Testing the wildland-urban interface fire evacuation tool WUI-NITY: A case study of a rural community

Afroza Mallick

Fire Safety Engineering
Lund University
Sweden

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Abstract

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Fire Safety Engineering
Lund University
P.O. Box 118
SE-221 00 Lund
Sweden

http://www.brand.lth.se

Telephone: +46 46 222 73 60

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TESTING THE WILDLAND-URBAN INTERFACE FIRE EVACUATION TOOL WUI-NITY:

A CASE STUDY OF A RURAL COMMUNITY

Afroza Mallick

Supervisor(s): Enrico Ronchi

Master thesis submitted in the Erasmus+ Study Programme

International Master of Science in Fire Safety Engineering

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সারাংশ

এই থিসিসটি মাল্টি-ফিজিক্স সিমুলেশনগুলির উপর ভিত্তি করে একটি অবাধে উপলভ্য প্ল্যাটফর্ম, নাম WUI-NITY, এর ব্যবহার করে WUI অপসারণ মডেল তৈরি করে। এই সিমুলেশন প্ল্যাটফর্মটিতে আগুন ছড়িয়ে পড়া, পথচারী চলাচল এবং ট্র্যাফিক চলাচলকে সম্বোধনকারী তিনটি উপ-মডেল অন্তর্ভুক্ত রয়েছে, যা গতিশীল দুর্বলতার মূল্যায়নে কার্যকর আউটপুট উত্‌পাদন করার জন্য তাদের মিথস্ক্রিয়তার প্রতিনিধিত্ব করে। থিসিসটির লক্ষ্য মডেলটির অপসারণ উপাদানটি বিবেচনা করে WUI গ্রামীণ জনগোষ্ঠীর অপসারণ পরিস্থিতিগুলির জন্য WUI-NITY প্ল্যাটফর্ম পরীক্ষা করা। এছাড়াও, নির্ধারিত ইনপুট মানগুলিতে মডেলের ফলাফলগুলির সংবেদনশীলতা তদন্ত করা হয়। রক্সবারো পার্ক (কলোরাডো, মার্কিন যুক্তরাষ্ট্র) WUI সম্প্রদায় পরিচালিত অপসারণ ড্রিলের ভিত্তিতে প্রথমে একটি ডিফল্ট দৃশ্য তৈরি করা হয়। প্ল্যাটফর্মের সংবেদনশীলতা পরীক্ষার জন্য পাঁচটি চলক মডেল ইনপুট নির্বাচন করা হয়েছিল। পনেরটি বিভিন্ন দৃশ্যপট তৈরি করতে চলক মানগুলি ডিফল্ট পরিস্থিতি থেকে পরিবর্তন করা হয়েছিল এক সাথে সংবেদনশীলতা বিশ্লেষণ পদ্ধতি (OAT) গ্রহণ করে । বিবেচিত চলকগুলি হল মোট জনসংখ্যা, এজেন্টদের প্রতিক্রিয়া সময়, বহির্গমন হিসাবে উপলভ্য লক্ষ্য সংখ্যা, আশ্রয় ক্ষমতা এবং বিপরীতমুখী ক্রম সক্রিয়করণ। WUI-NITY টিতে চালিত সিমুলেশনগুলি প্রতিটি চলকের প্রত্যাশিত প্রভাব ক্যাপচার করতে সক্ষম হয়েছিল। বেশিরভাগ পরিস্থিতিতে অপসারণ সময় পাঁচ মিনিটের দ্বারা পৃথক হয়। কিন্তু, দীর্ঘ প্রতিক্রিয়া সময় এবং একটি লক্ষ্য হিসাবে গোল এফ এর অপ্রাপ্যতা পরিস্থিতির জন্য মোট অপসারণ সময় এগার থেকে চল্লিশ মিনিটের দ্বারা পৃথক হয়। বিবেচনাধীন পরিস্থিতিগুলির মধ্যে রাস্তায় সীমিত ভিড় অন্তর্ভুক্ত ছিল। উপলভ্য লক্ষ্য এবং পরিবর্তনশীল আশ্রয় ক্ষমতা হিসাবে বিবেচিত পরিস্থিতিগুলির ফলাফল রোড নেটওয়ার্ক ডেটা দ্বারা অত্যন্ত প্রভাবিত হয়েছিল। যেহেতু অপসারণ করার সময়টির খুব বেশি পার্থক্য নেই, এই অবস্থায় বেশি আগ্রহ কত লোক দুর্বল অবস্থায় আছে তা চিত্রিত করা। WUI-NITY-তে চালানো সিমুলেশনগুলি থেকে এটি পাওয়া সম্ভব।

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List of Abbreviations

CWPP	Community Wildfire Protection Plan
FARSITE	Fire Area Simulator
GUI	Graphical User Interface
LWR model	Lighthill-Whitnam-Richards traffic evacuation model
NFPA	National Fire Protection Association
OAT	One at a time sensitivity analysis approach
OSM	Open Street Map
PERIL	Population Evacuation trigger algorithm
SIP	Shelter in Place
WUI	Wildland-Urban Interface

1. Introduction

Wildfires around the world are becoming more intense and more frequent in recent years because of climate change *(Duane, Castellnou, & Brotons, 2021)*. Together with an expanding wildland-urban interface (WUI) area and a growing population, an upward trend in the destruction caused by wildfires is anticipated *(Folk, Kuligowski, Gwynne, & Gales, 2019; Hammer, Stewart, & Radeloff, 2009; Radeloff et al., 2018)*. WUI is defined by *NFPA (2018)* as "an area where wildland fuels abut structures, with a clear line of demarcation between residential, business and public structures and wildland fuels". The term does not indicate a geographic location, as pointed out by *NFPA (2018)*. Rather it is concerned with "a set of conditions" that is prevalent is many communities around the world, including location of combustible structures, their density and availability. WUI area consists of a group of people who are diverse in terms of demographics, density, remoteness from each other, road accessibility, and contact with the wildland *(Bento-Gonçalves & Vieira, 2020; Folk et al., 2019)*. Highly coupled and non-linear interaction among these factors, along with local climatic conditions, complex topography, vegetation types, fuel loading and management procedures, and construction materials used for the built environment, make a WUI fire unique and more difficult to control *(Bento-Gonçalves & Vieira, 2020; Gaudet, Simeoni, Gwynne, Kuligowski, & Benichou, 2020; Manzello et al., 2018; Ronchi et al., 2017)*. WUI fires are those fires that ignite in the wildlands but spread into WUI areas, affecting both residents and their properties *(Bento-Gonçalves & Vieira, 2020)*. Recent wildfires in California exhibited fast spreading fire among WUI areas intensified by high wind and the availability of more fuel *(Wong, Broader, & Shaheen, 2020)*.

As pointed out by *Ronchi et al., (2017)*, a WUI fire is different from a building fire because of its "spatial dynamism, temporal iterations, the range of influential factors and the multi-level organizational involvement". These characteristics challenge the effective issuance of an evacuation order for a WUI community. The way the community responds to the evacuation order significantly affects the outcome of a WUI fire *(Gaudet et al., 2020)*. At the household level, there can be three types of protective actions taken in response to an evacuation order – evacuate, defend or shelter in place (SIP) *(Lovreglio, Kuligowski, Gwynne, & Strahan, 2019)*. Evacuation is the strategy to leave the threatened area and move towards a safe place, normally using a vehicle. Defend and SIP fall under the 'stay' strategy when people decide not to leave their house. The term defend is used when the householders protect their property and/or the occupants from wildfires, while the term SIP is used when the householders fail to defend their property and use it only for protection as a backup policy *(Lovreglio et al., 2019)*. Thus, it is important to understand the risk perception of the households as this affects what response is selected by them and when *(Lovreglio, Kuligowski, Walpole, Link, & Gwynne, 2020)*. External factors (such as evacuation warning, environmental cues and social cues), as well as internal factors (such as previous experience of a wildfire evacuation, education level of the household members, time spent in the residence property etc.), can influence how a household perceive the risk of a wildfire, and in turn affect the evacuation process *(Lovreglio et al., 2020)*. However, this is a gap, which requires further studies.

In response to an evacuation order, the most common protective action adopted by the households is to evacuate. WUI fire evacuation is generally conducted at the community scale. However, this action may not be feasible for all the households in a WUI community due to the dynamic nature of a wildfire *(Cova, Drews, Siebeneck, & Musters, 2009; Li, Cova, & Dennison, 2015; Vaiciulyte, Hulse, Veeraswamy, & Galea, 2021)*. The best available information on the factors that can influence wildfire vulnerability is required to issue an effective evacuation order. These factors include, but are not limited to – the extent of the fire, ignition source, rate of spread, type of fire (ground fire, crown fire, surface fire or ladder fire), fire line intensity, smoke distribution, smoke toxicity, visibility, relative humidity, temperature, wind speed and direction, precipitation, dry days, type of vegetation, fuel moisture content, amount of fuel available and its continuity, topography (aspect, slope and elevation), presence of fire barriers (natural or constructed), construction materials used in the WUI area, dimensions of the houses, management of the surrounding landscape, development density, community demography, population density, preferred protective actions by the community, training and past experiences, road capacity, traffic management, availability of water, proximity to water sources, location of fire stations and their response time *(Jämtheden & Wiberg, 2020)*. Failure to properly decipher and communicate the information about who should evacuate, at what time and which route should be chosen can negatively affect a threatened WUI community *(Larsen, Dennison, Cova, & Jones, 2011)* – leading them to select the wrong option and/or do so at the wrong time. Even when a proper evacuation order is issued, several additional factors can affect the performance during a WUI evacuation. These include – pre-evacuation time of a household, evacuating population, their route use, traffic demand, traffic movement rates, route capacity, background traffic, shadow evacuation, and confirmation/detection/notification activities, etc. *(Ronchi et al., 2017)*. Most communities have fewer accessible roads or have access to more dangerous roads to evacuate. These make the WUI communities more vulnerable to wildfires and challenges their timely safe evacuation, resulting in most of the fatalities reported during a wildfire *(Haynes, Handmer, McAneney, Tibbits, & Coates, 2010)*. Furthermore, the efficiency of the firefighters and emergency services in rescuing the threatened population is also hindered *(Folk et al., 2019; Manzello et al., 2018; Zhao, Lovreglio, Kuligowski, & Nilsson, 2020)*.

In the US, evacuation is the preferred response to an emergency to ensure public safety. On the contrary, defending in place is preferred in Australia (though not consistently across different regions), which is also practiced in North America as an alternative *(Walpole, Wilson, & McCaffrey, 2020)*. However, the aftermath of the 2009 Black Saturday bushfires raised questions regarding the efficiency of sheltering practices favored in Australia without any comprehensive planning and no or minimum prior preparation adopted by the households *(Blanchi, Whittaker, Haynes, Leonard, & Opie, 2018)*. The decision to stay or to leave largely depends on the households and can lead to delayed evacuation *(Walpole et al., 2020)*. Delayed evacuation can expose residents to worsening conditions and put their lives in danger. *Walpole et al., (2020)* pointed out that, decisions taken prior to an evacuation order greatly influence what a household might do in response to an actual situation. Education and training before wildfires can assist them in this decision-making process. Additionally, the improvement of situational awareness of incident commanders and firefighters during wildfire can enhance their response, help them mitigate conditions and ensure their response is better informed – potentially aiding threatened WUI residents *(Li, Cova, & Dennison, 2017)*.

Evacuation simulation models can be beneficial when planning for a large-scale evacuation *(Filippidis et al., 2020)*. The models allow the user to make projections and assess performance before an evacuation is conducted. They can also explore a range of scenarios (assuming the model can represent them), enabling performance and robustness of different strategies to be assessed. The safety of the evacuees during evacuation largely depends on the severity of the fire hazard, the use of the escape route and the mode of transport chosen to evacuate. The use of a tool which jointly considers the fire spread, pedestrian movement, and traffic movements is thus desired to plan for reducing risks in community evacuation *(Filippidis et al., 2020; Ronchi et al., 2017)*. Therefore, it is important to employ a credible and effective evacuation model which can comprehensively address the challenges posed by a WUI fire, assist in the improvement of situational awareness and ensure timely and safe evacuation of the exposed WUI communities *(Folk et al., 2019)*.

In order to model WUI fire evacuation and quantify its performance, a novel, freely available framework based on multi-physics simulations has been introduced *(Ronchi et al., 2017)*. The platform is named WUI-NITY, which has been developed using Unity3D game engine *(Ronchi et al., 2020; Wahlqvist et al., 2021)*. This simulation platform includes three sub-models addressing fire spread, pedestrian movement and traffic movement on the assumption that they interact among themselves to produce quantitative values. These values can then assist in the planning phase (pre-incident) by assessing the community design resource allocation or procedural effectiveness; or the decision-making phase (during an incident) by enhancing the situational awareness of different stakeholders and demonstrating the effectiveness of their response – assuming that the model can be executed sufficiently quickly. The platform can generate different numerical outputs (i.e., number of people left, number of cars currently in the system, average velocity of the cars, etc.) from the coupled sub-models, which can be used to produce vulnerability maps. This facilitates the paradigm shift from the current methods of risk assessment and mapping tools for wildfires to a more holistic approach *(Ronchi et al., 2017)*.

WUI-NITY can be used to educate and train the responders and the threatened community, as well as to study and learn from past WUI fire evacuations *(Wahlqvist et al., 2021)*. The project to introduce WUI fire evacuation modeling platform was undertaken by the Division of Fire Safety Engineering at Lund University (Sweden), along with an international research group including Imperial College of London (the UK), the National Research Council (Canada) and National Fire Protection Association (the US) *(Ronchi et al., 2017)*.

1.1 Objectives

The goal of the thesis is to test the WUI-NITY platform for WUI fire evacuation scenarios by taking into consideration the evacuation component of the model. WUI-NITY will be compared against a field dataset consisting of a community evacuation drill conducted in Roxborough, Colorado (USA). In addition, the sensitivity of the model results to the input values assigned will be investigated.

1.2 Delimitations

The scope of this thesis project is limited by time and available data. A complete validation of the modeling tool is beyond the scope of this work and requires the selection and assessment of several WUI fire evacuation case studies. This is not possible in the time available. The selection of a broader range of 'what if' scenarios for a given well-documented case study to model WUI fire evacuation has been therefore deemed more appropriate given the scope of this work. This should enable us to determine whether the model is at least capable of representing conditions evident during a representative situation, albeit without expanding to a wider set of situations. Furthermore, the absence of detailed data concerning the response of populations during a WUI fire evacuation across these different situations is another limitation for this thesis project. Better understanding of human behavior in WUI fire evacuation and the factors influencing their decision-making process requires further studies *(E. Kuligowski, 2021; E. D. Kuligowski, Walpole, Lovreglio, & Mccaffrey, 2020)*. Quantitative data for these factors is essential for the modeling of evacuation scenarios using WUI-NITY with increased accuracy.

Furthermore, the present study only concerns about the evacuation component of the WUI-NITY platform. It does not address the different fire locations, development of the fire and the products that might be produced (i.e., smoke). Thus, it is assumed for the scenarios under consideration in this study that the fire does not interfere with the community evacuation.

The project is expected to be an initial step towards the validation of the WUI-NITY platform, while also demonstrating the scope of the model in representing a range of different scenario conditions.

2. Methodology

The goal of the project can be achieved by modeling the response of the population to an evacuation order in WUI-NITY and by comparing it against a community evacuation dataset to test the performance of the model. At first, a literature review related to the selected case study and the modeling platform is conducted. Then the configuration of the selected scenarios for different variables and the modeling platform is described. Additionally, the output values used to present the results are briefly introduced.

2.1 Literature Review

2.1.1 Case study

According to *Radeloff et al., (2018)*, the US observed a rapid increase in the number of new houses in the WUI areas in recent decades. Consequently, this resulted in the expansion of areas susceptible to wildfires for many residents and their properties. The case study to use in this thesis project is based on an evacuation drill conducted in Roxborough Park located in Colorado in the US (Figure 1).

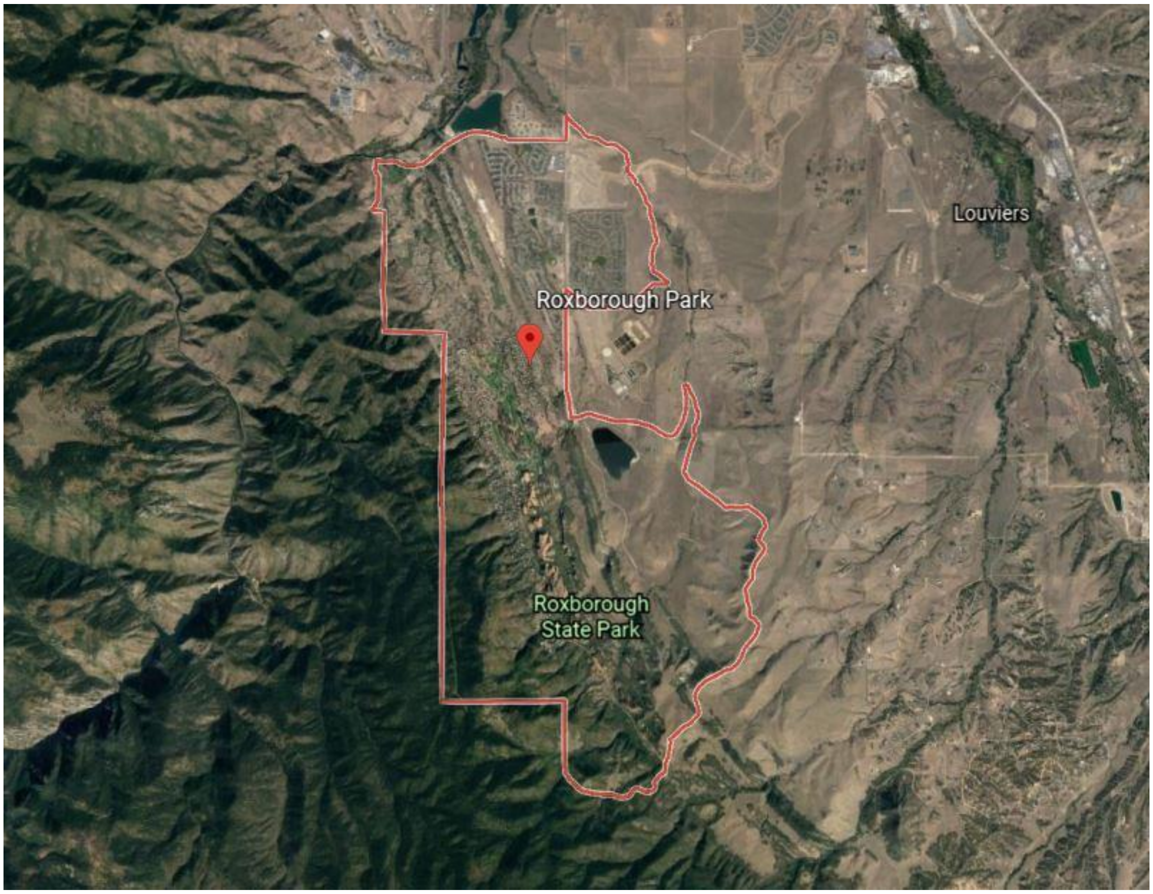

Figure 1: Roxborough Park community outline, retrieved from Google Earth.

The Roxborough community is a part of the Firewise program administered by National Fire Protection Association (NFPA)[1]. The Roxborough Park WUI community consists of 900 households in an area of approximately nine square kilometers. In the past, the community was exposed to two wildfires, namely 1996 Buffalo Creek Fire and 2002 Hayman Fire. The community has several egress routes, with an additional emergency evacuation route, information about which is included in the Community Wildfire Protection Plan (CWPP) prepared by the Roxborough Park Fire Mitigation Committee *(CWPP, 2007)*. This plan assists the residents in choosing a route in case of a wildfire approaching the community in question *(Ronchi et al., 2020)*.

Figure 2: Roxborough Park emergency egress map. Retrieved from CWPP (2007).

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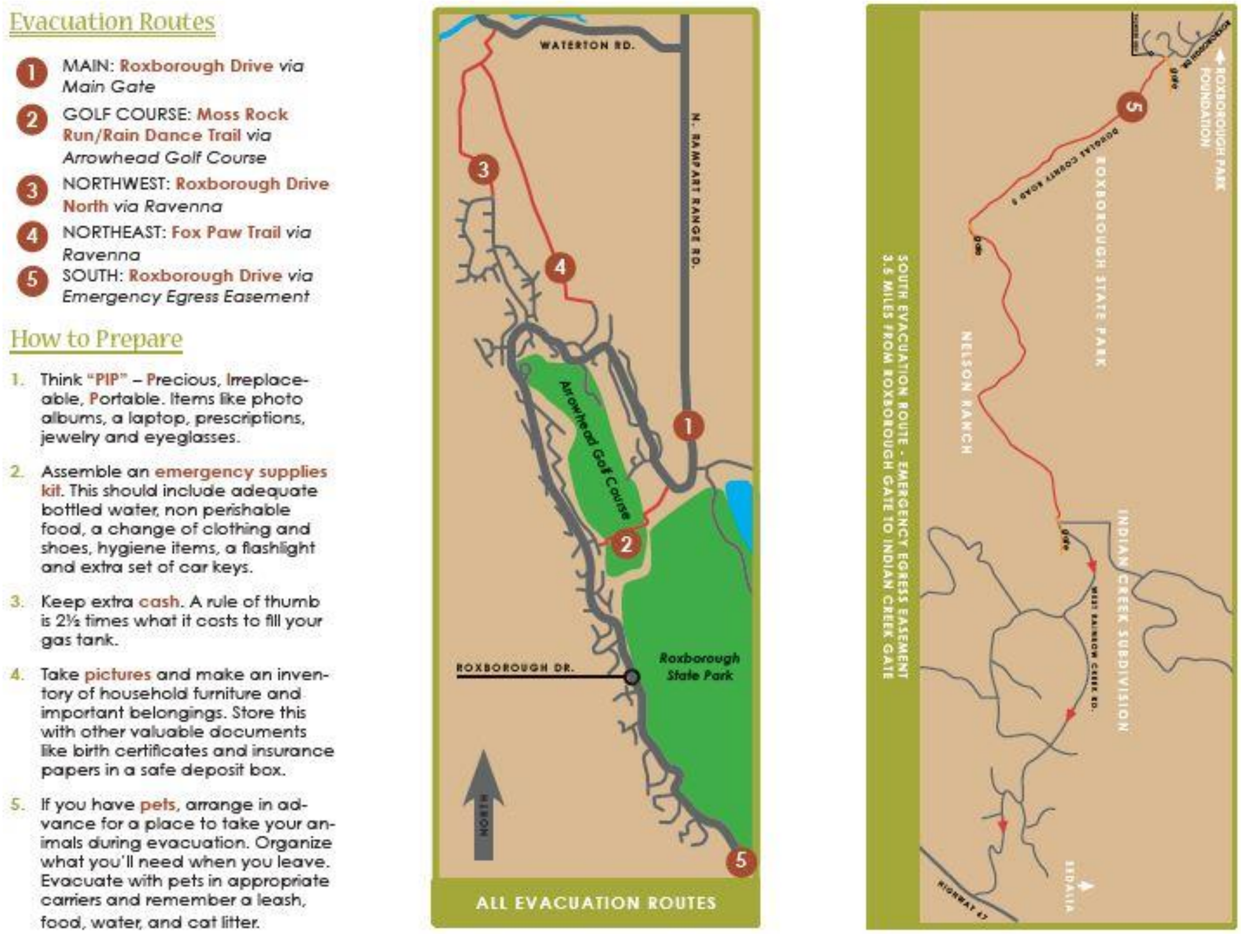
[1] The program provides a collaborative framework to help neighbors in a geographic area get organized, find direction and take action to increase the ignition resistance of their homes and community and to reduce wildfire risks at the local level. https://www.nfpa.org/Public-Education/Fire-causes-and-risks/Wildfire/Firewise-USA

2.1.2 Collected Data from the Drill

The evacuation drill was conducted on the 27th of July 2019 in Roxborough Park. The data collected from this drill has been used as the baseline for the thesis. A total of 133 households (484 people) registered for the drill, though some additional families may have joined the event. These households were informed about three egress routes they could access during the drill through a gate, which included Roxborough Drive via Main Gate (denoted R, route 1 in Figure 3), Roxborough Drive via emergency egress easement (denoted E, route 5 in Figure 3) and Fox Paw Trail to Ravenna (denoted F, route 4 in Figure 3). The additional route mentioned in the CWPP, which is accessible through a golf course (route 2 in Figure 3), was made unavailable for the drill. The words 'route' and 'gate' were used interchangeably in the report *(Ronchi et al., 2020)*.



Evacuation Routes

1. MAIN: Roxborough Drive via Main Gate
2. GOLF COURSE: Moss Rock Run/Rain Dance Trail via Arrowhead Golf Course
3. NORTHWEST: Roxborough Drive North via Ravenna
4. NORTHEAST: Fox Paw Trail via Ravenna
5. SOUTH: Roxborough Drive via Emergency Egress Easement

How to Prepare

1. Think "PIP" – Precious, Irreplaceable, Portable. Items like photo albums, a laptop, prescriptions, jewelry and eyeglasses.
2. Assemble an emergency supplies kit. This should include adequate bottled water, non perishable food, a change of clothing and shoes, hygiene items, a flashlight and extra set of car keys.
3. Keep extra cash. A rule of thumb is 2½ times what it costs to fill your gas tank.
4. Take pictures and make an inventory of household furniture and important belongings. Store this with other valuable documents like birth certificates and insurance papers in a safe deposit box.
5. If you have pets, arrange in advance for a place to take your animals during evacuation. Organize what you'll need when you leave. Evacuate with pets in appropriate carriers and remember a leash, food, water, and cat litter.

Figure 3: Roxborough Park community evacuation routes. Retrieved from the Roxborough Evacuation Guide (FIREWISE, 2011).

The participants were given questionnaires to comment on the timeline of their actions (i.e., time to access their vehicles, time to reach the destination, etc.), the route they chose out of the three accessible egress routes, and their final arrival point. Further information was collected from observations on the percentage of participants starting from one of the three pre-defined zones

(A, B and C) during the drill, pre-evacuation time of the households after receiving Code Red alert, and the number of people and their time of arrival at one of the three gates. During the drill, the fire was assumed to start from west or south-west of the community by taking into consideration the amount of vegetation and predominant wind direction from west *(Ronchi et al., 2020)*.

The report by *Ronchi et al., (2020)* provides the results of the evacuation drill. The self-reported pre-evacuation time of the full sample of the participants followed a lognormal distribution, ranging from zero to 90 minutes with a mean of 14.99 minutes and a standard error of 2.01 minutes. However, a more conservative approach that estimated pre-evacuation time based on the time of arrival at each gate provided a range of 120 minutes. Both time distributions follow a similar pattern. The data indicated that, approximately 60% of the population responded within 15 minutes after the order was given. In case of the gates chosen, both the surveys and the gate count observations showed that more participants chose Gate R. Their second choice was Gate E and lastly Gate F. The average arrival time from the observations indicated that more time was needed to reach Gate E (35.9 minutes) than Gate R (18.7 minutes). For Gate F, the value was 32.1 minutes. The evacuation time was also reported based on the results from the surveys and the estimates from the gate observations. Based on the surveys by the participants, the mean evacuation time was 31.13 minutes with a standard error of 2.87 minutes. The mean evacuation time from observations was 105.92 minutes with a standard error of 6.7 minutes. The results indicated that, self-reported evacuation time under predicted the observed evacuation time until the end of the drill conducted *(Ronchi et al., 2020)*.

2.1.3 WUI-NITY Platform

WUI-NITY is based on the coupling of three different modeling layers to produce dynamic vulnerability assessment of an emergency by providing quantitative outputs. The wildfire spread layer is simulated based on FARSITE (Fire Area Simulator) model, which models fire behaviors for surface, crown, spotting and fuel moisture *(Finney, 1998; Ronchi et al., 2020)*. For the pedestrian layer, an ad hoc pedestrian response and movement model is used. WUI-NITY includes a default population distribution based on the Gridded Population of the World v4[2] to model this layer *(Wahlqvist et al., 2021)*. The third layer in the platform is based on the Lighthill-Whitnam-Richards traffic evacuation model (LWR model), which requires less computational time and is easy to implement *(Lighthill & Whitham, 1995; Ronchi et al., 2020)*. In addition, “trigger buffer” perimeters are created using a sub-model named PERIL (Population Evacuation trigger algorithm) *(Mitchell, 2019)*. This perimeter can be any geographical feature surrounding an area of interest. When a fire intersects this perimeter, it is assumed to trigger the necessity of an evacuation for the population residing in that area *(Li et al., 2017)*. However, this feature is not tested in this work.

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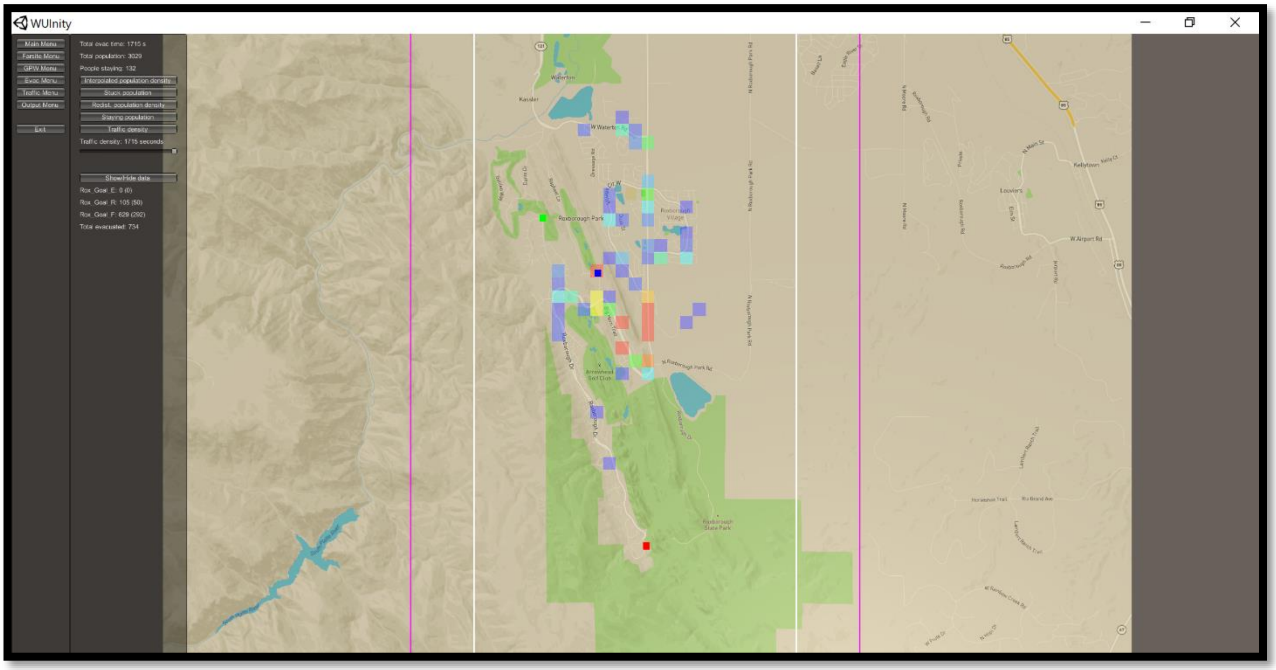
[2] https://sedac.ciesin.columbia.edu/data/collection/gpw-v4 *(Wahlqvist et al., 2021)*

In this study, the wildfire spread layer is not taken into consideration explicitly. Only the pedestrian and traffic models are considered for the simulation. Therefore, the Evac menu and Traffic Menu of the simulation platform are of interest. The Evac menu includes information about total population, maximum cars, household size, walking speed and time to evacuation order. The Traffic Menu includes information about capacity speed, effect of smoke on speed and the value of optical density. The input file used to run a simulation further includes other variables that are not visible in the GUI. These include the response curve, evacuation groups, evacuation goals, route choice, traffic accidents and lane reversal order. An example of the input file is added in Appendix 1 (section 8.1), which is loaded in the GUI of WUI-NITY to run the simulation. Simulations in this platform allow results to be examined at different levels – i.e., at the end of the simulation and the evolving conditions during the evacuation (Figure 4).



Total evac time: 1715 s
Total population: 3029
People staying: 132
Traffic density: 1715 seconds
Rox_Goal_E: 0 (0)
Rox_Goal_R: 105 (50)
Rox_Goal_F: 629 (292)
Total evacuated: 734

Figure 4: Screenshot of the Graphical User Interface (GUI) of the WUI-NITY platform during simulation.

A general description of the platform is provided by *(Wahlqvist et al., 2021)*. The population count for a certain area for the simulation is redistributed based on the road network provided by Open Street Map (OSM)[3]. The model then generates households over the area following the redistributed population. The default setting of WUI-NITY allocates one to five members and one car to evacuate for each household. However, access to maximum two cars based on the size of the household is permitted. Walking speed when moving towards the car ranges between 0.7 and 1 m/s *(Gwynne & Boyce, 2016)*. The platform calculates the maximum capacity of the roads based on the information from OSM (included in the input file, section 8.1). The present version of WUI-NITY does not model evacuation on foot and only considers private vehicles as the mean

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[3] http://www.openstreetmap.org *(Wahlqvist et al., 2021)*

of escape *(Wahlqvist et al., 2021)*. A guideline on how to run a simulation in the WUI-NITY by updating the input file is provided in Appendix 2 (section 8.2).

Once the simulation is done, the Output Menu appears in the GUI to visualize the result (Figure 4). As stated before, the simulation can also be run in real time to see how the scenario evolves over time. The output files are generated in .csv datasheets. A .csv file is produced for each run of a specific scenario. Again, separate files are generated to represent the pedestrian movement and the traffic movement for a defined time step. The pedestrian output files provide information related to "people left", "people started moving" and "people reached car" against time (in seconds). These files record data until the time the last agent have responded to the order and have reached their car to drive to the closest goal. The part of the population who decides not to evacuate is excluded from this calculation – especially given that these are not represented in the original data set. The traffic output files provide information on "injected cars", "exiting cars", "current cars in system", "exiting people", "average velocity [km/h]", "minimum velocity [km/h]", and "goal" (cumulative number of people reaching each goal). The traffic output files provide data starting from the start of the evacuation until the second the last car reaches a safe place. A sample of the output files is provided in Appendix 3 (section 8.3).

2.2 Configuration of the Scenarios

To test the modeling capability of WUI-NITY, several scenarios are introduced in this study. The default scenario (denoted s0 in this study) is constructed to calibrate the model based on the data collected from the evacuation drill in Roxborough Park – to simulate the conditions produced during the original drill. The s0 scenario is then used as the foundation to construct the other scenarios by adopting the one at a time (OAT) sensitivity analysis approach. The OAT approach, which is considered a "local sensitivity analysis approach", allows different scenarios to be produced by changing one variable at a time while keeping the other variables constant *(Saltelli et al., 2019)*. The main concern of this study is to test how different input variables can influence the evacuation process considering a limited number of scenarios. The OAT approach assists in decreasing the number of scenarios based on the variables considered. Therefore, the approach is implemented in this study.

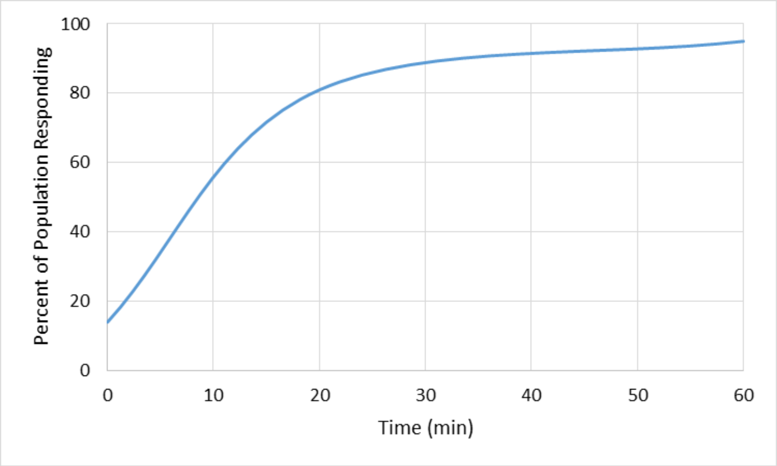
As discussed in section 2.1.3, several input variables are included in the Evac Menu and the Traffic Menu relating to the evacuation component of the WUI-NITY platform. These variables are considered to construct the scenarios to test their effect on the modeling capability of the platform. At first, test simulations are run in the WUI-NITY to check the likely influence of these different variables. After considering the effect of the variables on the evacuation, a shortlist of five possible variables to use is produced. The rest of the variables mentioned in section 2.1.3 are kept constant. The selected five variables and their short descriptions are presented in Table 1.

Table 1: Description of the selected variables for constructing different scenarios to simulate in the WUI-NITY platform.

Selected Variable	Description of the Variable
1. Total Population	Total number of people considered in the simulation that is redistributed in the selected study area based on the GPW v4 data *(Wahlqvist et al., 2021)*.
2. Response Time	Depending on a response distribution curve, which provides information on the percent of people evacuating by responding at a given period *(Wahlqvist et al., 2021)*.
3. Available Goals	The closest destination of the evacuating cars *(Wahlqvist et al., 2021)*. In this study, the goals are demarcated inside the study area as shelters. Agents are considered safe once they reach one of the closest goals.
4. Shelter Capacity	The maximum number of cars allowed in a particular goal. Once the shelter is filled, rest of the cars re-route to another goal.
5. Lane Reversal Order	Defined by *(Hausknecht, Au, Stone, Fajardo, & Waller, 2011)* as "the reversal of lanes in order to temporarily increase the capacity of the congested roads – can effectively mitigate traffic congestion during rush hour and emergency evacuation". This approach increases the capacity of the accessible roads *(Jämtheden & Wiberg, 2020)*.

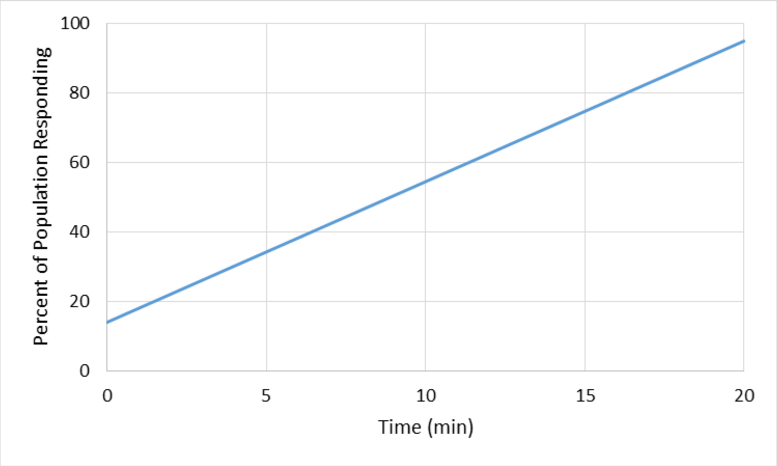
These variables are assigned certain values as presented in Table 2 for Scenario s0 – to approximate the initial conditions seen during the original evacuation drill. Instead of considering the fraction of the population that took part in the drill, the expected total population of the community is used for the first variable in the scenario, which is 3030 for approximately 900 households present in the Roxborough Park community *(Ronchi et al., 2020)*. The response curve used for the second variable is set as default in the WUI-NITY, which is derived from a literature review on pre-evacuation behavior *(Ronchi et al., 2020; Wahlqvist et al., 2021)*. The position of the available goals is based on the evacuation drill conducted in the study area *(Ronchi et al., 2020)*. Shelter capacity and lane reversal orders are not activated for Scenario s0.

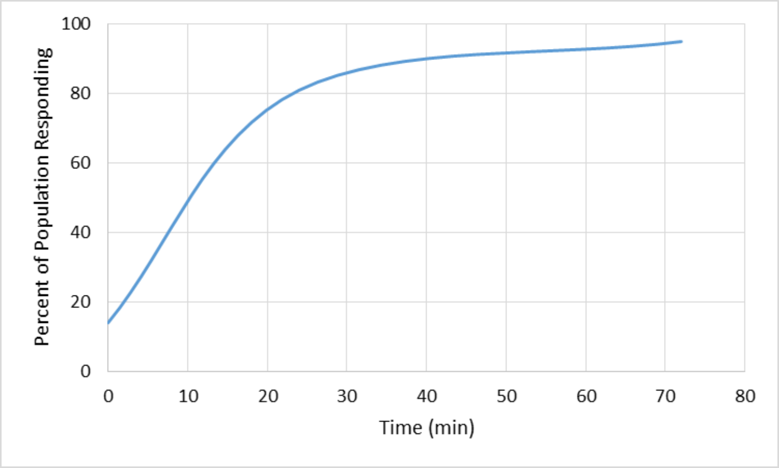
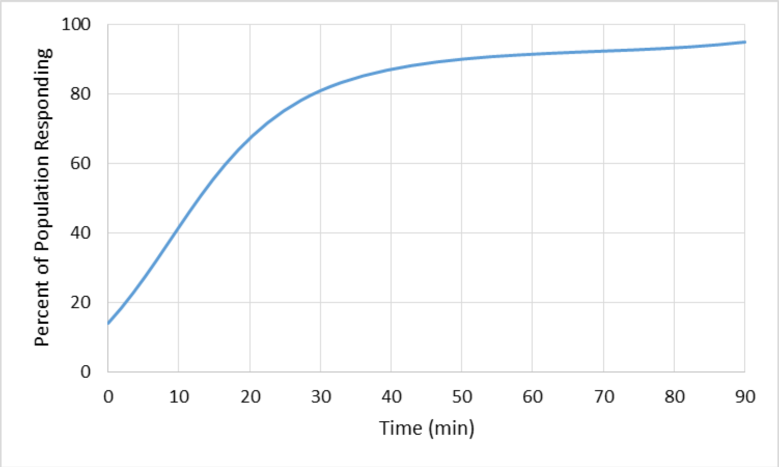
Table 2: Description of the values assigned for the default (s0) scenario for each variable.

Variables	Input Value
1. Total Population	3030.
2. Response Time	Derived response curve from literature. - 81% of the population respond within 20 minutes after the issued order. - 95% of the population respond within 60 minutes after the issued order. - 5% of the total population do not evacuate. 
3. Available Goals	All three goals (E, R and F) are available as exit.
4. Shelter Capacity	No max capacity of the shelters is mentioned. No rerouting of the cars is necessary.
5. Lane Reversal Order	The authority issues no order.

From the variables, 15 different scenarios are generated using the OAT approach. The scenarios are named with a number and a suffix depending on the changing factor for that scenario. Table 3 provides a description of the selected scenarios and how the variables are changed for each of them. Only the changes are mentioned for a particular scenario in the table, whereas the other variables are set to the default value. The purpose is to see the sensitivity of the outcomes to changes in these underlying conditions. The variations in these initial conditions may occur in reality.

Table 3: Description of the values assigned for the scenarios for each changing variable. Other variables for that particular scenario are identical to Scenario s0.

Scenarios	**Changing Variables**	**Description of the Input Value**
s1_pop	Total Population	A 25% increase in the population, 3788.
s2_pop	Total Population	A 50% increase in the population, 4545.
s3_res	Response Time	Instantaneous response from the population. • 95% of the population respond within 20 minutes after the issued order. • 5% of the total population do not evacuate. 
s4_res	Response Time	An extension of time taken to respond by 20%, effective after the issue of the evacuation order. • 81% of the population respond within 24 minutes after the issued order. • 95% of the population respond within 72 minutes after the issued order. • 5% of the total population do not evacuate.

		
s5_res	Response Time	An extension of time taken to respond by 50%, effective after the issue of the evacuation order. • 81% of the population respond within 30 minutes after the issued order. • 95% of the population respond within 90 minutes after the issued order. • 5% of the total population do not evacuate. 
s6_ER	Available Goals	Only two goals available (E and R). • Evacuees choose the closest goal from their random initial position.
s7_EF	Available Goals	Only two goals available (E and F). • Evacuees choose the closest goal from their random initial position.
s8_RF	Available Goals	Only two goals available (R and F). • Evacuees choose the closest goal from their random initial position.

s9_E	Available Goals	Only one goal available (E)
s10_R	Available Goals	Only one goal available (R)
s11_F	Available Goals	Only one goal available (F)
s12_capE	Shelter Capacity	Max 50 cars can take shelter in Goal E, rest of the cars re-route to the nearest goal.
s13_capR	Shelter Capacity	Max 50 cars can take shelter in Goal R, rest of the cars re-route to the nearest goal.
s14_capF	Shelter Capacity	Max 50 cars can take shelter in Goal F, rest of the cars re-route to the nearest goal.
s15_lane	Lane Reversal Order	An order issued for 30 minutes, starting from 900s to 2700s.

For each scenario, each variable is assigned a value to test how the simulated results differ in each case. These values are not based on literature. However, they have been defined using the values derived from the s0 scenario as a benchmark. The number of people for Scenarios s1_pop and s2_pop is increased by 25% and 50% respectively to test how an increase in the number of people in the system affects the results – exploring the impact of the Total Population variable on the results produced.

Response Time is extended to varying degrees for Scenarios s4_res and s5_res, while keeping the percent of population responding along that time constant. Thus, the shape of the response time distribution remains the same for each scenario. In Scenario s3_res, an instantaneous response is assumed.

The number of Available Goals is examined along with evacuees assumed to select their nearest route given their starting location (Scenarios s6_ER – s11_F). In these scenarios, the number of Available Goals is reduced to two goals and one goal from the initial value in Scenario s0. The combination of each goal determines the different scenarios constructed from Scenarios s6 to s11 (with suffix relating to the available goals).

The final set of scenarios looks at the impact of shelter capacities on the evacuation process. A maximum number of 50 cars is assumed for the variable shelter capacity. Three different scenarios are constructed – Scenarios s12 to s14 – with each scenario name having a suffix relating to which goal is considered. Fewer cars are considered in the scenarios, to test how rerouting may affect the results compared to the default scenario.

For the last scenario (s15_lane), when the lane reversal order is active, a random period is considered to check the impact of this variable on the scenario using WUI-NITY. The period starts when a large number of people has already responded to the evacuation order and are expected to be on the road.

2.3 Model Configuration and Simulation

The thesis employs WUI-NITY version 0.05 pre alpha to simulate the scenarios. As WUI-NITY is a probabilistic model, it is necessary to assess the number of runs required to examine the impact of behavioral uncertainty on the output of each scenario considered. By employing an iterative evaluation method to produce a stable evacuation curve *(Ronchi, Reneke, & Peacock, 2014)*, 20 runs for each scenario have been considered as convergence is already met.

Each scenario is then simulated in the WUI-NITY platform, considering a time step of one second. Further information is provided in Appendix 2 (section 8.2) about the setup of the simulations. The output files are produced in the designated folder for the model. The output values from each run for a scenario is compiled in a single document. The average value, the cumulative value and the integral value of each column is then calculated as needed. Average total evacuation time for each scenario is calculated from the column “Time (s)”. To present the results relating to the selected variables, different columns from the generated output files are used. Pedestrian output file is only included for the variables “Total Population” and “Response Time”, as these two relate to how people are moving before entering the road network. For the last three variables, the traffic movement output files are of utmost importance. The same number of people respond at the same period for the scenarios involving these three variables, so pedestrian output files are not considered.

The set of information that can represent the condition of the roads during evacuation are selected for each case, as presented in Table 4. For a changing input variable corresponding to a specific scenario, a set of columns from the output files of that particular scenario is considered.

Table 4: Output results considered for each changing variable.

Input variables	Columns selected from the output files
1. **Total Population**	– Current cars in system (traffic) – Exiting people (traffic) – People left (pedestrian)
2. **Response Time**	– Current cars in system (traffic) – Injected cars (traffic) – People reached car (pedestrian)
3. **Available Goals**	– Avg. v (km/h) (traffic) – Current cars in system (traffic) – Exiting cars (traffic) – Goal: Rox_Goal_E (traffic)

	– Goal: Rox_Goal_R (traffic) – Goal: Rox_Goal_F (traffic)
4. Shelter Capacity	– Avg. v (km/h) (traffic) – Current cars in system (traffic) – Goal: Rox_Goal_E (traffic) – Goal: Rox_Goal_R (traffic) – Goal: Rox_Goal_F (traffic)
5. Lane Reversal Order	– Avg. v (km/h) (traffic) – Current cars in system (traffic) – Exiting cars (traffic)

To visualize the number of people left to respond to the evacuation order, information is gathered from the column "*people left*" in the pedestrian output file. Information on the number of people who reached their car at a certain time step is taken from the column "*people reached car*", which is also in the pedestrian output file. The rest of the values are taken from the traffic output files. The number of cars present in the road over time is used from the column "*current cars in the system*". Information on the number of cars being introduced in the system over time and the number of cars reaching one of the available goals can be derived from the columns "*injected cars*" and "*exiting cars*" respectively. It is also of interest to depict congestion on the road over time, information about which can be collected from the column for "*average speed*" *(Ronchi et al., 2020)*. The cumulative number of people reaching each goal over time can also be generated from the platform, which is taken from the "*goal*" column in the output file.

Outputs extracted at the end of the simulation provide insights into the dynamic condition in the roads during evacuation. Some information can also be extracted at any point during the simulation, such as the number of people who evacuate, the number of people who stay, and the time when cars need to re-route for the variable Shelter Capacity. Graphs are generated from these data to visualize the conditions during the evacuation for each scenario. The results gathered from these output files are presented in section 0. The discussion (section 4) relates to the results gathered and the reason they are being examined.

3. Results

This section provides the results for each variable corresponding to a set of scenarios and allows comparison of these scenarios with the default scenario. The relevant results from Scenario s0 (default) are presented first, followed by the results from the other scenarios. The following sub-sections introduce the other scenarios and compare them with Scenario s0 based on the five selected variables.

3.1 s0 (Default) Scenario

The default scenario (s0), which closely reflects the conditions from the evacuation drill conducted in Roxborough Park, is considered as the base to compare how the results differ for each variable. Similar to the drill, Scenario s0 also considers the access to all three routes. Furthermore, the goals are not given any shelter limit. Presence of fire and smoke is not considered either. However, only 484 people participated in the drill and reported to have evacuated within a mean time of 31.13 minutes (31 minutes and 7 seconds) *(Ronchi et al., 2020)*. In Scenario s0, the total population represents the expected population of the study community, which is 3030. The average total evacuation time is 76.91 minutes (one hour 16 minutes and 54 seconds). As fewer people took part in the evacuation drill, the total evacuation time increased for Scenario s0. More people start to leave their homes to evacuate using a private vehicle in the beginning (Figure 5). By the end of the evacuation, most people have reached one of the three goals (Figure 6). An average of 144 people out of 3030 stays in the threatened area.

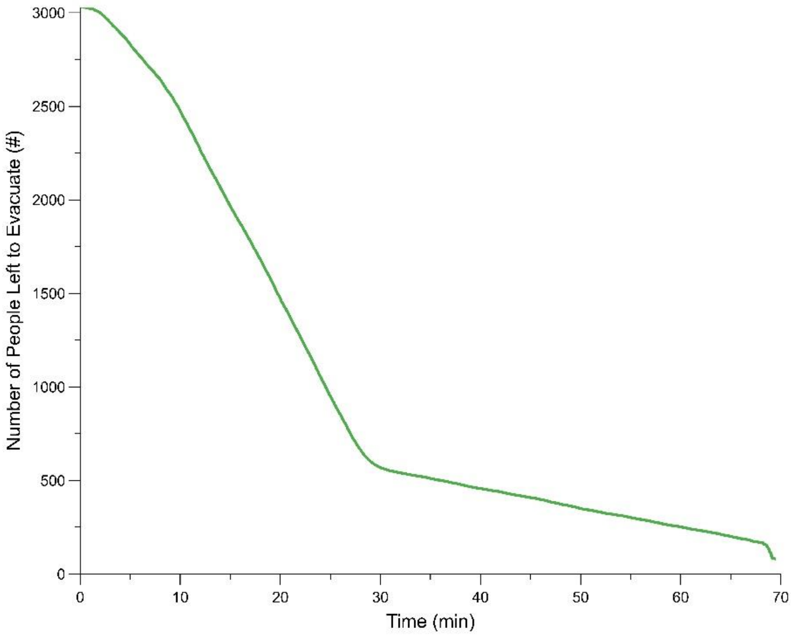


Figure 5: Number of people left in the threatened area time in Scenario s0.

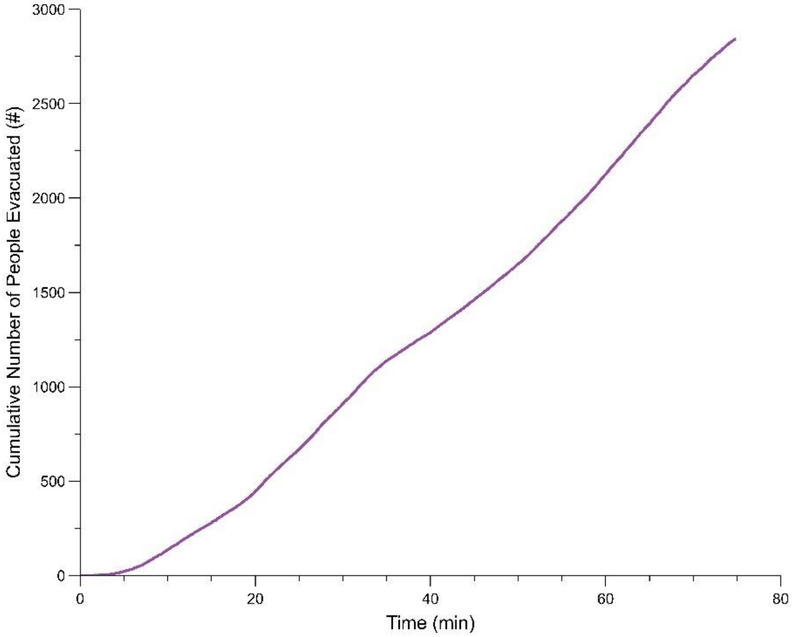


Figure 6: Cumulative number of people evacuated from the threatened area in Scenario s0.

As evident from Figure 7, more cars are being injected in the system than the number of cars exiting (which refers to people reaching a safe area). This is seen especially after the first 20 minutes, by which time 81% of the population have already responded. As a result, average velocity of the cars starts to drop around this time (Figure 8). There are more cars in the roads during this period that may have led to congestion. The velocity of the cars rises again at around 70 minutes when most of the cars have reached one of the three goals (E, R or F). On average, only one people use Goal E to evacuate for Scenario s0, while 400 people use Gate R and 2440 people use Gate F. None of the goal is assigned a maximum capacity, so the cars do not need to re-route. A lane reversal order is not introduced in this scenario.

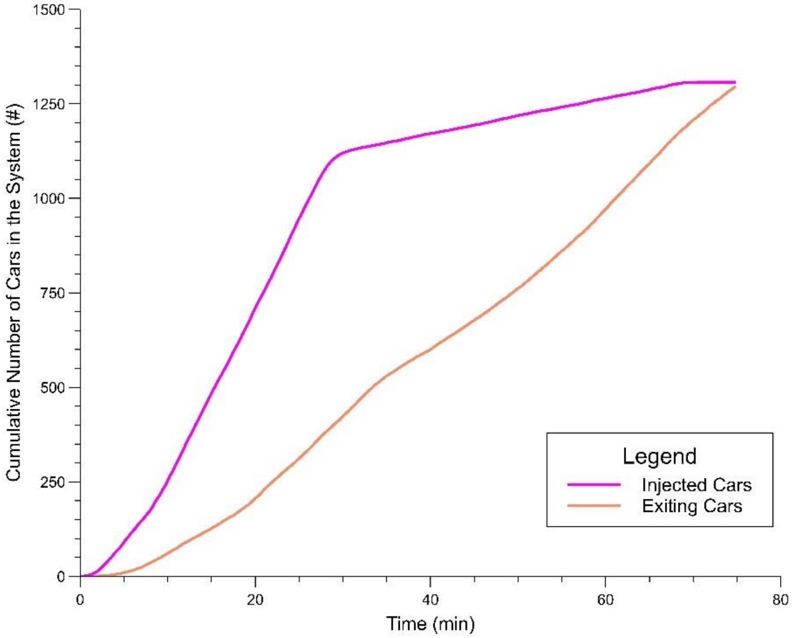


Figure 7: Cumulative numbers of cars injected and exiting the system in Scenario s0.

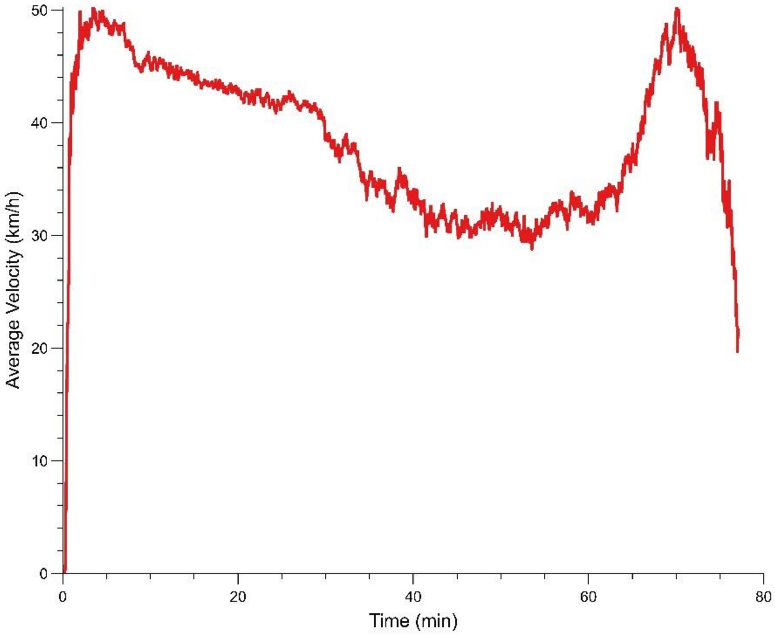


Figure 8: Average velocity of the cars in Scenario s0.

3.2 Variable 1: Total Population

The first group of scenarios (s1_pop and s2_pop) looks at the modeling capability of WUI-NITY platform by changing the total population. Scenarios s1_pop and s2_pop consider an increase in the population by 25% (3788) and 50% (4545) respectively. Five percent of the population in each scenario do not evacuate. As expected, the increasing number of populations influences the total evacuation time for each scenario, as shown in Table 5. However, increasing population do not affect the evacuation time proportionately. For Scenario s1_pop, the evacuation time increases by 1.42% and for Scenario s2_pop by 4.02%.

Table 5: Simulated average total evacuation time for a changing population.

Scenarios	**s0 (default)**	**s1_pop**	**s2_pop**
Total Evacuation Time (min)	76.91	78	80

Figure 9 represents the average number of people left in the threatened area over time. By 20 minutes, most people have responded to the order. Thus, the number of people left significantly drops after this period. As 5% remains in the threatened area, the lines do not cross the x-axis.

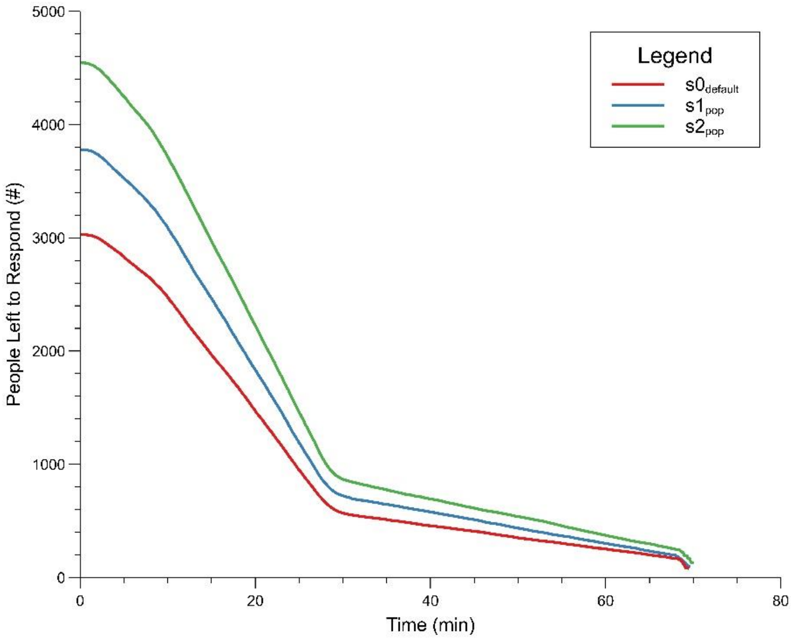


Figure 9: Evacuation time distribution for the population left to respond to the evacuation order considering the variable "Total Population".

As people start to respond and evacuate using their cars, more cars are present in the system with time (Figure 10). Again, the number of cars present peaks after 20 minutes as most people have responded by this time and used their cars to evacuate the threatened area.

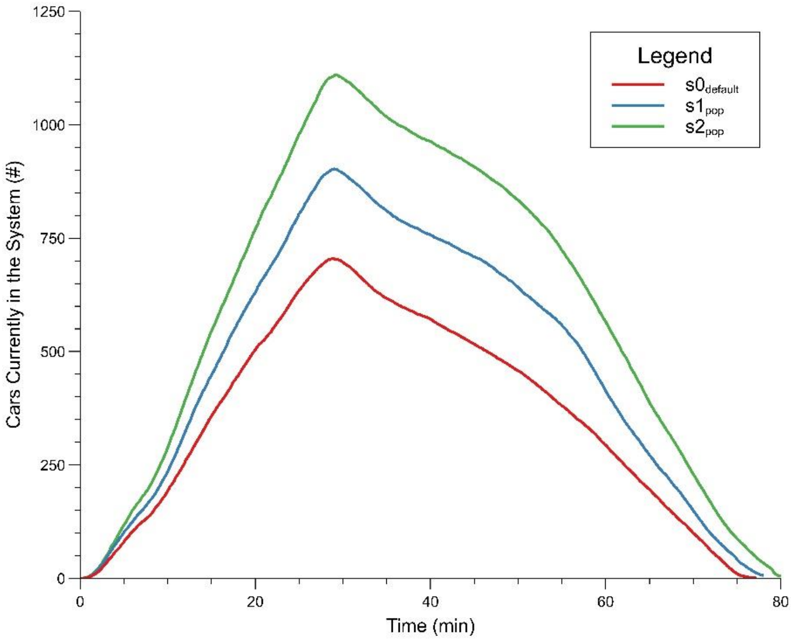


Figure 10: Evacuation time distribution for the number of cars present in the system considering the variable "Total Population".

Furthermore, the integral of the curve of people left in the threatened area is also produced by calculating the number of people left to evacuate the area over time. The calculation is recommended for introducing dynamic vulnerability assessment as an "integrated assessment" of the changing conditions during an evacuation *(Ronchi et al., 2020)*. The values are provided in Table 6, where larger number correspond to greater vulnerability. The higher the integral value, the larger the area is under the graph (Figure 11). This means that more people remain in the threatened area *(Ronchi et al., 2020)*. With time, fewer people are left in vulnerable condition as the area under the graph decreases.

Table 6: Results of vulnerability assessment considering the variable "Total Population" based on aggregate results from multiple simulations.

Scenarios						
s0	**Time**	10 min	20 min	30 min	40 min	50 min
	Integral	5758809	5588897	5183549	4510569	3631988
		60 min	70 min	80 min	90 min	100 min
		2504696	1068300	-	-	-
s1_pop	**Time**	10 min	20 min	30 min	40 min	50 min
	Integral	6950834	6760395	6295580	5533893	4539831
		60 min	70 min	80 min	90 min	100 min
		3238940	1489170	-	-	-

S2_pop	Time	10 min	20 min	30 min	40 min	50 min
	Integral	8495394	8284237	7767272	6915251	5802169
		60 min	70 min	80 min	90 min	100 min
		4332723	2323351	-	-	-

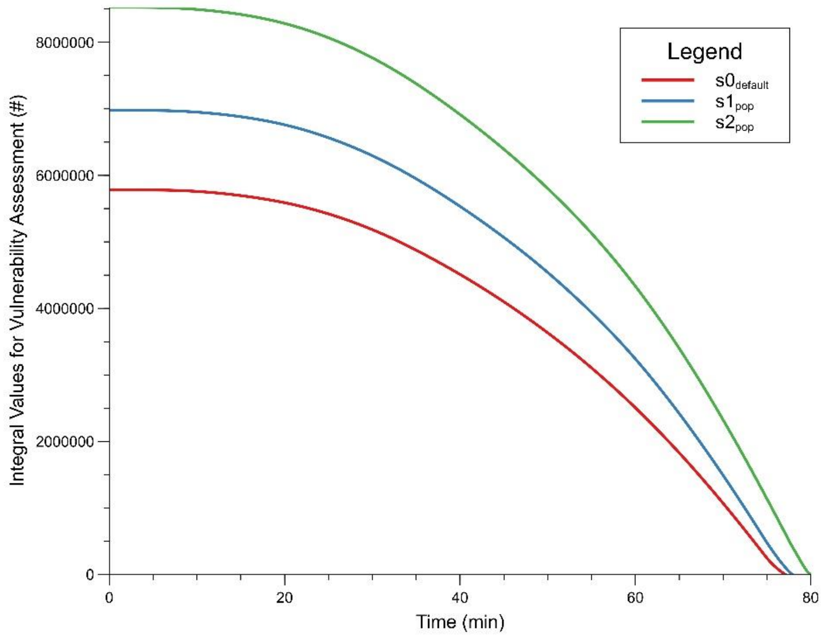


Figure 11: Integral values for vulnerability assessment considering the number of people left in the threatened area over time considering the variable "Total Population".

Key Finding:

- Even though the evacuation times are similar, the numbers of people remaining in the area – who are still vulnerable – are different. Given the higher number of people in scenarios s1_pop and s2_pop, more people are left in the threatened area at the same time.
- By the end of the total evacuation period, most cars have already reached the goals. Thus, the number of cars on the road reaches zero, considering everyone evacuating has reached the closest goal from their initial random position.
- The evacuation time is similar even with more people accessing more vehicles, which implies no great congestion in the roads.

3.3 Variable 2: Response Time

The changes made in the response curves for Scenarios s3_res, s4_res and s5_res highly influence the total evacuation time for each scenario (Table 7). For Scenario s3_res, the total evacuation time decreases from Scenario s0 by 8.7%. For the other scenarios, the total evacuation time increases by 14.42% and 38.75% respectively. As mentioned earlier, only the time to response is shifted for the scenarios. The same percentage of people respond at the given timeline set for these scenarios, as presented in Table 3. 5% of the population do not respond and stay behind.

Table 7: Simulated average total evacuation time for a changing response time.

Scenarios	**s0 (default)**	**s3_res**	**s4_res**	**s5_res**
Total Evacuation Time (min)	76.91	70.22	88	106.71

In these scenarios, the total population size is kept constant (at 3030). However, more people are left in the threatened area for Scenario s5_res (95% people responds within 90 minutes) than for Scenario s3_res (instantaneous response within the first 20 minutes), as people take more time to respond and reach their cars (Figure 12).

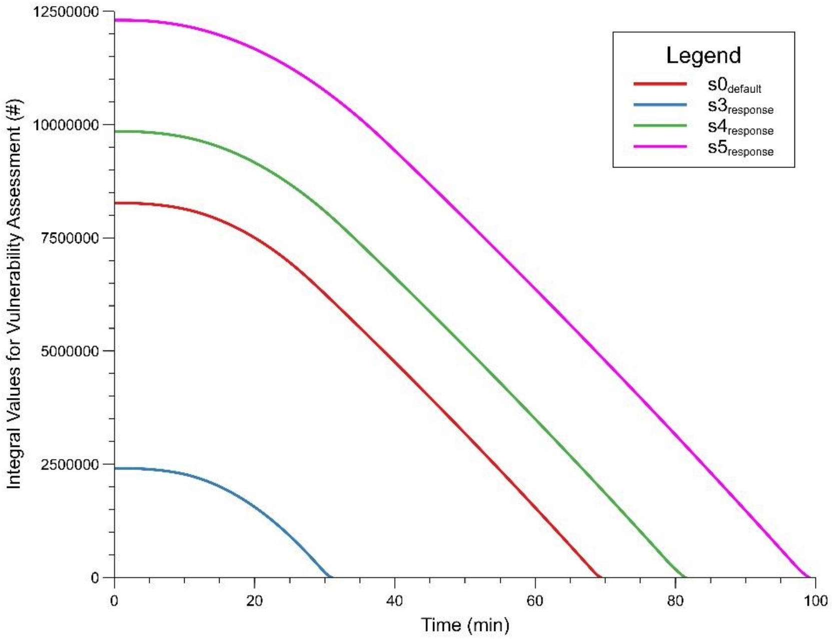


Figure 12: Integral values for vulnerability assessment considering the number of people responding to the evacuation order over time considering the variable "Response Time".

As people respond for longer period, the time taken for people to exit the threatened area is larger. This impacts the values for vulnerability assessment, as provided in Table 8.

Table 8: Results of vulnerability assessment considering the variable "Response Time" based on aggregate results from multiple simulations.

Scenarios						
s0	**Time**	10 min	20 min	30 min	40 min	50 min
	Integral	5758809	5588897	5183549	4510569	3631988
		60 min	70 min	80 min	90 min	100 min
		2504696	1068300	-	-	-
s3_res	**Time**	10 min	20 min	30 min	40 min	50 min
	Integral	5038267	4863404	4414194	3678945	2742348
		60 min	70 min	80 min	90 min	100 min
		1551242	18277			
s4_res	**Time**	10 min	20 min	30 min	40 min	50 min
	Integral	7366975	7204004	6821052	6176181	5295757
		60 min	70 min	80 min	90 min	100 min
		4183674	2812057	1198138	-	-
s5_res	**Time**	10 min	20 min	30 min	40 min	50 min
	Integral	10434997	10270312	9911976	9300230	8415521
		60 min	70 min	80 min	90 min	100 min
		7281011	5905930	4339220	2687673	996389

Figure 13 provides information on the cumulative number of cars injected in the system over time. The number of cars currently present in the system against time in presented in Figure 14.

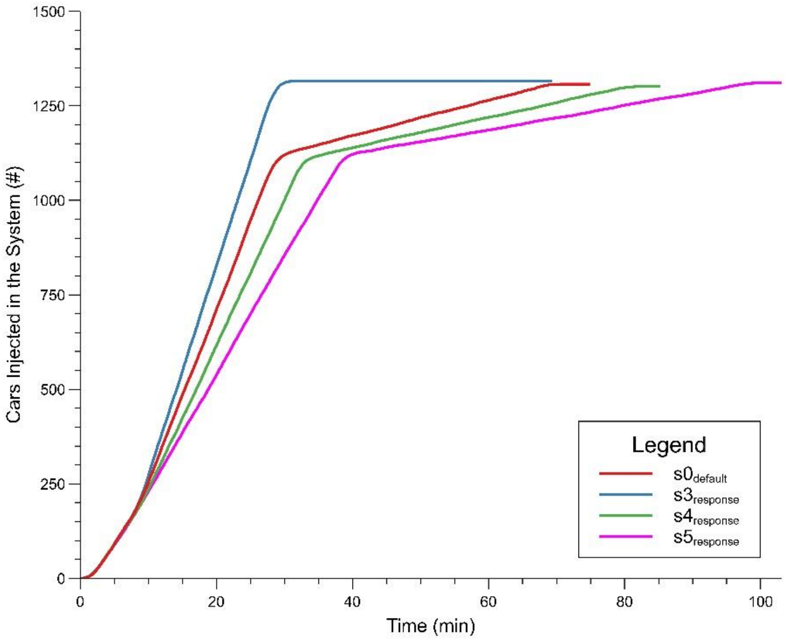


Figure 13: Evacuation time distribution for the cumulative number of cars injected in the system considering the variable "Response Time".

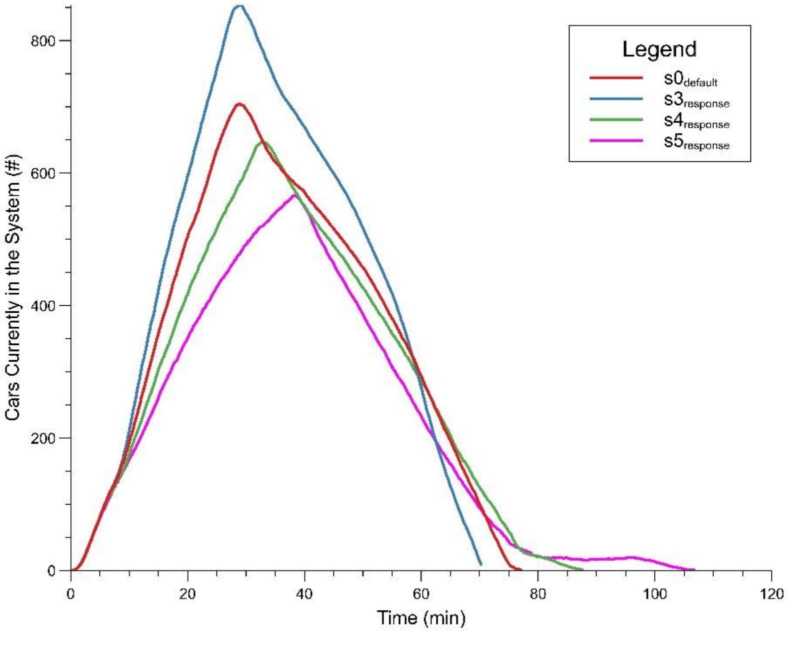


Figure 14: Evacuation time distribution for the cars present in the system considering the variable "Response Time".

Key Finding:

- S3_res has an instantaneous response, so a higher number of vehicles access the road network at the same time. However, the total evacuation time is lower than the default scenario. The roads are not overloaded even with the presence of a large number of cars within a short period. The road network system seems to have enough capacity.
- As expected, in case of scenarios s4_res and s5_res, the evacuation time is more than the s0 scenario because of the longer response time. The cars are distributed in the road over a longer period. There is a lower chance for congestion.

3.4 Variable 3: Available Goals

Scenario s0 considers three goals (labeled E, R and F), which were used in the evacuation drill in the study community (see Section 2.1). The number of available goals is decreased to two for the three Scenarios s6_ER, s7_EF and s8_RF. Again, the number is decreased to only one for the next three Scenarios s9_E, s10_R and s11_F. The suffix represents the available goal(s) for that specific scenario. The average total evacuation time for these six scenarios depend a lot on the relative positions of the available goals in the community and the capacity of the associated routes (Figure 15).

Figure 15: Position of the available gates. Retrieved from the WUI-NITY platform. Red square represents Goal E, green square Goal R and blue square Goal F.

For the scenarios when two goals are available, the average evacuation time increases by 4%, 0.9% and 0.4% respectively (Table 9).

Table 9: Simulated average total evacuation time when two goals are available.

Scenarios	s0	s6_ER	s7_EF	s8_RF
Total Evacuation Time (min)	76.91	79.94	77.6	77.22

For the next three scenarios, only one goal is available for evacuation. So, people are forced to choose the goal that is available in the scenario simulated. It can be observed that evacuation time is longer when only Goal E is available compared to the other scenarios. As a result, evacuation time increases by 51% for Scenario s9_E. For the other scenarios, the increase is by 15% and 1.07% respectively when compared with Scenario s0 (Table 10).

Table 10: Simulated average total evacuation time when only one goal is available.

Scenarios	s0	s9_E	s10_R	s11_F
Total Evacuation Time (min)	76.91	116.05	88.43	77.73

Therefore, the position of the goals and the road network leading towards them highly influences the result for these six scenarios when compared against Scenario s0. It should be noted that the capacity of the roads is here based on the information included in OSM, which is mentioned in the input file (Appendix 1, section 8.1).

Availability of fewer goals leads to more cars being present in the threatened area – i.e., still being vulnerable (Figure 16). However, as mentioned before, the availability of only Goal E when the other goals are not available highly influences the result.

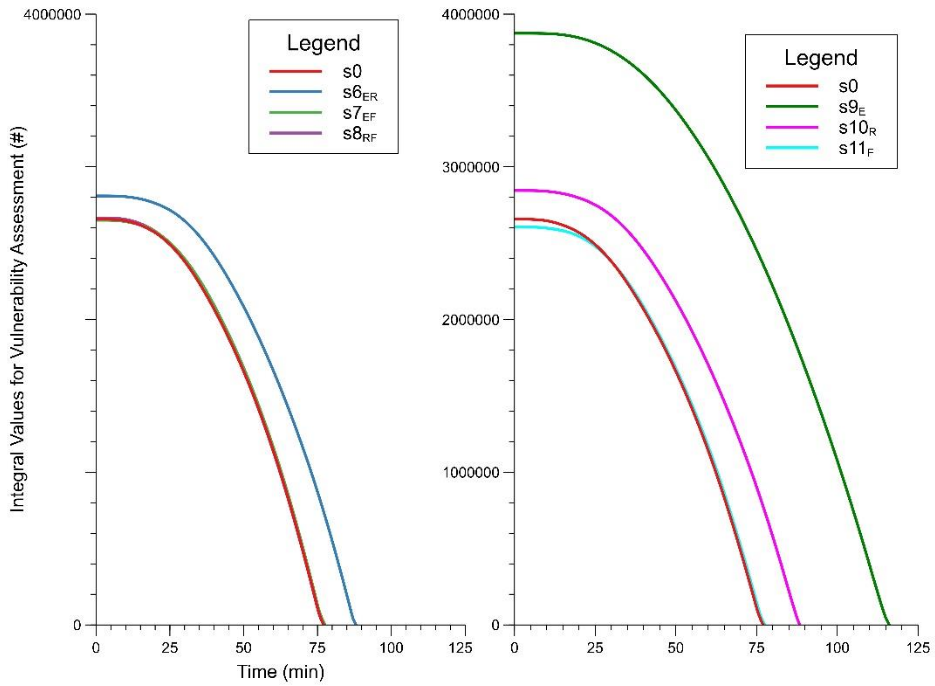


Figure 16: Integral values for vulnerability assessment considering the number of cars exiting the threatened area over time considering the variable "Goal Availability". Left graph represents availability of two goals; right graph represents availability of only one goal. The axes have the same values.

A similar pattern is noticed when plotting the number of cars present in the road during the evacuation (Figure 17). This is also evident from the distribution of average velocity over time for the different scenarios (Figure 18).

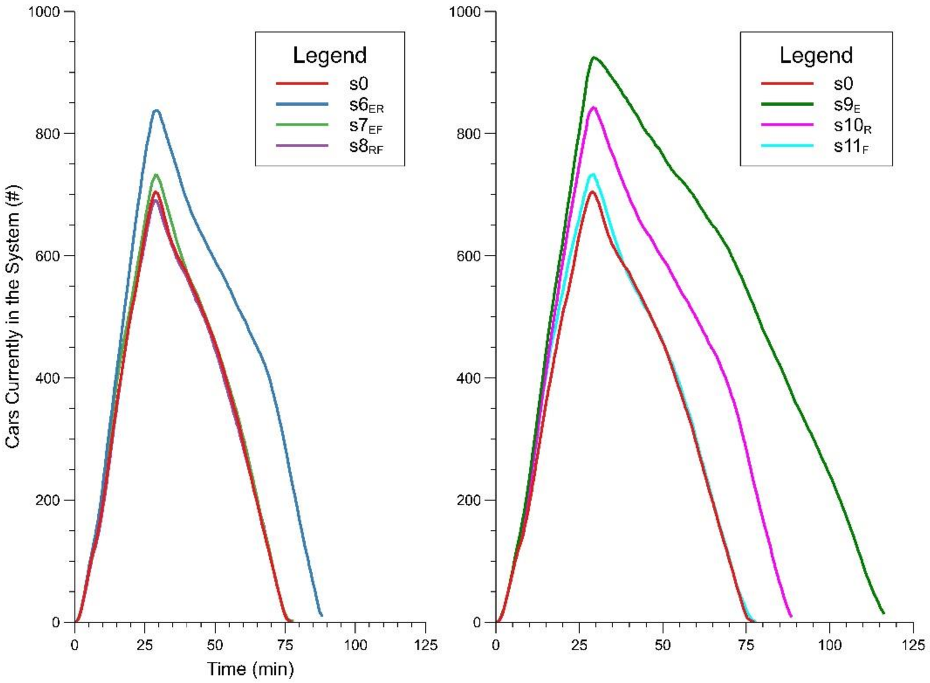


Figure 17: Evacuation time distribution for the cars present in the system considering the variable "Goal Availability". Left graph represents availability of two goals; right graph represents availability of only one goal. The axes have the same values.

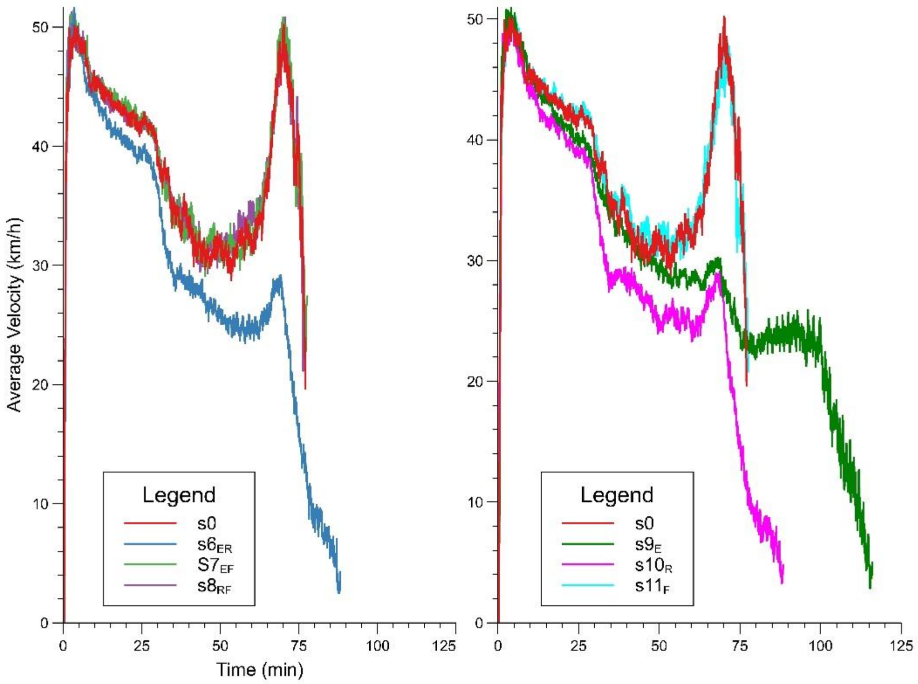


Figure 18: Evacuation time distribution for average velocity of the cars in the system considering the variable "Goal Availability". Left graph represents availability of two goals; right graph represents availability of only one goal. The axes have the same values.

The model produces other output on goal arrivals for each scenario. This is represented in the following figures by plotting the number of people reaching a certain goal considered in the relevant scenarios. Figure 19 shows arrivals at Goal E during Scenarios s6_ER, s7_EF and s9_E.

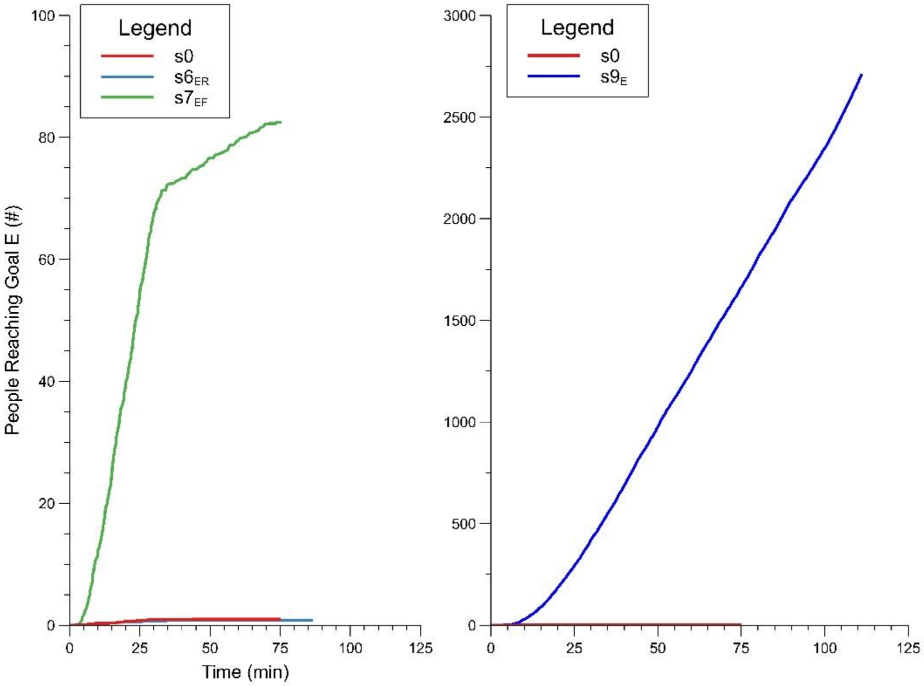


Figure 19: Evacuation time distribution for people reaching Goal E considering the variable "Goal Availability". Left graph represents availability of two goals; right graph represents availability of only one goal. The axes have the same values.

In case of Goal R, availability of Goal E does not influence the result much. Thus, the evacuation time and the number of people reaching R remains similar for Scenarios s6_ER and s10_R (Figure 20). However, presence of Goal F significantly influences the result. Scenario s8_RF closely follows the trend seen in Scenario s0.

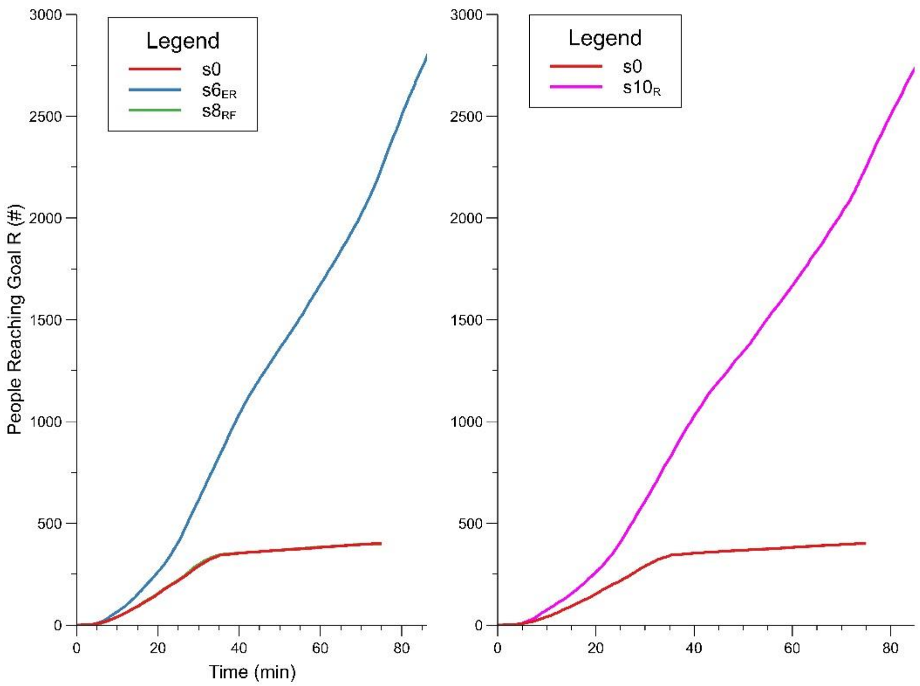


Figure 20: Evacuation time distribution for people reaching Goal R considering the variable "Goal Availability". Left graph represents availability of two goals; right graph represents availability of only one goal. The axes have the same values.

Again, the availability of both Goal F and R influences the total evacuation time and the number of people reaching a specific goal. Therefore, Scenarios s7_EF and s11_F shows similar result while the result from Scenario s8_RF closely follows Scenario s0 (Figure 21).

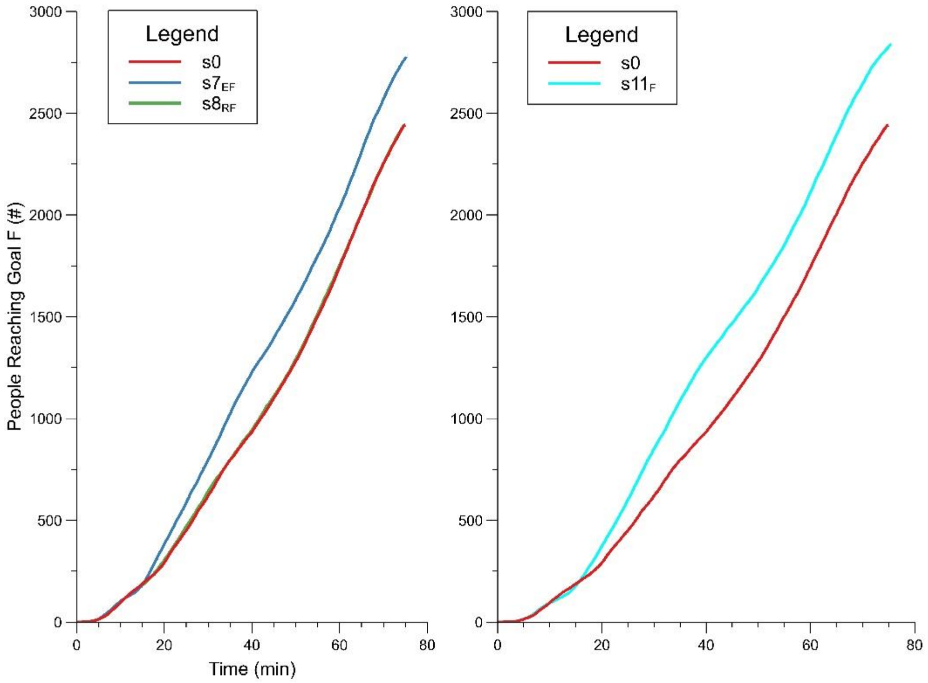


Figure 21: Evacuation time distribution for people reaching Goal F considering the variable "Goal Availability". Left graph represents availability of two goals; right graph represents availability of only one goal. The axes have the same values.

The values for vulnerability assessment are presented in Table 11.

Table 11: Results of vulnerability assessment considering the variable "Goal Availability" based on aggregate results from multiple simulations.

Scenarios						
s0	**Time**	10 min	20 min	30 min	40 min	50 min
	Integral	5758809	5588897	5183549	4510569	3631988
		60 min	70 min	80 min	90 min	100 min
		2504696	1068300	-	-	-
s6_ER	**Time**	10 min	20 min	30 min	40 min	50 min
	Integral	6134047	6040747	5788758	5292737	4569718
		60 min	70 min	80 min	90 min	100 min
		3661710	2557100	1207184	-	-
s7_EF	**Time**	10 min	20 min	30 min	40 min	50 min
	Integral	5744254	5603647	5218514	4564623	3679790
		60 min	70 min	80 min	90 min	100 min
		2551725	1118806	-	-	-
s8_RF	**Time**	10 min	20 min	30 min	40 min	50 min
	Integral	5787400	5617432	5200762	4520622	3636273

		60 min	70 min	80 min	90 min	100 min
		2500279	1063519	-	-	-
s9_E	**Time**	10 min	20 min	30 min	40 min	50 min
	Integral	8425567	8368542	8191592	7861677	7361105
		60 min	70 min	80 min	90 min	100 min
		6692148	5857129	4859255	3691151	2361492
s10_R	**Time**	10 min	20 min	30 min	40 min	50 min
	Integral	6187385	6092145	5841595	5349722	4634093
		60 min	70 min	80 min	90 min	100 min
		3731264	2626375	1273894	-	-
s11_F	**Time**	10 min	20 min	30 min	40 min	50 min
	Integral	5709759	5590052	5226811	4577804	3696392
		60 min	70 min	80 min	90 min	100 min
		2578837	1146273	-	-	-

Key Finding:

- The selection of goals when more than one goal is available does not reflect the data collected from the drill.
- Given the algorithm in use in WUI-NITY by default, evacuating people choose the closest route to the goals. The agents are randomly distributed in the simulation based on the accessibility to the roads. More people choose Goal F in the simulations while in the drill more people chose Goal R.
- Only one person on average reach Goal E in each scenario, given the goal is made available. Goal E seems to be inaccessible in the simulations, which can be because of the underlying road map drawn in the OSM.

3.5 Variable 4: Shelter Capacity

A maximum shelter capacity of 50 cars for one of the three available goals is set for Scenarios s12_capE, s13_capR and s14_capF. The suffix denotes which goal is given a limit of max cars permitted. As previously mentioned, Goal F is more accessible than Goal E due to the road network presented in the OSM. Thus, Scenario s12_capE does not influence the total evacuation time (Table 12), as people choose the other goals over Goal E. This results in the decrease of the evacuation time by 0.38% from Scenario s0. Capping goal R in Scenario s13_capR increases the evacuation time by 1.43%. However, when Goal F is off limit more time is taken to evacuate (an increase of 15.23%), as more cars need to re-route to the other available goal. The cars start re-routing when the goal reaches the maximum capacity. Average re-routing time for Scenario s13_capR is 16 minutes after the start of the evacuation, whereas for Scenario s14_capF it is 11.6 minutes.

Table 12: Simulated average total evacuation time for max shelter capacity of a goal.

Scenarios	s0	s12_capE	s13_capR	s14_capF
Total Evacuation Time (min)	76.91	76.62	78.01	88.62

By plotting the number of cars present in the system throughout the required evacuation time (Figure 22) and the average velocity of the cars over time (Figure 23), the effect of changing the value of this variable can be seen. In case of Scenario s14_capF, more cars remain in the system for a longer time and the average velocity drops significantly. The other scenarios produce similar results to Scenario s0 during the whole period. The number of people reaching one of the three available goals for each scenario can be seen in Figure 24.

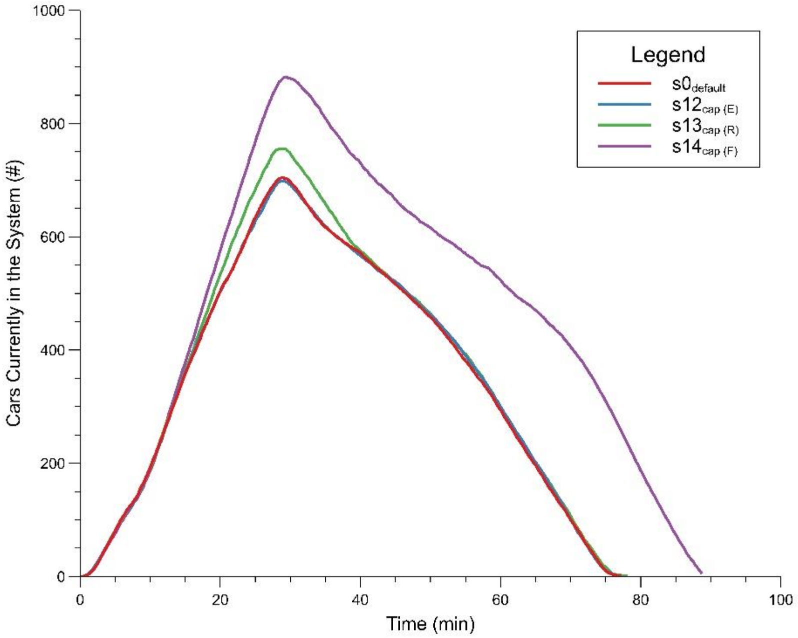


Figure 22: Evacuation time distribution for the cars present in the system considering the variable "Shelter Capacity".

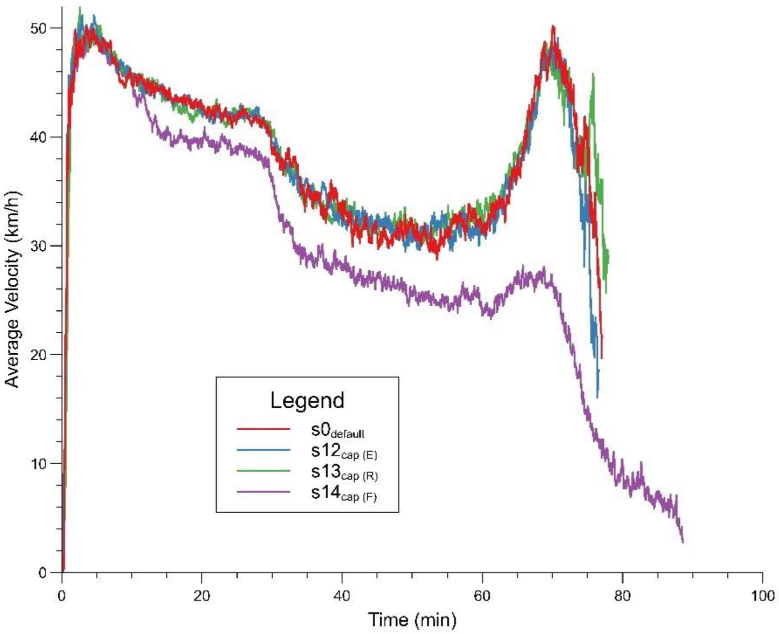


Figure 23: Evacuation time distribution for average velocity of the cars in the system considering the variable "Shelter Capacity".

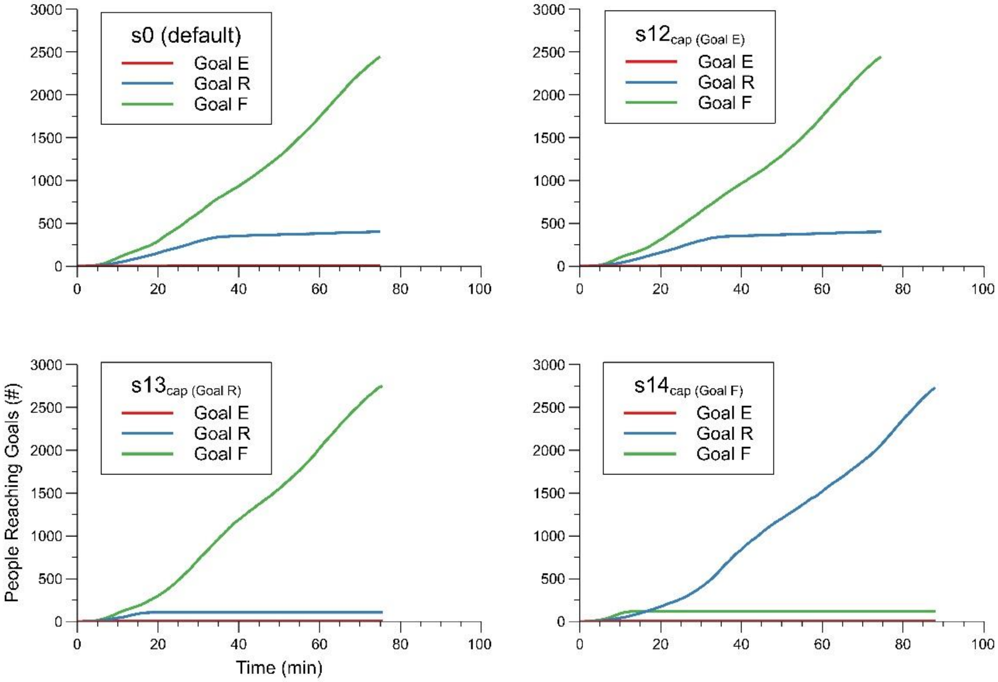


Figure 24: Evacuation time distribution for the number of people reaching the goals considering the variable "Shelter Capacity". Top left graph represents the default scenario, and right graph represents shelter capacity at Goal E. Bottom left graph represents shelter capacity at Goal R, and right graph represents shelter capacity at Goal F. The axes have the same values.

The values for vulnerability assessment are presented in Table 13.

Table 13: Results of vulnerability assessment considering the variable "Shelter Capacity" based on aggregate results from multiple simulations.

Scenarios						
s0	**Time**	10 min	20 min	30 min	40 min	50 min
	Integral	5758809	5588897	5183549	4510569	3631988
		60 min	70 min	80 min	90 min	100 min
		2504696	1068300	-	-	-
s12_capE	**Time**	10 min	20 min	30 min	40 min	50 min
	Integral	5726916	5554595	5134802	4448642	3558627
		60 min	70 min	80 min	90 min	100 min
		2428494	987476	-	-	-
s13_capR	**Time**	10 min	20 min	30 min	40 min	50 min
	Integral	5817544	5655987	5299870	4659379	3775294
		60 min	70 min	80 min	90 min	100 min
		2650058	1214992	-	-	-
s14_capF	**Time**	10 min	20 min	30 min	40 min	50 min
	Integral	6141242	6013535	5781113	5342471	4653195
		60 min	70 min	80 min	90 min	100 min
		3767792	2681725	1354005	-	-

Key finding:

- Setting maximum capacity for Goal E does not affect the result and is similar to the default result.
- The result also does not differ much from the s0 scenario when Goal R is given a limit of maximum 50 cars.
- Capping Goal F significantly increases the evacuation time, as more people must re-route to the closest goal. As a result, average velocity decreases, indicating possible congestion in the roads.

3.6 Variable 5: Lane Reversal Order

For Scenario s15_lane, a lane reversal order is assumed to have been issued by the authority for 30 minutes. The order starts from 15 minutes after the announcement of the evacuation order. By this time, about 80% of the population should have already responded to the evacuation order. Given the simple road network system in Roxborough Park community, the issued order does not significantly change the total evacuation time taken by the simulated population (Table 14). Lane reversal order can effectively decrease congestion in the roads during an emergency.

As there is no great congestion in the roads during Scenario s0, the evacuation time increases by 0.18% only for Scenario s15_lane.

Table 14: Simulated average total evacuation time for a lane reversal order.

Scenarios	**s0**	**s15_lane**
Total Evacuation Time (min)	76.91	77.05

As a result, similar trend is seen when the cars present in the system is plotted against time for these two scenarios (Figure 25). The number of cars in the system reaches the peak soon after 81% of the population respond to the evacuation order within the first 20 minutes.

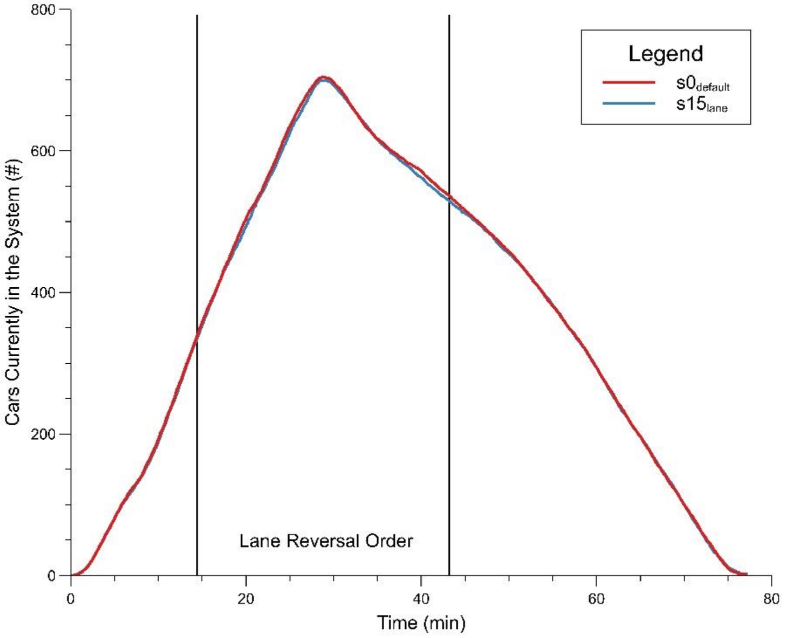


Figure 25: Evacuation time distribution for the cars present in the system considering the variable "Lane Reversal Order".

Apparently, there seems to be no significant change when a lane reversal order is issued. However, zooming in to the period when the order is issued, the subtle change is visible between Scenarios s0 and s15_lane. During the 30 minutes when the order is in effect, more cars exit the system (Figure 26). The average velocity also fluctuates for Scenario s15_lane compared to Scenario s0 (Figure 27).

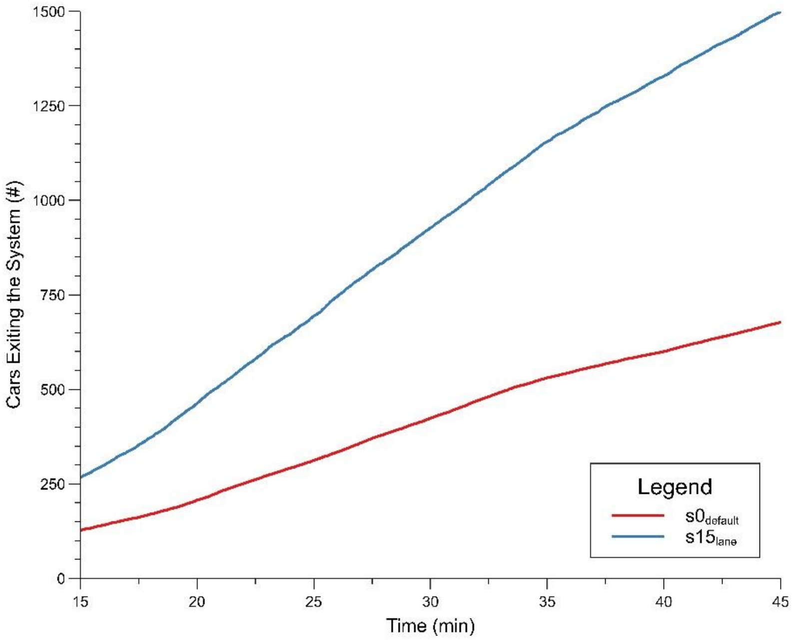


Figure 26: Evacuation time distribution for cumulative number of cars exiting the system considering the variable "Lane Reversal Order".

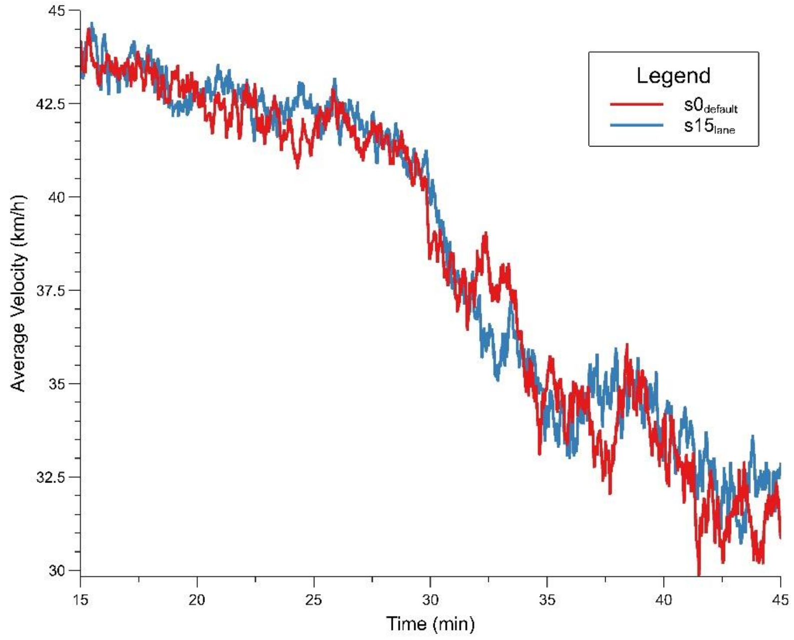


Figure 27: Evacuation time distribution for average velocity of the cars present in the system considering the variable "Lane Reversal Order".

The values for vulnerability assessment are presented in Table 15.

Table 15: Results of vulnerability assessment considering the variable "Lane Reversal Order" based on aggregate results from multiple simulations.

Scenarios						
s0	**Time**	10 min	20 min	30 min	40 min	50 min
	Integral	5758809	5588897	5183549	4510569	3631988
		60 min	70 min	80 min	90 min	100 min
		2504696	1068300	-	-	-
s15_lane	**Time**	10 min	20 min	30 min	40 min	50 min
	Integral	5842437	5675377	5257312	4571630	3671543
		60 min	70 min	80 min	90 min	100 min
		2531398	1083888	-	-	-

Key findings:

- Since in this scenario there is no significant congestion in the roads, so the results do not differ to a large extent.
- More cars are exiting the system during the order for the scenario s15_lane when compared with the s0 scenario.
- The minimum speed considered in the fundamental diagram in these scenarios is 5 km/h. Changing this value may have an impact on the result.

4. Discussion

The WUI-NITY platform allows the simulation of various ‘what-if’ scenarios by changing different input variables. In this study, five different variables are selected to test the modeling capability of the platform. The result section presents how these variables influence total evacuation time required for the study community in different scenarios. Even though the evacuation times are similar for most of the scenarios, the conditions during a particular scenario are different. This is evident from the graphs that show the fluctuation of data over time for different scenarios. The following subsections discuss the influence of different variables.

4.1 Influence of Variable 1: “Total Population”

The total evacuation time increases disproportionally with increasing population, while other variables are kept constant. However, the evacuation time does not change significantly from the s0 (default) scenario. Therefore, the impact of increasing population may be found in the evolving conditions during the event rather than just in the eventual outcome.

As evident from the results presented in section 3.2, the end times are similar but the overall condition during the evacuation is more critical for s2_pop. This is because more people are left in the vulnerable area at the same time. As 95% of the total population respond at the same period, more people are expected to be in the roads with the increasing population for each scenario. Hence, more people are left in threatened area at a given time for s2_pop than for s0. A timely evacuation order is therefore important to ensure the safety of the growing number of residents in WUI areas.

As reported by *Ronchi et al., (2020)*, the number of people in each car may be assumed to depend on the size of the household. This number is assigned randomly in the WUI-NITY platform within a user-defined interval. While the number of total cars in the system remains similar, with increasing number of people for the scenarios, the probability of having multiple people per private vehicle increases. Given the similar total evacuation time even with increasing people, no congestion in the roads is expected. The roads have the capacity to include more cars during evacuation. However, this may not be the case for other growing WUI areas around the world.

4.2 Influence of Variable 2: “Response Time”

The overall performance is more sensitive to response delays than it was to population size. The changes in the response time influence the results significantly for the scenarios s3_res, s4_res and s5_res (section 3.3). In case of instantaneous response from the total evacuating population in the scenario s3_res, required evacuation time is less than the s0 scenario. When people respond to the evacuation order over a longer period, required evacuation time significantly increases. This shows the importance of a shorter response time for a WUI community threatened by a wildfire.

However, when people move quickly over a short period, more cars will be on the roads at the same time. This may lead to congestion if the road network has insufficient capacity to cope with the demand. In this study, no congestion is apparent in case of instantaneous response from the populace, as the evacuation time is less than in the default scenario. This implies that the system has the capacity for more people even when the demand is not distributed. In case of an extended response time for the scenarios s4_res and s5_res, the cars are injected in the system over an extended period and take more time to reach the closest goal. This also implies that there is little chance of congestion in the road. If people respond over a longer period, there will be less cars in the system, reducing the chance of a blockage. However, this also depends on the fire scenario that is not within the scope of in this study. If the evacuation order is not given timely and people respond late to the order, their lives will be in danger while evacuating.

4.3 Influence of Variable 3: “Available Goals”

The results produced from this variable is sensitive to the relative position of the selected goals and to how the road network is added in the OSM (section 3.4). Total evacuation time is longer when only Goal E is available for scenario s9_E. The results do not differ from the s0 scenario when Goal F is made available in the scenarios s7_EF, s8_RF and s11_F. Presence of Goal R in the scenarios s6_ER and s10_R increases the total evacuation time for the population, as people do not have access to Goal F. The location of Goal E does not influence the result for s6_ER and s7_EF. This is because people still have access to Goals R and F respectively, which is closer to their initial random location within the community.

Similarly, more cars are present in the road at a certain time for s9_E. The average velocity decreases significantly for this scenario, which is likely caused by congestion in the road as the whole population moves towards the same goal. Nevertheless, this pattern is mitigated when Goal F is available as an exit in the simulations for scenarios s7_EF, s8_RF and s11_F. Results from this scenarios are similar to the s0 scenario where all goals are available as exits. Again, for s6_ER and s10_R, the results differ slightly from the s0 scenario.

Even though the survey results showed that 31% of the participants chose to evacuate to Goal E *(Ronchi et al., 2020)*, in the simulations hardly any agent chose this if Goal R and/or Goal F are also made available. However, when considering the Goals R and F, WUI-NITY successfully simulates the scenarios. The accuracy of the underlying road network in OSM plays a significant role when simulating the scenarios considering a specific goal. It is assumed that there exist a road leading to Goal E, which is known by the residents but does not appear in OSM. Without any knowledge about the actual roads in Roxborough Park in real life, it is hard to tamper with the OSM data. This provides an insight to the importance of an accurate road network added in OSM, which can assist in the simulations in WUI-NITY.

4.4 Influence of Variable 4 “Shelter Capacity”

The similar conditions as mentioned earlier in section 4.3 also apply for this variable. The results are affected in case of s12_E. Nevertheless, this is not as prominent as for the previous scenarios.

When the maximum capacity is reached for a goal, a message appears in the GUI of WUI-NITY stating that the other cars have started rerouting. In case of two cars reaching the capped shelter at the same time, it is also stated in the GUI that additional cars are present in that goal. As most cars head for Goal F, the maximum capacity is reached fast and the cars to start rerouting quickly. As previously mentioned, Goal E does not receive many evacuees in the simulations. As a result, capping the shelter limit for this goal does not change the outcome from the s0 scenario and illustrates similar trends. However, in case of s13_capR and s14_capF, most of the population re-route to the nearest goal (Goal F and Goal R respectively). Thus, most of the simulated agents exit via one of these two goals for these two scenarios. As the average velocity is provided for the overall scenario, it is not possible to check if congestion occurred near one specific goal for s13_capR and s14_capF. However, the total evacuation time is similar to the s0 scenario for these two scenarios. Therefore, it can be concluded that the road network is not blocked over time.

4.5 Influence of Variable 5 “Lane Reversal Order”

The result from the s15_lane scenario does not differ from the s0 scenario (section 3.6). This implies that the activation of a lane reversal order is not necessary in this scenario, as the roads have more capacity than demand. This is also evident from the other scenarios previously discussed. Even with more cars in the system at a specific time when people responded instantaneously (section 4.2) the roads are not congested.

However, during the period when the order is active, more cars exit the system in the scenario s15_lane than in the s0 scenario. The minimum capacity speed considered in these scenarios is 5 km/h. Changing this value may have an impact on the result.

4.6 General Use of WUI-NITY Platform

The impact of increasing population in a WUI community can be controlled by introducing effective evacuation planning, i.e., by making sure that the road network has enough capacity for a given population to evacuate. However, the decision to respond to an order depends largely on individual households and emergency communication strategies. WUI-NITY is not yet capable of considering household decision-making process given the lack of data and understanding related to this. Expected number of cars in the system during an evacuation can fluctuate if people decide to remain in their homes even after an order to evacuate is issued *(Ronchi et al., 2017)*. As reported by *McCaffrey, Velez, & Briefel (2013)* in their study, people who evacuated in past wildfires tend to search for more information related to the fire condition, evacuation and road blockage than those who stayed behind. Furthermore, the respondents expressed lower satisfaction level in receiving the information that they deem important *(McCaffrey et al., 2013)*. The WUI-NITY platform can generate this information given that the necessary data is included for simulations. Dissemination of these findings require a prompt communication strategy, i.e., a tool that can provide effective information about wildfires and evacuation with up to 360 characters using the Wireless Emergency Alert (WEA) system *(Doermann, Kuligowski, & Milke, 2021)*.

The WUI-NITY platform offers information related to the dynamic progress of an emergency *(Wahlqvist et al., 2021)*. The simulations run in this platform provide insight on the overall situation rather than just producing a result. This is one of the reasons that simulation tools are useful. The results produced depend more on the evolving scenario during the evacuation than the total evacuation time. If the model can represent the key factors, they can identify and explore such relationships. Given enough data related to the fire and the threatened community is available, the platform can simulate possible scenarios in a speedy manner. This can assist the emergency responders to improve their situational awareness by predicting the evolution of the emergency. This can further aid them in issuing a timely evacuation order with necessary information related to who needs to evacuate, at what time and which routes can be used to evacuate. However, the results produced depend on the accuracy of the input data (i.e., routes plotted in OSM, population count in the area of interest, possible response time of the households, etc.).

5. Conclusions

This study tests the modeling capability of the WUI-NITY platform for use in rural communities. Time constraints and limitations of data concerning household behavior uncertainty during a wildfire narrow the scope of the work. Five different input variables are considered to test the modeling capability of WUI-NITY to capture how changing the input values of one variable led to a different result. These variables include total population, response time of the agents, available goals as exits, shelter capacity of one goal to maximum 50 cars and issue of a lane reversal order. In total, 15 scenarios were generated starting the default scenario, which is based on the evacuation drill conducted by Roxborough Park WUI community. The simulations effectively capture the expected results related to a particular variable. The scenarios present no great congestion in the roads. In this condition, the variable response time presents more sensitivity to the output result and overall conditions than the other variables. When people respond within a small time frame, the total evacuation time decreases and less people are left in the threatened area over time. However, as the time frame increases and people respond late, the situation changes significantly. More people are left in the threatened time over a longer period. Consequently, the total evacuation time also increases. Random initial position of the agents in the platform allows them to choose Goal F via the closest routes instead of Goal E. It should be noted that the OSM road network could be edited in order to provide a more accurate representation of the scenarios.

The modeling platform is still on its development stage. This offers opportunity for further studies with a different set of scenarios to check the functionality of other variables used in the model (i.e., effect of smoke, different route choice, background traffic, shadow evacuation, intermediate trips, accident during evacuation, etc.). The present study only focuses on the evacuation component of the model. However, consideration of fire spread in the study can meaningfully influence the results produced. Future studies can include a range of scenarios including the coupling of all three layers. Case studies involving varying geographical areas, varying sizes and presence of emergency responders in the system can further evaluate the modeling capability of WUI-NITY. The platform assists in the investigation of different scenarios by coupling evacuation strategies employed by the authorities with varying fire conditions. It is expected that additional features will be introduced in WUI-NITY to further enhance its modeling capability considering a range of what-if scenarios. Thus, it can be a valuable tool in the pre-event cases to educate the vulnerable residents by studying past evacuations and during-event to increase the situational awareness of the emergency responders *(Wahlqvist et al., 2021)*.

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Afroza Mallick
Lund University, 2021

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00979-x

8. Appendices

8.1 Appendix 1: Default Input File for WUI-NITY

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            1,
            2
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            "b": 1.0,
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            2
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            1,
            2
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            1.0
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```

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    },
    {
      "OneHour": 6.0,
      "TenHour": 7.0,
      "HundredHour": 8.0,
      "LiveHerbaceous": 60.0,
      "LiveWoody": 90.0
    },
    {
      "OneHour": 6.0,
      "TenHour": 7.0,
      "HundredHour": 8.0,
      "LiveHerbaceous": 60.0,
```

```
          "LiveWoody": 90.0
        },
        {
          "OneHour": 6.0,
          "TenHour": 7.0,
          "HundredHour": 8.0,
          "LiveHerbaceous": 60.0,
          "LiveWoody": 90.0
        },
        {
          "OneHour": 6.0,
          "TenHour": 7.0,
          "HundredHour": 8.0,
          "LiveHerbaceous": 60.0,
          "LiveWoody": 90.0
        },
        {
          "OneHour": 6.0,
          "TenHour": 7.0,
          "HundredHour": 8.0,
          "LiveHerbaceous": 60.0,
          "LiveWoody": 90.0
        },
        {
          "OneHour": 6.0,
          "TenHour": 7.0,
          "HundredHour": 8.0,
          "LiveHerbaceous": 60.0,
          "LiveWoody": 90.0
        },
        {
          "OneHour": 6.0,
          "TenHour": 7.0,
          "HundredHour": 8.0,
          "LiveHerbaceous": 60.0,
          "LiveWoody": 90.0
        }
      ]
    }
  }
}
```

8.2 Appendix 2: Guidance on Setting up the Simulation

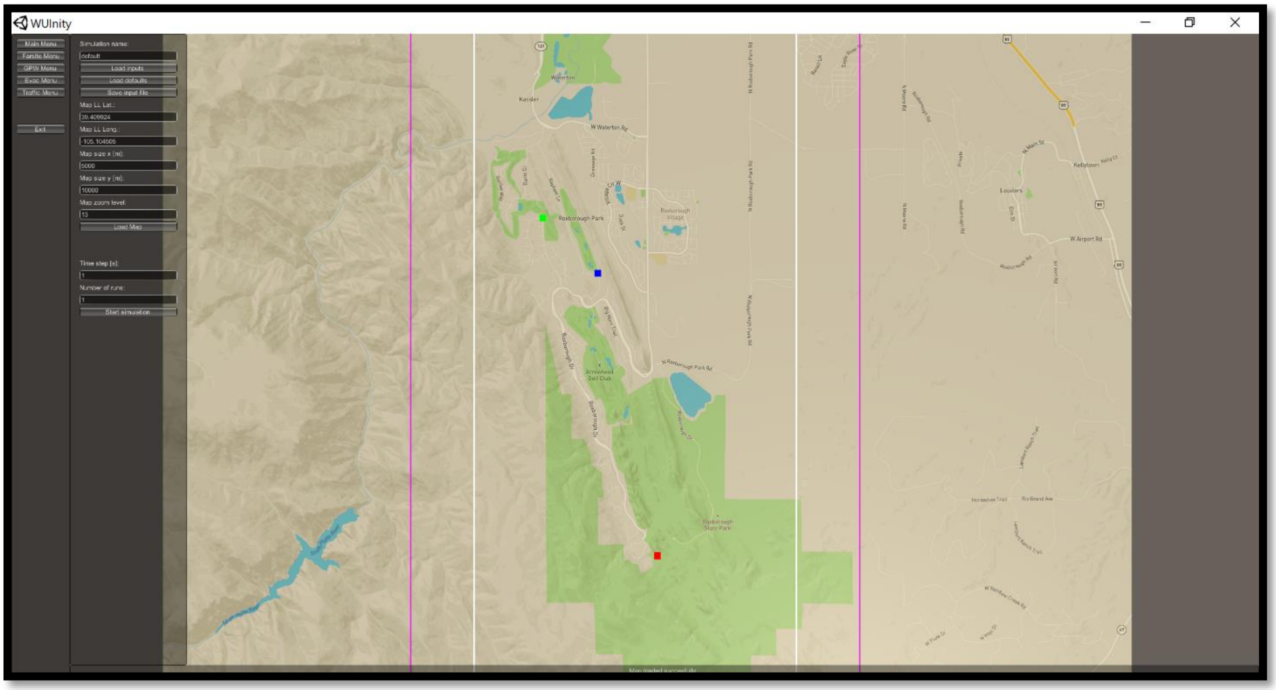
The modeling platform WUI-NITY is included in a folder, which contains several sub-folders to include input and output files among others. The software does not need additional installation procedure and can be used if the required input files are in the designated sub-folders. The input file (.wui) to use for simulation in the WUI-NITY platform includes 564 command lines. It is recommended to use Notepad++ to edit the inputs for different scenarios. The input file needs to be in the specified folder (WUInity_Data > Resources > _input).

Only the command lines (blue colored as presented in Appendix 8.1) related to the scenarios considered in this study are changed for the different simulations. The rest of the command lines are left unchanged and are like the default input file (s0). Appendix 8.2 provides a general guideline on the setting up of the input file for the simulation. The lines that needed to be updated related to the scope of this thesis is provided in the following section.

MAIN MENU: The following command lines are part of the Main Menu as seen in the GUI of the WUI-NITY.

"simName": "s0",

This line represents the name of the file. The name written in this line needs to be typed in the box under Simulation Name in the Main Menu (Figure 28) for the input file to be loaded for simulation.



Simulation name: default

Map LL Lat.: 39.409924

Map LL Long.: -105.104505

Map size x [m]: 5000

Map size y [m]: 10000

Map zoom level: 13

Time step [s]: 1

Number of runs: 1

Figure 28: Main Menu of the WUI-NITY platform in default setting.

For different scenarios, this line has been changed from s0 to s1, s2, …, s15 depending on which simulation is run in the model.

```
"deltaTime": 1.0,
```

This line represents the time step of the results produced. 1.0 indicates that values will be generated for each second until the end of the evacuation in the output files. This command line remains unchanged for all the scenarios.

```
"numberOfRuns": 20,
```

This represents the number of runs considered for each simulation. It is an important command line to ensure that convergence is met to reduce the behavior uncertainty. A number of 20 runs per simulation is calculated to have met convergence. This line also remains unchanged for the other scenarios. 20 output files each for pedestrian movement and traffics movement are produced after the simulations.

```
"lowerLeftLatLong": {
  "x": 39.409924,
  "y": -105.104505
},
```

This set of command lines provide the latitude (x) and longitude (y) of the study area. The point only relates to the lower left corner of the map. These coordinates are for Roxborough Park, Colorado.

```
"size": {
  "x": 5000.0,
  "y": 10000.0
},
```

As the previous set of lines provide only one point of the whole map, the size of the whole map to be included in the GUI is given using this set of commands. Depending on the values inserted as x and y, the size of the map changes starting from the given coordinates as the base point.

EVAC MENU: The following command lines, which start with *"evac":*, are part of the Evac Menu as seen in the GUI of the WUI-NITY. This part deals with the pedestrian movement.

```
"overrideTotalPopulation": true,
```

This line is kept as 'true' so that the provided population number is used in the simulation. When this is false, the platform calculates the number of people based on the population input file (GPW – Gridded Population of the World) and cell size.

```
"totalPopulation": 3035,
```

The number of people considered for the scenarios is added here. The number is higher than the expected number of people in the scenarios, so that the effective number is produced in the output files. Roxborough Park community has a population of 3030. In the input file 3035 is given, which gives approximately 3029 people in the output.

This command line is updated for s1_pop and s2_pop scenarios, as these two consider total population as variable.

```
"responseCurve": {
  "dataPoints": [
    {
      "probability": 0.14000000059604646,
      "timeMinMax": {
        "x": -420.0,
        "y": 0.0
      }
    },
    {
      "probability": 0.8100000023841858,
      "timeMinMax": {
        "x": 0.0,
        "y": 1200.0
      }
    },
    {
      "probability": 0.949999988079071,
      "timeMinMax": {
        "x": 1200.0,
        "y": 3600.0
      }
    }
  ]
},
```

This set of commands under response curve provides data points related to the cumulative probability of the percent of people responding at a given time period (x as minimum second and y as maximum second). While other commands can be changed in the GUI itself, this part must be updated in the input file. As these lines represent, after the evacuation order starts at 420 seconds, 14% of the population already responded. By 1200 seconds, 81% people would have responded and by 3600 seconds, 95% people would have responded. Therefore, 5% of the population do not respond and stay at their homes.

These command lines are updated for s3_res, s4_res and s5_res scenarios, as they consider response time as variable.

TRAFFIC MENU: The following command lines, which start with *"traffic":*, are part of the Traffic Menu as seen in the GUI of the WUI-NITY. This part deals with the vehicle movement during evacuation.

```
"evacuationGoals": [
  {
    "name": "Rox_Goal_E",
    "latLong": {
      "x": 39.428084,
      "y": -105.073434
    },
    "color": {
      "r": 1.0,
      "g": 0.0,
      "b": 0.0,
      "a": 1.0
    },
    "blocked": false,
    "maxFlow": 0,
    "goalType": 0,
    "cumulativeWeight": 0.0,
    "maxCars": 0,
    "currentPeople": 0
  },
```

The default input file includes the three goals that were used in the evacuation drill conducted in Roxborough Park, Colorado (here only one goal is shown). These are not changed as the drill is considered the base for this study. Instead, this set is updated to relate to a specific scenario to simulate. Under this section, each goal is given a particular name, geographic coordinates (latitude and longitude), color to visualize in the GUI, among others.

For the scenarios s6_ER to s11_F, one or two of the three goals are deleted from the input file. In such case, a new .rc file is created in the input folder of WUI-NITY. The file stores information related to the goal(s) selected for a particular scenario. As there are six different scenarios considering available goals, six .rc files are produced.

One of the lines under the goals section, “maxCars”, relates to the capacity of the shelter for that specific goal. Default is 0, meaning there is no limit to the number of cars to enter. This line has been updated for the scenarios s12_capE, s13_capR and s14_capF.

```
"routeChoice": 1,
```

This line shows the type of route (fastest, closest, forcemap, random, weighted and evacgroup) chosen by the agents during simulation. The default is set to 1, which lets the model to choose the closest routes for the evacuating agents. This is not changed for any of the scenarios given the simple road network in the selected study area.

```
"stallSpeed": 5.0,
```

This command line shows the minimum speed of the vehicles if congestion occurs during evacuation. This is named as capacity speed in the GUI. The default is set to be 5 kilometers, which is kept constant.

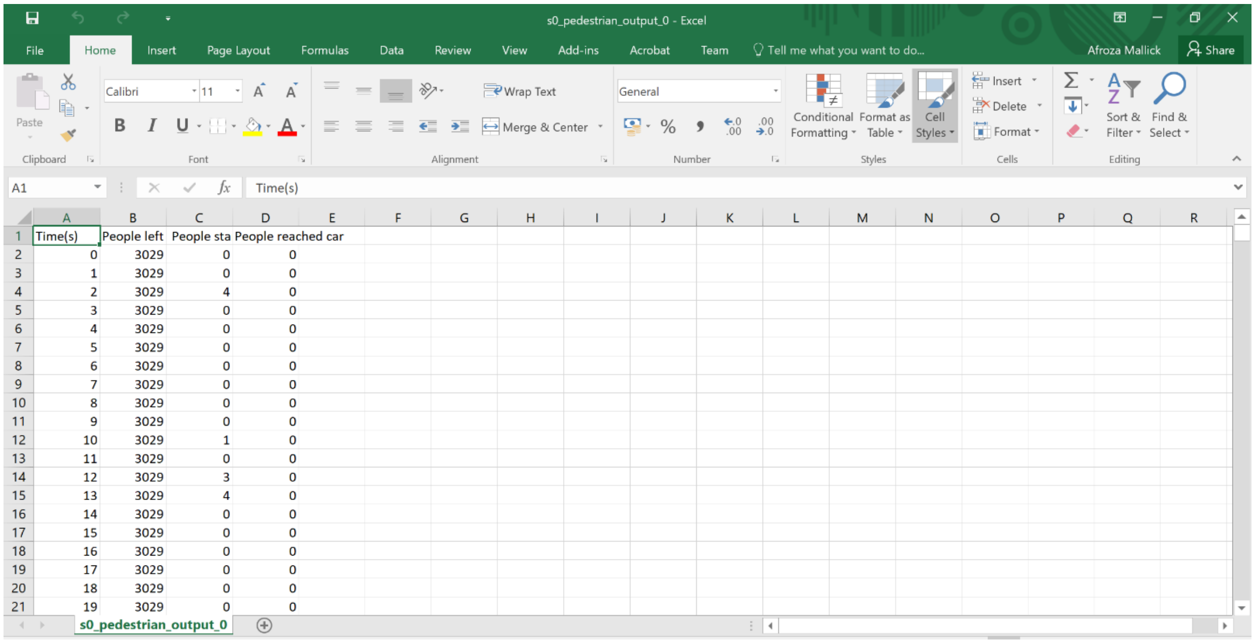
```
"reverseLanes": [
  {
    "startTime": 3.4028234663852887e38,
    "endTime": 3.4028234663852887e38,
    "isActive": false
  }
      ],
```

This set of commands introduce a lane reversal order in the simulation. When the order is not active (false), an indefinite time is inserted for the “startTime” and “endTime”. This part is updated for scenario s15. In such case, true is written for “isActive” line. The start and end time is set in seconds according to the scenario.

The rest of the commands relate either to the Farsite Menu or to the GPW Menu. These parts are out of the scope for this study, so the default setting of the WUI-NITY is considered.

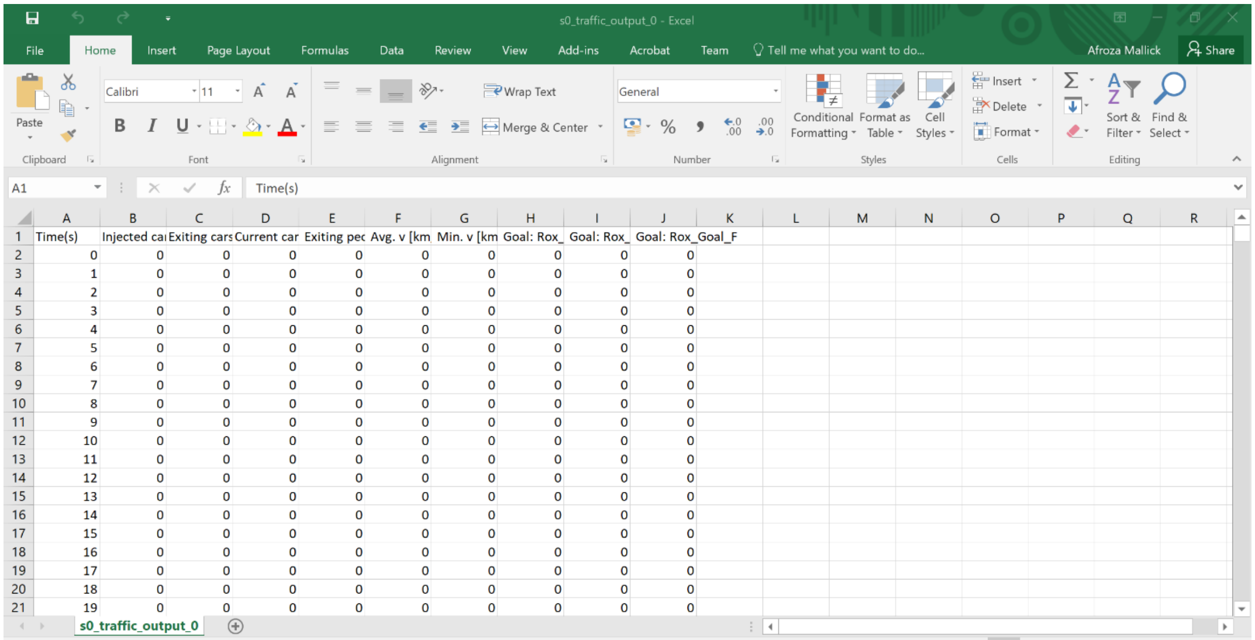
8.3 Appendix 3: WUI-NITY Output Files

Two different .csv files are generated for each run in the WUI-NITY platform. They are pedestrian output (see an example in Figure 29) and traffic output (see an example in Figure 30).



Time(s)	People left	People sta	People reached car
0	3029	0	0
1	3029	0	0
2	3029	4	0
3	3029	0	0
4	3029	0	0
5	3029	0	0
6	3029	0	0
7	3029	0	0
8	3029	0	0
9	3029	0	0
10	3029	1	0
11	3029	0	0
12	3029	3	0
13	3029	4	0
14	3029	0	0
15	3029	0	0
16	3029	0	0
17	3029	0	0
18	3029	0	0
19	3029	0	0

Figure 29: Screenshot of an example of the Pedestrian Output file



Time(s)	Injected ca	Exiting cars	Current car	Exiting pec	Avg. v [km	Min. v [km	Goal: Rox_	Goal: Rox_	Goal: Rox_Goal_F
0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0

Figure 30: Screenshot of an example of the Traffic Output file