools for planning, decision making as well as personnel training activities. The actual rationale behind this set of questions is to gain more insight into resources, capacities and needs of emergency organisations in charge of evacuation management. Collecting this information is essential to ensure that the development of evacuation modelling tools will be appropriately embedded to support decision making and operational needs, and that they will be able to be used by the staff in the command and control centres. Specific objectives of this part include:

- Understand current policies involved in large-scale evacuation management.
- Determine the importance of key factors that influence evacuation procedures.
- Discuss tools presently utilised to manage large-scale evacuation.
- Discuss the potential use of evacuation tools within the Common Operating Picture (COP), Command and Control (C2) tools, and training environments.

Part 2 consists of six sections:

2.2.2.1 Section 1. Evacuation policy

The interviewee is asked to describe their organisation's policy on evacuation due to wildfires or other incidents such as floods. It is also important to note when the decision to evacuate is taken over the decision to shelter-in-place during wildfire incidents.

2.2.2.2 Section 2. Evacuation plans and factors influencing evacuation procedures

In this section, the interviewee is asked to describe how their organisation plans or coordinates an evacuation plan during a large-scale evacuation incident. The questions asked in this section are as follows:

- Does your organisation have a detailed plan on how to evacuate an area/region during a wildfire incident or other hazards such as floods?
- What factors/parameters do you take into consideration when determining the evacuation procedures?

2.2.2.3 Section 3. Decision support tools for managing large scale evacuation

This section queries the interviewee on the decision support tools that they currently utilise for managing large scale evacuations. The questions asked in this section are:

- What tools do you utilise to assist in decision making?
- What are the pedestrian and vehicle evacuation issues you encounter during pre-incident planning and live decision making phase and how do you currently tackle these issues?
- What are the current limitations for non-modelling approaches?

2.2.2.4 Section 4. Evacuation modelling tools for managing large-scale evacuation

This section is to determine if the end-user organisations currently utilise evacuation models during the planning and preparation phase and during live incident management phase. The questions asked in this section are:

- What evacuation modelling tools do you use for pre-incident planning? Do you find them useful?
- What evacuation modelling tools do you use for live decision making? Do you find them useful?
- What are the current limitations for evacuation modelling approaches from the perspective of both pre-incident planning and live decision-making?
- Would you like something better than what you currently have for evacuation management purposes?
- Would you consider an urban-scale evacuation model that only considered pedestrian evacuation to be useful for wildfire applications?
- What type and levels of expertise do the people responsible for evacuation management have?
- During pre-incident planning processes, how long are you prepared to wait to get results for a particular evacuation simulation scenario? (e.g. minutes, hours, tens of hours, days, etc.)
- During a live incident, how much time would be required to update or modify an evacuation plan once it is known that conditions have changed? (e.g. minutes, tens of minutes, hours, tens of hours, etc.)

2.2.2.5 Section 5. Timing and dissemination of evacuation notifications and alarms

In this section, the interviewee is asked about the different warning systems available that are addressed to threatened communities. The questions asked in this section are:

- What are the major factors determining the timing for the issuing of the evacuation warnings?
- What methods do you use to warn the population?
- How do you determine the timing of the evacuation orders?

2.2.2.6 Section 6. Common Operational Picture (COP) and training tools for managing large scale evacuation

This section seeks to understanding the current use of COPs by different organisations as well as understand their purposes on using training tools to enhance fire management skills. The questions asked in this section are:

- Does your organisation utilise a COP? What are the evacuation related features that are available on your COP?

- Does your organisation utilise any tools to train operational managers for crisis situations? Please provide details.

2.2.3 PART 3. IDENTIFYING KEY EMERGENCY EVACUATION MODELLING REQUIREMENTS

Part 3 includes a list of evacuation modelling features and capabilities that have been identified based on literature review, analysis of other evacuation models, and insight into evacuation modelling principles in other evacuation domains (buildings, ships, aircrafts, etc.). Each interviewee is asked to rank or score each feature laid on the table based on their perceived value and their categorisation into priorities and constraints. Moreover, the interviewee has freedom to contribute with additional relevant features that stray from the interview initial guide.

The main **objective** of this part is to discern, categorise, and prioritise evacuation modelling requirements applied to wildfires (and other hazards) and fed back to the development of further capabilities in ***urbanEXODUS***.

The 'MoSCoW' method [Greer and Ruhe 2004; Miranda 2011] has been employed to identify key modelling requirements in Part 3. The rationale behind this choice is that it provides a good framework for optimally allocating the various evacuation modelling features depending upon their relevance. Prioritization is composed of four categories from the perspective of the interviewee: 'Must have', 'Should have', 'Could have' and 'Won't have' (see Figure 1). The meaning of these criteria are explained below:

- The **'Must have'** ranking is given for those requirements that are a basic requirement without which the system will not serve its purpose.
- The **'Should have'** ranking criteria is given for those requirements that are important but not vital.
- The **'Could have'** ranking criteria is given for those requirements that are desirable but less important.
- The **'Don't need'[4]** ranking criteria is given for those requirements that are not required.

Rather than simply a discretionary *a priori* decision, the weighting of each specific entity takes into account the feasibility of being accomplished throughout the course of a given project. The most important ones are meant to be implemented first, whereas the less important ones are pushed into the background and only are implemented if sufficient resources are available [Greer and Ruhe 2004].

[4] 'Don't need' has been modified from the original 'Won't have' in The 'MoSCoW' method to best suit the rankings of the requirements of this research.

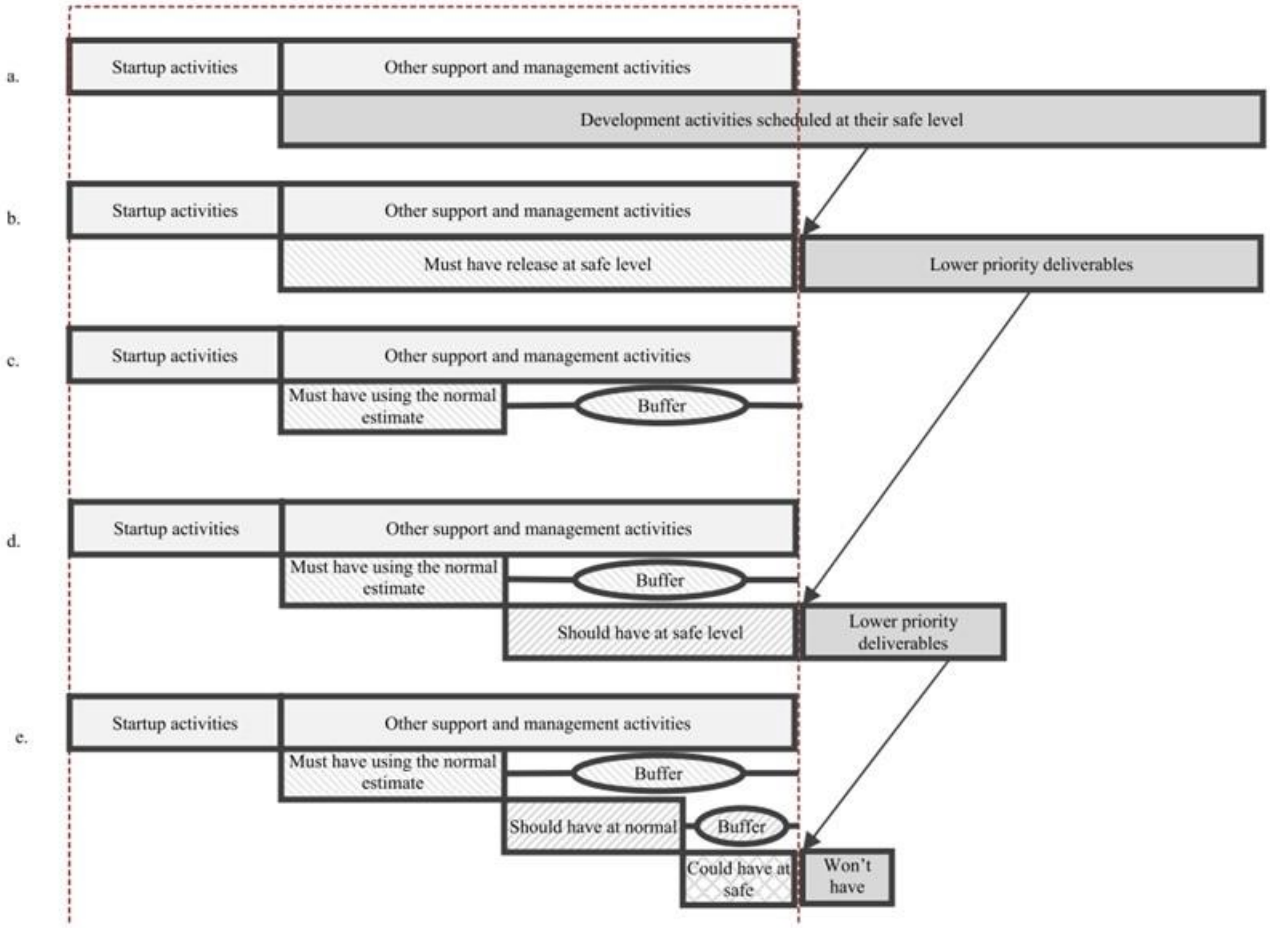

Figure 1. Example of time boxing planning assessment applying MoSCoW method. Source: Miranda [2011].

Part 3 consists of seven sections. These sections and the main questions asked in them are listed next.

2.2.3.1 Section 1. Inputs for evacuation models

What are the evacuation input features that are desirable in an evacuation model?

2.2.3.2 Section 2. Outputs for evacuation models

- What are the evacuation output features that are desirable in an evacuation model?
- How would you like to visualise the evacuation simulation results?

2.2.3.3 Section 3. Evacuation routing features

- What are the routing features you require from evacuation models?

2.2.3.4 Section 4. Simulation speeds vs reliability

- How should evacuation models be calibrated to provide the right balance between speed and accuracy from the perspective of both Planning (P) and Live decision making (L)?

2.2.3.5 *Section 5. Factors affecting pedestrian walking speeds*

- Existing models do not represent variation in walking speeds due to the nature of terrain. What terrain features should be represented in the evacuation models?

2.2.3.6 *Section 6. Integration between wildfire and evacuation simulation tools*

- Does your organisation utilise a fire simulation tool to predict fire behaviour and spread?
- If your organisation uses a fire simulation tool, then please name it and specify its functionalities.
- If your organisation does not utilise a fire simulation tool then how do you predict the fire behaviour and spread?
- What are the desirable outputs from integrating fire and evacuation simulations?

2.2.3.7 *Section 7. Vehicle evacuation*

- What vehicle related capabilities would be useful in an evacuation model that can represent both vehicle and pedestrian evacuation?

2.3 Design of online survey

The interviews typically took around 1-2 hours to complete. It also proved difficult to get the availability of end-users to participate in the interviews for this duration. Therefore, a shortened version of the interview questions were prepared as an online survey. This version was preferred for participants who could not spend as much time or did not have the availability to participate in the interview in person. Furthermore, the online survey has the advantage that it could be taken by a large number of people from different parts of the world.

The fact that it contains a reduced number of questions does not reduce its relevance as compared with the interview questionnaire. While the online survey mainly focuses on the end-user requirements, the interview questionnaire is intended to provide an in-depth understanding of emergency management processes, protocols and requirements and so more than one member of the same organisation or from multiple agencies working under the same emergency management system may provide useful information. Hence, only one member of each target organisation is sufficient for the in-depth interview questionnaire, while additional personnel may complete the online survey, provided they have experience in evacuation management.

A major difference between the interviews and the online survey was that participants were asked to rank the importance of the suggested model functionaries in the interview questionnaire whereas in the online survey they were simply asked to state whether they wanted or did not want these model functionalities. Therefore, these responses from the interview and online questionnaires had to be analysed differently by utilising different weighting for the ranking of the end-user requirements. The methodologies used for the weighting of end-user requirements is explained in Section 4.2.

The online version of the survey is currently active at:

https://fseg.gre.ac.uk/surveys/projects/index.php?r=survey/index&sid=352993&lang=en.

A copy of this survey has also been provided in "Annex II: Online survey".

3. SECONDMENTS RELEVANT TO THIS TASK

3.1. ER secondment 1

Prof Ed Galea (Fellow id: 10), the GEO-SAFE project coordinator performed two visits to RMIT each lasting 0.5 person months. This secondment involved various tasks in WP2, WP4 and WP7. However, in this report, the focus is on the work performed in Task 2.4. In these secondments, Prof Galea had meetings with key members of staff in the following organisations - Australasian Fire and Emergency Authorities Council (AFAC), Bushfire and Natural Hazards CRC (BNHCRC), Melbourne University and RMIT. He delivered two public lectures which were attended by numerous end-users, practitioners, fire fighters, scientists and the general public. There was interesting exchange of knowledge between the staff at RMIT who work on large scale vehicular evacuation models. It was interesting to note that they utilise the PHOENIX fire model and incorporate the fire into their evacuation simulation model. A lot of information with regards to the fire models utilised in Australia was gathered. The meeting with staff from CNRS-LAAS (GEO-SAFE partner) was useful as it established the scope for UoG to collaborate to utilise optimisation within the evacuation simulation environment. The ideas discussed related to reducing the effort required in brute force approach to identify for example optimal location refuge areas, but also to rapidly identify alternative strategies during an evolving situation when for example a road is closed due to fire or tree falls, etc, again reducing the effort required to identify a satisfactory alternative evacuation strategy. This visit also involved project management related issues such as requesting BNHCRC and Melbourne University to sign the MoU.

Prof Galea had a range of meetings with GEO-SAFE partners including RMIT and other partners that were attending the 'Partnering researchers and industry to transform wildfire and disaster risk reduction' workshop from 22-23 Nov 2016. Prof Galea also met with a range of end-users including, AFAC Urban Operations Group, a national group representing the needs of the urban firefighting agencies; Emergency Management Victoria; Metropolitan Fire and Emergency Services Board; Bushfire and Natural Hazards CRC (BNHCRC) and New South Wales Fire and Rescue Service.

3.2. ER secondment 2

Dr Anand Veeraswamy (Fellow id: 23), a post-doctoral researcher performed a one month secondment at RMIT, Melbourne. The key GEO-SAFE tasks performed in this secondment was on Task 2.4: Explore requirements of Large-scale evacuation modelling which is the focus of this report. However, the secondment also involved working on Task 4.2: Integrate urbanEXODUS with fire spread models details of which will be provided in D4.2.

The main objectives of this secondment were to:

- Supervise GEO-SAFE secondee and PhD student, David Martin Gallego
- Develop the end-user requirements interviews and surveys (Task 2.4)
- Obtain more participants and contacts —end-users and wildfire developers for David to interview (Task 2.4)
- Investigate the coupling between wildfire and evacuation simulation tools (Task 4.2)
- Address Project management issues (WP7)

Dr Veeraswamy attended and presented the GEO-SAFE project and UoG's role in the project in the Bushfire Standards Technical Group Meeting (BSTG), which was attended by staff from AFAC, New South Wales Rural Fire Service, Victoria Country Fire Service, South Australia Country Fire Service, Country Fire Authority, Fire and Emergency department West Australia. The BSTG is made up of representatives from bushfire related fire authorities in all Australian and New Zealand jurisdictions. Dr Veeraswamy presented the research performed by UoG-FSEG in the session titled the 'GEOSAFE wildfire presentation'. The presentation provided a brief overview of the GEO-SAFE project followed by a description of the current state of the large evacuation modelling developments and projected developments in the scope of the project. The meeting ended with a request for end-users to complete the FSEG on-line questionnaire identifying the requirements for evacuation planning and real-time incident management; collaboration on linking wild fire and smoke models with urbanEXODUS; access to already collected raw interview data generated from interviews with wild fire survivors.

A meeting with a senior GIS/ICS Business analyst at Emergency Management Victoria provided an insight into their work related to developing evacuation plans for communities. There was a discussion on how EMV utilise the Phoenix fire simulation tool to determine the fire risk and the roads that will be affected by the fire. One of the aims is to provide key summary data to the incident controllers that will be useful to them during the response phase. EMV is also working with RMIT staff who utilise MATSIM to simulate a vehicle-based evacuation.

Dr Veeraswamy attended two GEO-SAFE weekly meetings organised where the GEO-SAFE secondees in the host organisation share their research work and share the knowledge gained. There was also a monthly meeting, MoMeet, organised by RMIT where GEO-SAFE secondees share their work with the rest of the consortium and other organisations.

During the course of the secondment, there were many useful meetings with staff from GEO-SAFE partner, PCF. PCF is liasing on behalf of UoG-FSEG, GEO-SAFE coordinators to get another end-user organisation (INFOCA from Andalusia Spain) into the project. The discussions were about the background of INFOCA and what could be their roles and responsibility in the project.

Following were the key duties related to Task 2.4 performed by Dr Veeraswamy during his secondment at RMIT:

- Reviewed and finalised the End-user requirements questionnaire and online survey.
- Supervised PhD student David who was also on secondment at RMIT.
- Performed literature review on large-scale evacuation models and wildfire simulation tools.
- Attended and presented UoG's role in the GEO-SAFE project at the Bushfire Standards Technical Group meeting.
- Reviewed a paper on large-scale evacuation modelling for the Safety Science Journal.
- Revised and updated a journal paper on large-scale evacuation modelling which is related to the GEO-SAFE project.
- Attended two weekly meetings (WeMeet) between GEO-SAFE secondees at RMIT and one monthly meeting (MoMeet) between GEO-SAFE partners and external organisations.
- Had formal and informal meetings with RMIT staff and other GEO-SAFE secondees.
- Provided assistance in defining the key responsibilities of a new partner INFOCA who were due to join the project consortium in the next amendment.

3.3. ESR secondment

David Martin Gallego (Fellow id: 22), a doctoral researcher visited the Royal Melbourne Institute of Technology (RMIT) for four months from 20/10/2017 to 23/02/2018. The main purpose of this secondment was for Task 2.4: Explore requirements of Large-scale evacuation modelling which is the focus of this report. However, he also worked on Task 4.2: Integrate urbanEXODUS with fire spread models details of which will be provided in D4.2. He established contacts and arranged meetings with fire researchers and fire managers to discuss details involving the integration of evacuation simulation tools with wildfire spread simulation tools.

On his secondment David Martin conducted interviews with incident commanders, civil protection authorities, and police officers involved in wildfire emergency planning and management to determine what they require from a large-scale evacuation model that can be utilised to better manage wildfire evacuations.

The main objectives of the interviews were:

Get a closer understanding of how evacuation is currently managed in the face of wildfire emergency scenarios, and what tools are used to support risk-informed decision making across planning and live emergency contexts.

Identify potential training and operational applications of evacuation modelling tools in the management of wildfire emergency scenarios.

Document large-scale evacuation model requirements (i.e. features to be incorporated into these models) that will assist incident commanders to make informed decisions across planning and live emergency contexts.

Work done and achievements:

During his secondment in Australia David Martin had meetings with staff from 9 Australian organisations, 4 face-to-face interviews and 11 online surveys with emergency personnel experienced in wildfire evacuation management. This served him to accomplish one the main objectives of his PhD relevant to gathering end-user requirements for large-scale evacuation models.

Furthermore, he established contact with other relevant people who are part of the Australian fire research and management community. These included wildfire managers, firefighters, developers of wildfire modelling tools, and fire-related researchers who with he could discuss about other aspects of relevance to the development his PhD such as the management of evacuation within the Australian Incident Command System, the present wildfire risk situation in the country, and the current and potential use of evacuation, wildfire and smoke modelling tools to better manage wildfires incidents. These meetings provided an opportunity for David to explain his work in the frame of the GEO-SAFE project, acquire a good insight into ongoing research and management concerns in Australia with regards to wildfire evacuation, and establish synergies between his research and the work developed at these organisations.

Combining interviews and meetings David established contact with fire-related personnel associated with the following organisations:

- Victoria Police (VICPOL), as evacuation managers during wildfire emergencies.
- Emergency Management Victoria (EMV), as coordinators of wildfire emergencies at the strategic level and potential incident commanders.
- Country Fire Authority (CFA), as managers of community safety during wildfire emergencies and potential incident commanders.
- Department of Environment, Land, Water and Planning (DELWP), as collaborators in community safety during wildfire emergencies, users of fire and smoke modelling tools and potential incident commanders.
- Australasian Fire and Emergency Service Authorities Council (AFAC), as developers of capabilities relevant to wildfire predictive systems and community's responses to wildfire risk.
- Bushfire and Natural Hazards — Cooperative Research Centre (CRC), as the main research centre in Australia that works alongside emergency services.
- University of Melbourne, as developers of Phoenix, the most popular wildfire simulation tool in Australia widely used by wildfire organisations for risk assessment and strategic management planning.

- Data61 — CSIRO (Commonwealth Scientific and Industrial Research Organisation), as developers of Spark, a new promising wildfire simulation model that is expected to integrate evacuation-related features.
- Center for Environmental Safety and Risk Engineering (CESARE) — University of Victoria, as researchers on physics-based approaches to modelling wildfires.

Finally, throughout the secondment David established permanent contact with other GEO-SAFE secondees who became a very important support for the development of his work in Australia. They assisted him to reach key contacts for the interviews and other meetings and played an important part in enhancing his knowledge in some key areas of his PhD. Overall, this secondment helped David to collect data to accomplish key tasks to complete his PhD. Moreover, regarding his career as a researcher this secondment helped him gain knowledge and expertise within his area of research and allowed him to know more closely how its associated professional sphere operates.

4. RESULTS AND ANALYSIS

This section presents the analysis of the data gathered from eighteen participants involved in end-user requirement's interviews/surveys that have been conducted by UoG to date (September 2018). Seven of these were face-to-face interviews while eleven were responses from online surveys. There were ten participants from Australia, four from United Kingdom and one each from Ireland, Italy, Netherlands and Spain. A list with all the organisations interviewed is presented in Table 1. While the primary outcome of this analysis is to determine the key end-user evacuation modelling requirements it was interesting to analyse the differences in the modelling requirements in various regions (even within a country) which differ in the nature of the hazards experienced, socio-economic conditions and operational policies.

Table 1: Emergency management organisations interviewed.

Organisation	***Country***	***Logo***
Victoria Police (VICPOL)	Australia	
Emergency Management Victoria (EMV)	Australia	
Country Fire Authority (CFA)	Australia	
Department of Environment, Land, Water and Planning (DELWP)	Australia	
Australasian Fire and Emergency Service Authorities Council (AFAC)	Australia	
Bushfire and Natural Hazards — Cooperative Research Centre (CRC)	Australia	
An Garda Síochána — Ireland's National Police and Security Service	Ireland	

National Firefighters Corps — Corpo nazionale dei Vigili del Fuoco (CNVVF)	Italy	
Safety Region IJsselland (SRIJ)	Netherlands	Veiligheidsregio IJsselland Brandweer | GHOR | Politie | Gemeenten
Pau Costa Foundation (PCF) — Fire Ecology and Management	Spain	PAU COSTA FOUNDATION
Bracknell Forest Council	UK	Bracknell Forest Council
Thames Valley Police and Hampshire Constabulary	UK	THAMES VALLEY POLICE
Royal Berkshire Fire and Rescue Service	UK	

One of the reasons for the number of participants (18) recruited for the interview/questionnaires not being large is due to the selective recruitment of the participants. Only those organisations that were involved with large-scale evacuation management were approached. Furthermore, only one participant from each organisation was chosen as the policies/procedures across the entire organisation is expected to be the same. Two members of the same organisation or of organisation working under the same emergency management system may provide the same information. Therefore, it was considered to be sufficient to interview one member of each target organisation. Finally, most of the organisations that were contacted have a large area of jurisdiction at the regional level.

The analysis of the questionnaires have been grouped into two main parts:

- Policies, procedures, and tools related to evacuation management.
- Key emergency evacuation modelling requirements.

4.1. Policies, procedures, and tools related to evacuation management

This section describes the analysis of the responses provided by the participants in the secondment part of the interview where they were asked to describe their organisation's current policies, procedures and tools related to evacuation management that during major wildfire disasters. In this part of the interview, the participants were posed open ended questions encouraging them to discuss the management practices carried out by their organisations, and therefore the most relevant comments highlighted by the participants will be presented and analysed.

4.1.1. Evacuation policies

The questions relevant to this section are listed below along with the analyses of the responses given by the participants:

Question 1: What is you organisation's policy on evacuation due to wildfires or other incidents such as floods?

There was a wide consensus among the participants that evacuation management decisions involve cooperation between several organisations. Different disaster management authorities, firefighters, police officers, as well as other forest fire and civil protection services, come together to define the current fire management scenario, share their assessments on the ongoing incident, and define a collective strategy.

Defining a collective strategy involves assigning the roles and responsibilities to the staff responding to the incident. Within the organisations interviewed, the management of evacuation is assigned to law enforcement services (i.e. police) and to the civil protection services, who are given the role of '**Evacuation Manager'**. However, in the event of wildfires the evacuation managers rely on the decision-making capabilities and skills of forest-firefighting organisations. Personnel in these organisations are composed of operations specialists on wildfire-specific events, and include trained analysts in predicting wildfire behaviour and spread, frequently with the aid of wildfire simulation tools. These personnel are given the role of "**Incident Commander"** (**"Incident Controller"** in Australia) and their involvement is crucial in risk assessment and decision-making.

Decision-making processes on wildfire evacuation are largely dependent on the emergency regulations established in each country and may vary between different regions within a country. As a result it is more appropriate to refer to regulations at the jurisdiction level. In some jurisdictions, evacuation is mandatory, whereas in others it is just advisory. In **Australia**, evacuation is mandatory in some states (e.g. New South Wales) but is advisory in other states (e.g. Victoria). In the jurisdictions where evacuation is mandatory, the authorities have more control over the movement of the population, as evacuation is an order that people must follow. However, even when evacuation is mandatory, the outcomes of the evacuation process are only predictable to a certain extent, as not everyone will obey the evacuation order. In contrast, within jurisdictions where evacuation is not mandatory, the fire authorities have less control over the movement of the population, as evacuation is a recommendation that people may, or may not, follow, thereby leaving the final decision to evacuate to the individual. In these cases, the outcomes of the evacuation process are less predictable than in jurisdictions where evacuation is mandatory. In the **UK**, while evacuation is mandatory during terrorist attacks and nuclear incidents, it is advisory during wildfire events.

Key Finding for Evacuation Modelling 1: Regional impact on decision making - Clearly, the nature of jurisdiction in which the evacuation model is being used and more specially, whether mandatory or advisory evacuation advice is provided by authorities, is an important distinction that will need to be factored into evacuation models as it will impact not only the proportion of people likely to evacuate, but the time required to make a decision to begin the evacuation movement phase.

Question 2: How is the decision to evacuate taken over the decision to shelter-in-place in large-scale disasters?

All interview participants concurred that evacuation is a viable option provided everyone can be safely evacuated from the threatened area before the fire arrives.

Therefore, evacuation processes are undertaken when the Incident Commander deems it necessary due to the potential risk to life. This decision is made in conjunction with Evacuation Managers (role usually assigned to a police officer) who are responsible for organising the evacuation process. The decision to evacuate or shelter-in-place is also highly dependent on each region/jurisdiction, and not on each country.

There are an array of factors that Incident Commanders take into consideration when deciding whether it is best to evacuate or shelter-in-place. These factors have been grouped into the following three categories:

1. **Fire impact**

Fire impact refers to the characteristics of the fire that can impact on a populated area (rate of spread, intensity, smoke emissions and dispersion, spotting…). This is usually determined as part of a risk assessment along with the identification and the analysis of impact probabilities and population vulnerability.

According to the interview participants the nature of the fire impact is the first factor to take into consideration when deciding between evacuation and shelter-in-place. All the participants agreed that evacuation would be the best choice especially if everyone can be safely evacuated before the fire impacts a threatened area. This is because evacuation offers the highest level of protection for members of the public and can be achieved without endangering emergency response personnel.

The interview participants from **Australia** and Southern European countries such as **Italy** and **Spain** recognised that timely evacuation is the best option in areas where residents are poorly prepared to resist the impact of fire. In these regions there is usually a combination of factors (e.g. severe fire weather that increases the amount of vegetation fuels available to burn), that favours the rapid spread of fires which quickly endangers large densely populated areas (e.g. urban areas settled in densely forested landscapes where houses and vegetation intermingle). Particularly in **Australia**, where some towns may be located in the middle of massive wild areas, interview participants believed that when the predictions for severe fire conditions are high the only safe approach is leaving early, and so the message given to communities at risk is to leave before the fire even starts. The rationale behind this strategy lies in the fact that the progression of fire can become rather unpredictable, especially in the event of spotting fire throwing embers that initiate new fires far ahead of the flame front[5]. In contrast, interview participants from regions where large wildfires are less frequent, such as the **Netherlands**, **Ireland** and the **UK** were more inclined to believe that a safe evacuation can be performed during the incident. Interviewees from the UK suggested that evacuation is only considered when fire has already reached an area or is imminent. In these regions, fire presents more difficulties to progress (e.g. combustible vegetation are less available due to higher levels of humidity), and therefore there is usually more time to prepare the community to evacuate.

The following factors are associated with fire impact that can influence the decision to evacuate or shelter-in-place:

- Characteristics of the fire danger (propagation speed, fire intensity, smoke, embers)
- Time available before the fire reaches the populated area.
- Time required to evacuate the entire population at risk without being exposed to fire hazards (heat, smoke, embers).
- Time required to warn and prepare the people before evacuating.

Key Finding for Evacuation Modelling 2: Impact of fire development - The importance of fire development to the decision making process of evacuation managers highlights the need to couple evacuation simulation models with wildfire spread models that are capable of assimilating changing meteorological conditions to compute the spread of fire.

2. Community preparedness

Community preparedness relates to the level of awareness, attitudes, and types of behaviours of at-risk communities that will determine their responses to evacuation warnings and hazard incidents in general.

Participants remarked the relevance of community fire preparedness when it comes to deciding the most appropriate strategy. Education campaigns focused on raising awareness and risk perception were highlighted as the mechanism to extend the responsibility for reducing wildfire risk to local administrations and residents in Wildland-Urban Interface (WUI) areas: local administrations should create defensible perimeters around the urban area to mitigate the impact of approaching fire, and residents should carry out defensive measures and keep safety zones around their private properties. Under these ideal circumstances, residents could stay and defend their individual property during wildfire events. However, until this scenario becomes reality fire authorities will prefer to evacuate rather than sheltering-in-place as it gives them more sense of control over the population. In this context, evacuation exercises embedded into community fire preparedness plans are considered to be both desirable and very important.

The following factors are associated with community preparedness that can influence the decision to evacuate or shelter-in-place:

- Community training in evacuation preparedness.
- Pre-designed evacuation plans.

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[5] Fire spotting distances tend to be large in Australian eucalyptus forests due to their shedding bark.

- Vulnerable households and individuals.
- People that may opt for self-evacuation.
- People that may refuse to evacuate.

Factors relevant to community fire preparedness are subject to further social (e.g. fire risk culture, past experiences with fire…) and economic (e.g. urban planning, housing development…) factors, each of which complicates the analysis.

Key Finding for Evacuation Modelling 3: Impact of local conditions on behaviour (community preparedness) - The importance of community preparedness to the decision making process of evacuation managers highlights the need for an ability to factor into evacuation models specifics associated with the preparedness of the local community as this may influence whether the population is likely to evacuate or shelter in place and also how long it may take them to start the evacuation movement phase.

3. Resources

Resources encompass the availability of human (e.g. emergency personnel) and physical assets (e.g. risk assessment tools, emergency equipment, medical resources…) that are needed to manage emergency evacuation.

The availability of resources was raised as a major concern for some of the interview participants. This mainly concerns **Australia**, as wildfires may occur in remote areas where the availability of resources is limited, and the time required for fire and rescue services to arrive may be excessive. Interviewees from **Australia** and **Spain** put forward the challenge in designing the location of assembly points and safe evacuation routes in mountainous regions. Such areas pose challenging conditions for fire suppression and rescue services, due to difficult accessibility, as well as for the evacuating population, due to the poor infrastructure design from the perspective of mass evacuation. Furthermore, towns located in some of these areas may only have a single route in and out, resulting in traffic congestion between incoming emergency vehicles and outgoing evacuating vehicles. In the **UK** it is common to bring buses or cars to take people to shelter locations.

The following factors are associated with resources that can influence the decision to evacuate or shelter-in-place:

- Available resources to assist evacuation managers to conduct the evacuation.
- Available resources to keep people protected during and after the evacuation.
- Viable shelters and safe zones.
- Safe evacuation routes.

Key Finding for Evacuation Modelling 4: Impact of resources on evacuation procedures - The availability of human and physical resources to the evacuation manager is also an important factor for evacuation modelling as it defines the available alternative strategies that could be investigated, through modelling, both in planning and in real-time applications.

4.1.2. Evacuation plans

In the following questions regarding the development of evacuation plans, participants had to select various responses and provide general understanding on how their organisation deals with evacuation planning.

Question 3: Does your organisation have a detailed plan on how to evacuate an area/region during a wildfire incident or other hazards such as floods?

The responses provided by the participants to *Question 3* are shown in Table 2. Respondents from both the interview questionnaire and the online survey responded to this question.

Table 2: Proportion of responses regarding the development of evacuation plans.

Option	**Proportions**		
	Interview questionnaire	**Online survey**	**Total**
Yes, a written evacuation plan exists.	**0%** **(0/4)**	**9%** **(1/11)**	**7%** **(1/15)**
Yes, an evacuation plan has been developed with the aid of computer simulation tools.	**0%** **(0/4)**	**0%** **(0/11)**	**0%** **(0/15)**
No, but an evacuation plan is developed during the ongoing incident as needed.	**100%** **(4/4)**	**82%** **(9/11)**	**87%** **(13/15)**
No, there is no evacuation plan at all.	**0%** **(0/4)**	**9%** **(1/11)**	**7%** **(1/15)**

87% of the participants declared that while evacuation plans do not formally exist, they are developed during the ongoing incident according to the nature of the incident and associated risk. The responsibility for the development of evacuation plans normally lies with local administrations. Emergency organisations normally act according to procedures and protocols that establish flexible frameworks for the implementation of the evacuation plans. While evacuation plans are tailored to the context of risk of a particular region, emergency procedures and protocols establish very general operational guidelines ensuring that any evacuation plan can fit into it. Thus, collaboration and cooperation between emergency organisations and the local government is essential, as they can identify and open refugee locations within the vicinity for the evacuees.

However, many municipalities with significant WUI areas do not have any evacuation plan. At most some communities might have evacuation exercises on how to evacuate, where evacuees are instructed to go to some designated areas. This lack of pre-established plans is probably due to the preference of emergency organisations to work according to flexible procedures that gives them more scope of action in the face of wildfire contingencies (e.g. sudden changes on fire behaviour and direction of spread). Many emergency authorities interviewed argued that in incidents where fire is an immediate threat to at-risk communities there is no time to follow an evacuation plan, as even sticking to standard procedures can sometimes be hard. Furthermore, evacuation plans are only useful if they are up to date, which is unusual even among municipalities that have developed a plan.

Table 3 splits the responses according to the nationality of the participants.

Table 3: Proportion of responses regarding the development of evacuation plans (grouped by nationality).

Option	Proportions					
	AU	**IE**	**IT**	**NL**	**ES**	**UK**
Yes, a written evacuation plan exists.	**0% (0/10)**	**100% (1/1)**	**0% (0/1)**	**0% (0/1)**	**0% (0/1)**	**0% (0/1)**
Yes, an evacuation plan has been developed with the aid of computer simulation tools.	**0% (0/10)**	**0% (0/1)**	**0% (0/1)**	**0% (0/1)**	**0% (0/1)**	**0% (0/1)**
No, but an evacuation plan is developed during the ongoing incident as needed.	**100% (10/10)**	**0% (0/1)**	**0% (0/1)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**
No, there is no evacuation plan at all.	**0% (0/10)**	**0% (0/1)**	**100% (1/1)**	**0% (0/1)**	**0% (0/1)**	**0% (0/1)**

In **Australia** the intervention of emergency services follows the Joint Standard Operation Procedure (JSOP), a general step-by-step guide to standardising procedures for the withdrawal and eventual return of the evacuating population. Australian fire authorities remarked that developing an evacuation plan during the ongoing incident depends on whether or not they have time to plan an evacuation. In cases when the plan is executed, they delineate evacuation sectors within the threatened area in such a way that residents are meant to evacuate sequentially. The organisation of sectors is based on the fire predictions and the characteristics of the area (topography, evacuation routes, number of people…).

In the **UK** emergency services utilise the METHANE (ETHANE for non-major incidents) model, which establishes a reporting framework with a common structure (understandable) for all the organisations involved in the incident. It includes key information that emergency organisations on the scene need to report and be aware of throughout the incident. The acronym METHANE stands for: M (Major Incident – Has a major incident been declared?); E (Exact Location); T (Type of Incident); H (Hazards); A (Access); N (Number of casualties); E (Emergency services). Differently from the JSOP procedures utilised in **Australia**, METHANE is not operationally-oriented but simply informative, and serves to support situational awareness to enable well-informed decision making.

Key Finding for Evacuation Modelling 5: Prepared evacuation plans - Most emergency services do not have prepared plans for large-scale evacuation, even in areas that are high-risk wildfire areas. This lack of planning may be the result of not having access to modelling tools that can be used to simulate large-scale evacuation and possibly also the data required to define the necessary scenarios. While evacuation plans prepared in advance of an incident may not be directly applicable to the unfolding emergency situation, they could provide the basis for real-time analysis that could be relatively easily adapted during the on-going emergency.

Question 4: If you develop evacuation plans, what kind of data do you take into consideration when determining the evacuation procedures?

The responses provided by the participants to *Question 4* are shown in Table 4. Only respondents from the online survey responded this question.

Table 4: Proportion of responses regarding the desired data for the development of evacuation plans (grouped by nationality).

Factor	**Proportions**						
	Online survey						
	AU	**IE**	**IT**	**NL**	**ES**	**UK**	**Total**
Total number of people to be evacuated.	**100% (6/6)**	**100 (1/1)**	**100 (1/1)**	**100 (1/1)**	**100 (1/1)**	**100 (1/1)**	**100% (11/11)**
Population demographics in the area.	**83% (5/6)**	**100 (1/1)**	**100 (1/1)**	**100 (1/1)**	**0% (0/1)**	**0% (0/1)**	**73% (8/11)**
Population dispersion in the area.	**67% (4/6)**	**100 (1/1)**	**0% (0/1)**	**100 (1/1)**	**100 (1/1)**	**100 (1/1)**	**73% (8/11)**
Available and Non-available (i.e. blocked) routes.	**100% (6/6)**	**100 (1/1)**	**100 (1/1)**	**100 (1/1)**	**100 (1/1)**	**100 (1/1)**	**100% (11/11)**
Available time before hazard impact.	**100% (6/6)**	**100 (1/1)**	**100 (1/1)**	**100 (1/1)**	**0% (0/1)**	**100 (1/1)**	**91% (10/11)**
Location of safe refuges.	**83% (5/6)**	**100 (1/1)**	**100 (1/1)**	**100 (1/1)**	**100 (1/1)**	**100 (1/1)**	**91% (10/11)**
Time of the day (day/night), day of the week (working day/holiday), and period of the year (summer, winter).	**100% (6/6)**	**100 (1/1)**	**100 (1/1)**	**100 (1/1)**	**0% (0/1)**	**100 (1/1)**	**91% (10/11)**
Weather conditions (windy/rainy/sunny/snowy day).	**83% (5/6)**	**100 (1/1)**	**0% (0/1)**	**100 (1/1)**	**0% (0/1)**	**0% (0/1)**	**64% (7/11)**

There was an option for participants to suggest additional factors that were not included by the interviewer and the participants did suggest a number of additional factors. These additional factors are presented in
Table 5 with a tick on the nationality of the participant(s) that suggested them.

Table 5: Additional data desired by the participants for the development of evacuation plans.

Other factors suggested by the participants	Proportions					
	Online survey					
	AU	IE	IT	NL	ES	UK
Vulnerable population (elderly and disabled population).	✓		✓			✓
Shelter of animals, livestock and pets.	✓			✓		
Critical assets, cultural heritage.				✓		
Public Events (festivals, rallies…).	✓					
Touristic areas.	✓					
Social media.		✓				✓
Community preparedness.	✓					✓
Availability of resources.		✓				
Ethnicity (people who do not speak the language).	✓					✓
Cooperation between organisations.	✓					

Based on the responses displayed in Table 4 and

Table 5, the factors used to assist in framing evacuation procedures have been grouped into always used (if selected by at least 90% of the respondents) and often used (if selected by more than 49% but fewer than 90% of the respondents).

The 'always used' factors are:

- Total number of people to be evacuated — 100% of the responders.
- Available and Non-available (i.e. blocked) routes — 100% of the responders.
- Available time before hazard impact — 91% of the responders.
- Location of safe refuges — 91% of the responders.
- Time of the day (day/night), day of the week (working day/holiday), and period — 91% of the responders.

The 'often used' factors are:

- Population demographics in the area — 73% of the responders.
- Population dispersion in the area — 73% of the responders.
- Weather conditions (windy/rainy/sunny/snowy day) — 64% of the responders.

There were a variety of reasons why some of the factors fall into the 'often used' category, some of these are described below. For the population demographics and dispersion in the area, participants argued that they would generally assume that in the target area there will be a variety of people. Furthermore, information concerning the population can be obtained during the emergency if required. A participant from **Australia** stated that they would not take into account demographics or dispersion prior to an emergency, as they would collect the information during the emergency. In these cases, this may be an issue in regions that had a large tourist population, as they substantially increase the number of people staying during peak seasons. Another participant from the same country pointed out that they would rely on the police to collect this type of information. Another participant from **Australia** considered that weather conditions were not important unless the conditions were very severe (heavy rain, snow…).

Some of the participants suggested additional factors that were missing out from the initial list in Table 4. In this sense, the most commented was the location of vulnerable structures and people. Interviewees from **Australia** and from the **UK** explained that when planning an evacuation they would initially focus on the location of people with special needs (e.g. old age homes, schools, hospitals, prisons…). For instance, nursing homes and hospitals are the most critical to evacuate, and might imply allocating many resources. In **Australia**, the police has a program to assist the vulnerable; whereas in the **UK**, they would normally keep a register of vulnerable people to know in advance where they are located. However, this response is odd as it relates directly to the demographics of the population. This response may indicate that the interviewee did not fully understand the nature of the question.

In **Australia**, participants remarked on tourism-oriented towns where the concern is more on the transients than locals. The locals are aware of the risks and are better prepared however, the transients will require greater assistance as they are unlikely to be aware of the risks. Moreover, interviewees from **Australia** and from the **UK** pointed out the ethnicity as an issue to account for. People from other ethnic groups (residents or tourists) may not understand emergency messaging as they may not speak the local language. The Australians also mentioned the importance of being aware of public events occurring in the local vicinity that, similar to touristic areas, may congregate very high number of people unfamiliar with the broader locality.

***Key Finding for Evacuation Modelling 6: Important parameters for evacuation planning* -** The most important parameters to evacuation managers in planning evacuation are; size of population to be evacuated, availability of evacuation routes, available time before hazard impact, location of safe refuges, time of day/day of week/period. It is thus essential that evacuation models make use of these parameters if they are to be accepted by evacuation managers. The importance of these parameters also suggests the type of data that may be available for use in evacuation modelling.

4.1.3. Decision support tools for managing large-scale evacuation

In the following questions about managerial decision making for large-scale evacuation, participants were asked about the software tools they utilise, the limitations of the non-modelling approaches they currently use, and if they would like something better than what they currently have. Additionally, they were asked if they would consider an evacuation model that only modelled pedestrian evacuation for wildfire applications.

Question 5: Do you use any sort of software tools to assist you in decision making?

The responses provided by the participants to *Question 5* are shown in Table 6. Only respondents from the interview questionnaire responded this question.

Table 6. Proportion of responses regarding the use of software tools for large-scale evacuation (grouped by nationality).

Option	Frequencies		
	Interview questionnaire		
	AU	UK	Total
Yes, and they have evacuation modelling capabilities.	**0%** **(0/4)**	**0%** **(0/3)**	**0%** **(0/7)**
Yes, but they do not have any evacuation modelling capabilities.	**75%** **(3/4)**	**100%** **(3/3)**	**86%** **(6/7)**
No, we do not use any software tools at all.	**25%** **(1/4)**	**0%** **(0/3)**	**14%** **(1/7)**

As observed in Table 6, while 86% of fire services interviewed employ some kind of software tools for risk assessment of wildfire events neither of them use evacuation simulation tools. One of the most widespread software tools currently being used are wildfire simulation tools for assessing the spread of fire. Hence, evacuation-related decisions are based on the progress of the fire. The movement and likely behaviour of the evacuating population is generally ignored. Finally, most of the agencies employ GIS systems (mainly *ArcGIS*) in combination with wildfire simulation tools to conduct spatial analysis of the spread and growth of fires across the landscape.

In **Australia** there are two main wildfire simulation models used at management level: *Phoenix*, and *Aurora*. *Phoenix* is widely used by most of the State and Federal agencies as well as private parties in Australia, whereas *Aurora* is the most popular in Western Australia. Finally, a new model called *Spark* has been recently developed (2013), though its capabilities to be used at management level are still being evaluated. In the **UK**, emergency organisations use *FIREMET* to predict fire weather conditions. For the particular risk of chemical spill, *FIREMET* is complimented with *CHEMET (Chemical Meteorology)* to track the dispersion of a chemical release. Interviewees from both countries made clear that the use any hazard simulation model is informative rather than determinative, meaning that the simulated results from these models are interpreted with caution, and other risk analyses need to be undertaken to complement the decision making process.

Key Finding for Evacuation Modelling 7: Current decision support tools for evacuation - The wildfire management community do not currently make use of large-scale evacuation modelling tools and so are unlikely to have any experience and knowledge of their capabilities. It is thus essential that this community is correctly informed of the current and potential future capabilities of large-scale evacuation modelling in order to manage expectations. Furthermore, it suggests that the current opinion of wildfire managers with regard to large-scale evacuation modelling may not be an informed opinion.

Question 6: Would you like something better than what you currently have for evacuation management purposes?

The responses provided by the participants *Question 6* are shown in

Table 7. Only respondents from the interview questionnaire responded this question.

Table 7. Proportion of responses regarding the desire for software tools for large-scale evacuation (grouped by nationality).

Option	Frequencies		
	Interview questionnaire		
	AU	**UK**	**Total**
Yes	**100% (4/4)**	**67% (2/3)**	**86% (6/7)**
No	**0% (0/4)**	**33% (1/3)**	**14% (1/7)**

In general, the interviewees expressed a desire for evacuation simulation tools. All interview participants from **Australia** were convinced that adding more sophisticated computational models would be beneficial for evacuation management, though they all qualified their interest by limiting their usefulness in certain emergency contexts.

Limitations raised by interview participants concerning the use of evacuation tools fell into three broad categories:

Model reliability

The actual outcomes of the evacuation are difficult to predict because of the uncertainty in the expected human behaviour during fire emergencies. As a result, appropriate representation of human behaviour of evacuees and the variability in human behaviour for different threat situations is also essential.

In **Australia**, the general experience is that wildfire simulation tools can predict with reasonable accuracy the rate and direction of fire spread. However, an important part of the equation is currently missing: an indication of how the community behaves during the evacuation. To address this gap, participants from **Australia** advocated that the development of evacuation models should be strongly linked to social research and towards a comprehensive conceptual model of evacuee decision-making. However, some of them recognized that it is impossible to keep track of all the people, even when the evacuation is mandatory. Similarly, participants from the **UK** also commented on the difficulty to embed stochastic and dynamic choices of the evacuees into evacuation models. Furthermore, they suggested that using local knowledge is one good available option to predict the evacuation outcomes, as local people know the availability of routes and safe places.

Model processing time

The model processing time refers to the time it takes for a model to process the inputs, run the simulation and provide the results. In pre-incident planning tasks the model processing time is less critical as planning usually occurs days or months before an incident. However, for live incident management tasks the model processing time is critical, as the model needs to run much faster than real-time. All participants agreed that for pre-incident planning tasks the time required to get the simulation results is not critical; however, during the live incident planning the processing time needs to be much faster than real-time. In fact, if the fire impact is imminent, rapid managerial decisions will need to be taken without any support tools. However, under these circumstances, this would suggest that the incident management activities may have started too late into the fire development.

Participants from **Australia** said that they could wait up to 30 minutes, which is the time required to complete the Joint Standard Operation Procedure (JSOP). In Australia, evacuation orders are mostly issued when the fire is a long way away from the populated area and never when the danger is imminent. This is due to two main factors: firstly, due to the lack of evacuation simulation tools the authorities do not have detailed evacuation plans and secondly, the wildfire simulation tools, though reasonably accurate, still cannot reliably predict the fire spread due to flying embers (spot fires) which can generate new fires at great distances ahead of the flame front.

Participants from the **UK** specified that they could wait about tens of minutes, depending on the availability of resources and the capability of moving them from one place to another. However, in live management situations conditions change quickly, and new decisions have to be continually made. One of the participants from the **UK** asserted that when this occurs they are not going to have time to run and analyse the outcomes of evacuation modelling.

Staff expertise in using evacuation software tools

Presently, none of the emergency organisations that were interviewed has used evacuation software tools, nor do have they personnel trained in evacuation-specific software. In fact, they do not generally have staff specially trained to handle evacuation situations. In spite of this, participants from Australia recognised that they have staff in their team with expertise in other GIS and software systems that can be trained in the use of evacuation software. Their main concern was that the trained staff should use the software tools regularly for them to be competent enough to employ these tools during a live incident. Participants from the UK were more reluctant about training their staff in the use of new software tools, especially when they are unwieldy. Nevertheless, they were willing to train their staff if these tools were simple to use and required minimal training.

Key Finding for Evacuation Modelling 8: Key features required by evacuation models for acceptance - Incident managers have identified a need for evacuation modelling tools to assist with decision making. As part of this need they have also identified three key requirements for evacuation models:

- **Reliability/Realistic agent decision making capability:** Incident managers suggested that it is important for simulated agents within evacuation models to have a decision making capability that not only reacts to the evolving situation but can be adapted to suit specifics of local conditions e.g. to represent local experience and knowledge. However, many issues associated with complex decision making can be addressed with a capability of running 'what if' scenarios. With such a framework, it is not essential to know precisely how a population will react, as a number of different scenarios can be run that explores the outcome of a range of possible reactions. However, for this to be useful, the model must be able to run quickly enough so that the scenarios required to cover the parameter space can be completed within a sufficient time so as to influence the decision. This point is explored in the next factor.

- **Speed of simulation/Fire time line:** Incident managers suggested that it is essential to have short simulation times, but also for placing the evacuation simulation into the context of the evolving fire timeline. It is clear that there is a disconnect between multiple timescales that are important in wildfire such as, the time required to make fire spread predictions, the time at which the fire will impact the targeted community, the time at which evacuation routes will become non-tenable, the time required to clear the targeted community, the time required to ensure that the community have cleared the potentially vulnerable evacuation routes, the time required for the targeted community to reach safety, the time required to prepare the evacuation simulations. This suggests that a general wildfire timeline model that addresses these issues is required to identify the actual time available to make evacuation decisions based on evacuation modelling.

- **Ease of use:** Incident managers suggested that easy to use models are essential if the technology is to be readily accepted. This suggests that user-interfaces must be simple to use and intuitive. Furthermore, it highlights the need for preparing models of high-risk areas in advance of the incident so that minimal input and scenario configuration is required. This is similar to the requirements for wildfire modelling, it is unreasonable to assume that a wildfire model will be configured from default settings to accommodate a specific fire scenario. It is likely that local specific data will have already been configured with the model such as geographical spatial information and the nature and dispersal of fuels.

Question 7: Would you consider an urban-scale evacuation model that only considered pedestrian evacuation to be useful for wildfire applications?

The responses provided by the participants to *Question 7* are shown in Table 8. Respondents from both the interview questionnaire and the online survey responded this question.

Table 8: Proportion of responses that considered as useful an urban-scale evacuation model that only considered pedestrian evacuation.

Response	**Proportions**						
	Interview questionnaire and online survey						
	AU	**IE**	**IT**	**NL**	**ES**	**UK**	**Total**
Yes	**20% (2/10)**	**0% (0/1)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**50% (2/4)**	**39% (7/18)**
No	**80% (8/10)**	**100% (1/1)**	**0% (0/1)**	**0% (0/1)**	**0% (0/1)**	**50% (2/4)**	**61% (11/18)**

As many as 61% of the interviews considered the representation of vehicles is essential in wildfire evacuation applications. This is mostly due to the participants from **Australia**, most of whom (8/10 - 80%) would not conceive wildfire evacuation scenarios without vehicles. They stated that if pedestrian movement is to be considered, then the interaction between vehicles and pedestrians needs to be modelled. The participant from **Ireland** and half of the participants from the **UK** (50%) concurred with that. However, 39% of the interviewees considered that a pedestrian only evacuation model would still be useful.

Interview participants highlighted some scenarios in which pedestrian evacuation needs to be modelled:

- Evacuation of coastal areas including holiday crowds.
- Certain hazards where all or most evacuation is done by foot (e.g. earthquakes, tsunamis, overcrowded events, terrorist incidents).

- Low intensity grass fire prompting people to evacuate by foot. Grass fires will generally stop at the boundary Wildland-Urban Interface, thus affecting only the houses that are in the front line of fire; whereas forest fires can more intensive (e.g. spotting phenomena) and may affect the inner parts of the urban area.
- As the base for benchmarking aimed to get specific estimates of pedestrian evacuation independently of vehicle evacuation.

Key Finding for Evacuation Modelling 9: Importance of vehicle simulation - Evacuation managers strongly suggest that evacuation models must have a capability to represent evacuation using vehicles. This is perhaps an obvious, but nevertheless important finding. In large-scale evacuation relating to wildfire, it is essential to include vehicles in the evacuation modelling capability. Pedestrian only modelling has application in very specialist application areas such as evacuation of coastal areas.

4.1.4. Evacuation notifications and orders

In this section the responses to the questions on the timing and dissemination of evacuation orders is described.

Question 8: Which of the following methods do you use to warn the population?

The responses provided by the participants to *Question 8* are shown in Table 9. Only the respondents from the interview questionnaire responded this question.

Additional factors were suggested by some of the participants. These are displayed at the end of Table 9 with a tick on the nationality of the participant(s) that suggested them.

Table 9: Proportion of responses regarding the methods used to warn the population.

Option	Frequencies		
	Interview questionnaire		
	AU	UK	Total
Phone calls	**50% (2/4)**	**33% (1/3)**	**43% (3/7)**
SMS messages	**100% (4/4)**	**67% (2/3)**	**86% (6/7)**
TV broadcast	**100% (4/4)**	**67% (2/3)**	**86% (6/7)**
Radio	**100% (4/4)**	**100% (3/3)**	**100% (7/7)**
Social media	**100% (4/4)**	**100% (3/3)**	**100% (7/7)**
Sirens	**75% (3/4)**	**0% (0/3)**	**43% (3/7)**

Signage	**25%** **(1/4)**	**0%** **(0/3)**	**14%** **(1/7)**
Flashing lights	**50%** **(2/4)**	**0%** **(0/3)**	**29%** **(2/7)**
Door to door knocking	**100%** **(4/4)**	**100%** **(3/3)**	**100%** **(7/7)**
Other methods added by the participants			
Traffic light control	✓		-
Loud speakers	✓		-
Mobile apps	✓		-

There is currently a broad variety of warning methods used by emergency organisations in evacuation situations to notify the population. Their frequency of use, however, is not the same, and that is observed in the responses from **Australia** and **UK**.

The most common method to notify evacuation warnings, both in **Australia** and in the **UK** are the radio, social media and door to door knocking (methods used by all respondents from both countries). In **Australia**, it is common to put ribbons on the doors to indicate that the house has been notified.

SMS messages and TV broadcast are likewise widely used in **Australia** (used by all respondents) and often used in the **UK** (both used by 67% of the respondents). Interview participants pointed out that the dissemination of alerts and warnings through radio, TV, and especially mobile SMS/texts may be more effective than door to door knocking when there is a scattering of houses around the affected area. The use of mobile phone apps is getting increasingly popular. For example, the government of the State of Victoria (**Australia**) has launched an app (*VicEmergency*) that allows people to access warnings and hazard-related information across the State.

The use of sirens, phone calls, and flashing lights are more often used in **Australia** (used by 75%, 50%, and 50% of responders, respectively) than in the **UK**, where they are rarely or never used (used by 0%, 33%, and 0% of responders, respectively). The police in **Australia** tends to employ sirens simultaneously with door to door knocking to notify the population. Occasionally, they may also employ traffic light controls and loud speakers. Signage is the most rarely used method in both countries (used by 25% of responders from Australia and 0% of responders from the UK), as only the **Australian** police appears to use it.

Key Finding for Evacuation Modelling 10: Alerting the population – Evacuation managers indicate that there are a variety of methods used to alert the population of the need to evacuate. These vary from the most resource intensive, the most time consuming but the surest of success i.e. door to door knock, to the least resource intensive, quickest but with large uncertainty of success i.e. radio and TV messaging. Newer approaches using social media, mobile phone apps and texting are also popular and may become the preferred route for notification. However, issues associated with coverage of the mobile phone network, especially in remote areas needs to be addressed. Clearly, evacuation models need to have an ability to represent the different modes of notification, or more precisely, the notification success rate associated with the different modes of notification.

Timing of evacuation orders (Timeline diagram for wildfire events)

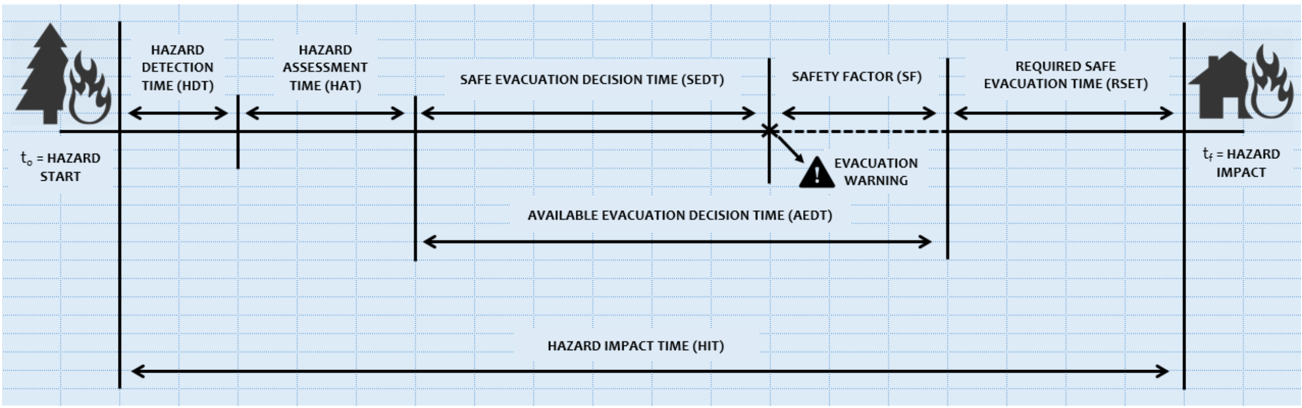


Figure 2: Timeline of events since the fire starts until the fire impact a populated area

The participants of the interview questionnaire were asked to leave their comments on the diagram showed in Figure 2 (for detailed information on the diagram see This deliverable provided a detailed analysis of the end-user requirements from large-scale evacuations due to wildfires. A total of 18 staff from 13 organisations in 6 countries (Australia, Ireland, Italy, Netherlands, Spain, and the UK) involved with wildfire evacuation/management were either interviewed or participated in an online survey to provide answers to open ended and specific questions designed for the purpose of collecting end-user requirements that will enhance current large scale evacuation models.

Analysis of these interviews/surveys suggest that there are four main contextual factors that could influence the end-user requirements, namely: management policies and strategies, mode of evacuation (vehicle versus foot), and wildfire hazard context.

Management policies and strategies varies across jurisdictions at local, regional, and national levels. In some jurisdictions, evacuation warnings are mandatory whereas in others it is advisory. In some jurisdictions, evacuation managers are generally supportive of evacuation, and in others, they are supportive of shelter-in-place. These factors are bound to result in varied evacuation dynamics and it is vital for evacuation models to consider these factors.

The mode of evacuation, notably pedestrian or vehicle-based evacuation, is a major contextual factor that influenced the prioritisation of the requirements. It was established that vehicle-based evacuation is the most common mode of evacuation during wildfire incidents, and as a result, most of the participants showed more interest in vehicle-related features than in pedestrian-based features. The few participants who showed high interest in pedestrian-based features were from jurisdictions where pedestrian evacuation is more common. Furthermore, modelling the evacuation of large urban areas needs to incorporate public transport as an additional form of mobility.

The wildfire hazard context, which refers to the characteristics of the fire regime (i.e. frequency, intensity, seasonality, type) also, had an influence on evacuation requirements. The responses of the participants from countries where large wildfires are recurrent and pose social and environmental calamities —group 1— were compared against the responses of the participants from countries where large wildfires are rather sporadic and rarely pose social or environmental calamities —group 2. The group 1 merged the responses of the participants from Australia, Italy and Spain, whereas the group 2 merged the responses of the participants from Ireland, the Netherlands and the UK. The nature of the fire hazard regime, determined the participants' desire for certain modelling requirements, notably for those related to real-time incident management (i.e. Ability to adjust the evacuation procedures or to compare model inputs/outputs of multiple scenarios), as well as for the performance factors that characterises the evacuation (slower/higher results combined with lower/higher accuracy).

Finally, the analysis of the interview/survey responses were distilled down into 22 key factors within 10 broad categories that identify the perceived needs and desires of the emergency management end-user community in relation to the use of urban-scale evacuation models for planning, real-time applications and community training. If urban-scale evacuation models are to be readily adopted by the emergency management community, it is suggested that they should address as many of these key factors as possible.

Task/Deliverable 2.4 has been accomplished through three staff secondments comprising two Experienced Researchers and one Early Stage Researcher performing six person months of secondments in RMIT, Australia. There were more than 15 meetings that took place between the UoG seconded staff and staff from Australian organisations.

Annex I: Interview questionnaire). The most notable comments are outlined below:

General comments

- Interviewees from **Australia** considered the diagram as helpful with caveats listed below. However, police respondents thought the timeline of limited usefulness due to the difficulty in fixing human behaviour across the stages of evacuation (especially during the warning and evacuation phases).
- Interviewees from the **UK** suggested that the diagram is only helpful when there is plenty of time to manage the evacuation, i.e. at least a margin of three hours before the fire impacts.

About the Evacuation Decision Time (AEDT and SEDT)

- The Evacuation Decision Time may be shorter if the evacuation plan is already in place.
- The Evacuation Decision Time could be in turn divided into three phases:
    - Time required to get all the resources assembled.
    - Time required to issue the evacuation warning.
    - Time required for all the emergency organisations involved to come up with a plan (assuming no plan already exists), and assign tasks and responsibilities.
- Upon arrival at scene of the incident, emergency personnel from both **Australia** and the **UK** establish the so-called "Golden Hour", which is an informal term referred to one hour window to take initial decisions for management and coordination activities. Interviewees suggested that in evacuation situations the "Golden Hour" could limit the time window for the Evacuation Decision Time.

About the Evacuation Warning

The manner in which the evacuation warning is represented in the timeline diagram (Figure 2) led participants to assume that the evacuation warning (Notification or Order) was represented as a fixed point in time. However, this is not the case. It is not the intent to suggest that the 'evacuation warning' event must occur at a given fixed point in time but that it can be issued anytime during the Available Evacuation Decision Time (AEDT). The implication is that the later it is given during the AEDT, the smaller the Safety Factor (SF) will be. Furthermore, it is accepted that the method used to issue the 'evacuation warning' will determine how long it takes for the 'at risk' community to be alerted of the need to evacuate e.g. a door-knock approach may take longer to alert everyone than an SMS alert, but the time associated with alerting the 'at risk' community is part of the Required Safe Evacuation Time (RSET).

The participants remarked that after issuing the first warning, evacuation managers come back to double check that everyone has evacuated.

About the Safety Factor

The participants suggested that the Safety Factor should be double or triple the RSET time obtained from the evacuation models. While it is accepted that this would be an ideal situation, it is not the intent of the diagram to suggest how long each factor is, but to identify that the duration of each factor is interlinked with the other factors, thus increasing the duration of one of the factors, will reduce the time available for the other factors. For example, if it takes too long to make the decision to alert residents, this will reduce the time available for the 'Safety Factor'. Similarly, if the RSET is very long, this will also reduce the time available for the 'Safety Factor'.

Key Finding for Evacuation Modelling 11: Timeline concept - The responses to the wildfire timeline concept while on the whole positive also had a number of negative comments. However, many of the negative comments displayed a lack of understanding of the intent of the timeline. An important consideration is that none of the time intervals in the timeline are intended to be definitive times of fixed duration but are all intended to be varying times which are scenario dependent. They are intended to demonstrate that interrelationship between the various key phases, and that by taking longer in one particular phase will mean that less time will be available for the other phases. However, the timeline is considered a useful concept and will be further refined.

4.1.5. Common Operation Picture (COP) and training tools

The questions relevant to this section are listed below along with the analyses of the responses given by the participants:

Question 9: Does your organisation utilise any type of COP (Common Operational Picture) for crisis situations?

The responses provided by the participants to *Question 9* are shown in Table 10. Only the respondents from the interview questionnaire responded this question.

Table 10: Proportion of responses regarding the use of COP (Common Operational Picture) for crisis situations.

Option	**Proportions**		
	Interview questionnaire		
	AU	**UK**	**Total**
Yes	**100% (4/4)**	**100% (3/3)**	**100% (7/7)**
No	**0% (0/4)**	**0% (0/3)**	**0% (0/7)**

All emergency organisations utilise some kind of incident response and management system, where they share operational information with the rest of organisations working in the incident. These are named COP (Common Operational Picture) in Australia, and JOP (Joint Operational Picture) in the UK. Unfortunately, evacuation-related data is currently missing or is very scarce in those systems.

In the State of Victoria (**Australia**), COPs are mainly managed by EMV (Emergency Management Victoria), which acts as a coordinating organisation defining the roles and responsibilities of all parties involved. COPs might contain specific information of former evacuations, notably statistics, reports and debriefs, but they are rarely used for live evacuation management. Along these lines, interview participants were generally in favour of embedding evacuation-related data into the COP, as it would help bring awareness up during the incident well before the decision to evacuate is made. Exceptionally, the police officer questioned that they would have time to make use of that data in the COP before or during the incident, given that they do not have people exclusively dedicated to evacuation.

Following is a collection of the evacuation-related data that interviewees from Australia would request for their COPs and JOPs:

- Evacuation plans (if available).
- Road lines and their capacity.
- List of resources for each organisation.
- Requests for emergency personnel to assist in the evacuation.
- General outputs of evacuation models (e.g. estimates of the time required to evacuate a specific town/region).

In the **UK**, JOPs are usually led by the police, and evacuation-related data is rarely found in them. Generally, interviewees from the UK did not consider there were benefits of incorporating evacuation data within the JOP, justifying that they might not have time to consult that information during the incident. Despite this, some interviewees put forward some key evacuation-related data that would be helpful to have in their JOPs:

- Location of vulnerable facilities and their associated total evacuation time.
- Transports available.
- Location of refuge centres.
- Location of critical infrastructure (e.g. gas pipe lines, electricity centres...).
- Access roads.
- Medical aid stations.

Key Finding for Evacuation Modelling 12: Incorporating the evacuation model within the COP/JOP - The management of large-scale emergencies involving wildfires incorporates a COP/JOP of some type however, currently this excludes evacuation data. There was a mixed response to whether or not it would be useful to include evacuation data. With the exception of the police, it was felt that evacuation data, in particular, evacuation plans, evacuation routes and their capacities, time required to evacuate a region, location of refuge centres, location of vulnerable communities and their associated evacuation times, etc. would be useful. In the UK, the police, as with the police in Australia felt that this would be less useful primarily because the authorities would not have the time to react to the information. This again highlights an important issue, if the evacuation models are to have any impact on evacuation management, they must be able to rapidly and reliably produce their advice.

Question 10: What are the tools that are utilised in your organisation to train operational managers for crisis situations?

The responses provided by the participants to *Question 10* are shown in Table 11. Only the respondents from the interview questionnaire responded this question.

Table 11: Proportion of responses regarding the use of tools for training purposes in crisis situations.

Option	Frequencies
	Interview questionnaire

	AU	UK	Total
Paper based desktop exercises	**75% (3/4)**	**67% (2/3)**	**71% (5/7)**
Full-scale field exercises	**50% (2/4)**	**0% (0/3)**	**29% (2/7)**
Augmented / Virtual reality environment	**25% (1/4)**	**0% (0/3)**	**14% (1/7)**
None	**25% (1/4)**	**33% (1/3)**	**29% (2/7)**

Paper-based desktop exercises are commonly used as a training tool to prepare operational managers for crisis situations (used by 71% of the responders). Full-scale field exercises (29%) and augmented/virtual reality environment (14%) are occasionally utilised. Some of the participants reported they combine two or more approaches. Evacuation-related features appear in some of these tools, but are absent in most cases.

In **Australia** emergency organisations use a wide range of tools for training purposes with paper based desktop exercises being the most popular (used by 75% of the responders). They are aimed to exercise emergency personnel’s knowledge so that they have an understanding of their work during an evacuation; that is, all factors to be considered during the decision making process (e.g. vulnerable people in the area, identification of untenable routes, interpretation of fire simulated results…). Occasionally, these exercises may take place out in the field, in the form of full-scale, and, more often, in the form of reduced-scale tests. While they use wildfire simulation tools to make predictions of spatial fire growth, evacuation-related features are just based on the insights the field might offer. Additionally, the Australian police uses a computer-based simulation system named HYDRA for disaster operations management. HYDRA enables the user to navigate within a virtual world while monitoring real-time operational decisions under emergency conditions. They have tested it for wildfire disaster scenarios, but it is never been applied to evacuation management purposes.

An interviewee from **Australia** recognised the potential utilisation of evacuation models for educational purposes to demonstrate the feasibility of practising safe and effective evacuation. As he explained, this could be done in a manner analogous to how the wildfire model *Phoenix* is currently used to demonstrate that fire can threaten entire urban communities, and how much time they have to react.

In the **UK** emergency organisations only utilise paper based desktop exercises (used by 67% of the responders). They do it primarily to test and validate emergency management plans. For each type of hazard they have specific training exercises, but none of them incorporate evacuation-related features. However, these exercises have rarely been applied to wildfire scenarios, because the recurrence frequency of major wildfire disasters in the UK is lower than for other hazards such as floods, cold weather episodes or terrorist attacks.

Interviewees from the UK highlighted that the use of evacuation simulation tools as part of their training programs can be a good option to reduce uncertainty around human behaviour. Finally, one interviewee suggested that evacuation simulation tools, when used for training purposes, should incorporate exercises to simulate communications among all emergencies organisations involved in order to build up their capacity of coordination.

Key Finding for Evacuation Modelling 13: Evacuation modelling for training - The vast majority of training of emergency management staff is through paper based desktop exercises. There is significant potential for the development of training environments that incorporate evacuation modelling tools for large-scale emergencies involving wildfires (and other disasters). Indeed, several of the respondents suggested that this would be a useful development. The training environment would be enhanced if it could also include the co-ordination between emergency organisations.

4.2. Key emergency evacuation modelling requirements

This section describes the analysis of the responses provided by the participants in the third part of the interview where a number of evacuation modelling requirements identified from the literature review were presented to the participants. Each requirement has been assigned a unique requirement ID in the following format: "EUR_<Code>_<ID>", where "EUR" is a fixed string denoting **E**nd**-U**ser **R**equirement, "<Code>" denotes the category of the requirement, and finally "<ID>" is a counter which starts from 1 for each requirement category.

In the face-to-face interview the participants were asked to rank each requirement on a scale of 0-4, however, in the online surveys participants were simply asked to state whether a requirement was needed or not needed. Due to this difference in the ranking system between the face-to-face interview and the online survey, a common weighting system was designed to be able to merge and compare the results. This is explained below:

- **For the interview questionnaire**, those requirements that were ranked as **'Must have'** and **'Should have'** have been reclassified as **'Necessary'**, whereas those requirements ranked as **'Could have'** and **'Don't need'** have been reclassified as **'Not necessary'**.
- **For the online survey**, those requirements that were selected by the participant were classified as **'Necessary'**, whereas those requirements that were not selected by the participant were classified as **'Not necessary'**.

Therefore, the total number of **'Necessary'** and **'Not necessary'** rankings associated with each end-user requirement has been calculated by summing up the results from the interview questionnaire and the online survey. The final results are shown in percentages and proportion of respondents reporting them as 'Necessary' (e.g. 75% (3/4) means that 3 out of 4 responders, or 75% of the respondents, have deemed a given requirement 'Necessary').

4.2.1. Evacuation modelling input parameters

The key input parameters for evacuation models, EUR_Inp_1 to EUR_Inp_4 (see Table 12), were identified and presented to the participants. A set of input parameters need to be imported into the evacuation model in order to configure the initial scenario. Following is a brief description of these end-user requirements related to modelling inputs:

<u>EUR_Inp_1 — Population data (number of people and their distribution):</u> The number of people and their distribution in the area is an important input parameter. Population data can vary significantly depending on the time of the day, day of the week, and other factors such as holiday season when there could be a large influx of transient population, etc. Large scale evacuation models need to be able to import population data in a standard format that can be specified by end-users.

<u>EUR_Inp_2 — Available and Non-available (i.e. blocked) routes:</u> Wildfires and other hazards may block some of the generally available evacuation routes. Evacuation models need to be able to identify blocked routes to accurately calculate the evacuation times and evacuation dynamics. Furthermore, firefighters may block routes leading to affected routes or for firefighting purposes. Therefore, it is vital for evacuation models to be able to dynamically represent blocked routes.

<u>EUR_Inp_3 — Hazard data (e.g. areas affected by flood, wildfire, etc.):</u> When a hazard is involved evacuation models need to take into account the influence of the hazards on the evacuation

process. For example, the advancing wildfire fire front can make certain routes untenable but also the smoke that travels much further than the fire front can also hinder the evacuation process.

EUR_Inp_4 — Terrain data of routes: The nature of the terrain (paved/unpaved) and slope plays an important role in the walking speeds of people and in turn on the evacuation dynamics and the overall evacuation times.

Table 12 shows the percentages and proportions of the participants that considered the identified input parameters to be necessary. These results are reported for the interviews and online survey separately and then the total which merges the results from both.

Table 12: Proportion of responses that considered the input parameters as necessary.

Requirement ID	End-user requirement	Proportion		
		Interview questionnaire	Online survey	Total
EUR_Inp_1	Population data (number of people and their distribution).	**100% (7/7)**	**91% (10/11)**	**94% (17/18)**
EUR_Inp_2	Available and Non-available (i.e. blocked) routes.	**86% (6/7)**	**100% (11/11)**	**94% (17/18)**
EUR_Inp_3	Hazard data (e.g. areas affected by flood, wildfire, etc.).	**100% (4/4)**	**100% (11/11)**	**100% (15/15)**
EUR_Inp_4	Terrain data of routes.	**100% (6/6)**	**64% (7/11)**	**76% (13/17)**

Hazard data (EUR_Inp_3) appeared to be the most crucial input parameter to include in evacuation models, with all participants regarding it as relevant. Population data (EUR_Inp_1) and route availability (EUR_Inp_2) were highly demanded (94%) by the participants. Finally, terrain data (EUR_Inp_4) was less popular, though still a significant proportion of participants (76%) deemed it to be important for evacuation modelling. The reason terrain data was not considered to be highly important was probably due to the fact that they assume that the evacuation is largely undertaken using vehicles, and vehicles are less affected by the terrain characteristics of roads than pedestrians. However, the nature of the terrain may also impact vehicles, e.g. paved roads versus unpaved roads, very steep roads versus normal grade roads, etc.

Table 13 splits the responses according to the nationality of the participants.

Table 13: Proportion of responses grouped by nationality that considered the input parameters as necessary.

Requirement ID	End-user requirement	Proportion					
		AU	IE	IT	NL	ES	UK
EUR_Inp_1	Population data (number of people and their distribution).	**100% (10/10)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**0% (0/1)**	**100% (4/4)**

EUR_Inp_2	Available and Non-available (i.e. blocked).	**100% (10/10)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**75% (3/4)**
EUR_Inp_3	Hazard data (e.g. areas affected by flood, wildfire, etc.).	**100% (10/10)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**100% (4/4)**
EUR_Inp_4	Terrain data of routes.	**70% (7/10)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**0% (0/1)**	**100% (3/3)**

There was general consensus that using hazard data (EUR_Inp_3) as an input in evacuation models was necessary to best represent the process of evacuation with 100% of all participants considering it to be necessary.

Only one participant from the UK did not consider the availability of routes (EUR_Inp_2) as crucial. He considered that the decision to block certain routes occurs throughout the ongoing emergency, and needs to rely on the knowledge of local organisations and residents.

Only the participant from Spain that did not think that the population data (EUR_Inp_1) was a required feature. Since this response was obtained through the online survey, which did not have a provision for the participants to provide a reason for their choice, it is not clear why the participant thought that this important feature was not required.

In Australia, a significant amount of participants (30%) did not think it was necessary to model the terrain data (EUR_Inp_4). As mentioned before, the participants from Australia assumed that most wildfire evacuation takes place with vehicles and hence they do not think it to be important to include terrain data within large-scale evacuation models. Only the participant from Spain did not consider terrain data to be important. This could be because inhabitants from towns located in the midst of large wild areas would opt for evacuating by vehicle in the event of wildfire.

Key Finding for Evacuation Modelling 14: Required input parameters - At least three quarters (76%) of the participants believe that important input parameters for evacuation models include; population size and distribution, availability of evacuation routes, hazard front location and nature of terrain. There were no significant differences concerning each of these across all the countries that participated, with the exception of terrain type, which was considered least important by the Australian participants.

4.2.2. Evacuation modelling outputs

The key output parameters for evacuation models, EUR_Out_1 to EUR_Out_11 (see Table 14), were presented to the participants. These output parameters provide end-users with risk-informed guidance for response strategies. Following is a brief description of these end-user requirements related to modelling outputs:

<u>EUR_Out_1 — Time required for all agents in the simulation to reach a place of safety:</u> The time required for the entire population to reach a safety zone as measured from the start of the evacuation simulation run.

<u>EUR_Out_2 — Time required to clear certain parts:</u> A threatened urban area can be divided into subsections according to the time at which different parts within the urban area become non-tenable. This output parameter refers to the time required for the population to clear the affected area.

EUR_Out_3 — Visualisation of congestion points: Visualisation of simulation outputs allows the user to identify regions of congestion within the evacuation road network.

EUR_Out_4 — Total time that agents spend in congestion: Amount of time spent by a given agent in each of the congestion points.

EUR_Out_5 — Heat map demonstrating route utilisation: The evacuation road network is divided into colour-coded sections to indicate the different degrees of utilisation: highly utilised routes are in red, medium utilised routes in orange, and less utilised routes in blue.

Visualisation of simulation outputs in specific software applications enables easier interpretation of the simulation outcomes. To achieve this, evacuation models can incorporate the ability to visualise the simulation outputs in software platforms such as:

- EUR_Out_6 — ArcGIS.
- EUR_Out_7 — Google Earth.
- EUR_Out_8 — Interactive maps on web browsers.

Evacuation models can likewise incorporate the ability to visualise the simulation outputs in software programs such as:

- EUR_Out_9 — Word.
- EUR_Out_10 — Excel.
- EUR_Out_11 — PDF.

Table 14 shows the percentage and proportion of the participants that considered these output parameters as necessary. All these results are reported for the interviews, but only some of them are reported for the online survey. When results from methods are reported, they are merged to calculate the total proportion.

Table 14: Proportion of responses that considered the output parameters as necessary.

Requirement ID	End-user requirement	Proportion		
		Interview questionnaire	Online survey	Total
EUR_Out_1	Time required for all agents in the simulation to reach a place of safety.	**100% (7/7)**	**82% (9/11)**	**89% (16/18)**
EUR_Out_2	Time required to clear certain parts.	**100% (4/4)**	**91% (10/11)**	**93% (14/15)**
EUR_Out_3	Visualisation of congestion points.	**86% (6/7)**	**100% (11/11)**	**94% (17/18)**
EUR_Out_4	Total time that agents spend in congestion.	**71% (5/7)**	**27% (3/11)**	**44% (8/18)**
EUR_Out_5	Heat map demonstrating route utilisation.	**100% (7/7)**	**82% (9/11)**	**89% (16/18)**
EUR_Out_6	Ability to visualise the simulation outputs in ArcGIS.	**67% (4/6)**	**-**	**67% (4/6)**
EUR_Out_7	Ability to visualise the simulation outputs in Google Earth.	**71% (5/7)**	**-**	**71% (5/7)**

EUR_Out_8	Ability to visualise the simulation outputs in interactive maps on web browsers.	**100% (6/6)**	**-**	**100% (6/6)**
EUR_Out_9	Ability to visualise the simulation outputs in Word.	**57% (4/7)**	**-**	**57% (4/7)**
EUR_Out_10	Ability to visualise the simulation outputs in Excel.	**83% (5/6)**	**-**	**83% (5/6)**
EUR_Out_11	Ability to visualise the simulation outputs in PDF.	**86% (6/7)**	**-**	**86% (6/7)**

Most of the output parameters were very popular (at least 89%) except EUR_Out_4 (Total time that agents spend in congestion), which was considered to be the least important, with 44% of the participants requesting it. This could be because the participants consider the key result to be the identification of the areas of congestion (EUR_Out_3), and therefore the total time that agents actually spend in congestion (EUR_Out_4) is not considered necessary. It is possible that the participants did not realise that the total time spent by agents in congestion is also an important factor for determining evacuation efficiency and has an impact on the total evacuation times. The fact that a larger proportion of participants in the interview questionnaire (71%) suggested that it was relevant, compared to a lower proportion in the online participants (27%), may imply that the online participants did not realise the importance of this factor.

Another interesting result is that the time required to clear certain parts (EUR_Out_2) was slightly more requested (93%) than the time required for all agents to reach a place of safety (EUR_Out_1 - 89%). This is counter intuitive as the time required for all agents to reach safety should be more important output parameter than the time required to clear certain parts. The reason behind these results could be because in some areas staged evacuation is carried out where different regions are evacuated sequentially and hence authorities are more interested in the time required to clear certain parts than the overall evacuation time.

Moreover, the option to incorporate a heat map that displays the route utilisation (EUR_Out_5) was considered to be an important requirement with 89% of all participants considering this to be a necessary feature.

With regards to the visualisation and consultation of simulated outputs, participants highlighted clear preferences for some visualisation platforms over others. The ability to visualise the simulation outputs in interactive maps on web browsers (EUR_Out_8) was considered to be a necessary feature by all participants. The popularity of GIS systems in web domains, and especially in the field of disaster management and the nature of the problem —visualising urban scale evacuation—, makes the visualisation of the simulation outputs in interactive maps on web browsers (EUR_Out_8) a crucial feature. To a lesser extent, participants required outputs which are compatible with other GIS systems such as ArcGIS (67% - EUR_Out_6) and Google Earth (71% - EUR_Out_7). Finally, outputs were also highly demanded in software tools such as Excel (83% - EUR_Out_10) and PDF (86% - EUR_Out_11), and less demanded in Word (57% - EUR_Out_9).

Table 15 shows the percentage and proportion of participants that considered the output parameters (EUR_Out_1 – EUR_Out_11) to be necessary but this time with the responses split by nationalities of the participants.

Table 15: Proportion of responses grouped by nationality that considered the output parameters as necessary.

Requirement ID	End-user requirement	Proportion					
		AU	**IE**	**IT**	**NL**	**ES**	**UK**
EUR_Out_1	Time required for all agents in the simulation to reach a place of safety.	**90% (9/10)**	**100% (1/1)**	**100% (1/1)**	**0% (0/1)**	**100% (1/1)**	**100% (4/4)**
EUR_Out_2	Time required to clear certain parts.	**100% (10/10)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**0% (0/1)**	**100% (1/1)**
EUR_Out_3	Visualisation of congestion points.	**100% (10/10)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**75% (3/4)**
EUR_Out_4	Total time that agents spent in congestion.	**60% (6/10)**	**0% (0/1)**	**0% (0/1)**	**0% (0/1)**	**0% (0/1)**	**50% (2/4)**
EUR_Out_5	Heat map demonstrating route utilisation	**90% (9/10)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**0% (0/1)**	**100% (4/4)**
EUR_Out_6	Ability to visualise the simulation outputs in ArcGIS.	**50% (2/4)**	**-**	**-**	**-**	**-**	**100% (2/2)**
EUR_Out_7	Ability to visualise the simulation outputs in Google Earth.	**75% (3/4)**	**-**	**-**	**-**	**-**	**67% (2/3)**
EUR_Out_8	Ability to visualise the simulation outputs in interactive maps on web browsers.	**100% (4/4)**	**-**	**-**	**-**	**-**	**100% (2/2)**
EUR_Out_9	Ability to visualise the simulation outputs in Word.	**50% (2/4)**	**-**	**-**	**-**	**-**	**67% (2/3)**
EUR_Out_10	Ability to visualise the simulation outputs in Excel.	**100% (3/3)**	**-**	**-**	**-**	**-**	**67% (2/3)**
EUR_Out_11	Ability to visualise the simulation outputs in PDF.	**75% (3/4)**	**-**	**-**	**-**	**-**	**100% (3/3)**

The participant from the Netherlands regarded the time required to clear certain parts (EUR_Out_2) as necessary, and regarded the total time to evacuate the entire population (EUR_Out_1) as not necessary, probably bearing in mind sequential or staged evacuation strategies.

The response from the only participant from Spain is the opposite as he considered the total time to evacuate (EUR_Out_1) to be necessary and the time required to clear certain parts (EUR_Out_2) as not necessary. However, it should be noted that majority of the total participants thought both of them to be necessary (89% and 93% respectively).

The output feature of displaying a heat map showing route utilisation (EUR_Out_5) was well received by most of participants except for one participant from Australia and one from Spain. Participants from all nationalities concurred with the time spent in congestion being the least relevant.

With regards to the visualisation and consultation of simulated outputs, the preferences of the participants from Australia and the UK coincided to a great extent. Along these lines, it is worth commenting briefly how their preferences differed with respect to the use of GIS systems:

Participants from both countries deemed as crucial the visualisation of simulation outputs on a web browser (EUR_Out_8). However, compatibility with ArcGIS (EUR_Out_6) was requested more in the UK than in Australia (100% versus 50%), denoting that they may employ more ArcGIS software for disaster management purposes. Finally, compatibility with Google earth (EUR_Out_7) was requested more in Australia than in the UK (75% versus 67%), denoting their interest for web reference tools during emergencies.

Key Finding for Evacuation Modelling 15: Requested output parameters - With the exception of two output factors (time spent in congestion and output parameters displayed in WORD) all the output factors suggested were considered to be of significance. This is an important finding as it highlights important evacuation model output parameters that will be of value to emergency managers.

4.2.3. Use of evacuation models on portable electronic devices

Two portable electronic devices that could be used to configure, run and display the evacuation simulation, EUR_Dev_1 to EUR_Dev_2 (see Table 18), were presented to the participants. While evacuation models are basically designed to be used in computers or laptops, adapting them to be used on portable handheld devices can enhance their utility in a decision making environment. In this sense, evacuation models can incorporate the ability to specify scenario inputs and review the simulation outputs using electronic devices such as:

- Tablets — EUR_Dev_1.
- Mobiles — EUR_Dev_2.

Table 16 shows the percentage and proportion of the responses that considered these electronic devices to be necessary. These requirements were only presented in the interview questionnaire.

Table 16: Proportion of responses that considered the electronic devices as necessary.

Requirement ID	End-user requirement	Proportion
		Interview questionnaire
EUR_ Dev_1	Ability to specify scenario inputs and review results on tablets.	**71% (5/7)**
EUR_ Dev_2	Ability to specify scenario inputs and review results on mobiles.	**29% (2/7)**

As observed in Table 16, participants shower greater preference for reviewing the simulated results on tablets (EUR_ Dev_1) over reviewing them on mobile phones (EUR_ Dev_2), with 71% and 29% of the participants regarding it as relevant respectively.

Table 17 splits the responses according to the nationality of the participants.

Table 17: Proportion of responses grouped by nationality that considered the modelling capabilities as necessary.

Requirement ID	End-user requirement	Proportion	
		AU	UK
EUR_ Dev_1	Ability to specify scenario inputs and review results on tablets.	**100% (4/4)**	**33% (1/3)**
EUR_ Dev_2	Ability to specify scenario inputs and review results on mobiles.	**25% (1/4)**	**33% (1/3)**

While all the participants from Australia welcomed the use of evacuation models on tablets (EUR_ Dev_1), only one to a third (33%) of the participants in England considered it as important. These results coincide with the general interest they have for the use of models: participants from Australia are the ones that expressed more interest in the use of the evacuation models, and so are they the ones that express a greater interest in extending their utility to tablet devices. On the other hand, both the participants from Australia and the UK gave little relevance to using evacuation models in mobile phones (EUR_ Dev_2), with 25% and 33% approval, respectively. The consideration expressed by the Australians is so low in this case to emphasize their preference for tablets over mobile phones. However, the response of the participants may have been based on a lack of knowledge concerning how portable devices could be used in real-time applications by authorities in the field to update evacuation scenario specifications e.g. by identifying that a route had been compromised and so was no longer available.

Key Finding for Evacuation Modelling 16: Mobile devices - While having an ability to display and interact with evacuation model input/output on tablet devices was considered a valuable feature by Australian participants, this was not considered an important feature for UK participants. The participants from neither region felt it was necessary to display the results on mobile phones. However, participant responses to this question may have been biased by a lack of knowledge of how portable devices could be used in real-time applications by authorities in the field to update evacuation simulations by for example identifying routes that had been compromised.

4.2.4. Routing features in pedestrian and vehicle evacuation

The key evacuation routing features in pedestrian evacuation, EUR_Rou_1_Ped to EUR_Rou_8_Ped, and vehicle evacuation, EUR_Rou_1_Veh to EUR_Rou_8_Veh, (see Table 18), were presented to the participants. Evacuation models need to represent agent decision-making and behaviour, thereby enabling appropriate movement of evacuating agents (pedestrians and vehicles) across the road network. Following is a brief description of these end-user requirements related to routing features:

EUR_Rou_1_Ped and EUR_Rou_1_Veh — Utilise the shortest route: Agents select the shortest distance route to the nearest refuge location.

EUR_Rou_2_Ped and EUR_Rou_2_Veh — Consider the capacity of routes in agent route selection: Agents select routes with higher capacity and not just distance.

EUR_Rou_3_Ped and EUR_Rou_3_Veh — Minimisation of the overall evacuation times: Agents utilise routes that minimise the total evacuation time.

EUR_Rou_4_Ped and EUR_Rou_4_Veh — Utilisation of routes with uniform capacity: Agents select routes that do not become narrow and wide at different locations.

EUR_Rou_5_Ped and EUR_Rou_5_Veh — Utilisation of the safest routes: Agents select routes which take them effectively away from the danger, e.g. fire, flood water, debris, etc., even at the cost of increasing evacuation times.

EUR_Rou_6_Ped — Utilisation of routes with gentler slopes: Agents select routes with gentle slope and avoid routes with steep slopes. This only applies to pedestrian evacuation.

EUR_Rou_7_Ped and EUR_Rou_7_Veh — Consider the nature of the terrain of the routes: Agents select paved and well-maintained routes rather than unpaved and rough routes.

EUR_Rou_8_Ped and EUR_Rou_8_Veh — Evacuation guidance: The evacuation process is assisted by marshals advising evacuees on what routes to utilise, when to start evacuating…

Table 18 shows the percentage and proportion of the responses that considered these routing features to be necessary. These requirements were only presented in the interview questionnaire.

Table 18: Proportion of responses that considered the routing features as necessary.

Requirement ID	End-user requirement	Proportion
		Interview questionnaire
EUR_Rou_1_Ped	Utilisation of the shortest route.	**86% (6/7)**
EUR_Rou_1_Veh		**86% (6/7)**
EUR_Rou_2_Ped	Consider the capacity of routes in agent route selection.	**57% (4/7)**
EUR_Rou_2_Veh		**86% (6/7)**
EUR_Rou_3_Ped	Minimisation of the overall evacuation times.	**86% (6/7)**
EUR_Rou_3_Veh		**100% (7/7)**
EUR_Rou_4_Ped	Utilisation of routes with uniform capacity.	**57% (4/7)**
EUR_Rou_4_Veh		**71% (5/7)**
EUR_Rou_5_Ped	Utilisation of the safest routes.	**100% (7/7)**
EUR_Rou_5_Veh		**100% (7/7)**
EUR_Rou_6_Ped	Utilisation of routes with gentler slopes.	**43% (3/7)**
EUR_Rou_7_Ped	Consider the nature of the terrain of the routes.	**57% (4/7)**
EUR_Rou_7_Veh		**50%**

		(3/6)
EUR_Rou_8_Ped	Evacuation guidance.	**0% (0/4)**
EUR_Rou_8_Veh		**0% (0/4)**

For vehicle based evacuation, the agent based routing decision making features that were considered most important, in order of priority was, agents selecting routes based on; safety (100%), minimise evacuation time (100%), shortest distance (86%), route capacity (86%), and uniform capacity (71%).

For pedestrian based evacuation, the agent based routing decision making features that were considered most important, in order of priority was, agents selecting routes based on; safety (100%), minimise evacuation time (86%), shortest distance (86%), route capacity (57%) and uniform capacity (57%). Thus the ranked order of the route selection capabilities for both pedestrian and vehicle based evacuation are identical.

The utilisation of routes with gentler slopes (EUR_Rou_6_Ped), which was a requirement that only applied to pedestrian modelling, was given little consideration (43%) by the participants.
Finally, evacuation guidance assisted by marshals (EUR_Rou_8_Ped and EUR_Rou_8_Veh) was considered irrelevant for modelling approaches, with no participant regarding it as relevant neither in pedestrian nor in vehicle modelling. The rationale behind this lack of interest in guidance features is to avoid underestimations on the evacuation time window. Thus, if the evacuation simulation failed to generate precise estimates, it would occur on the conservative side. In the same manner, when using wildfire models they would normally want to obtain the outcomes of free fire spread, without including the suppression efforts that would underestimate the extent of propagation. However, this consideration only takes into account of marshals redirecting agents to optimise evacuation times. In some situations, marshals redirecting agents may be due to the route being considered unsafe. Table 19 splits the responses according to the nationality of the participants.

Table 19: Proportion of responses grouped by nationality that considered the routing features as necessary.

Requirement ID	**End-user requirement**	**Proportion**	
		Interview questionnaire	
		AU	**UK**
EUR_Rou_1_Ped	Utilisation of the shortest route.	**75% (3/4)**	**100% (3/3)**
EUR_Rou_1_Veh		**100% (4/4)**	**67% (2/3)**
EUR_Rou_2_Ped	Consider the capacity of routes in agent route selection.	**50% (2/4)**	**67% (2/3)**
EUR_Rou_2_Veh		**100% (4/4)**	**67% (2/3)**
EUR_Rou_3_Ped	Minimisation of the overall evacuation times.	**75% (3/4)**	**100% (3/3)**
EUR_Rou_3_Veh		**100% (4/4)**	**100% (3/3)**
EUR_Rou_4_Ped	Utilisation of routes with uniform capacity.	**50% (2/4)**	**67% (2/3)**
EUR_Rou_4_Veh		**75% (3/4)**	**67% (2/3)**
EUR_Rou_5_Ped	Utilisation of the safest routes.	**100% (4/4)**	**100% (3/3)**

EUR_Rou_5_Veh		**100% (4/4)**	**100% (3/3)**
EUR_Rou_6_Ped	Utilisation of routes with gentler slopes.	**25% (1/4)**	**67% (2/3)**
EUR_Rou_7_Ped	Consider the nature of the terrain of the routes.	**50% (2/4)**	**67% (2/3)**
EUR_Rou_7_Veh		**33% (1/3)**	**67% (2/3)**
EUR_Rou_8_Ped	Evacuation guidance.	**0% (0/4)**	**-**
EUR_Rou_8_Veh		**0% (0/4)**	**-**

Similar preferences were expressed by participants from Australia and the UK for the most popular agent based route selection capability i.e. an ability for agents to select the safest route, either for pedestrian or vehicle based evacuation. Agent route selection based on minimising evacuation time was the second most popular route selection capability. After these two features, there was no clear favourites amongst the other capabilities with the exception of shortest distance selected by the UK participants for pedestrian based evacuation simulation.

Key Finding for Evacuation Modelling 17: Agent route selection - For both pedestrian and vehicle based evacuation simulation, evacuation managers suggested that agent route selection decision making algorithms should be based on an ability for agents to select routes based on, in order of priority, safety, minimising evacuation time, minimising evacuation distance, route capacity, and uniform capacity. There was no difference between the UK and Australian preferences for the top two approaches.

4.2.5. Evacuation simulation performance factors

The key evacuation simulation performance factors, EUR_Per_1 to EUR_Per_4 (see Table 20), were presented to the participants. End-users were in this case asked to assess the appropriateness of different performance factors in the operational management of evacuation situations. There are two fundamental aspects that directly affect the usefulness of evacuation model predictions: computational speed and accuracy. Ideally, evacuation models should provide fast results with high accuracy; however, they have limitations in power and computational capacities. In light of this, evacuation models can be fine-tuned to generate the desired combined levels of computational speed with accuracy:

EUR_Per_1 — Fast results with low accuracy.

EUR_Per_2 — Slow results with high accuracy.

EUR_Per_3 — Reasonably fast results with reasonable accuracy.

EUR_Per_4 — First provide fast results with low accuracy followed by slower results with high/reasonable accuracy.

Table 20 shows the percentage and proportion of the responses that considered these performance factors to be necessary. These requirements were only presented in the interview questionnaire.

Table 20: Proportion of responses that considered the simulation performance factors as necessary.

Requirement ID	End-user requirement	Proportion
		Interview questionnaire
EUR_Per_1	Fast results with low accuracy.	**33% (2/6)**
EUR_Per_2	Slow results with high accuracy.	**50% (3/6)**
EUR_Per_3	Reasonably fast results with reasonable accuracy.	**57% (4/7)**
EUR_Per_4	First provide fast results with low accuracy followed by slower results with high/reasonable accuracy.	**71% (5/7)**

The preferences of the participants when balancing between speed and was not very evident. In general, participants preferred to get slow results with high accuracy (EUR_Per_2 – 50%) over fast results with low accuracy (EUR_Per_1 – 33%). Nevertheless, participants were more inclined to regard the other two options provided to them.

The option that had greatest support was to first provide fast results with low accuracy followed by slower results with high/reasonable accuracy (EUR_Per_4 – 71%); whereas the second was to get reasonably fast results with reasonable accuracy (EUR_Per_3 – 57%).

Table 21 splits the responses according to the nationality of the participants.

Table 21: Proportion of responses grouped by nationality that considered the simulation performance factors as necessary.

Requirement ID	End-user requirement	Proportion	
		AU	UK
EUR_Per_1	Fast results with low accuracy.	**33% (1/3)**	**33% (1/3)**
EUR_Per_2	Slow results with high accuracy.	**0% (0/3)**	**100% (3/3)**
EUR_Per_3	Reasonably fast results with reasonable accuracy.	**50% (2/4)**	**67% (2/3)**
EUR_Per_4	First provide fast results with low accuracy followed by slower results with high/reasonable accuracy.	**75% (3/4)**	**67% (2/3)**

Dissimilar concerns were more evident in this case between the participants from Australia and the UK. Participants from Australia seemed to be more concerned with simulation speed than accuracy, while for the participants from UK it was opposite. This denotes that in Australia emergency services need to take quick decisions to be prepared when unpredictable fire behaviour occurs, whereas in the UK they would wait a bit longer in exchange for more reliable results. An example of that is that all the participants from the UK asserted that they could wait to obtain slow results if the accuracy is high (EUR_Per_2), but none of the participants from Australia concurred with this view.

If the model first provides fast results with low accuracy followed by slower results with high/reasonable accuracy (EUR_Per_4), participants from Australia are generally more agree than participants from the UK (75% vs 67%). However when the model provides reasonably fast results with reasonable accuracy (EUR_Per_3), participants from Australia are less agreeable than participants from the UK (50% vs 67%).

Key Finding for Evacuation Modelling 18: Speed versus accuracy - Evacuation managers in Australia and UK had very different views on the importance of speed versus accuracy. When it comes to speed versus accuracy, evacuation managers in the UK preferred high accuracy at the expense of speed, while Australians preferred fast results over accuracy. However, evacuation managers from both regions agreed that a two stage process would be acceptable, where fast low accuracy results were first provided, enabling decision makers to make some decisions, followed by more accurate results in slower time. Clearly, if evacuation model predictions are to have any impact on decision making, they need to be produced quite quickly with as much accuracy as possible.

4.2.6. Terrain modelling factors in pedestrian evacuation

The key terrain modelling features, EUR_Ter_1 to EUR_Ter_3 (see Table 22), were presented to the participants. Terrain modelling factors need to be considered to accurately represent the performance of pedestrians walking over various types of surfaces.

Firstly, terrain features can be modelled according to the gradient of terrain:

<u>EUR_Ter_1 — Model slopes (uphill/downhill) of routes:</u> Slope angles have an impact on walking speeds of evacuees. Therefore, ascending and descending slopes at different inclinations need to be taken into consideration to better understand the pedestrian mobility in outdoor environments

Secondly, terrain features can be modelled according to the nature of terrain:

<u>EUR_Ter_2 — Model paved/unpaved roads:</u> The nature of terrain can be simply classified as paved or unpaved. Paved terrains improve pedestrian walkability with respect to unpaved terrains.

<u>EUR_Ter_3 — Model land cover type on unpaved grounds:</u> Unpaved roads can further classified based on the land cover type (e.g. paved, gravel, sand, grass…) as well as take into account various elements in the landscape (e.g. density of grass, presence of shrubs, slash remains…).

Table 22 shows the percentage and proportion of the responses that considered these terrain modelling factors to be necessary. These requirements were only presented in the interview questionnaire.

Table 22: Proportion of responses that considered the terrain features as necessary.

Requirement ID	End-user requirement	Proportion Interview questionnaire
EUR_Ter_1	Model slopes (uphill/downhill) of routes.	**83% (5/6)**
EUR_Ter_2	Model paved/unpaved roads.	**66% (4/6)**
EUR_Ter_3	Model land cover type on unpaved grounds.	**50% (3/6)**

Though there were not great differences with regards to the modelling of terrain-related features, the consideration of slopes (EUR_Ter_1) was the best valued (83%). On the other hand, there were more participants that considered sufficient modelling the nature of the road as simply paved or unpaved (EUR_Ter_2 – 66%) than participants that considered that further details on the land cover type (e.g. grass, gravel… type) for unpaved grounds (EUR_Ter_3 – 50%) were necessary.

Table 23 splits the responses according to the nationality of the participants.

Table 23: Proportion of responses grouped by nationality that considered the terrain features as necessary.

Requirement ID	**End-user requirement**	**Proportion**	
		AU	**UK**
EUR_Ter_1	Model slopes (uphill/downhill) of routes.	**75% (3/4)**	**100% (2/2)**
EUR_Ter_2	Model paved/unpaved roads.	**50% (2/4)**	**100% (2/2)**
EUR_Ter_3	Model land cover type on unpaved grounds.	**50% (2/4)**	**50% (1/2)**

Because the above modelling features are only related to pedestrian evacuation, the participants from Australia showed less concern for them than the participants from the UK. The greatest differences were observed with the representation of slopes (EUR_Ter_1) and paved/unpaved roads (EUR_Ter_2), which was highly regarded in the UK (100% in both cases), and relatively regarded in Australia (75% and 50% respectively). Finally, incorporating further details on the land cover type (EUR_Ter_3) was equally considered by the participants from Australia and the UK (50%).

Key Finding for Evacuation Modelling 19: Representing terrain features in pedestrian evacuation models - Evacuation managers in Australia and UK both agreed that when simulating pedestrian evacuation it was essential that the model was able to take into consideration the impact of route gradient. However, the need to represent the nature of the route surface was less strongly supported. All of the UK but only half of the Australian participants thought it was important to take into consideration the impact of unpaved surfaces on evacuation performance. Furthermore, 50% of both the UK and Australian participants felt it would be important to consider the impact of the nature of the unpaved surface on evacuation performance.

4.2.7. Integration with hazard simulation tools

The nature of the coupling between wildfire and evacuation simulation tools was explored with participants. The key features of wildfire simulation tools, EUR_Haz_1 to EUR_Haz_4 (see Table 24) that could be coupled within evacuation simulations in order to evaluate the impact on evacuation were presented to the participants. The following is a brief description of these end-user requirements related to the integration of hazard simulation tools:

<u>EUR_Haz_1 — Ability to seamlessly interact with hazard simulation software</u>: The dynamics of fire is actually subject to enormous variability, mainly due to the speed and direction of the wind driving the propagation of fire. As a result, in scenarios with dynamic forecast weather conditions wildfire models may need to constantly recalculate the fire spread predictions. Due to this evacuation models require a seamless integration with simulation components of wildfire models.

<u>EUR_Haz_2 — Model the effect of fire spread across urban/rural areas:</u> The progression fire is subject to various factors associated with the topography, fuel, and meteorology. Wildfire simulation models need to account for these factors to predict the time-evolving fire perimeter

across the landscape. Exposure to convective and radiative heat from the fire flames can cause severe injuries or death.

EUR_Haz_3 — Model the effect of smoke spread across urban/rural areas: Smoke dispersion from the fire ahead of the fire front can severely reduce visibility on evacuation routes making evacuation dangerous (causing delays or fatal accidents) or impossible while inhalation of smoke products (particulates, toxic and irritant gases) can cause discomfort, serious injury and death.

EUR_Haz_4 — Model the effect of spotting fire across urban/rural areas: Flying embers from spotting fires can be blown at some distance ahead of a fire's front, falling on evacuation routes used by people and igniting new spot fires and even creating new fire fronts. Similar to smoke, spotting fire can led to undesired accidents during the evacuation process.

Table 24 shows the percentage and proportion of the responses that considered these fire hazard simulated data to be necessary. All these results are reported for the online survey, but only some of them are reported for the interview questionnaire. When results from methods are reported, they are merged to calculate the total proportion.

Table 24: Proportion of responses that considered the wildfire simulation features as necessary.

Requirement ID	**End-user requirement**	**Proportion**		
		Interview questionnaire	**Online survey**	**Total**
EUR_Haz_1	Ability to seamlessly interact with hazard simulation software.	**-**	**91% (10/11)**	**91% (10/11)**
EUR_Haz_2	Model the effect of fire spread across urban/rural areas.	**100% (7/7)**	**100% (11/11)**	**100% (18/18)**
EUR_Haz_3	Model the effect of smoke spread across urban/rural areas.	**86% (6/7)**	**82% (9/11)**	**83% (15/18)**
EUR_Haz_4	Model the effect of spotting fire across urban/rural areas.	**71% (5/7)**	**73% (8/11)**	**72% (13/18)**

The majority of participants remarked that they need to interact with the simulation of hazard predictive models seamlessly during an ongoing incident (EUR_Haz_1 – 91%). Currently, there are a few approaches that provide a loose integration between evacuation and wildfire simulation tools, but a seamless integration that automatically adjusts to spatiotemporal dynamics of both simulation is still lacking.

With regards to modelling features provided by wildfire models, the spread of fire across threatened areas (EUR_Haz_2) was considered as the most crucial requirement to perform the integration between fire and evacuation models. All participants from both the interview questionnaire and the online survey regarded it as relevant. The spread of smoke (EUR_Haz_3) was also given remarkable importance (83%). The least relevance was given for modelling spotting fire due to firebrands (EUR_Haz_4 – 72%).

Table 25 shows the percentage and proportion of participants that considered the integration of fire hazard data (EUR_Haz_1 – EUR_Haz_4) to be necessary but this time with the responses split by nationalities of the participants.

Table 25: Proportion of responses grouped by nationality that considered the wildfire simulation features as necessary.

Requirement ID	End-user requirement	Proportion					
		AU	**IE**	**IT**	**NL**	**ES**	**UK**
EUR_Haz_1	Ability to seamlessly interact with hazard simulation software.	**100% (6/6)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**0% (0/1)**
EUR_Haz_2	Model the effect of fire spread across urban/rural areas.	**100% (10/10)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**100% (4/4)**
EUR_Haz_3	Model the effect of smoke spread across urban/rural areas.	**80% (8/10)**	**0% (0/1)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**100% (4/4)**
EUR_Haz_4	Model the effect of spotting fire across urban/rural areas.	**90% (9/10)**	**0% (0/1)**	**100% (1/1)**	**100% (1/1)**	**0% (0/1)**	**50% (2/4)**

Only the participant from the UK considered that the interaction with hazard simulation tools (EUR_Haz_1) during ongoing emergency was not necessary. It is understandable that the only objection to this requirement comes from a participant from a country where large catastrophic wildfires are rarer rather than from a country where such wildfires are more frequent, such as Australia, Italia or Spain.

With regards to modelling features provided by wildfire models, all the participants agreed on the importance of modelling the spread of fire (EUR_Haz_2), but not all had the same opinion regarding smoke (EUR_Haz_3) and spotting fire (EUR_Haz_4). Participants in Australia were more concerned about modelling spotting fire (EUR_Haz_4 – 90%) than modelling smoke (EUR_Haz_3 – 80%). The rationale behind this adoption relies on the argument that, in the event of strong winds, spotting fire is a common phenomenon that contributes significantly to the spread of fire, in part due to the shedding bark of eucalyptus trees. Along these lines, participants from the UK showed opposite preferences, with smoke (EUR_Haz_3) being considered more relevant than spotting fire (EUR_Haz_4) (100% vs 50%). This is because in this country spotting fire spread mechanisms are more rarely observed.

Furthermore, participants from Ireland and from Spain were the only ones that did not give any importance to modelling spotting fire, whereas only the participant from Ireland downplayed the modelling of smoke. Since these responses were obtained through the online survey, it is not clear why the participants thought that this important feature was not required.

Key Finding for Evacuation Modelling 20: Integration with wildfire models – The vast majority of the participants (91%) agreed that wildfire and evacuation models should be coupled and also that the impact of the smoke produced by wildfires should be represented within evacuation models (83%) as these can compromise evacuation routes.

4.2.8. Real-time incident management

The key evacuation related capabilities that could be used in real-time management applications, EUR_Tim_1 to EUR_Tim_5 (see Table 26), were presented to the participants. It is noted that modelling capabilities that can be used in real-time incident management applications can also be used in training applications. The following is a brief description of these end-user requirements related to real-time management applications:

EUR_Tim_1 — Ability to play-back previously run evacuation simulations: An ability to play-back the simulated scenario, essentially going back in time, enabling the evacuation manager to examine the potential cause of issues that may impact evacuation efficiency.

EUR_Tim_2 — Ability to rapidly configure new scenarios and run the evacuation simulation live during the incident: Rapid configuration of the evacuation scenario enables the user to set up input parameters (e.g. number of people and their distribution, routes to utilise, presence of hazards, etc.) for multiple evacuation simulations. By running the simulation live the end-user can gain the ability to monitor and manage the process of evacuation with the aid of simulation tools.

EUR_Tim_3 — Ability to dynamically change certain parameters during the simulation: Readjusting simulation parameters in the course of the simulation (e.g. response times for certain regions, capacity of safe refuges, etc.) enables the user to prepare for quick and efficient decision making in the presence of real-time evacuation information.

EUR_Tim_4 — Ability to adjust the evacuation procedures based on real field observations: Emergency situations are very dynamic, with conditions that influence the outcome of an evacuation changing during the incident e.g. an evacuation route may become unexpectedly compromised e.g. falling tree, bridge collapse, etc., which will impact evacuation efficiency. The evacuation simulation needs to adjust to these conditions. An evacuation model that allows the user to adjust the evacuation procedures based on real field observations would greatly enhance its usability.

EUR_Tim_5 — Ability to adjust the evacuation procedures based on deployment decisions made by the evacuation commanders: Unforeseen circumstances in the course of the incident (e.g. hazard impact, evacuation performance, availability resources…) may prompt incident commanders to re-direct management actions at the tactical and strategical levels. An evacuation model that allows the user to adjust the evacuation procedures based on the deployment decisions made by the evacuation commanders would improve its usefulness in an adaptive management scenario.

EUR_Tim_6 — Ability to adjust the evacuation procedures based on the allocation of resources: The redistribution, availability, and utilisation of resources may change in space and time through the incident. Moreover, Incident Commanders may want to test the outcomes of different evacuations scenarios based on the employment of resources. An evacuation model that allows the user to adjust the evacuation procedures based on the allocation of resources would enhance the setting of more realistic spatial parameters in the simulation.

EUR_Tim_7 — Ability to adjust the evacuation procedures based on live input such as sensors and satellite imagery: The development of new methods for data acquisition, especially sensors and satellite imagery, can be a qualitative leap in the prediction of disaster scenarios. An evacuation model that allows the user to adjust the evacuation procedures based on live input from sensors and satellite imagery would significantly improve the reliability of model results.

EUR_Tim_8 — Ability to compare model inputs/outputs of multiple scenarios: Incident Commanders may want to run a number of what-if scenarios to assess how people react to different evacuation procedures and hazards. By comparing model inputs/outputs of multiple scenarios the user can evaluate the appropriateness of various evacuation strategies given their different outcomes.

EUR_Tim_9 — Ability to simulate faster than real-time: During real-time emergencies incident commanders need to take quick decisions on whether and when to evacuate in order to protect people from catastrophe. Along these lines, faster than real-time simulation performance anticipates the impact of fire on the at-risk communities, enabling early response and informed decision-making.

EUR_Tim_10 — Ability to be incorporated into a Common Operating Picture (COP): COPs (in Australia) and JOPs (in the UK) are used by emergency organisations to share information and capabilities in the management of live incidents. The integration of evacuation models within these management systems would provide valuable information derived from the simulated outputs (e.g. the availability of routes, the location of critical regions…)

EUR_Tim_11 — Ability to visualise the simulation results in GIS systems: GIS systems (e.g. ArcGIS, QGIS, Google Earth…) are frequently used by emergency organisations to visualise the propagation of the hazard and to identify communities likely to be affected. In view of this, evacuation models used for real-time management purposes need to generate their simulated outputs in file formats that can be directly visualised in GIS systems.

Table 26 shows the percentage and proportion of the responses that considered these real-time management applications to be necessary. Some of these requirements were only presented in the online survey, whereas some other were only presented in the interview questionnaire.

Table 26: Proportion of responses that considered the modelling capabilities for live management situations as necessary.

Requirement ID	End-user requirement	Proportion	
		Interview questionnaire	**Online survey**
EUR_Tim_1	Ability to play back previously run evacuation simulations.	-	**55% (6/11)**
EUR_Tim_2	Ability to rapidly configure new scenarios and run the evacuation simulation live during the training session.	-	**73% (8/11)**
EUR_Tim_3	Ability to dynamically change certain parameters during the simulation.	-	**91% (10/11)**
EUR_Tim_4	Ability to adjust the evacuation procedures based on real-time observations.	**86% (6/7)**	-
EUR_Tim_5	Ability to adjust the evacuation procedures based on deployment decisions made by the evacuation commanders.	**100% (7/7)**	-

EUR_Tim_6	Ability to adjust the evacuation procedures based on allocation of resources.	**100% (7/7)**	**-**
EUR_Tim_7	Ability to adjust the evacuation procedures based on live input such as sensors and satellite imagery.	**71% (5/7)**	**-**
EUR_Tim_8	Ability to compare model inputs/outputs of multiple scenarios.	**86% (6/7)**	**-**
EUR_Tim_9	Ability to simulate faster than real-time.	**-**	**82% (9/11)**
EUR_Tim_10	Ability to be incorporated into a Common Operating Picture (COP).	**-**	**100% (11/11)**
EUR_Tim_11	Ability to visualise the simulation results in GIS systems.	**-**	**100% (11/11)**
EUR_Tim_12	Generate scenarios that can be used in community education and awareness.	**-**	**Requirement suggested by the participants**
EUR_Tim_13	Ability to provide different modes to view the evacuation simulations — 2D, 3D, and virtual reality— and being able to switch between these modes.	**-**	**Requirement suggested by the participants**
EUR_Tim_14	Feedback options, a real life like environment including sound.	**-**	**Requirement suggested by the participants**
EUR_Tim_15	Interact with hazards and contemplating the effects of different alarm times.	**-**	**Requirement suggested by the participants**
EUR_Tim_16	Ability to fast forward the simulation by hours or days.	**-**	**Requirement suggested by the participants**

The results reflect the participants' desire for extending the use of evacuation simulation tools for real-time incident applications. The participants recognised the importance of the ability for users to dynamically change certain parameters during the simulation (EUR_Tra_3 - 91%), such as agents' response times or the capacity of safe refuges. The ability to adjust these parameters based on deployment decisions made by the evacuation commanders (EUR_Tim_5) and the allocation of resources (EUR_Tim_6) were both highly demanded features with 100% of the participants requesting them. Participants also consider important to adjust the evacuation procedures based on real-time observations (86% - EUR_Tim_4) and available sensors and satellite imagery (71% - EUR_Tim_7)

Furthermore, participants also considered it was important to have the ability to compare model inputs/outputs of multiple scenarios (86% - EUR_Tim_8). The ability to rapidly configure new scenarios and run the evacuation simulation live during a training session (EUR_Tim_2) was considered slightly less significant (73%), as was the ability to play back simulations (EUR_Tim_1).

Finally, all participants pointed out that evacuation tools need to be incorporated into COP/JOP systems (EUR_Tim_10), and produce outputs that can be visualised in GIS systems (EUR_Tim_11), and still a great proportion (82%) indicated that they need to run simulations faster than real-time (EUR_Tim_9). Table 27 splits the responses according to the nationality of the participants.

Table 27: Proportion of responses grouped by nationality that considered the modelling capabilities for live management situations as necessary.

Requirement ID	End-user requirement	Proportion					
		AU	**IE**	**IT**	**NL**	**ES**	**UK**
EUR_Tim_1	Ability to play back previously run evacuation simulations.	**33% (2/6)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**0% (0/1)**	**100% (1/1)**
EUR_Tim_2	Ability to rapidly configure new scenarios and run the evacuation simulation live during the training session.	**50% (3/6)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**
EUR_Tim_3	Ability to dynamically change certain parameters during the simulation.	**83% (5/6)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**
EUR_Tim_4	Ability to adjust the evacuation procedures based on field observations.	**100% (4/4)**	**-**	**-**	**-**	**-**	**67% (2/3)**
EUR_Tim_5	Ability to adjust the evacuation procedures based on deployment decisions made by the evacuation commanders.	**100% (4/4)**	**-**	**-**	**-**	**-**	**100% (3/3)**
EUR_Tim_6	Ability to adjust the evacuation procedures	**100% (4/4)**	**-**	**-**	**-**	**-**	**100% (3/3)**

	based on allocation of resources.						
EUR_Tim_7	Ability to adjust the evacuation procedures based on live input such as sensors and satellite imagery.	**75% (3/4)**	**-**	**-**	**-**	**-**	**67% (2/3)**
EUR_Tim_8	Ability to compare model inputs/outputs of multiple scenarios.	**100% (4/4)**	**-**	**-**	**-**	**-**	**67% (2/3)**
EUR_Tim_9	Ability to simulate faster than real-time.	**83% (5/6)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**0% (0/1)**
EUR_Tim_10	Ability to be incorporated into a Common Operating Picture (COP).	**100% (6/6)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**
EUR_Tim_11	Ability to visualise the simulation results in GIS systems.	**100% (6/6)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**
EUR_Tim_12	Generate scenarios that can be used in community education and awareness.	**Requirement suggested by the participants**					
EUR_Tim_13	Ability to provide different modes to view the evacuation simulations — 2D, 3D, and virtual reality— and being able to switch between these modes.	**Requirement suggested by the participants**					

EUR_Tim_14	Feedback options, a real life like environment including sound.	**Requirement suggested by the participants**	**-**	**-**	**-**	**-**	**-**
EUR_Tim_15	Interact with hazards and contemplating the effects of different alarm times.	**-**	**-**	**Requirement suggested by the participants**	**-**	**-**	**-**
EUR_Tim_16	Ability to fast forward the simulation by hours or days.	**-**	**Requirement suggested by the participants**	**-**	**-**	**-**	**-**

Even though the preferences of the participants from different countries for real-time applications coincided to a great extent, the most significant differences arouse in the following requirements:

Along with the participant from Spain, most of the participants from Australia (66%) did not think that the play-back capability (EUR_Tim_1) was useful for real-time purposes. Since this response was obtained through the online survey, it is not clear why the participants thought that this important feature was not required. While the ability to rapidly configure new scenarios during real-time simulations (EUR_Tim_2) was considered as important by most of the participants, just half of the interviewees from Australia agreed.

Adjusting evacuation simulation procedures based on field observations (EUR_Tim_4) was more valued by the Australian participants than those from the UK (100% versus 67%), probably because for wildfire damages to be foreseeable, emergency services cannot just rely on the predictive tools, but require on-site observations to warn about rapid and sudden changes in fire behaviour.

It is worth commenting the comparison of model inputs/outputs for multiple scenarios (EUR_Cap_12) was also more highly valued by the Australian participants than those from the UK (100% versus 67%), denoting that emergency services want to compare a range of 'what-if' scenarios in order to account for the statistical variations of the unfolding event.

Additional requirements for real-time management applications were suggested by some of the participants. Participant from Australia suggested the practical applicability for community education and awareness (EUR_Tim_12), the possibility to differ through 2D, 3D, and VR visualizations (EUR_Tim_13), and the recreation of sound for a better representation of the real environment (EUR_Tim_14). The participant from Italy brought about the ability to compare the effects on the evacuation of different alarm times (EUR_Tim_15). Finally, the participant from Ireland required the ability to fast forward the simulated scenario by hours or days (EUR_Tim_16).

Key Finding for Evacuation Modelling 21: Capabilities required by a real-time evacuation modelling system – There was general agreement on the most desirable features that a real-time evacuation modelling system should have to assist incident managers. The most highly desirable features included an ability to dynamically change a simulation during the incident, including, changing population parameters, changing route availability (based on live input from the field or sensors), changing procedures due to resource allocation; coupling model output to the COP/JOP; faster than real-time performance and the ability to compare model outcomes for different scenarios. The participants also suggested that desirable features would include an ability to test the impact of different alarm options, using the modelling environment for local community education and having an ability to provide 2D, 3D and virtual reality graphical output.

4.2.9. Modelling vehicular evacuation

The key modelling capabilities for vehicle evacuation, EUR_Veh_1 to EUR_Veh_9 (see Table 28), were presented to the participants. The following is a brief description of these end-user requirements related to modelling vehicular evacuation:

<u>EUR_Veh_1 — Location of private vehicles and their capacity:</u> Private vehicles are usually the main form of mobility for the residents of Wildland-Urban Interface areas. Thus, capturing the location and capacity of private vehicles could help assign the number of people using this transportation means in the evacuation.

<u>EUR_Veh_2 — Location, availability and capacity of public transport services:</u> Public transport services may be an alternative when people do not have their own private vehicle or when the evacuation routes are not available. Therefore, evacuation models need to account for the location, availability, and capacity of the public transport services as well as expect the amount of people that will use them.

<u>EUR_Veh_3 — Travel time incurred by people leaving their starting locations and accessing public/private vehicles:</u> The total evacuation time of people using some transport mode need to compute the time required to access these transports. This corresponds to the time since the leave their start location until they reach the means of transport.

<u>EUR_Veh_4 — Loading time for private/public vehicles:</u> Time required for people to board private vehicles/public after reaching them. In private vehicles, it is the time people spend packing the car's boot, get the children on board… In public transport services it is the waiting time since they reach the departure location until the next bus, train or tram leaves.

<u>EUR_Veh_5 — Transport of evacuees by buses, fire engines, etc. to shelter/refuge locations:</u> When the population do not have any transportation means or are warned against using their private vehicles due to hazardous conditions, emergency managers may opt for providing their own transportation resources to assist in the evacuation. This would consist of buses, taxis, fire engines, helicopters that would facilitate the movement of people towards shelter locations.

<u>EUR_Veh_6 — Traffic management controls:</u> Traffic management controls consist of temporary measures to assist in the management of the evacuation. In this case evacuation models would incorporate marshal agents placed in specific locations with the purpose of supervising the process of evacuation (e.g. inform evacuees about shelter refugees available, prevent evacuees from using compromised routes, etc.).

<u>EUR_Veh_7 — Ability for vehicles to be diverted from routes with roads that are compromised or are about to be compromised:</u> The presence of fire or smoke can influence the movement of vehicles across the road network. Behaviour modelling applied to vehicles will lead to movement of traffic away from compromised areas.

<u>EUR_Veh_8 — Interaction between pedestrians and moving vehicles:</u> When both pedestrian and vehicle evacuation take place simultaneously in the simulated network, they interfere with each other and hence may slow down the evacuation process.

<u>EUR_Veh_9 — Interaction between incoming emergency vehicles and outgoing evacuating vehicles:</u> Traffic flows resulting from mass evacuation of vehicles leaving the threatened area may hinder the access of emergency vehicles (e.g. firefighters, medical services…) attempting to enter

the threatened area. These interactions may lead to congestion in areas with few and narrow roads, and irregular intersections. Therefore, evacuation models need to incorporate the ability to represent interactions between incoming and outgoing vehicle in such conditions.

Table 28 shows the percentage and proportion of the responses that considered these modelling capabilities to be necessary. These results are reported for the interviews and online survey separately and then the total which merges the results from both.

Table 28: Proportion of responses that considered the features and capabilities for modelling vehicles as necessary.

Requirement ID	**End-user requirement**	**Proportion**		
		Interview questionnaire	**Online survey**	**Total**
EUR_Veh_1	Location of private vehicles and their capacity.	**50% (2/4)**	**45% (5/11)**	**47% (7/15)**
EUR_Veh_2	Location, availability and capacity of public transport services.	**50% (2/4)**	**82% (9/11)**	**73% (11/15)**
EUR_Veh_3	Travel time incurred by people leaving their starting locations and accessing public/private vehicles.	**25% (1/4)**	**82% (9/11)**	**67% (10/15)**
EUR_Veh_4	Loading time for public/private vehicles.	**50% (2/4)**	**73% (8/11)**	**67% (10/15)**
EUR_Veh_5	Transport of evacuees by buses, fire engines, etc. to shelter/refuge locations.	**71% (5/7)**	**82% (9/11)**	**78% (14/18)**
EUR_Veh_6	Traffic management controls.	**86% (6/7)**	**91% (10/11)**	**89% (16/18)**
EUR_Veh_7	Ability for vehicles to be diverted from routes with roads that are compromised or are about to be compromised.	**100% (4/4)**	**91% (10/11)**	**93% (14/15)**
EUR_Veh_8	Interaction between pedestrians and moving vehicles.	**29% (2/7)**	**55% (6/11)**	**44% (8/18)**
EUR_Veh_9	Interaction between incoming emergency vehicles and outgoing evacuating vehicles.	**71% (5/7)**	**100% (11/11)**	**89% (16/18)**

The most popular features to represent the movement of evacuating vehicles are the ability to divert when a route is compromised (EUR_Veh_7 – 93%), and the interaction between incoming emergency vehicles and outgoing evacuating vehicles (EUR_Veh_9 – 89%). The former was considered as an essential feature to represent agent's movement and behaviour across the road network; while the latter was in relation to wildfires affecting rural areas with few exits and only one way in one way out, especially in roads over mountainous areas.
The two least favoured features were the location of private vehicles and their capacity (EUR_Veh_1 – 47%), and the interaction between pedestrians and moving vehicles (EUR_Veh_8 - 44%). Participants that disregarded the location of private vehicles and their capacity argued that such information is usually provided by the local municipality, which would provide them with an approximation of vehicles in the area depending on the time of year, local festivities, and special events. Nevertheless this information is a key parameter in specifying the evacuation scenario and so must be available to the evacuation model. The participants that disregarded the interaction between pedestrians and moving vehicles argued that in emergency situations the interaction of vehicles with pedestrian is not as relevant as the interaction with other vehicles. Table 29 splits the responses according to the nationality of the participants.

Table 29: Proportion of responses grouped by nationality that considered the features and capabilities for modelling vehicles as necessary.

Requirement ID	End-user requirement	Proportion					
		AU	**IE**	**IT**	**NL**	**ES**	**UK**
EUR_Veh_1	Location of private vehicles and their capacity.	**50% (5/10)**	**0% (0/1)**	**100% (1/1)**	**0% (0/1)**	**0% (0/1)**	**100% (1/1)**
EUR_Veh_2	Location, availability and capacity of public transport services.	**60% (6/10)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**
EUR_Veh_3	Travel time incurred by people leaving their starting locations and accessing public/private vehicles.	**70% (7/10)**	**100% (1/1)**	**100% (1/1)**	**0% (0/1)**	**0% (0/1)**	**100% (1/1)**
EUR_Veh_4	Loading time for public/private vehicles.	**60% (6/10)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**0% (0/1)**	**100% (1/1)**
EUR_Veh_5	Transport of evacuees by buses, fire engines, etc. to shelter/refuge locations.	**80% (8/10)**	**0% (0/1)**	**100% (1/1)**	**100% (1/1)**	**0% (0/1)**	**100% (4/4)**
EUR_Veh_6	Traffic management controls.	**100% (10/10)**	**100% (1/1)**	**0% (0/1)**	**100% (1/1)**	**100% (1/1)**	**75% (3/4)**
EUR_Veh_7	Ability for vehicles to be diverted from	**100% (10/10)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**0% (0/1)**	**100% (1/1)**

	routes with roads that are compromised or are about to be compromised.						
EUR_Veh_8	Interaction between pedestrians and moving vehicles.	**40% (4/10)**	**100% (1/1)**	**100% (1/1)**	**0% (0/1)**	**0% (0/1)**	**50% (2/4)**
EUR_Veh_9	Interaction between incoming emergency vehicles and outgoing evacuating vehicles.	**100% (10/10)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**100% (1/1)**	**50% (2/4)**

When split into nationalities the results show a great disparity, and hence it is difficult to discern clear patterns. In spite of this, it is worthwhile remarking a few observations:

The participant from Spain was the one that questioned more vehicle-related modelling features followed by the participant from the Netherlands.

Half of the participants from Australia (50%) considered that the location and capacity of private vehicles (EUR_Veh_1) were details unnecessary for a modelling approach. This consideration seemed to be shared by most of the participants, except for the ones from Italy and the UK. It is suggested that this response represents a misunderstanding on the part of some of the participants. Clearly, if the population are to make use of private vehicles for evacuation, it is essential that the models has initial locations of the private vehicles and their capacity. This is essential initial information for the model.

While the relevance of modelling public transport services (EUR_Veh_2) was considered highly relevant, it was questioned by some participants from Australia (just 60% considered it relevant). This is probably because in Australia evacuation mostly occurs by private vehicles, and so they would assume that most of people would have means to evacuate. Along these lines, participants clarified that they would only address it in particular contexts in which they had the knowledge that people do not have their vehicles to evacuate (e.g. touristic areas).

The travel time for people to reach public/private vehicles (EUR_Veh_3) and the loading time for vehicles (EUR_Veh_4) were downplayed by the participant from Spain. The rest of participants generally considered both relevant, except the participant from the Netherlands that downplayed the loading time. Amongst the participants from Australia, a slightly lower proportion regarded the travel time to means of transport (EUR_Veh_3 – 70%) and the loading time for vehicles (EUR_Veh_4 – 60%) as relevant.

Only the participants from Spain and Ireland regarded providing evacuees with transport means to shelter locations (EUR_Veh_5) as not important. A high proportion of the participants from Australia (up to 80%) considered this to be relevant.

Traffic management controls (EUR_Veh_6) was generally well considered, only being considered of low relevance by the participant from Italy and one the participants from the UK.

As commented previously, the ability for vehicles to be diverted from compromised routes (EUR_Veh_7) was one of the most popular and only the participant from Spain considered it not to be relevant.

There were marked divisions amongst the participants in regards to modelling the interactions between pedestrians and vehicles (EUR_Veh_8). In Australia and the UK, countries where more than one participant was interviewed, just half of the interviewees considered it to be to be relevant (notably, 40% in Australia and 50% in the UK). As regards the other participants, half, the ones from Ireland and Italy, did consider it to be important, and the other half, the ones from Spain and the Netherlands, did not.

The only feature which all participants concurred with was the need for modelling the interaction between incoming emergency vehicles and outgoing evacuating vehicles (EUR_Veh_9). The participants from Australia provided some reasons for their choice. According to them, a large volume of pedestrians and vehicle movements may take place simultaneously in areas with very few options of escape (e.g. roads with one way in one way out). Furthermore, in major events where chaotic situations occur, vehicle accidents are very likely to happen causing the blockage or narrowing of roads. In both cases, the access of emergency vehicles to the area would interfere with the traffic flow of outgoing vehicles.

***Key Finding for Evacuation Modelling 22: Representing vehicles in evacuation modelling* –** The most important factors to be included in evacuation models that include the use of vehicles are; providing vehicles with an ability to divert if the route ahead is compromised; represent the interaction between vehicles leaving and entering the affecting region; provide a means to divert vehicles through instruction from the authorities (road blocks); represent the evacuation through means of public transport. Other issues that were considered important included; time for pedestrians to access vehicles and boarding time for vehicles. Low on the list was the need to include the interaction of pedestrians with vehicles however, this was highlighted as an issue in special scenarios for example involving situations where there is limited road access. Identifying the initial location and capacity of private vehicles was considered a low priority (about 50%) but this was because many authorities assumed that they would already know this information, nevertheless, clearly this is an important initial condition for evacuation models.

4.3. Key factors relating to evacuation modelling identified by the participants' responses

The responses provided by the participants have highlighted a number of key issues that are of great importance to evacuation model developers as they highlight the needs perceived by the end-users. Prioritising these needs will not only ensure that the urban-scale evacuation models will meet the needs of the intended user base, but will also increase the likelihood that these models will be adopted by their intended users. It is noted that a broad range of end-users from a variety of countries have participated in this survey, and while there have been some differences in the views expressed by the participants, on the whole there has been broad agreement. Where there has been disagreement, this is primarily due to the different perceived requirements of the regions based on the different fire conditions experienced and the different requirements of the jurisdictions. Furthermore, some of the replies must be viewed from the context that the targeted end-users have no experience of urban-scale evacuation models and so may not be aware of capabilities and requirements of such models or indeed how they may be used to address the challenges currently faced by the incident managers.

1) **Current adoption of urban-scale evacuation models in wildfire incident management:**

Key Finding for Evacuation Modelling 7: Current decision support tools for evacuation - The wildfire management community do not currently make use of large-scale evacuation modelling tools and so are unlikely to have any experience and knowledge of their capabilities. It is thus essential that this community is correctly informed of the current and potential future capabilities of large-scale evacuation modelling in order to manage expectations. Furthermore, it suggests that the current opinion of wildfire managers with regard to large-scale evacuation modelling may not be an informed opinion.

2) **Stated requirements for urban-scale evacuation models:**

Key Finding for Evacuation Modelling 8: Key features required by evacuation models for acceptance - Incident managers have identified a need for evacuation modelling tools to assist with decision making. As part of this need they have also identified three key requirements for evacuation models:

- **Reliability/Realistic agent decision making capability:** Incident managers suggest that it is important for simulated agents within evacuation models to have a decision making capability that not only reacts to the evolving situation but can be adapted to suit specifics of local conditions, e.g. to represent local experience and knowledge. However, many issues associated with complex decision making can be addressed with a capability of running 'what if' scenarios. With such a framework, it is not essential to know precisely how a population will react, as a number of different scenarios can be run that explores the outcome of a range of possible reactions. However, for this to be useful, the model must be able to run quickly enough so that the scenarios required to cover the parameter space can be completed within a sufficient time so as to influence the decision. This point is explored in the next factor.
- **Speed of simulation/Fire time line:** Incident managers suggest that it is essential to have short simulation times, but also for placing the evacuation simulation into the context of the evolving fire timeline. It is clear that there is a disconnect between multiple timescales that are important in wildfire such as, the time required to make fire spread predictions, the time at which the fire will impact the targeted community, the time at which evacuation routes will become non-tenable, the time required to clear the targeted community, the time required to ensure that the community have cleared the potentially vulnerable evacuation routes, the time required for the targeted community to reach safety, the time required to prepare the evacuation simulations. This suggests that a general wildfire timeline model that addresses these issues is required to identify the actual time available to make evacuation decisions based on evacuation modelling.
- **Ease of use:** Incident managers suggest that easy to use models are essential if the technology is to be readily accepted. This suggests that user-interfaces must be simple to use and intuitive. Furthermore, it highlights the need for preparing models of high-risk areas in advance of the incident so that minimal input and scenario configuration is required. This is similar to the requirements for wildfire modelling, it is unreasonable to assume that a wildfire model will be configured from default settings to accommodate a specific fire scenario. It is likely that local specific data will have already been configured with the model such as geographical spatial information and the nature and dispersal of fuels.

3) **Identified challenges that urban-scale evacuation models need to be addressed if they are to be accepted:**

Key Finding for Evacuation Modelling 1: Regional impact on decision making - Clearly, the nature of jurisdiction in which the evacuation model is being used and more specially, whether mandatory or advisory evacuation advice is provided by authorities, is an important distinction that will need to be factored into evacuation models as it will impact not only the proportion of people likely to evacuate, but the time required to make a decision to begin the evacuation movement phase.

Key Finding for Evacuation Modelling 2: Impact of fire development - The importance of fire development to the decision making process of evacuation managers highlights the need to couple evacuation simulation models with wildfire spread models that are capable of assimilating changing meteorological conditions to compute the spread of the fire.

Key Finding for Evacuation Modelling 3: Impact of local conditions on behaviour (community preparedness) - The importance of community preparedness to the decision making process of evacuation managers highlights the need for an ability to factor into evacuation models specifics associated with the preparedness of the local community as this may influence whether the population is likely to evacuate or shelter in place and also how long it may take them to start the evacuation movement phase.

Key Finding for Evacuation Modelling 4: Impact of resources on evacuation procedures - The availability of human and physical resources to the evacuation manager is also an important factor for evacuation modelling as it defines the available alternative strategies that could be investigated, through modelling, both in planning and in real-time applications.

4) **Current lack of preplanning for large-scale evacuation:**

Key Finding for Evacuation Modelling 5: Prepared evacuation plans - Most emergency services do not have prepared plans for large-scale evacuation, even in areas that are high-risk wildfire areas. This lack of planning may be the result of not having access to modelling tools that can be used to simulate large-scale evacuation and possibly also the data required to define the necessary scenarios. While evacuation plans prepared in advance of an incident may not be directly applicable to the unfolding emergency situation, they could provide the basis for real-time analysis that could be relatively easily adapted during the on-going emergency.

5) **Important capabilities required for planning applications of urban-scale evacuation modelling:**

Key Finding for Evacuation Modelling 6: Important parameters for evacuation planning - The most important parameters to evacuation managers in planning evacuation are; size of population to be evacuated, availability of evacuation routes, available time before hazard impact, location of safe refuges, time of day/day of week/period. It is thus essential that evacuation models make use of these parameters if they are to be accepted by evacuation managers. The importance of these parameters also suggests the type of data that may be available for use in evacuation modelling.

6) **Important capabilities required for training applications of urban-scale evacuation modelling:**

Key Finding for Evacuation Modelling 13: Evacuation modelling for training - The vast majority of training of emergency management staff is through paper based desktop exercises. There is significant potential for the development of training environments that incorporate evacuation modelling tools for large-scale emergencies involving wildfires (and other disasters). Indeed, several of the respondents suggested that this would be a useful development. The training environment would be enhanced if it could also include the co-ordination between emergency organisations.

7) **Important capabilities required for real-time applications of urban-scale evacuation modelling:**

Key Finding for Evacuation Modelling 21: Capabilities required by a real-time evacuation modelling system – There was general agreement on the most desirable features that a real-time evacuation modelling system should have to assist incident managers. The most highly desirable features included an ability to dynamically change a simulation during the incident, including, changing population parameters, changing route availability (based on live input from the field or sensors), changing procedures due to resource allocation; coupling model output to the COP/JOP; faster than real-time performance and the ability to compare model outcomes for different scenarios. The participants also suggested that desirable features would include an ability to test the impact of different alarm options, using the modelling environment for local community education and having an ability to provide 2D, 3D and virtual reality graphical output.

Key Finding for Evacuation Modelling 16: Mobile devices - While having an ability to display and interact with evacuation model input/output on tablet devices was considered a valuable feature by Australian participants, this was not considered an important feature for UK participants. The participants from neither region felt it was necessary to display the results on mobile phones. However, participant responses to this question may have been biased by a lack of knowledge of how portable devices could be used in real-time applications by authorities in the field to update evacuation simulations by for example identifying routes that had been compromised.

8) Importance of including vehicles in urban-scale evacuation modelling:

Key Finding for Evacuation Modelling 9: Importance of vehicle simulation - Evacuation managers strongly suggest that evacuation models must have a capability to represent evacuation using vehicles. This is perhaps an obvious, but nevertheless important finding. In large-scale evacuation relating to wildfire, it is essential to include vehicles in the evacuation modelling capability. Pedestrian only modelling has application in very specialist application areas such as evacuation of coastal areas.

Key Finding for Evacuation Modelling 22: Representing vehicles in evacuation modelling – The most important factors to be included in evacuation models that include the use of vehicles are; providing vehicles with an ability to divert if the route ahead is compromised; represent the interaction between vehicles leaving and entering the affecting region; provide a means to divert vehicles through instruction from the authorities (road blocks); represent the evacuation through means of public transport. Other issues that were considered important included; time for pedestrians to access vehicles and boarding time for vehicles. Low on the list was the need to include the interaction of pedestrians with vehicles however, this was highlighted as an issue in special scenarios for example involving situations where there is limited road access. Identifying the initial location and capacity of private vehicles was considered a low priority (about 50%) but this was because many authorities assumed that they would already know this information, nevertheless, clearly this is an important initial condition for evacuation models.

9) General urban-scale evacuation model features considered important incident managers:

Key Finding for Evacuation Modelling 10: Alerting the population – Evacuation managers indicate that there are a variety of methods used to alert the population of the need to evacuate. These vary from the most resource intensive, the most time consuming but the surest of success i.e. door to door knock, to the least resource intensive, quickest but with large uncertainty of success i.e. radio and TV messaging. Newer approaches using social media, mobile phone apps and texting are also popular and may become the preferred route for notification. However, issues associated with coverage of the mobile phone network, especially in remote areas needs to be addressed. Clearly, evacuation models need to have an ability to represent the different modes of notification, or more precisely, the notification success rate associated with the different modes of notification.

Key Finding for Evacuation Modelling 14: Required input parameters - At least three quarters (76%) of the participants believe that important input parameters for evacuation models include; population size and distribution, availability of evacuation routes, hazard front location and nature of terrain. There were no significant differences concerning each of these across all the countries that participated, with the exception of terrain type, which was considered least important by the Australian participants.

Key Finding for Evacuation Modelling 15: Requested output parameters - With the exception of two output factors (time spent in congestion and output parameters displayed in WORD) all the output factors suggested were considered to be of significance. This is an important finding as it highlights important evacuation model output parameters that will be of value to emergency managers.

Key Finding for Evacuation Modelling 17: Agent route selection - For both pedestrian and vehicle based evacuation simulation, evacuation managers suggested that agent route selection decision making algorithms should be based on an ability for agents to select routes based on, in order of priority, safety, minimising evacuation time, minimising evacuation distance, route capacity, and uniform capacity. There was no difference between the UK and Australian preferences for the top two approaches.

Key Finding for Evacuation Modelling 20: Integration with wildfire models – The vast majority of the participants (91%) agreed that wildfire and evacuation models should be coupled and also that the impact of the smoke produced by wildfires should be represented within evacuation models (83%) as these can compromise evacuation routes.

Key Finding for Evacuation Modelling 18: Speed versus accuracy - Evacuation managers in Australia and UK had very different views on the importance of speed versus accuracy. When it comes to speed versus accuracy, evacuation managers in the UK preferred high accuracy at the expense of speed while Australians preferred fast results over accuracy. However, evacuation managers from both regions agreed that a two stage process would be acceptable, where fast low accuracy results were first provided, enabling decision makers to make some decisions, followed by more accurate results in slower time. Clearly, if evacuation model predictions are to have any impact on decision making, they need to be produced quite quickly with as much accuracy as possible.

Key Finding for Evacuation Modelling 12: Incorporating the evacuation model within the COP/JOP - The management of large-scale emergencies involving wildfires incorporates a COP/JOP of some type however, currently this excludes evacuation data. There was a mixed response to whether or not it would be useful to include evacuation data. With the exception of the police, it was felt that evacuation data, in particular, evacuation plans, evacuation routes and their capacities, time required to evacuate a region, location of refuge centres, location of vulnerable communities and their associated evacuation times, etc. would be useful. In the UK, the police, as with the police in Australia felt that this would be less useful primarily because the authorities would not have the time to react to the information. This again highlights an important issue, if the evacuation models are to have any impact on evacuation management, they must be able to rapidly and reliably produce their advice.

Key Finding for Evacuation Modelling 19: Representing terrain features in pedestrian evacuation models - Evacuation managers in Australia and UK both agreed that when simulating pedestrian evacuation it was essential that the model was able to take into consideration the impact of route gradient. However, the need to represent the nature of the route surface was less strongly supported. All of the UK but only half of the Australian participants thought it was important to take into consideration the impact of unpaved surfaces on evacuation performance. Furthermore, 50% of both the UK and Australian participants felt it would be important to consider the impact of the nature of the unpaved surface on evacuation performance.

10) Incident timeline:

Key Finding for Evacuation Modelling 11: Timeline concept - The responses to the wildfire timeline concept while on the whole positive also had a number of negative comments. However, many of the negative comments displayed a lack of understanding of the intent of the timeline. An important consideration is that none of the time intervals in the timeline are intended to be definitive times of fixed duration but are all intended to be varying times which are scenario dependent. They are intended to demonstrate that interrelationship between the various key phases, and that by taking longer in one particular phase will mean that less time will be available for the other phases. However, the timeline is considered a useful concept and will be further refined.

5. CONCLUSIONS

This deliverable provided a detailed analysis of the end-user requirements from large-scale evacuations due to wildfires. A total of 18 staff from 13 organisations in 6 countries (Australia, Ireland, Italy, Netherlands, Spain, and the UK) involved with wildfire evacuation/management were either interviewed or participated in an online survey to provide answers to open ended and specific questions designed for the purpose of collecting end-user requirements that will enhance current large scale evacuation models.

Analysis of these interviews/surveys suggest that there are four main contextual factors that could influence the end-user requirements, namely: management policies and strategies, mode of evacuation (vehicle versus foot), and wildfire hazard context.

Management policies and strategies varies across jurisdictions at local, regional, and national levels. In some jurisdictions, evacuation warnings are mandatory whereas in others it is advisory. In some jurisdictions, evacuation managers are generally supportive of evacuation, and in others, they are supportive of shelter-in-place. These factors are bound to result in varied evacuation dynamics and it is vital for evacuation models to consider these factors.

The mode of evacuation, notably pedestrian or vehicle-based evacuation, is a major contextual factor that influenced the prioritisation of the requirements. It was established that vehicle-based evacuation is the most common mode of evacuation during wildfire incidents, and as a result, most of the participants showed more interest in vehicle-related features than in pedestrian-based features. The few participants who showed high interest in pedestrian-based features were from jurisdictions where pedestrian evacuation is more common. Furthermore, modelling the evacuation of large urban areas needs to incorporate public transport as an additional form of mobility.

The wildfire hazard context, which refers to the characteristics of the fire regime (i.e. frequency, intensity, seasonality, type) also, had an influence on evacuation requirements. The responses of the participants from countries where large wildfires are recurrent and pose social and environmental calamities —group 1— were compared against the responses of the participants from countries where large wildfires are rather sporadic and rarely pose social or environmental calamities —group 2. The group 1 merged the responses of the participants from Australia, Italy and Spain, whereas the group 2 merged the responses of the participants from Ireland, the Netherlands and the UK. The nature of the fire hazard regime, determined the participants' desire for certain modelling requirements, notably for those related to real-time incident management (i.e. Ability to adjust the evacuation procedures or to compare model inputs/outputs of multiple scenarios), as well as for the performance factors that characterises the evacuation (slower/higher results combined with lower/higher accuracy).

Finally, the analysis of the interview/survey responses were distilled down into 22 key factors within 10 broad categories that identify the perceived needs and desires of the emergency management end-user community in relation to the use of urban-scale evacuation models for planning, real-time applications and community training. If urban-scale evacuation models are to be readily adopted by the emergency management community, it is suggested that they should address as many of these key factors as possible.

Task/Deliverable 2.4 has been accomplished through three staff secondments comprising two Experienced Researchers and one Early Stage Researcher performing six person months of secondments in RMIT, Australia. There were more than 15 meetings that took place between the UoG seconded staff and staff from Australian organisations.

ANNEX I: INTERVIEW QUESTIONNAIRE

The questionnaire used to gather end-user requirements is presented below:

End-user requirements from large-scale evacuation models	
Name: Click here to enter text.	**Date:** Click here to enter a date.
Position/department: Click here to enter text.	
Institution (country): Click here to enter text.	

The interview has 3 main parts. The first part of the questionnaire involves presentations from the interviewer and the interviewee providing a brief overview of their organisations and their roles. The second part will pose a number of open-ended questions related to the performance of evacuation management tasks and the third part will consist of a series of questions referring to specific model requirements that the participant will be asked to rank based on their perceived value and their categorisation into priorities and constraints.

- ## PART 1. PRESENTATIONS

- ### Section 1. Presentation by interviewer

A Short presentation from the interviewer providing an overview of the Fire Safety Engineering Group (FSEG), the GEO-SAFE project and our (FSEG) role in the project.

- ### Section 2. Presentation by interviewee

Please provide a brief overview of your organisation, organisation structure, your roles and responsibilities. (The main focus will be on large scale evacuation management duties.)

What are your designations at the strategic/tactical/operational levels?

• PART 2. UNDERSTANDING CURRENT POLICIES/PROCEDURES/TOOLS RELATED TO EVACUATION MANAGEMENT

• Section 1. Evacuation policy

1. **What is you organisation's policy on evacuation due to wildfires or other incidents such as floods?**

2. **How is the decision to evacuate taken over the decision to shelter-in-place in large-scale disasters?**

• Section 2. Evacuation plans and factors influencing evacuation procedures

3. **Does your organisation have a detailed plan on how to evacuate an area/region during a wildfire incident or other hazards such as floods? (Tick the option that applies)**	
3.1. Yes, a written evacuation plan exists	
Please provide details: Does the plan provides flexibility, adapting to different and changing circumstances? How often is the evacuation plan updated? Are the people simply asked to evacuate outside the threatened region or are they asked to evacuate to designated refuge locations? What is the evaluation criteria for the designation of assembly points (capacity, proximity, open spaces, public buildings…)?	
3.2. Yes, an evacuation plan has been developed with the aid of computer simulation tools	
Please provide details: Does the plan provides flexibility, adapting to different and changing circumstances? How often is the evacuation plan updated? Are the people simply asked to evacuate outside the threatened region or are they asked to evacuate to designated refuge locations? What is the evaluation criteria for the designation of assembly points (Capacity, proximity, open spaces, public buildings…)?	
3.3. No, but an evacuation plan is developed during the ongoing incident as needed	
Please provide details: Are the people simply asked to evacuate outside the threatened region or are they asked to evacuate to designated refuge locations? What is the evaluation criteria for the designation of assembly points (Capacity, proximity, open spaces, public buildings…)?	
3.4. No, we are not interested in developing an evacuation plan	

3.5. Other, please specify:

4. Which of these factors/parameters do you take into consideration when determining the evacuation procedures? (Tick any that apply, please provide further information if necessary)

4.1. Total number of people to be evacuated	
4.2. Population demographics in the area (Please specify what data you utilise to know the population demographics and how accurate it is.)	
4.3. Population day-time distributions. (Please specify what data you utilise to estimate population distribution and how accurate it is.)	
4.4. Number and location of people with special needs (e.g. old age homes, schools, hospitals, prisons…)	
4.5. Characteristics of the household (elderly people, children, pets, number of cars…)	
4.6. Required time to evacuate (based on evacuation predictions)	
4.7. Available time to evacuate (based on fire spread and behaviour predictions)	
4.8. Time of the day (day/night) and day of the week (working day/holiday)	
4.9. Weather conditions (rainy/sunny/snowy day)	
4.10. Response times of people	
4.11. Preparedness levels of people	

4.12. Availability of staff to assist evacuees in the evacuation process	
4.13. Availability of vehicles to transport evacuees	
4.14. Availability and Non availability (i.e. blocked) of routes	
4.15. Availability of assembly locations	
4.16. Others, please list any that applies:	

• Section 3. Decision support tools for managing large-scale evacuation

5. **Do you use any sort of software tools to assist you in decision making?**

5.1. Yes, and they have evacuation modelling capabilities ***(Go to question 8)***	
Please, name what tools you currently use for both pre-incident Planning and Live decision-making.	
Please, describe what you use them for, how you use them, and how useful they are.	
Yes, but they do not have any evacuation modelling capabilities ***(Go question to 6)***	
Please, name what tools you currently use for both pre-incident Planning and Live decision-making.	
Please, describe what you use them for, how you use them, and how useful they are.	
No, we do not use any software tools at all ***(Go to question 6)***	

6. **How are the following issues of pedestrian and vehicle evacuation considered for both pre-incident Planning and Live decision-making?**

6.1. How do you determine the required evacuation time for an entire region?

6.2. How do you determine the time required to evacuate a specific part of a region?

6.3. How do you determine the arrival times or rate of arrival of evacuees at refuge locations?

6.4. How do you determine the time required to alert a population?

6.5. How do you determine whether or not congestion is likely to occur and be of concern?

6.6. How do you determine where congestion is likely to occur?

6.7. How do you determine what routes may be compromised by fire or smoke and what are the best routes to be utilised?

7. What are the current limitations for non-modelling approaches?	
7.1. Lack of reliability (results do not match with actual outcomes to a satisfactory level?)	
7.2. Lack of repeatability (It is difficult to examine the effects that different evacuation procedures produce for a given user-defined configuration scenario)	
7.3. Lack of accuracy (The results do not provide precise time and spatial location data for the evacuating population and neither provide aspects such as human behaviour, interaction between evacuees or between evacuees and the environment)	
7.4. Others, please specify:	

Go to 'Question 11'.

- ## Section 4. Evacuation modelling tools for managing large-scale evacuation

8. What evacuation modelling tools do you use for pre-incident Planning? Do you find them useful?

8.1. What are their main inputs?

8.2. What are their main outputs?

9. What evacuation modelling tools do you use for Live decision making? Do you find them useful?

9.1. What are their main inputs?

9.2. What are their main outputs?

10. What are the current limitations for evacuation modelling approaches from the perspective of both pre-incident Planning and Live decision-making?

10.1. Slow speed of computation (the model's runtime is too slow to be of use for live usage)	
10.2. Cumbersome to input large amounts of diverse data (maps, population, hazards)	
10.3. Low reliability (the model results do not match to a satisfactory level with the actual outcome)	
10.4. Lack of user friendly GUI (it is relatively difficult to input/output data and analyse results)	
10.5. Lack of compatibility with other systems (GIS and other systems)	
10.6. Others, please specify:	

10.7. What is missing that would make them more useful?

11. Would you like something better than what you currently have for evacuation management purposes?

12. Would you consider an urban-scale evacuation model that only considered pedestrian evacuation to be useful for wildfire applications?

12.1. Yes.	
Please specify In what type of scenarios this would be useful.	

12.2.	No.	

13. **What type and levels of expertise do the people responsible for evacuation management have?**
    13.1. Do you have expertise to run computer-based simulation tools or specialists available to run the tools?

    13.2. Do you have expertise to run web-based (browser-based) simulation tools or specialists available to run the tools?

14. **During pre-incident Planning processes, how long are you prepared to wait to get results for a particular evacuation simulation scenario? (e.g. minutes, hours, tens of hours, days, etc.)**

15. **During a live incident, how much time would be required to update or modify an evacuation plan once it is known that conditions have changed? (e.g. minutes, tens of minutes, hours, tens of hours, etc.)**

• Section 5. Timing and dissemination of evacuation notifications and orders

16. **What are the major factors determining the timing for the issuing of the evacuation warnings?**

16.1.	Characteristics of the transportation networks	
16.2.	Characteristics of the road/pedestrian routes networks	
16.3.	Vulnerability of people	
16.4.	Vulnerability of houses	
16.5.	Intensity and Rate Of fire Spread (ROS) of hazard	
16.6.	Others, please specify:	

17. **Which of the following methods do you use to warn the population?**

17.1.	Phone calls	
17.2.	SMS messages	
17.3.	TV broadcast	

17.4.	Radio	
17.5.	Social media	
17.6.	Sirens	
17.7.	Signage	
17.8.	Flashing lights	
17.9.	Door to door knocking	
17.10.	Others	

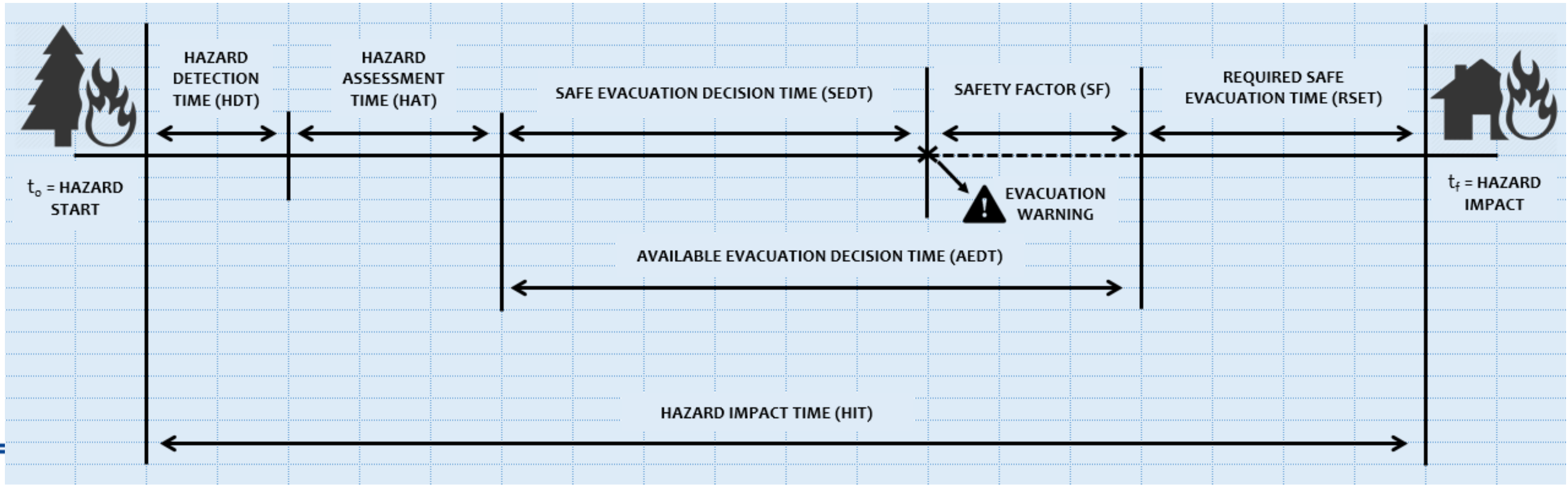
18. Timing of evacuation warnings.

A spreading wildfire threatens communities in its path, each at a different time. It is important to know how much time is available to issue evacuation orders for the different communities. We will show you a figure to explain a concept we have developed on when to issue evacuation orders to communities in the path of a spreading wildfire. We value your comments and feedback on the usefulness of this concept.

Timing of evacuation orders

When a spreading wildfire threatens human communities in its path, each at a different time, it is important to know how much time is available to prepare for evacuation, and when to issue evacuation orders for these threatened communities. The diagram bellow shows a timeline of events since the fire starts until the fire impact a town/village/community. This illustrates a concept we developed to determine how much time is available to make the decision to evacuate and when to issue evacuation warnings.

1) When a fire is ignited in the wildland, it usually takes some time before the authorities receive the warning and get the emergency management operations underway. This corresponds to the Hazard Detection Time (HDT).
2) Initially, the time at which the fire will impact the town (Hazard Impact Time-HIT) is not known. However, once the hazard assessment is performed, the HIT can be estimated. This is to be done during the Hazard Assessment Time (HAT) with the aid of wildfire simulation tools. The hazard assessment is always based on the worst case scenario in order to provide a reliable safety level (i.e. free fire propagation with adverse weather conditions).
3) After the HAT the Required Safe Evacuation Time (RSET) can be determined with the aid of evacuation simulation tools. The simulation of the evacuation can be performed before the incident, as part of a planning exercise, or during the incident, using faster than real-time evacuation simulation tools or a best guess estimate. This should help commanders elucidate whether there is enough time to evacuate and, if so, provide them with good criteria to evaluate and decide the best procedures. This decision-making process takes place during the Available Evacuation Decision Time (AEDT). It is noted that the RSET includes the time required to alert the community (after the decision to alert the community is made), the time for the community to respond to the alert and the time required to get to a place of safety.
4) However, a Safety Factor (SF) needs to be applied to account for stochastic elements of simulation tools, human behaviour, and other unforeseen events that could delay the evacuation (e.g. road blocks). The SF can expand leftwards in the timeline diagram dependent on the time needed to determine the most appropriate evacuation procedures (SEDT). Hence, we recommend that the Evacuation Warning takes places at "HIT – (RSET + SF)" at the latest. This will ensure that a SF is available for the evacuation.
5) The Evacuation Warning is not a fixed point in time. In the diagram it represents the last time at which the full desired SF is available. Actually, the Evacuation Order is a period that must take place during the AEDT or, in other words, between the start of the SEDT and the end of SF. The earlier the Evacuation Warning is called, the greater is the SF at the expense of the SEDT. However, if the Evacuation Warning is called after the AEDT (i.e. during the RSET) there is no SF at all, and so the evacuation is likely to result in injuries and/or fatalities.
6) Finally, the Evacuation Warning is also a statement of when the command or advice to evacuate is issued. In some jurisdictions the evacuation is mandatory while in others it is only advisory. For modelling purposes, appropriate response times must be used to represent the nature of the region.

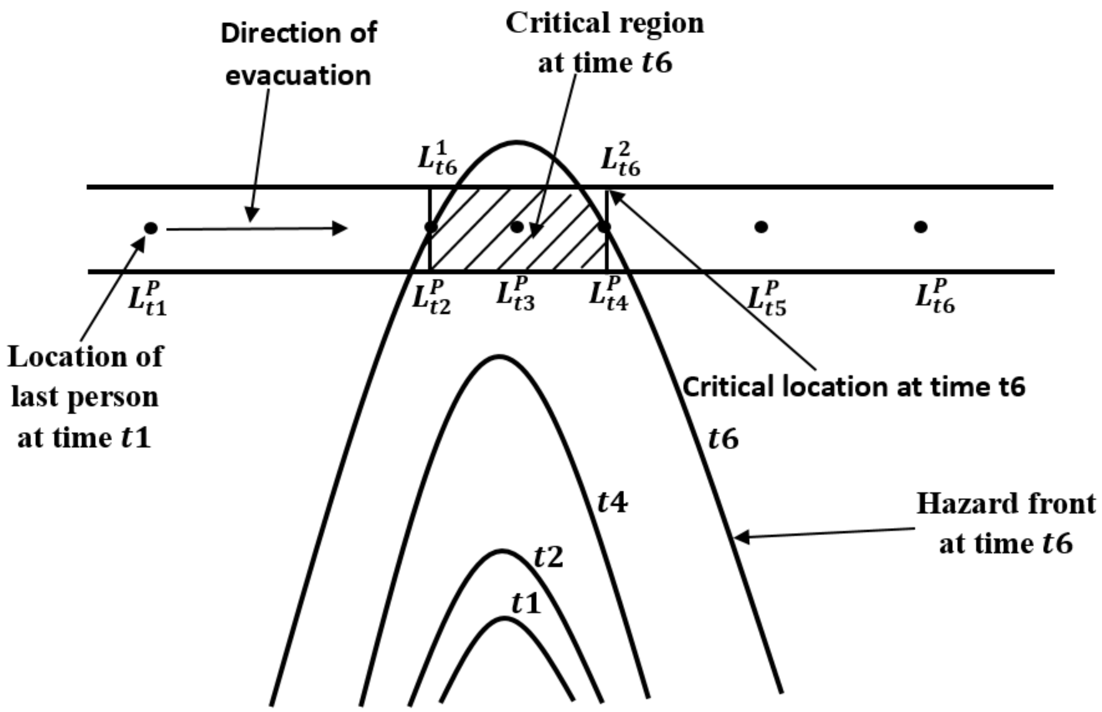


18.1. What should be the safety factor? Should the RSET be doubled?

18.2. Do you find this concept useful?

Important Definitions:

Required Safe Evacuation Time (RSET): This is the time estimate of how long it will take to evacuate the threatened community from the time to warn them to the time for them to get to a place of relative safety. This is not the time to get to the refuge (although it could be), it is the time required for the population to pass safely by the last area on the evacuation route that will be compromised. Please see figure below for an illustration of the concept of determining when a person has reached safety. This time also includes the time for the population to respond and start moving, so delays are included.



Safety Factor: We need to have a safety factor as we do not want to evacuate the community just before the fire reaches it. This is required to take into account delays due to unforeseen events.

Safe Evacuation Decision Time (SEDT): This is the time we have to calibrate and perform the evacuation simulations to determine the most appropriate evacuation procedures. This is worked backwards from knowing how long it will take to evacuate the threatened community (either through an earlier calculation or a best guess). It is called SAFE because it takes into account the Safety Factor. This is the time that the evacuation team has available to do their calculations. It is a constraint on the advice team.

Available Evacuation Decision Time (AEDT): This is the actual evacuation decision time. It excludes the Safety Factor.

Formulas:

1. $SEDT = AEDT - SF$ **or** $SEDT = HIT - RSET - SF$

The time available to make a **safe** evacuation decision time needs to take into account the safety factor. SEDT represents the time that is available to make evacuation decisions before issuing an official evacuation order.

2. $AEDT = HIT - RSET$

The time available to make evacaution decisions is the time it takes for the fire to each a community minus the time that is estimated to evacuate the community. This excludes the safety factor. AEDT represents not only the time to make a safe evacuation decision but also the time available to alter evacuation plans after issing an official evacuation order.

• Section 6. Common Operational Picture (COP) and Training tools for managing large-scale evacuation

19. Does your organisation utilise any type of COP (Common Operational Picture) for crisis situations?	
19.1. Yes.	
Please specify what evacuation-related data is available on your COP.	
Please, specify what evacuation-related data would you like to see on the COP.	
Please, specify, how this data utilised for Live decision-making.	
19.2. No.	

20. Does your organisation utilise any tools to train operational managers for crisis situations?	
20.1. Yes, paper based desktop exercises	
Please specify the evacuation related features that are available.	
Please, specify additional evacuation related features would you find useful.	
20.2. Yes, full--scale field exercises	
Please specify the evacuation related features that are available.	
Please, specify additional evacuation related features would you find useful.	
20.3. Yes, computer-based tools with augmented / virtual reality environment	
Please, name the tool used.	
Please specify the evacuation related features that are available.	
Please, specify additional evacuation related features would you find useful.	
20.4. No	

• PART 3. IDENTIFYING KEY EMERGENCY EVACUATION MODELLING REQUIREMENTS

As part of the GEO-SAFE project we will be developing a large scale evacuation model that could be utilised in the planning phase of an evacuation incident due to wildfires. Following is a list of important evacuation modelling features that we have identified. However, we value your insight on the importance of these features for large scale evacuation modelling.

Please, rank the importance of the following evacuation model features based on the value they could have on your day to day operations involving evacuation management.

• Section 1. Inputs for evacuation models

21. What are the evacuation input features that are desirable in an evacuation model?	**Must have**	**Should have**	**Could have**	**Don't need**
21.1. Population data (number of people and their distribution)				
21.2. Available and Non-available (i.e. blocked) routes				
21.3. Hazard data (e.g. flood, wildfire, etc.)				
21.4. Terrain data of routes (e.g. gradients and nature of terrain (paved/unpaved))				
21.5. Others, please specify:				

• Section 2. Outputs for evacuation models

22. What are the evacuation output features that are desirable in an evacuation model?	**Must have**	**Should have**	**Could have**	**Don't need**
22.1. Total evacuation time (time for the last person to reach the safe refuge or leave the area)				
22.2. Total clearance times (times to clear certain parts of the evacuation area)				
22.3. Areas that experience critical congestion (i.e. areas with critical vehicle/population density)				
22.4. Times spent in congestion (percentage of overall evacuation time spent stationary due to congestion)				
22.5. Heat map for route utilisation (e.g. highly utilised routes will be red, medium utilised routes will be orange, less utilised routes will be blue.)				
22.6. Others, please specify:				

23. What are the preferable evacuation modelling capabilities from the perspective both pre-incident Planning and Live decision-making?		Must have	Should have	Could have	Don't need
23.1. Ability to visualise the simulation results in GIS systems	**23.1.1.** ArcGIS				
	23.1.2. Google Earth				
	23.1.3. Interactive maps on web browsers				
	23.1.4. Others, please specify:				
23.2. Ability to visualise the simulation results in non-GIS systems	**23.2.1.** Excel				
	23.2.2. Word				
	23.2.3. PDF				
	23.2.4. Others, please specify:				
23.3. Ability to constantly adjust the evacuation procedures based on:	**23.3.1.** Real field observations				
	23.3.2. Deployment decisions made by the evacuation commanders				
	23.3.3. Allocation of resources				
	23.3.4. Live input such as sensors and satellite imagery				
	23.3.5. Others, please specify:				
23.4. Ability to provide faster than real-time results					
23.5. Ability to compare model inputs/outputs of multiple scenarios					
23.6. Ability to specify scenario inputs and review results on tablets					
23.7. Ability to specify scenario inputs and review results on mobiles					
23.8. Others, please specify:					

- ## Section 3. Evacuation routing features

24. Please rate the importance of representing the following routing features in large scale evacuation models in pedestrian (P) and vehicle (V) evacuation?		Must have	Should have	Could have	Don't need
24.1. Shortest route selection (i.e. ability of agents to utilise the shortest distance route to the nearest refuge location)	p				
	V				
24.2. Consider the capacity of routes in agent route selection (i.e. ability of agents to select routes with higher capacity and not just distance)	p				
	V				
24.3. Model the minimisation of overall evacuation times (i.e. agents in the simulation utilise routes that minimise the total evacuation time)	P				
	V				
24.4. Model the utilisation of routes with uniform capacity (i.e. agents choose routes that do not become narrow and wide at different locations)	P				
	V				
24.5. Model the utilisation of the safest routes (away from danger, e.g. fire, flood water, debris, etc. even at the cost of increasing evacuation times)	P				
	V				
24.6. Preference of agents to choose routes with gentler slopes (only for pedestrians)	P				
24.7. Consider the nature of the terrain of the routes (i.e. paved routes rather than unpaved routes)	P				
	V				
24.8. Evacuation guidance (i.e. evacuation assisted by marshals advising evacuees on what routes to utilise, when to start evacuating…)	P				
	V				
24.9. Others, please, specify:	P				
	V				

- ## Section 4. Simulation speed vs reliability (Remove or replace by live purposes)

25. How should evacuation models be calibrated to provide the right balance between speed and accuracy from the	Must have	Should have	Could have	Don't need

perspective of both Planning (P) and Live decision making (L)?				
25.1. Fast results with low accuracy				
25.2. Slow results with high accuracy				
25.3. Reasonably fast results with reasonable accuracy				
25.4. First provide fast results with low accuracy followed by slower results with high/reasonable accuracy				
25.5. Others, please specify:				

- ## Section 5. Factors affecting pedestrian walking speeds

26. Existing models do not represent variation in walking speeds due to the nature of terrain. What terrain features should be represented in the evacuation models?	**Must have**	**Should have**	**Could have**	**Don't need**
26.1. Slope (uphill/downhill)				
26.2. Paved/unpaved paths				
26.3. Land cover type on unpaved grounds (gravel, density of grass, presence of shrubs, slash remains…)				
26.4. Others, please specify:				

- ## Section 6. Integration between wildfire and evacuation simulation tools

Presently there is little integration between wildfire and evacuation simulation tools. However, we feel that there are benefits to integrate the wildfire simulation outputs within evacuation simulation tools in order to evaluate the influence of fire on the evacuating population.

27. Does your organisation utilise any wildfire simulation model to predict fire behaviour and spread?	
27.1. Yes.	
Please name it and explain why this choice.	
Please specify the limitations of these tools (e.g. they lack the capability to represent smoke, embers…).	
27.2. No, but we use other tools to predict wildfire behaviour and spread	
Please name those tools.	
Please specify the limitations of these tools.	

27.3. No, we do not use any tools at all.	
Please specify the evacuation related features that are available.	
Please, specify additional evacuation related features would you find useful.	

28. What are the desirable outputs from integrating fire and evacuation simulations?	Must have	Should have	Could have	Don't need
28.1. Coupling between evacuation and fire simulation tools such as PHOENIX, SPARK, etc. to model the effect of fire spread across urban/rural areas (e.g. blocked roads, time available to evacuate, etc.).				
28.2. Currently wildfire fire models do not predict the generation and propagation of smoke. Would it be useful for these models to represent smoke so evacuation models coupled with fire models can represent the effect of smoke on visibility and mobility, effect of toxic fire products on individuals, etc.?				
28.3. Currently not all wildfire fire models can represent spotting (new fires ignited by embers ahead of the flaming front). Would it be useful for these models to represent spotting so evacuation models coupled with fire models can represent the effect of embers on the evacuating population (e.g. people returning back home rather walking under a rain of embers).				
28.4. Others, please specify:				

- ## Section 7. Vehicle evacuation

29. What vehicle related capabilities would be useful in an evacuation model that can represent both vehicle and pedestrian evacuation?	Must have	Should have	Could have	Don't need
29.1. Represent the location of private vehicles and their capacity (number of people that can be accommodated).				

29.2. Represent the locations, availability and capacity of public transport services (bus, trains, boats, etc).				
29.3. Estimate the time incurred by people leaving their starting locations ad accessing public/private vehicles.				
29.4. Estimate the times required to board public/private vehicles.				
29.5. Model transport of evacuees by buses, fire engines, etc. to shelter/refuge locations				
29.6. Model traffic management controls (temporary measures to facilitate emergency evacuation)				
29.7. Model the ability for vehicles to be diverted from routes with roads that are compromised/about to be compromised by fire hazards or are required for fire suppression actions.				
29.8. Model interaction between pedestrians and moving vehicles (e.g. vehicle gives way to pedestrians, pedestrians waiting for a gap to cross the road, etc.)				
29.9. Model interaction between incoming emergency vehicles and outgoing evacuating vehicles				
29.10. Others, please specify:				

ANNEX II: ONLINE SURVEY

This is a short version of a detailed interview that has been designed to capture end-user requirements for large-scale evacuation simulation. This work forms part of the Fire Safety Engineering Group (FSEG) of the University of Greenwich, contribution to the EU Horizon 2020 GEO-SAFE project (http://fseg.gre.ac.uk/fire/geo-safe.html). For further information or any questions, please send an email to **Mr David Martin (dm1905a@gre.ac.uk) or Dr Anand Veeraswamy (va25@gre.ac.uk)** or FSEG Director and GEO-SAFE co-ordinator Prof Ed Galea (e.r.galea@gre.ac.uk). Once completed, please scan the questionnaire and email it to us or if you prefer, request WORD version of this document.

Name: Click here to enter text.	**Date:** Click here to enter a date.
Position/department: Click here to enter text.	
Institution, State and Country: Click here to enter text.	

1. **What is your organisation's policy on evacuation due to wildfires or other incidents such as floods? How is the decision to evacuate taken over the decision to shelter-in-place in large-scale disasters?**

2. **Does your organisation have a detailed plan on how to evacuate an area/region during a large-scale incident (e.g. wildfire, flood, chemical spill, other hazard)? (Tick one option, and please provide further information)**
   a) Yes, a written evacuation plan exists
      Please provide details:
   b) Yes, an evacuation plan has been developed with the aid of computer simulation tools and is in place
      Please provide details:
   c) No, but an evacuation plan is developed during the ongoing incident as needed.
      Please provide details on the methodology used:
   d) No, there is no evacuation plan at all
   e) Other, please specify………

3. **If you develop evacuation plans, what kind of data do you take into consideration when determining the evacuation procedures? (Tick any that apply, and please provide further information if necessary)**
   a) Total number of people to be evacuated
   b) Population demographics in the area
   c) Population dispersion in the area
   d) Available and Non-available (i.e. blocked) routes
   e) Available time before hazard impact
   f) Location of safe refuges
   g) Time of the day (day/night), day of the week(working day/holiday), and period of the year (summer, winter)
   h) Weather conditions (windy/rainy/sunny/snowy day)

i) Other, please list any that apply………

4. If you had access to an evacuation simulation tool, what are the main data <u>inputs</u> you would like to specify when defining a new scenario? (Tick any that apply, and please provide further information if necessary)

a) Population data (number of people and their distribution)
b) Available and Non-available routes (i.e. blocked roads that are compromised by fire, car accidents, etc. or that are being used by suppression services)
c) Hazard data (e.g. areas affected by flood, wildfire, etc.)
d) Terrain data relating to routes (e.g. gradients and nature of terrain (paved/unpaved) influencing the speed of evacuation)
e) Other, please list any that apply………

5. What are the main data <u>outputs</u> you require from an evacuation simulation tool? (Click all that apply, but please provide further information if necessary)

a) Total evacuation time (i.e. time for the last person to reach the safe refuge or leave the area)
b) Total clearance times (i.e. times to clear certain parts of the evacuation area)
c) Areas that experience critical congestion (i.e. areas with critical vehicle/population density)
d) Total time spent by people in heavy congestion (i.e. percentage of overall evacuation time spent stationary due to congestion)
e) Heat map demonstrating route utilisation (i.e. hotter colours indicating high usage, colder colours indicating lower usage)
f) Other, please specify………

6. What <u>wildfire hazard related capabilities</u> should an evacuation simulation tool include? (Click all that apply but please feel free to provide further information and requirements)

a) Coupling between evacuation and fire simulation tools such as PHOENIX, SPARK, etc. to model the effect of fire spread across urban/rural areas (e.g. blocked roads, time available to evacuate, etc.).
b) Currently wildfire fire models do not predict the generation and propagation of smoke. It would be useful for these models to represent smoke so evacuation models coupled with fire models can represent the effect of smoke on visibility and mobility, effect of toxic fire products on individuals, etc.
c) Currently not all wildfire fire models can represent spotting (new fires ignited by embers ahead of the flaming front). It would be useful for these models to represent spotting so evacuation models coupled with fire models can represent the effect of embers on the evacuating population (e.g. people returning back home rather walking under a rain of embers).
d) Other, please specify………

7. **What <u>evacuation related capabilities</u> would you like to see in a <u>training tool</u> for incident managers? (Click all that apply but please feel free to provide further information as required)**
   a) Ability to play back previously run evacuation simulations during the training session so as to train for the incident response of a hypothetical evacuation scenario.
   b) Ability to rapidly configure new scenarios by modifying the number of people and their distribution, routes to utilise, presence of hazards, etc. and run the evacuation simulation live during the training session.
   c) Ability to dynamically change certain parameters during the simulation, such as response times for certain regions, capacity of safe refuges, etc.
   d) Other, please specify………

8. **What additional <u>features</u> would an evacuation simulation tool need to be used in <u>Real-Time incident management applications</u> compared to planning applications? (Click all that apply but please feel free to provide further information as required)**
   a) Ability to simulate faster than real-time – if so what is the minimum capability – e.g. 2x, 3x, 5x, 10x, etc.
   b) Ability to be incorporated into a Common Operating Picture (COP) tool
   c) Ease of use (e.g. not requiring a software specialist)
   d) Ability to seamlessly interact with hazard simulation software (e.g. wildfire or flood simulation)
   e) Ability to visualise the simulation results in GIS systems such as ArcGIS, Google Maps…
   f) Other, please specify………

9. **Do you consider an urban-scale evacuation model that <u>only</u> considered <u>pedestrian evacuation</u> to be useful for wildfire applications? (If 'Yes', please specify in what type of scenarios this would be useful)**
   a) Yes
      a. If 'Yes', please specify in what type of scenarios this would be useful
   b) No

10. **What <u>vehicle specific capabilities</u> would be useful in an evacuation model that can represent both vehicle and pedestrian evacuation? (Click all that apply but please feel free to provide further information as required)**
   a) Represent the location of private vehicles and their capacity (number of people that can be accommodated).
   b) Represent the location, availability and capacity of public transport services (bus, trains, boats, etc.)

c) Estimate the travel time incurred by people leaving their starting locations and accessing public/private vehicles
d) Loading time for public/private vehicles.
e) Model transport of evacuees by cars, buses, etc. to local shelter/refuge locations
f) Model traffic management controls (temporary measures to facilitate emergency evacuation)
g) Model the ability for vehicles to be diverted from routes with roads that are compromised/about to be compromised by fire hazards or are required for fire suppression actions
h) Model interaction between pedestrians and moving vehicles (e.g. vehicle gives way to pedestrians, pedestrians waiting for a gap to cross the road, etc.)
i) Model interaction between incoming emergency vehicles and outgoing evacuating vehicles
j) Other, please specify………