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Ronchi, Enrico; Rein, Guillermo; Gwynne, Steve M. V.; Intini, Paolo; Wadhwani, Rahul

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*Total number of authors:*
5

LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

# Framework for an integrated simulation system for Wildland-Urban Interface fire evacuation

*Ronchi, E. [1]; Rein, G. [2]; Gwynne, S.M.V. [3], Intini, P. [1,4], Wadhwani, R. [2,5]*
*[1] Department of Fire Safety Engineering, Lund University, SE-22100, Lund, Sweden.*
*[2] Department of Mechanical Engineering, Imperial College London, SW7 2AZ, London, UK*
*[3] National Research Council Canada, K1A 0R6, Ottawa, Canada*
*[4] Department of Civil, Environmental, Building Engineering, and Chemistry, Polytechnic University of Bari, 70125 Bari, Italy*
*[5] Centre for Environmental Safety and Risk Engineering, Victoria University, VIC 3030, Melbourne, Australia*

## ABSTRACT

The negative consequences of fires in case of evacuation in wildland-urban interfaces (WUI) are a global issue that affect many communities around the world. To date, there is a lack of a comprehensive tool able to aid decision making in case of WUI fire evacuation. To address this issue, this paper presents a design specification for a simulation system for the quantification of evacuation performance in case of Wildland-Urban Interface fire incidents. This includes three main modelling components, namely 1) fire spread, 2) pedestrian movement and 3) traffic. To date, the development and use of modelling tools for disaster assessment have mostly been performed in isolation (i.e., with limited coupling between fire models, pedestrian models and traffic models). This paper presents the results of the review of these three core modelling components and the requirements for their integration into an integrated toolkit. A systematic approach for the review has been developed and applied with the goal of identifying the key features needed for the integration. This framework aims at assessing evacuation performance for both evacuation planning as well as decision support applications. Such a framework might be used to predict how the evacuation develops based on different fire conditions and according to different evacuation decisions. This paper presents some of the key findings of the modelling framework specification, namely: 1) the level of granularity of each type of model in relation to the scenario (i.e. spatial and temporal scale) and their applications (for all layers under consideration) and 2) the required data exchange among different models.

## 1 INTRODUCTION

Large fires in wildland-urban interfaces (WUI) occur worldwide and they are associated with severe negative consequences including massive community displacement, property losses, social disruption, short- and long-term damage to infrastructure, injuries, and in some instances fatalities of evacuees and responders [1]. WUI fires have triggered in several occasions the evacuation of thousands of people. This issue is increasing over time as more people live in areas at high risk of wildfires. The severity of future WUI incidents in new areas and areas already susceptible to wildfires is deemed to grow. Therefore, WUI incidents are likely to become more severe and affect more people.

Work has been conducted by Lund University, Imperial College, the National Research

Council Canada, and the National Fire Protection Association in order to develop a design specification for a simulation system that would quantify evacuation performance in relation to WUI incidents [2]. This system includes sub-models that address fire propagation, the pedestrian performance, and vehicular transport (i.e., traffic) (see Figure 1). The system is based on the multidisciplinary basis that these models can communicate with each other in order to provide quantitative and qualitative feedback before and during an incident. This paper focuses on a small part of this work, although an important part.

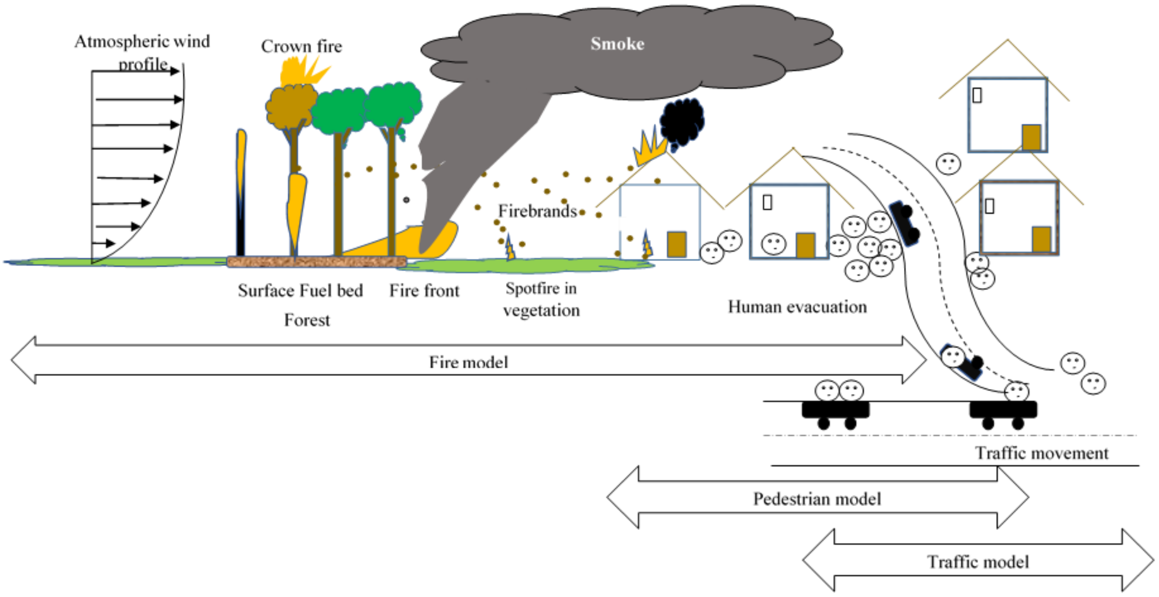

*Fig. 1. Schematic representation of a typical wildfire approaching a WUI community and how this is associated with different fire evacuation modelling layers.*

An integrated system would enhance situational awareness of interested parties as to the effectiveness of different design and response decisions – with those involved having a better appreciation of current and future scenario conditions that can then affect decisions made. [3]. To date, no integrated system that can provide such information is available. In order to successfully respond to a disaster, those involved must have an understanding of current and future events that affect it [4]. In this context, the definition of shared situational awareness is strictly relevant since it refers to "*the degree to which team members have the same situation awareness on shared situation awareness requirements*" [5].

Actual WUI fire incidents like the 2016 Fort McMurray fire, Canada or the 2016 Haifa fire, Israel [2] show how important the availability of predictions of future conditions that inform decision making might be. These incidents represent two situations in which an improved situational awareness might have improved the associated evacuation. During the 2016 Fort McMurray fire in Canada, multiple evacuations were triggered by the wildfire [6]. During the course of the event, areas which were considered safe due to temporary favourable wind conditions had to later be evacuated at a later stage due to the evolution of the fire (with some populations being evacuated several times). During the 2016 Haifa fire, which was associated with severe weather condition, excessive fuel load and strong winds, the fire-front approached the city of Jerusalem and caused the evacuation of over 75,000 people. This evacuation was completed only a few minutes before the fire reached the residents' homes. This can be considered as a "near miss" scenario, in which much more catastrophic consequences could have occurred. In both cases, an increased situational awareness could have been a significant help to reduce the consequences of the wildfires; i.e. to prevent multiple evacuations in the former case and increase the margin between evacuation and fire arrival in the latter case.

The present paper focuses primarily on detailing the system specification of an ideal modelling framework rather than discussing the preliminary work completed in the project that assessed the required features of such a toolkit and the review of existing modelling tools. It discusses the relationship between the spatial and temporal scale of WUI incidents and the types of model functionality required. In this context, a key role is played by the information needed to execute each of the models and the required information exchange between them. A key determinant in the application of such a system is the spatial and temporal scale of the incident in relation to the information available, user requirements/available resources and the time available to produce actionable results. This work examines a variety of modelling tools capable of representing fire behaviour, pedestrian movement and traffic at different scales and at different levels of granularity to determine which attributes of each model might be employed (given the constraints available).

The three core modelling areas (fire, pedestrian, traffic) were reviewed by assessing models that might reasonably be included within the suggested system. It should be noted that the model reviews were not designed to judge the models examined or suggest failings in the original application area of the models. Instead, they were conducted to examine the current functionality and model assumptions - to develop a set of questions to determine required model functionality and performance within an integrated simulation system.

Based on the work conducted, the key outcomes presented in this paper relate to:

1. The level of granularity needed in each of the key core components in relation to their application (real-time decision support or evacuation planning).
2. A detailed specification of the data exchange needed to create a suite of simulation tools that can forecast the progress of a wildfire incident and the effectiveness of pedestrian and traffic responses, according to the time and information available, incident scale, model capabilities and resources available.

## 2 SCALES OF WUI INCIDENTS

The first step for the assessment of the requirements of an integrated system for WUI incidents is the definition and classification of the spatial scales of the cases under consideration. A general definition of WUI areas is given [7], [8]. A WUI is defined as an area in which:

- There is at least one house in 1 acre (1 ac = about 4000 $m^2$);
- Wildland vegetation covers more than 50 % of the area (WUI ‘Intermix’) or wildland covers less than 50 % of the area included in a distance lower than 1.5 miles (2.4 km) of an area that is heavily vegetated (>75% wildland vegetation) and larger than 5 km (WUI ‘interface’).

However, the type of urban settlements constituting a WUI can be very different, and they can have a large influence on the evacuation process. The definition of the spatial domains is a quite complex issue in WUI incidents given the presence of the spotting phenomena [9], [10] which might lead to the appearance of fire-fronts far away from the starting location of the fire. The combination of several variables also affects the spatial boundaries of the fire itself and the population involved in the evacuation (e.g. topography, household density, road network configuration, etc.). Different categories of spatial scale have therefore been suggested when referring to different modelling domains. The terminology employed for their definition varies significantly among different modelling domains, but it can still be grouped into different classes in relation to the spatial scale under consideration. Table 1 presents the classes adopted in the present work for the three modelling domains under consideration (the classes start from 1 that is the smallest spatial scale to 5 that is the largest).

*Table 1. Classes of spatial scales in different modelling domains*

| **Spatial class** | **Modelling domain** | | |
|---|---|---|---|
| | **Fire** | **Pedestrian** | **Traffic** |
| 1 | tree | individual | individual |
| 2 | plot | room | corridor |
| 3 | forest | structure | regional |
| 4 | region | multi-structure | state |
| 5 | multi-region | community | multi-state |

It should be noted that the spatial scale of a WUI incidents in an integrated modelling framework should consider the combination of the scales of different domains, i.e. there might be scenarios in which different classes apply for different modelling domains. For instance, a very large fire at multi-state level [spatial class 5] with a limited number of households may involve a lower number of entities in the pedestrian (e.g., multi-structure, [spatial class 4]) and traffic domain (e.g., traffic is triggered only at a regional level [spatial class 3]. This classification allows the consideration not only of the area involved by the fire itself but also population/household density as a variable. Peculiar cases might, such as the 2003 Okanagan fire in Canada [2], also involve WUI interfaces placed only on one side of a town, requiring the hazard response to be focused on one location (subsequently affecting the spatial scale for the pedestrian and traffic domain). The location of the WUI interface should, therefore, be taken into consideration while analysing WUI incidents.

Besides the spatial scale, the evacuation process heavily relies on the prediction of the propagation of the hazard over time; i.e. the duration and dynamics of the event. This issue also presents several complex variables, since the evolution of wildfire might involve the re-start of fire-fronts at different points in time at locations where the threat had previously been considered temporarily over.

## 3 METHODOLOGY FOR DEVELOPING AN INTEGRATED SYSTEM

The system specification and the data exchange requirements were developed by reviewing a range of different subject areas and by receiving regular feedback from a standing technical committee. Initially, a set of real-world WUI fire case studies such as such as the Fort McMurray fire, Canada, 2016, the Victoria fire, Australia, 2009 and others involving major evacuation or damage were examined [2]. This analysis was conducted to determine the type of conditions that developed, the responses employed and the evacuation performance. This was made to better understand the subject matter to be simulated. Incident timelines and factors that influence the incident outcome were identified to examine key phases of the incident, inform expected model content and the sub-populations active in the incident as well as to identify model functionality, potential end users and application types.

During the analysis of past WUI incidents, a timeline was developed and applied to categorize key factors. This timeline was derived from those employed in fire engineering for building design (the so-called RSET timeline - required safe egress time). This required the development of an engineering time-line for WUI incidents. This is a simplification which only refers to a single location and assumes that should an incident reappear in the same location (e.g. reignite, be subject to firebrands, etc.), a new timeline is employed. Nevertheless, this simplified approach has been useful to further understand the usability of modelling tools at different stages of the evacuation process and assess the key information needed by decision makers. The WUI RSET timeline is presented in Figure 2, along with the elements that constituted it. This timeline might also be expressed in the form of a simplified equation to determine overall evacuation time:

$$t_T=t_d+t_{FDA}+t_{FDI}+t_N+t_{prep}+t_{foot}+t_{veh}+t_{ref} \tag{1}$$

where $t_T$ is the time for the population to reach safety, $t_d$ is the time for the incident to be detected after ignition, $t_{FDA}$ is the time spent by the fire department assessing the situation on site, $t_{FDI}$ is the time spent by the fire department intervening and attempting to control the incident, $t_N$ is the time for the population to be notified once intervention has been deemed unsuccessful, $t_{prep}$ is the time for a resident to complete preparations after they have initially been notified, $t_{foot}$ is the time for the population to move on foot, $t_{veh}$ is the time for the population to move into a vehicle, and finally $t_{ref}$ is the time for the individual to be on-boarded at a place of safety. It should be noted that the elements of the time-line could possibly be place in different orders, i.e. the sequence of the events might be different.

The spatial component in a WUI incident represents a significantly more important variable than the timelines used for buildings since the area threatened might change over time. This simplification could be reflected in a modified WUI timeline which indicates the return to an earlier phase of the timeline (this indicated with a feedback loop in Figure 2).

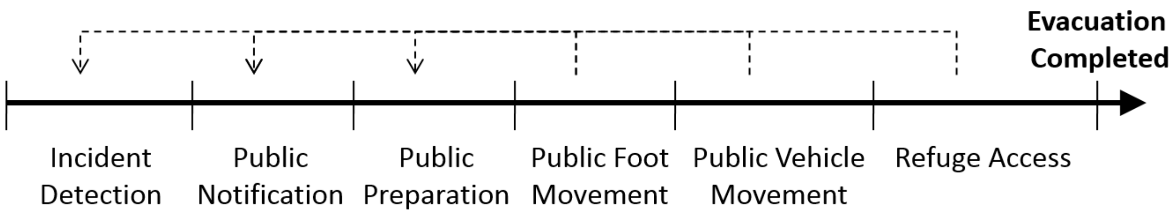

*Fig. 2. WRSET (WUI RSET) timeline with feedback loop.*

In a typical building engineering approach, the derived required safe egress time value (here, WRSET) would be compared against an available safe egress time (the time at which conditions are deemed untenable – recast here as WASET) to determine the safety margin produced. This safety margin is critical as it represents a crude estimate of the buffer zone between evacuee safety and them potentially being exposed to untenable conditions. Safety factor coefficients would normally be applied to account for unknowns in such calculations and inherent inaccuracies or factors not represented in this assessment ($\alpha$ in the formulation below refers to all uncertainties). Typically, $\alpha >> 1.0$ to ensure that the prediction of WRSET is sufficiently increased to account for these inaccuracies, omissions and simplifications.

$$WASET - \alpha WRSET = Safety\ Margin \tag{2}$$

The inclusion is important in building engineering timelines; it is even more so in WUI timelines, given the complexity, dynamism and scale of the incident dynamics.

Several technologies were also examined that make use of predicted data including risk assessment tools and online mapping systems. These were reviewed to understand potential technological end users of the proposed system better. Finally, a set of existing integrated systems were examined to assess the current state of the art and likewise establish the key components that need to be included and how they should interact.

After this preliminary review of case studies, development of a WRSET time-line and study of existing tools, the analysis of the three main modelling layers of WUI fire evacuation scenarios was performed for each of the three specific subject domains [11]–[16], this being expanded to evaluate the specific requirements of WUI fire scenarios. A systematic approach for reviewing the model characteristics was employed (see Figure 3).

This includes the development of a common review template which was later modified to fit different modelling layers. Key variables and sub-models which are present in the three components were identified and assessed. This included the analysis of the most common modelling approaches used to produce output required for the integration and the associated needed inputs. This work permitted the identification of the characteristics of an ideal model for WUI fire evacuation were identified and existing models were evaluated in relation to a set of previously identified criteria. Based on this work, this paper presents the system specification for an integrated tool in terms of exchange between inputs and outputs between models. Furthermore, the focus of this paper is to present the recommended level of granularity for each modelling component in relation to the scenario under consideration. In other word, this work may act as a blueprint for implementation of an integrated system.

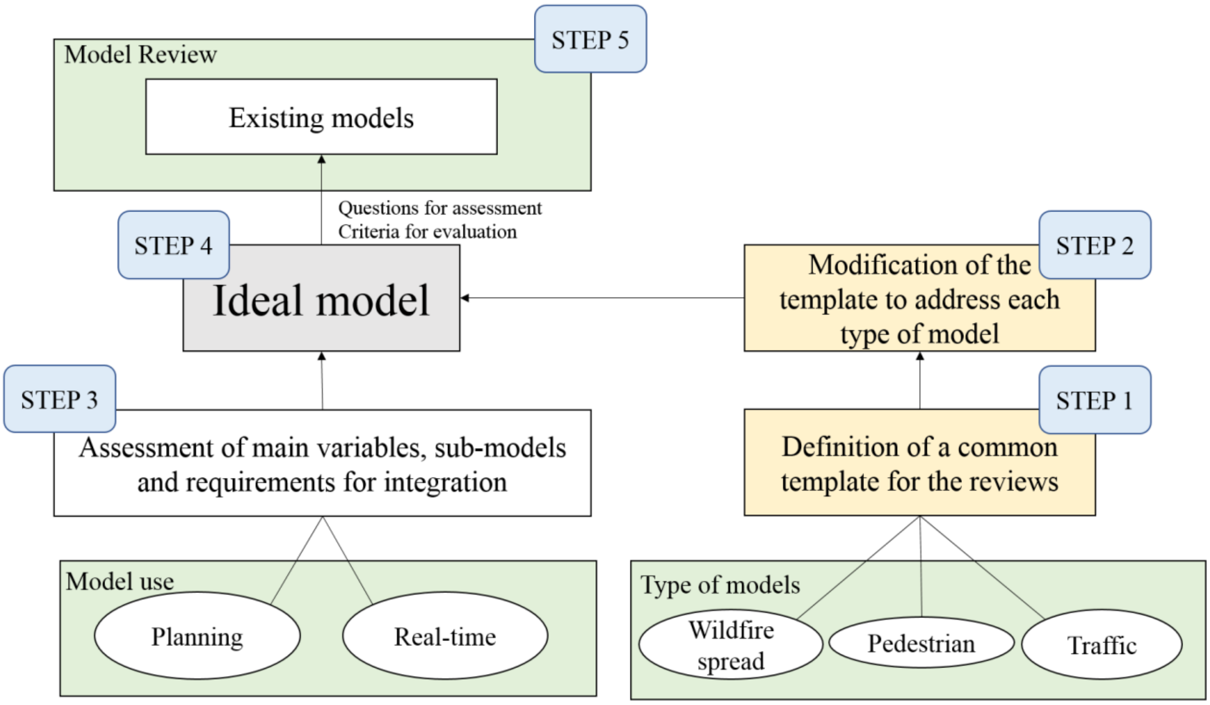

*Fig. 3. Systematic approach employed for model assessment.*

## 4 SYSTEM SPECIFICATION

The systematic approach developed for the analysis of model capabilities has been employed for the identification of an ideal modelling framework which considers the characteristics of each core modelling tool and their integration. This is reflected in the level of granularity to be adopted in relation to the scenario and application under consideration as well as the required data exchange. The work conducted during the assessment of the modelling tool capabilities allowed us to (a) better identify the influence that the modelling domains have on each other, (b) the impact of model granularity on this exchange and (c) the capacity to simulate scenarios given temporal and spatial issues.

### 4.1 Level of model granularity

The criticality of model refinement and its impact on the results produced can be investigated by recognising the differences between the data collected in relation to the aggregation level under consideration [17]. This implies that it is of particular importance for a modeller to assess the selection of a certain level of granularity for modelling [17]; i.e., whether it is constraining performance without benefitting the outcome. The level of refinement represents model granularity; i.e. an increased granularity refers to the increased modelling resolution, while a reduced granularity can be considered as a reduction in resolution (e.g., where simulated entities are aggregated to compile results or are simulated in a simplified manner). Levels of granularity are generally classified into two extreme categories of level of resolution (e.g., simplified vs refined) along with intermediate hybrid solutions [18]. The present work employs this three-point scale of model granularity.

Although not definitive, suggested limits for the model application given the three broad model categorisations are shown below (see Figures 4, 5 and 6). These limits are intended to describe current performance constraints in terms of the computational burdens of the models given the spatial classes previously defined and the time available for the simulation (which depends on the application of the modelling work). Different categories apply for each of the models under consideration given the different subject domains addressed:

a) Simplified models can refer to an empirical modelling approach for wildfire spread, flow-based for pedestrian modelling, macroscopic for traffic modelling
b) Refined models can refer to a physics-based approach for wildfire spread, agent-based for pedestrian modelling, microscopic for traffic modelling
c) Hybrid models refer to a combination of the different level of granularity for all models (e.g., a mesoscopic approach for traffic models) – either by employed a moderately granular approach throughout or adopted a varied degree of granularity for different aspects of the modelling process.

Figures 4, 5 and 6 provides information on the achievable level of granularity in relation to the temporal scale of the event (i.e., the time within which the simulated results need to be delivered) and the spatial scale (i.e., the elements that should be simulated) – for each of the three model domains. The temporal scale can also be divided in relation to the application type (i.e. real-time application vs. a planning application). This places different performance pressures and constraints on the system performance. The spatial scale in the Figures 4, 5 and 6 is presented considering an increasing spatial area for each modelling tool. The categories used were determined by the background analysis conducted and the model reviews themselves; e.g., previous application types and terminology used. It should be noted that this involves a degree of subjective assessment; however, this type of analysis would certainly need to be conducted in the development of the proposed system to understand the propagation of limiting performance factors throughout the system.

Figures 4, 5 and 6 show that less refined models are by definition not able to represent scenarios at the more refined scale – irrespective of the time available. This is because this type of models is simply not able to simulate these entities given their level of modelling resolution. For instance, a simplified pedestrian model based on flow calculations is not able to represent the movement or decision-making of individual evacuees. In contrast, such models can often be the only tools usable for the study of scenarios on a larger scale when results are needed in real-time. The reduced computational burden placed by such simplified approaches means that they can be employed at larger scales and in a reduced time-frame.

More refined models allow scenarios to be simulated with increased granularity, but they are not generally usable for real-time application given the requirement of a high computational time, especially involving larger spaces.

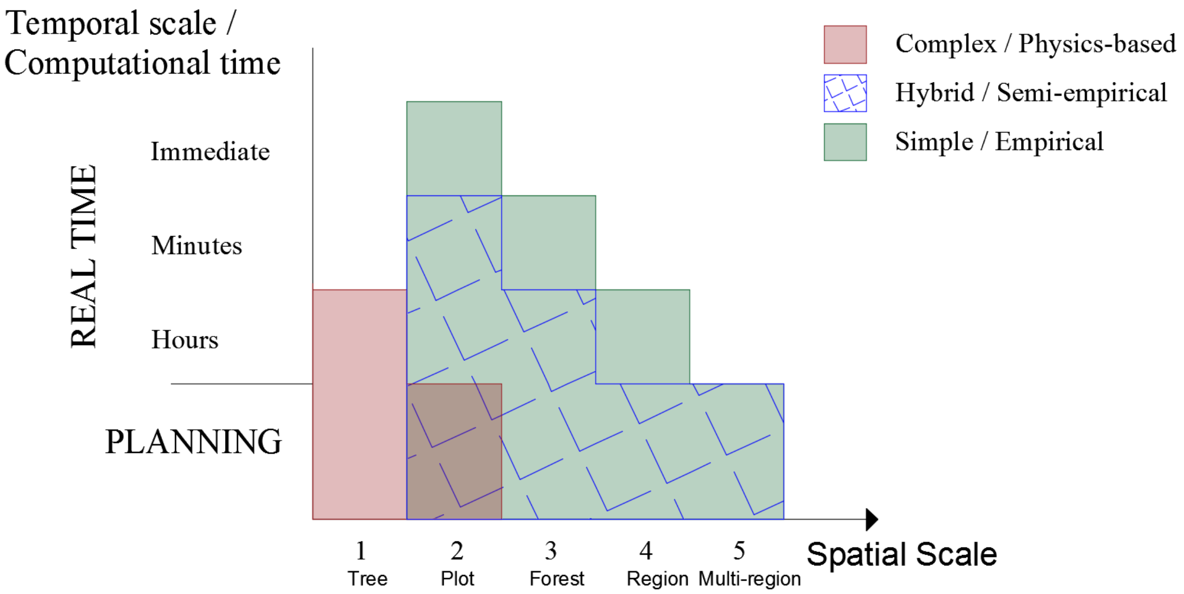

*Fig. 4: Potential model application scales given model granularity for wildfire models. The spatial scale for the fire models are divided into five categories and they are related to the temporal scale of the event (for both real-time and planning applications).*

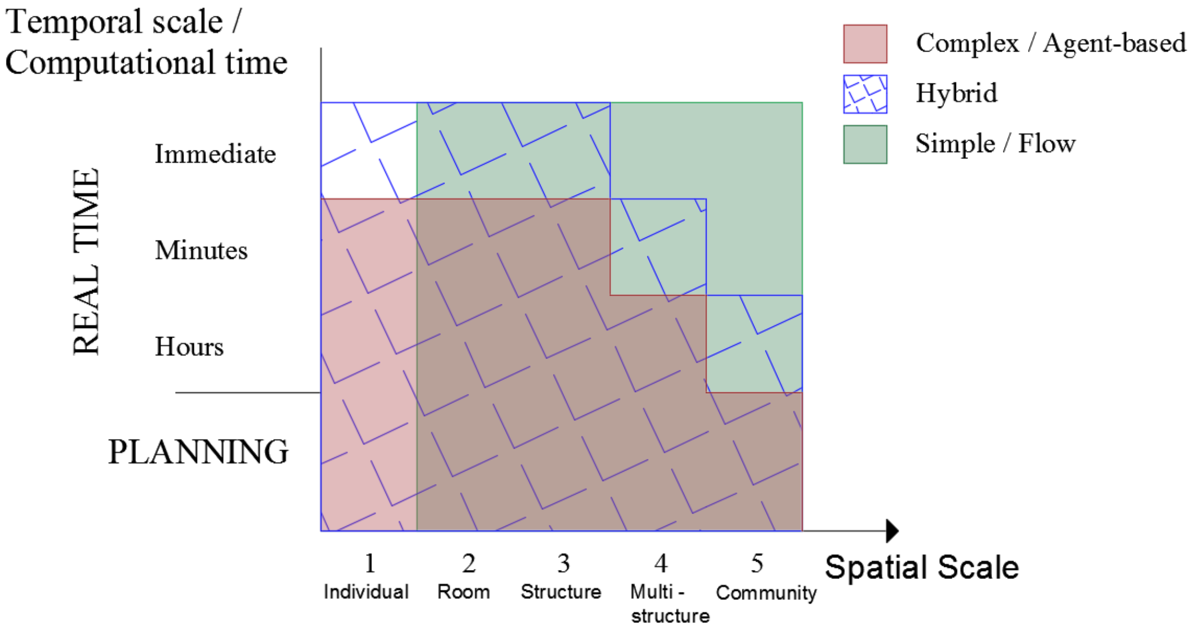

*Fig. 5: Potential model application scales given model granularity for pedestrian models. The spatial scale for the pedestrian models are divided into five categories and they are related to the temporal scale of the event (for both real-time and planning applications).*

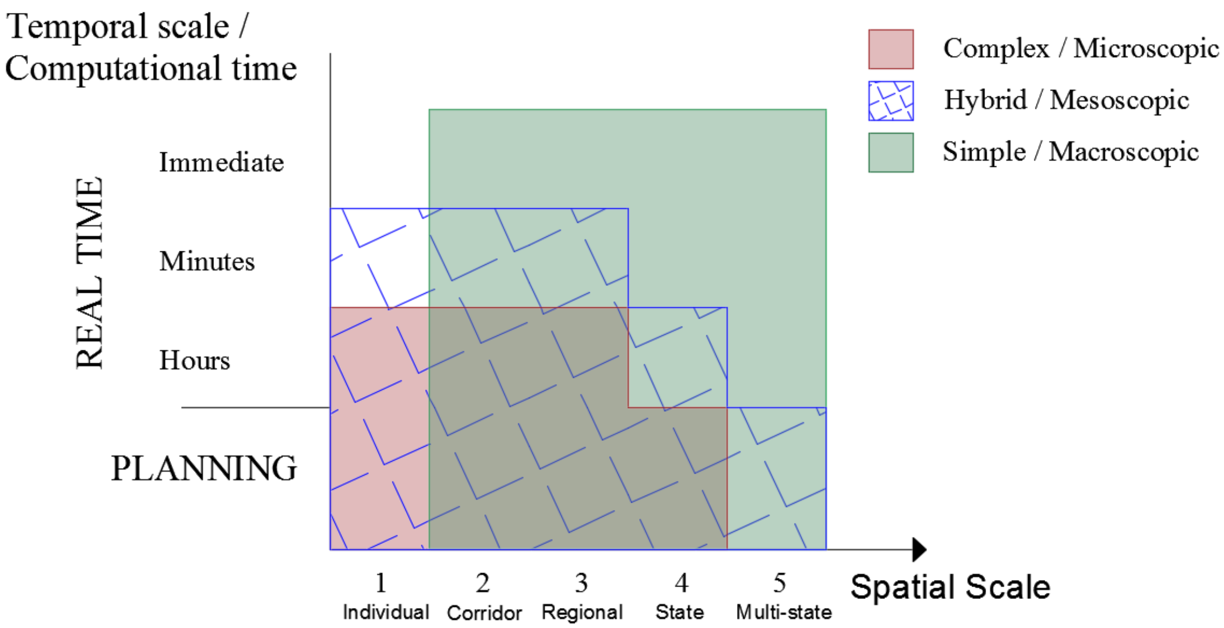

*Fig. 6: Potential model application scales given model granularity for traffic models. The spatial scale for the traffic models are divided into five categories and they are related to the temporal scale of the event (for both real-time and planning applications).*

The application areas for the three modelling domains are shown in Figures 4, 5 and 6. The same approach is adopted in each case – only the terminology employed on the x-axis differs to reflect the classes used in each domain. In each graph a polygon is included to represent the application types for each of the modelling granularities. The granularity terms employed in each figure also reflect those employed in each modelling domain. These polygons overlap in a number of areas, indicating that more than one modelling approach might be applied for certain scenarios.

## 4.2 Required data exchange

A key aspect of the system specification concerns the required exchange of data between modelling components. The integrated system would need to be highly coupled in order to involve the required exchange of information between the models and between the system and the user. Ignoring the connection between the components would both reduce the integration of the system and artificially isolate the simulated conditions from each other – potentially producing results that diverge from expectation. The assessment of the required inputs/outputs exchange between different models is presented in Table 2. This simple analysis is based on (a) the model reviews and the current modelling capacity to reflect the output of the adjacent models employed, and (b) the examination of previous incidents and background material. It is important to note that this assessment is reliant on the type of model under consideration and the expected impact on the other modelling domains that it might have. The exchange of information between the models is not symmetrical This asymmetry is primarily due to the different theoretical and empirical maturity of the three subject domains, but also the sophistication of the models currently available, and the computational limitations associated with each domain. This exchange will certainly evolve; i.e. the polygons shown in Figures 4, 5 and 6 and the model relationships shown in Table 2 will develop along with technical and theoretical capabilities. Only the primary modelling elements are here discussed, rather than the secondary elements that, although important, can be indirectly represented by the primary elements or included in other external data-sets or models. For instance, the actions of emergency responders are not included in Table 2 but are instead implicitly represented in the wildfire model through the impact of these actions on the development of the fire.

*Table 2: Required data exchange for different types of models.*

| Modelling Component | | *Input to sink model* | | | |
|---|---|---|---|---|---|
| | | *→Wildfire* | *→Pedestrian* | *→Traffic* | *→Other* |
| *Output from source model* | *Wildfire→* | x | ✓ | ✓ | x |
| | *Pedestrian→* | x | x | ✓ | x |
| | *Traffic→* | x | ✓ | x | x |
| | *Other →* | ✓ | ✓ | ✓ | ✓ |

A simple example from Table 2 may help the interpretation of the information presented. In row 1 of Table 2, the output from the (source) *Wildfire* model and its impact on other (sink) models are charted. The *Wildfire* model is deemed to affect both the *Pedestrian* and *Traffic* models in some way. This contrasts with the first column of results, which shows that only the output from *Other* model has an impact on *Wildfire* models. The present work thus allows to identify the mutual relationships between models at a higher level as well as identifying the required data exchange and communication that should be included in an integrated system.

The model information exchange (the nature of the inputs/outputs) can be presented in different formats:
1) numerical results [N] (e.g. the evacuation was completed in X seconds),
2) graphical results [G] (e.g. an image of the congestion produced on a particular route),
3) tabular results [T] (e.g. a table showing the vehicle numbers at several junctions within several time windows),
4) qualitative (or descriptive) results [Q] or geospatial [GS] (e.g. a GIS map of the area impacted by the fire-front or the routes adopted by pedestrian and vehicle traffic),
5) animated results expressed as a time-based sequence of numerical instances [A] (e.g. the evolution of the traffic queue at a particular junction over time).

Table 3 presents a summary of the key data exchange requirements between models. A legend using the initial letter of each data format within brackets is used after each inputs/outputs for exchange is presented. The variables listed in Table 3 refer to the information provided by a source model (identified in column 1) as an output that affects the initial conditions of a sink model (identified in row 1). There are also a number of interactions between external *'Other'* models that are not presented in Table 3. The identification and analysis of these interactions are out of the scope of the present work, thus they have been left out of this paper.

*Table 3: List of required data exchange between wildfire, pedestrian, traffic and other models.*

| **Modelling Component** | *→Wildfire* | *→Pedestrian* | *→Traffic* | *→Other* |
|---|---|---|---|---|
| *Wildfire→* | x | Data affecting pedestrian movement [N, G, Q]<br>Condition of evacuation routes [N, G]<br>Status of structures of interests [G, Q]<br>Access to communication and utilities [N, Q]<br>Available cues for pedestrian risk perception [N, Q] | Road network accessibility and capacity [N, G, Q]<br>Transportation mode availability [Q]<br>Status of structures of interests [G, Q]<br>Vehicle availability [Q]<br>Data affecting route availability, selection and driving performance [N, G, Q]<br>Available cues for risk perception affecting driver choices [Q] | x |
| *Pedestrian→* | x | x | Pedestrian location during the event [N, G, Q, A]<br>Pedestrian arrival times to vehicles [N, G, A]<br>Departure time from vehicle [N, G, T, A]<br>Role of the person boarding [Q]<br>Boarding time of a vehicle [N, G, A]<br>Status of pedestrians [G, Q] | x |
| *Traffic→* | x | Vehicle availability to pedestrians [N, G]<br>Public transport availability [G, Q]<br>Vehicle location during the event [N, G, T, A]<br>Accessibility, capacity of vehicles, current occupancy level [N, G, A]<br>Vehicle boarding time [N, T, A]<br>Status of vehicles [N, G, A]<br>Vehicle performance [N] | x | x |
| *Other →* | Fuel data [N, G, GS, T]<br>Weather conditions [N, G, GS, A]<br>Geographical information [N, G, GS] | Initial population size [N, G, A]<br>Pedestrian initial location [N, G]<br>behavioural response model affecting pedestrian evacuation decision [Q]<br>behavioural response model affecting departure time [N, G, T]<br>Status of pedestrians [Q, A]<br>Type of terrain from GIS models [N, G, GS]<br>Impact of emergency response intervention [N, G, GS, A] | Network configuration [N, G, GS, Q]<br>Initial location and properties of vehicles [N, G, GS, Q]<br>Available modes of transport [N]<br>Availability of road network [G, GS]<br>Background traffic [N, G, GS, T, A]<br>Rescue service [G, Q, A]<br>Weather conditions [N, G, GS, Q, A]<br>Traffic management measures [G, Q] | Out of the scope of this work |

This information exchange would depend on the models employed and the host environment for their integration. These sub-models might be developed independently and their interaction represented via information exchange. There are several modelling environments that although predominantly address wildfire, also house a sub-model regarding evacuee response [19]. Similarly, an evacuee sub-model might also be housed within (and be an input to) a traffic model [20]. This implies that the integration between models may take place in different manners. The present study suggests that regardless of the starting modelling environment used for the integration, the listed data exchange needs should be ensured.

## 5 DISCUSSION

Decisions made during community planning, property upkeep, emergency planning, public education, responder training and during the evacuation itself are all heavily reliant on the information available; i.e. the evidence on which the WUI response is based. The emergency response to WUI fires includes the ability of the affected community to prepare for the hazards, adapt to the evolving conditions of the incident and recover from disruptions in the immediate aftermath of the incident and in the longer term. This is achieved through the efforts of the community itself and emergency responders. To ensure that this preparation and response is adequate, the effectiveness of the pre-incident decisions and decisions taken during the incident needs to be understood in order to allow assessment of these decisions before they are finalized; i.e. before they are put into practice. Both design and emergency response are key elements in addressing the occurrence, development, and impact of WUI incidents. Efforts to inform and improve these elements will impact the frequency and severity of such WUI incidents. This work addresses this need by presenting a system specification for a toolkit able to provide numerical evidence to support the design and emergency response processes.

In order to achieve an improved situation awareness, a multi-component modelling framework has to be sensitive to an array of constraints and requirements - given different types of application, data availability, end users, incident attributes and time constraints. For instance, addressing this last point, an internal component that is able to switch between fire/pedestrian/traffic sub-models of different levels of granularity (and therefore computational expense) should be included to ensure that the system can perform in the time available. The system would then be able to monitor and manage the models used in accordance with the scale of the scenario being examined (e.g. area involved, duration, etc.). This is key as the system is intended for use as a planning tool (prior to an incident) and as a tool to aid the decision-making process of emergency responders (during an incident).

The assessment of the required level of model scope and refinement highlights the (a) importance of accurately denoting model granularity and (b) the relationship between this granularity and what results can reasonably be generated [21], [22]. Model granularity affects the viability of application scales given the time and resources available (i.e. whether the application is required in real-time or during evacuation planning).

It should be noted that the recommendations for different levels of granularity should not be purely based on the assessment of the tool for an individual subject domains (wildfire, pedestrian, or traffic). It should address instead the sensitivity of the overall results of the influence of one modelling domain on another. This means that the propagation of inaccuracies between models should be examined, along with the potential wastage of dedicating resources in the more refined representation in one domain that is then not reflected in an adjacent area (or the projected results). The developer/user should aim for a ‘consistent level of crudeness’ to avoid discrepancy in the resolution of the modelling results, as well as the propagation of uncertainties.

The list of outputs and inputs for exchange between different modelling layers are also reported in this paper in order to inform the development of a comprehensive multi-layer toolkit. An indication of the data format for the relationships outlined was presented. While assessing different types of models, it has been possible to identify the main requirements for data exchange between the three different types of models (fire, pedestrian, traffic) as well as other external models/information (e.g. weather conditions).

## 6. CONCLUSION

To date, there are no integrated modelling tools that are able to inform decision making during WUI fire incidents considering fire, pedestrian and traffic components. To address this issue, this article describes the process adopted for the development of a system specification for an integrated modelling tool for WUI incidents. Key findings concerning level of granularity in relation to spatial and temporal issues and required data exchange are presented. The work deliberately set out to help future developers of such an integrated simulation system - an essential aid for planning and emergency decision-making. The material developed spans the key areas of WUI fire evacuations (fire, pedestrian, and traffic), and will be freely and publically available. It is hoped that this work will be a valuable and accessible resource; a resource that encourages and supports the development of a simulation system that can estimate the outcome of emergency scenarios and give decision-makers insights into the consequences of their decisions before they are taken. This tool will help improve the situational awareness of decision makers and therefore better inform their responses to avoid or mitigate the consequences of WUI events.

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