Using computer models, big data, and GIS to improve community wildfire evacuation planning

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Keywords: traffic simulation, fire spread modeling, big data, GIS, wildfire evacuation planning

Introduction

Wildfires have caused significant loss of life and property in the American west in recent fire seasons. A recent study has found increasing trends of larger and more frequent wildfires in the western U.S. in the past few decades (Dennison, Brewer, Arnold, & Moritz, 2014). Meanwhile, more and more people move to live in the wildland urban interface (WUI), and the WUI has been rapidly growing in the past few decades (Radeloff et al., 2018). These duel trends pose a huge challenge for wildfire management.

When a wildfire threatens a WUI community, incident commanders (ICs) need to issue protective action recommendations (PARs) to the residents to maximize public safety. The primary PARs include evacuation and shelter-in-place, and evacuation is the primary PAR in the U.S (Cova, Drews, Siebeneck, & Musters, 2009). Wildfire evacuation is a complex process, and ICs need to consider many factors such as fire spread, evacuation route systems (ERS), and evacuation traffic before they could make effective PARs (Cova et al., 2017). Many computer models such as traffic simulation models (Cova & Johnson, 2002), the protective action trigger model (Cova et al., 2017; Li, Cova, & Dennison, 2015), and fire spread models (Beloglazov, Almashor, Abebe, Richter, & Steer, 2016; Li, Cova, & Dennison, 2019) have been widely used to facilitate evacuation decision-making. The recent research on wildfire evacuation modelling focuses on coupling different computer models to enable ICs to consider different human and natural systems in their decision-making (Beloglazov et al., 2016; Li et al., 2019). While most research uses a few simple evacuation scenarios in evacuation traffic simulation (Wolshon & Marchive, 2007), relevant work on how to systematically consider a variety of evacuation scenarios for wildfire evacuation planning is lacking. This paper aims to fill this gap by exploring how to use computer models, big data, and GIS to improve community wildfire evacuation planning.

Method

We employ a variety of data and couple different computer models in our method, and the flowchart of the whole procedure is shown in Figure 1. We use environmental data (topographic and fuel model data) and historical weather data to perform fire spread modelling. Based on the derived fire perimeters, we construct different evacuation scenarios and provide inputs for evacuation traffic simulation. Specifically, we can derive the roads that will be crossed by the fire from fire spread modeling, and these roads will be closed during traffic simulation. We use parcel data to generate travel demand. Specifically, we derive residential parcels based on parcel type first. Then, we use other types of data (e.g., household vehicle occupancy data and home vacancy rate data from American Community Survey) to calculate evacuation travel demand for the study area. Specifically, we identify the occupied residential parcels first and then use a Poisson distribution to generate the number of vehicles for each occupied residence. Once evacuation travel demand is generated, we proceed to specify the egresses based on the constructed evacuation scenarios. Then we use a microscopic traffic simulation model to perform evacuation traffic simulation and derive evacuation time estimate (ETE). This process is repeated *n* times for each evacuation scenario, and we will derive n different ETEs. Note that the distribution of the selected residential parcels and the number of vehicles for each residence vary in each simulation. Lastly, the derived ETEs can be further used as the input for the protective action trigger model to derive wildfire evacuation triggers for a WUI community.

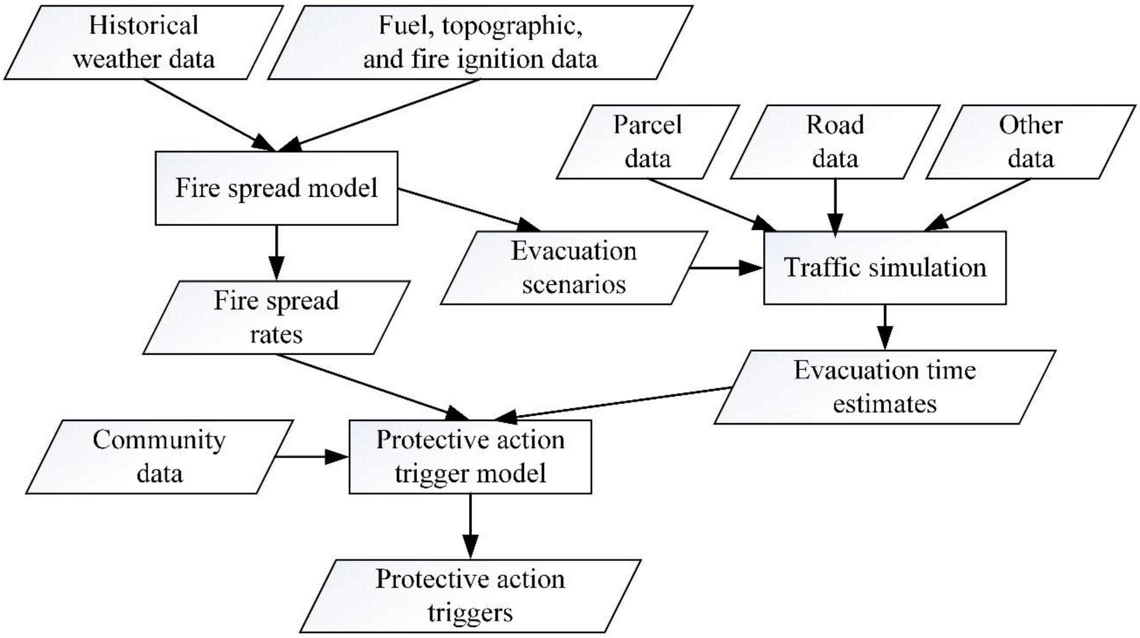

Figure 1: The flowchart of the modeling procedure.

The implementation of the method is as follows. We download the environmental data from the LANDFIRE project (Rollins, 2009) and use the FlamMap software to perform fire spread modeling based on the historical weather data (Dennison, Cova, & Moritz, 2007). Then we examine the derived fire perimeters and the ERS in each fire spread scenario to construct different evacuation scenarios. We use an open-source microscopic traffic simulation package MatSim to perform evacuation traffic simulation. The road network data are downloaded directly from OpenStreetMap, and the JOSM software and its MatSim plugin are used to code the road network for MatSim. Lastly, we use a C program to derive the trigger buffers for Truckee (Cova, Dennison, Kim, & Moritz, 2005).

Results

We use Truckee, California as the study site to illustrate the effectiveness of the proposed method. Truckee is an incorporated town in Nevada County, California. According to the 2010 Census data, Truckee has 16,180 residents. This town is surrounded by a large amount of flammable fuels and could represent many WUI communities in the American west. As a resort town near Lake Tahoe, Truckee attracts a large number of tourists during the vacation season every year. The parcel data include a total of 17,743 parcels, and 13,753 residential parcels are selected out for travel demand modeling. We used the QGIS software to extract the centroids of the parcels. As shown in Figure 2, the evacuation route system (ERS) in Truckee includes several exits including interstate highway 80 (I-80), highway 89, and highway 267. Specially, I-80 and highway 89 pass through Truckee. Highway 89 South and highway 267 end at Lake Tahoe. As for population distribution, Truckee has several large neighbourhoods including Tahoe Donner, Donner Lake, Glenshire, and Prosser Lakeview Estates. Specifically, the Tahoe Donner neighbourhood in north-western Truckee has a large collection of homes and a limited number of egresses. The home occupancy rate in the vacation season could be very high, which poses a significant wildfire risk to the residents.

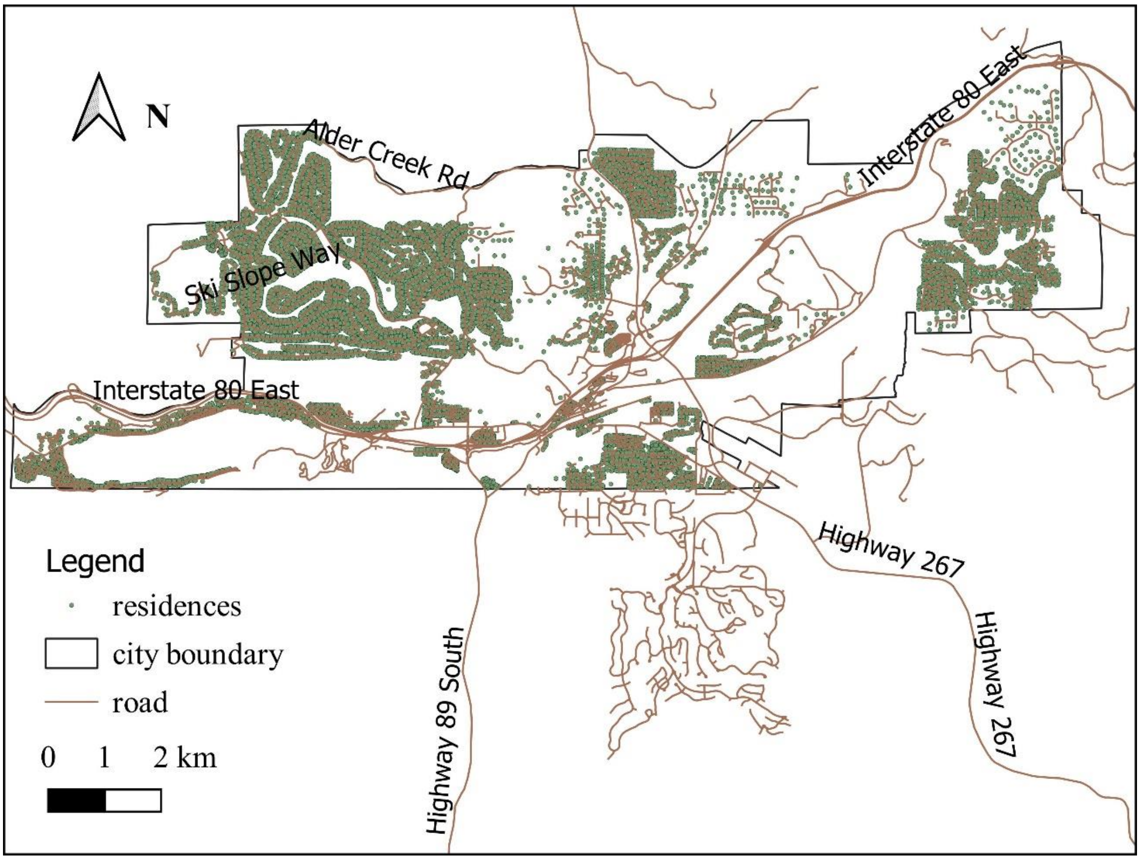

Figure 2: The map of Truckee, California

We implemented a baseline evacuation scenario for Truckee. In this scenario, we used all the residential parcels in evacuation travel demand modeling. We assume that the average number of vehicles for each household is 2. It is also assumed that the residents will depart within 60 minutes and use the closest egress in the evacuation and no road is closed during the evacuation. This scenario was run once, and the derived ETE is 393 minutes. The evacuation traffic after one hour and four hours is visualized in Figure 3 and 4, respectively. From the preliminary results, we can see that the residents in Tahoe Donner will have difficulty during wildfire evacuation if the house occupancy rate is very high. We will continue to use fire spread modeling to develop a series of evacuation scenarios and more systematically examine evacuation traffic patterns. The final results will be summarized to improve wildfire evacuation planning in this area.

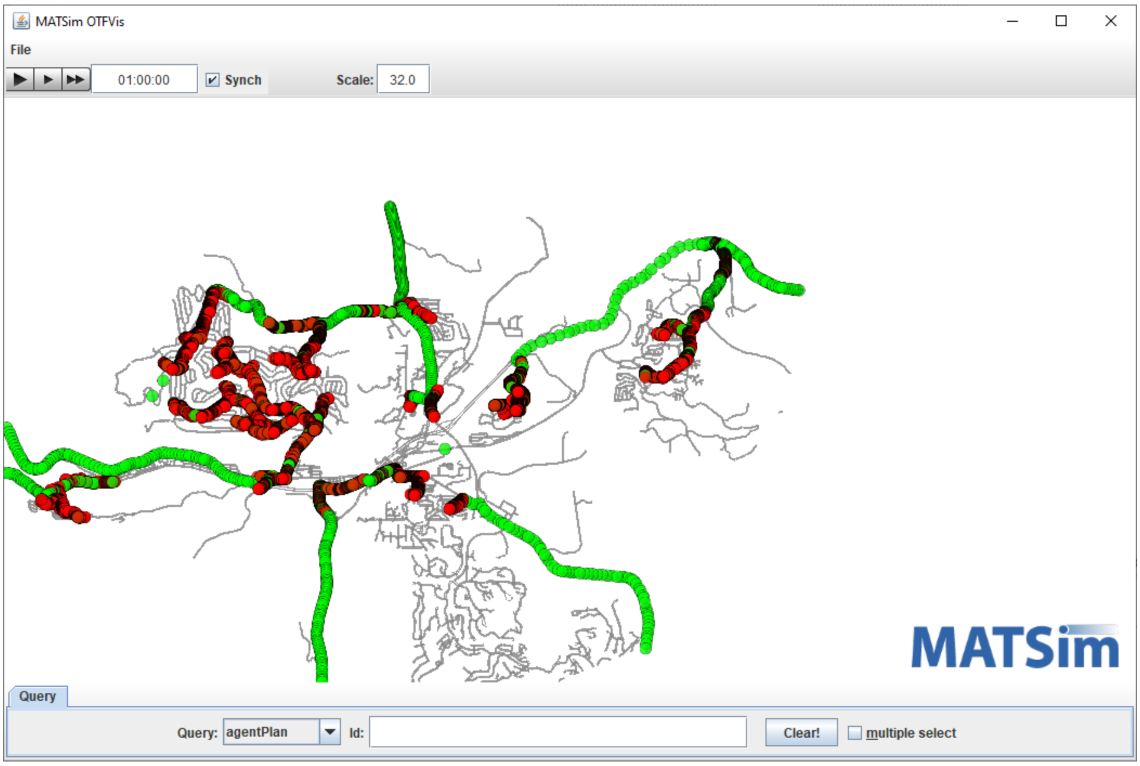

Figure 3: The evacuation traffic distribution after one hour

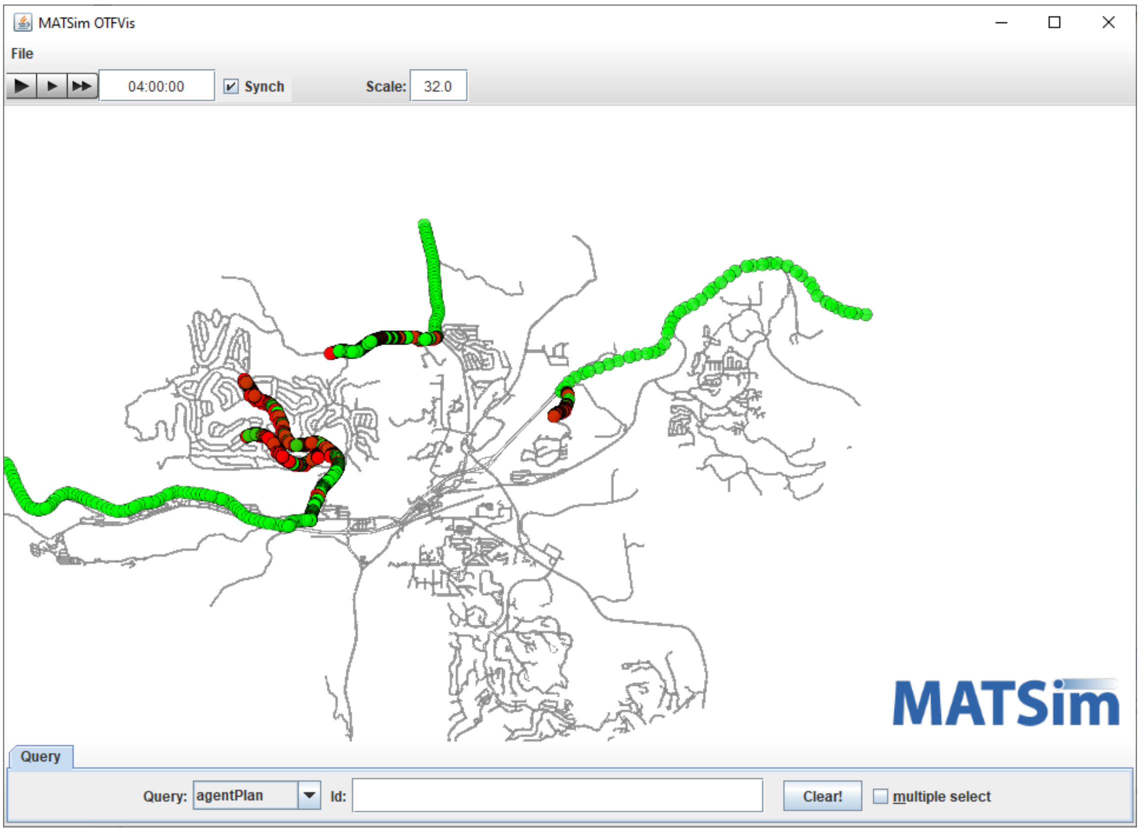

Figure 4: The evacuation traffic distribution after four hours

Discussion and Conclusion

We propose a new method that incorporates computer models, big data, and GIS for wildfire evacuation planning. The preliminary results indicate that the proposed method could take into account different evacuation scenarios and improve community wildfire evacuation planning. However, note that this study site is much larger than the previous study site Julian, California (Li et al., 2019). This poses a significant challenge in computation for evacuation researchers and practitioners. We also need to further examine whether the proposed method could be scalable and applied to larger study areas.

Acknowledgements:

The author would like to thank the Town of Truckee, California for providing relevant GIS data for the research.

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