Modeling Small Area Evacuation:
Can Existing Transportation Infrastructure Impede Public Safety?

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Abstract

Interest in neighborhood evacuation was piqued by the evacuation disaster associated with the Oakland Hills fire of 1991. During that disaster, 25 people were killed. Many counties have now mapped high fire risk areas with the objective of developing special fire attack programs as well as evacuation plans. Much of the special interest has focused on what is termed the urban-wildland interface. Urbanizing development into high fire risk areas at this interface is at the highest risk of possible evacuation. Development on the interface has been increasing throughout the western United States. It is important that modeling techniques be explored to estimate this risk in such areas by estimating the time it would take to clear a residential neighborhood if an evacuation is needed. Previous work has proposed a simple formula called the clearing time estimate, or *CTE*, based upon a measure of bulk lane demand. Bulk lane demand represents the total vehicle demand leaving a neighborhood vs. the number of lanes of roadway leaving a neighborhood. It makes sense that neighborhoods with high bulk lane demand might have greater problems in evacuation than areas with low levels of bulk lane demand. Cova and Church (1997) have presented techniques to map areas based upon estimated bulk lane demands and have as a part of that work presented a map of potential evacuation vulnerability for the Santa Barbara, Ca. area. One of the areas in Santa Barbara that has a high bulk lane demand and falls within an acknowledged high fire risk area is the Mission Canyon neighborhood. The main arterial associated with this neighborhood is a Caltrans asset (State Highway 192). To test the efficacy of the bulk lane demand model, this report presents a special transportation simulation model that was developed for this neighborhood to test evacuation scenarios. The simulation model was developed using a special purpose micro-scale traffic simulation system, called Paramics. Results indicate that without special evacuation plans in place, this neighborhood may not be able to evacuate in a timely manner during a wildfire. This report concludes with a set of recommendations for both the neighborhood and small-scale evacuation in general

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1. Introduction

Traditional transportation analysis focuses on the classical peak travel demands of weekday morning journey-to-work and afternoon journey-from-work trips. A focus on those times when traffic is at the peak makes sense when attempting to provide acceptable levels of service throughout the day. However, it is important to recognize that traffic modeling and transportation system capabilities have been analyzed within the context of special events or circumstances as well. One of these special event circumstances involves emergency evacuation. Typically, evacuation planning is associated with a well defined scenario, like a radioactive release from a nuclear power plant or the evacuation of a low lying coastal zone that might be subject to a hurricane. The possible event, such as an evacuation of the area that surrounds a power plant or the low lying coastal region, generally has a footprint that is relatively easy to define in advance. The zone or footprint that is defined for the possible evacuation scenario is called the evacuation planning zone (EPZ). Much of the focus of evacuation planning involving transportation systems, such as streets, roads and highways has been directed at well defined large areas, e.g. coastal cities, where a possible need for evacuation might occur and might involve large numbers of people. To clear such large areas may take many hours and require significant personnel resources, changes in signal operations, road closures, dedicated radio communications so that people are kept informed, preplanned staging areas for relief efforts, as well as many other elements. Recognition for the size of the evacuation problem and the need for advanced planning is the greatest for large EPZ areas.

The planning focus for events that may involve the evacuation of a small area typically center on personnel training and resource planning. For example, in California many communities have special program task forces for disaster planning that conduct mock drills involving many agencies and organizations to test communication systems, coordination and personnel skills in dealing with a special event. But, because the size and the location of a disaster event, like a hazardous material spill or a wildfire is hard to predict, the focus has been on general planning and mock drills rather than attempting to develop neighborhood specific evacuation plans. There are, however, growing concerns for ensuring that safe evacuation of small areas, like neighborhoods and building complexes, can take place. This is especially true for those places that may face higher risks of a disaster. This report addresses the problem of neighborhood evacuation modeling. Before we delve into modeling evacuation at that scale we will review evacuation modeling at other scales, like large EPZs. We then discuss how one might identify which neighborhoods should be considered candidates for evacuation planning. Finally we present an application of a micro-scale traffic simulation model to a neighborhood to estimate the extent to which a possible evacuation problem exists and discuss how such a model can be used to assist in evacuation planning and education. We give specific details of the simulation model applied to a high fire risk neighborhood of Santa Barbara, California and show that an evacuation at this small scale might easily overwhelm the ability of the local roads and streets to safely clear the neighborhood within an acceptable clearing time. We conclude with a set of recommendations.

2. Background

Emergency evacuation can be a life or death situation, where the lack of safe exit routes and the time that it might take to safely exit can be directly related to lives lost. For example, in 1991 25 people lost their lives while attempting to flee their Oakland Hills (CA) neighborhood during a wildfire. Most of these people lost their lives within the first 30 minutes of the fire as it raced through the neighborhood fanned by high winds. Depending on the type of event that precipitates the evacuation, like a wildland fire, some of the routes that people would normally take are obstructed in some way. Either the routes are too crowded, blocked by the disaster or damaged sufficiently enough to cause slower egress rates. An evacuation event can be defined according to a number of characteristics (e.g. one of three exits is blocked). It is common to define an event scenario as a set of specific characteristics. Scenarios are then defined to represent a range of possible instances of an event that underlies an evacuation. Each event scenario can then modeled to identify the likely outcome of the scenario as well as help craft evacuation plans, designate evacuation routes, and identify mitigation strategies.

Over the last two decades there has been considerable interest in modeling evacuation for a well-defined zone and event scenario, like the evacuation of a low lying coastal zone that may be subject to a hurricane surge. To analyze an evacuation scenario for a well-defined footprint, or EPZ, a number of different approaches have been used. They range from simple indices, e.g. the number of people on a ship divided by the number of seats provided in all life boats, to sophisticated simulation models. Most of the research has been concentrated on two distinct problems, evacuation of buildings and evacuation of large areas, like entire cities or coastal plains. Some of the earliest research on building evacuation was done by Chamlet, Francis and Saunders (1982). Their paper describes three models they developed to analyze clearing time, bottleneck locations, and general performance of a building in the event of an evacuation. The most important of these models is the dynamic model that represents the evacuation of a building as it evolves over time (Chamlet, Francis and Saunders 1982). With these models they were able to make general estimates of clearing time for a specific building. This paper has played an important role in subsequent research as people have used this work to facilitate research of their own. An example of this is found in Choi et al. (1988) where they expand the research of Chamlet et al. (1984) by taking variable arc capacities into consideration and modeling them as a network with side constraints. The focus of this work deals with the fact that congestion in a hallway, staircase or other passageway will cause slower rates of movement. Related optimizing network flow model research applied to evacuation includes, Choi, Francis, Hamacher, and Tufecki (1984), Horn, O'Callaghan and Garner (1998), Lovas (1998), Sherali (1991), and Tufekci and Kisko (1991).

As an alternative to network flow models inspired by Chalmet et al. (1982), researchers have also modeled building evacuation using simulation. For example, Feinberg and Johnson (1997) present a simulation procedure called 'FIRESCAP' that emphasizes behavioral characteristics of individuals in modeling an evacuation. They stress the importance of behavioral aspects such as cooperativeness, competitiveness and social constructs such as a pairs (e.g. married couples) or individuals. Their simulation model uses these behavioral characteristics as stochastic variables in a Monte Carlo sampling framework to create graphical snapshots of the evacuation evolving over time. Lovas (1998) has presented a model inspired by reliability theory where evacuees are modeled as discreet flow objects with certain attributes on a network represented by links and nodes. The EXODUS model, developed at the University of Greenwich by the Fire Safety Engineering Group, is a multi-agent, visual simulation model that has been developed to model people evacuating a building in great detail. EXODUS comprises five core interacting sub-models: the Occupant, Movement, Behavior, Toxicity and Hazard sub-models. Many papers have been written involving the use, validation, and effectiveness of EXODUS (see for example, Galea et al. (1996), Galea 1998, Cole (1996), Gwynne et al. (2001) and Owen et al. (1996)).

Evacuation modeling applied to large areas has involved the use of similar approaches. An excellent review of evacuation modeling applied to large areas can be found in Southworth (1991). Simulation has been the preferred tool of choice. Examples include OREMS, MASSVAC, and TEVACS. The Oak Ridge Evacuation Modeling System (OREMS) is an excellent example of a simulation model designed to analyze possible evacuation scenarios of large areas, where the road network involves major linkages like primary arterials and highways. Demands are based upon small areas or transportation analysis zones. The principal objective is to estimate clearing times and identify bottlenecks. MASSVAC is a simulation model designed for the analysis and evaluation of evacuation plans for urban areas threatened by natural disasters (Hobeika 1985). It is capable of simulating the flow on highway networks and identifying the available efficient routes from a hazard area to the nearest shelters and calculating the evacuation time for the network. Hobeika and Changkyun (1998) have extended MASVAC by integrating a user equilibrium (UE) assignment algorithm into MASSVAC. Han (1990) also developed a simulation model, called TEVACS, to analyze large-scale evacuation. This model was configured to specifically address the evacuation of large cities in Taiwan. Large cities in Taiwan do not rely predominantly on the automobile to evacuate. Instead there is a mix of autos, public transportation, motorcycles and bicycles that should be included in the model to truly address the problem. To handle the variety of modes in the evacuation, Han converts each mode into a universal unit called the PCU or Passenger Car Unit. These units are then used over routes with varying capacities to determine the time and scope of the egress. TEVACS is very flexible where many of the parameters can be changed and tested for their sensitivity in controlling an evacuation. Outputs from this model include network clearance time and a map of the identified traffic bottlenecks. Related research on evacuation using simulation includes that of Seagle, Duchessi and Belardo (1985), MacGregor (1991), Hara (1978), Hobeika and Jamei (1985) and Thompson and Marchant (1995).

Even though there has been considerable work in modeling evacuation, it has been directed to different geographical scales than that of a neighborhood, namely large areas like cities and small places like buildings. Cova and Church (1995) were the first to analyze the potential for evacuation difficulty at the neighborhood scale. Subsequent work by Cova and Church (1997) and Church and Cova (2000) described how to search for neighborhoods that might be particularly vulnerable to evacuation difficulty and how to develop maps of potential evacuation difficulty. They developed a network partitioning optimization model that can be used to look for small contiguous areas within a network that have a large resident population compared to exit capacity. In applying their model to Santa Barbara, they identified several neighborhoods that have disturbingly high ratios of demand to exit capacity and therefore may be particularity vulnerable to an evacuation disaster. With the exception of this work, evacuation modeling at the neighborhood scale has been basically ignored. Even though a neighborhood might have a high ratio of resident population to exit capacity, it is still important to estimate clearing time, just as is done for buildings and larger areas. Possible approaches for this include capacity analysis techniques from the highway capacity manual and simulation techniques. Since the most widely accepted tool to do this is simulation, it makes sense to take neighborhood at high risk and simulate an evacuation as a proof of concept. Unfortunately, existing network evacuation simulation models involving cars and trucks are not geared to the scale and details of the neighborhood. For example, the level of characterization of the neighborhood elements in a system such as MASVAC would not match the level of characterization needed to make the model accurate at a neighborhood scale. To do this would require a micro-scale, multi-agent transportation simulation model where individual vehicle behavior is modeled and where origin zones for traffic are represented by individual driveways. Micro-scale traffic simulation models have been developed, however, they have not been applied to a neighborhood evacuation problem. The main objective of this report is to present an application of a micro-scale transportation simulation model analyzing evacuation at the neighborhood scale. We will also discuss how such a modeling approach can be useful in not only characterizing the problem but search for mitigation strategies that may be useful in planning for a safe evacuation.

3. Identifying neighborhoods at risk and defining the EPZ

Little is known about small area evacuation as it is nearly impossible to measure accurately during an emergency (Church and Cova 2000). But, there has been an interest in looking for those areas that might be difficult to evacuate safely in an emergency. Church and Cova suggest that a neighborhood is vulnerable to an evacuation disaster if the demand to flee from a neighborhood overwhelms the capacity of the transport network to carry the traffic attempting to evacuate. They define the ratio of evacuation demand (in vehicles) to exit capacity (in numbers of exit lanes leaving the neighborhood) as bulk lane demand. They suggest that the higher the value of bulk lane demand, the longer it will take to clear the neighborhood in the event of an evacuation and the more vulnerable a neighborhood is in the event of an evacuation**.** Given this basic assumption, they developed an optimization model that can be used in conjunction with road network data and demographic data to find neighborhoods that have high levels of bulk lane demand. Essentially, their model delineates the neighborhood about a point (e.g. an intersection) that maximizes bulk lane demand. One may think of such a neighborhood as the one defined about the point that represents the greatest risk in evacuating in a timely manner. Thus, the model finds the worst case neighborhood about a point that has the highest bulk lane demand. By applying this model for selected intersections across a road network, it is possible to classify each street segment in terms of worst-case bulk lane demand values. Once this is done, a map of the network can be developed depicting evacuation difficulty across the network, like a flood plain map or a map of seismic risk. Cova and Church (1997) have presented a map of evacuation difficulty (or vulnerability to a timely evacuation) for the Santa Barbara area. Their model has now been used in other areas of southern California, Sardinia, Italy, and Australia.

Many types of location based risk exist. Examples, include earthquakes, floods, wildfire, tsunamis, landslides, avalanches, hurricanes, tornadoes, diseases, hazardous materials spills. The most common form of depicting location based risk is a map, e.g. a 100-year flood plain. Many communities and counties now publish maps of location based risk for different types of risk. For example, Jefferson County, Colorado has published a map of high fire risk areas within Jefferson County. The high fire risk areas involve an estimated population of 64,000. Given the size and number of people involved, they plan to develop evacuation plans for this region of the county, in the event that evacuation might be needed.

By superimposing a map of evacuation difficulty over a map of location based risk (like wildfire risk), one can identify those areas that face a higher than average probability of needing to evacuate and also display potential problems in evacuating (as estimated by bulk lane demand). Figure 1 gives a map of the Santa Barbara, California area with a highlighted neighborhood that has been identified previously by Cova and Church as having high bulk lane demand and is also recognized by the County of Santa Barbara Fire Department as in a high risk wildfire area. We suggest that small areas with both high location based risk and high bulk lane demand be targets for further evacuation analysis. Specifically, identifying small areas for detailed evacuation analysis or EPZs at the neighborhood scale can be accomplished by overlaying maps of location-based risk with maps of evacuation vulnerability. The remainder of this report will deal with modeling evacuation for this neighborhood as the EPZ.

4. Evacuation modeling using a micro-scale traffic simulation model

In this section we present an evacuation simulation model for the neighborhood that is depicted in Figure 1. The Mission Canyon neighborhood (MCN), as described above, lies within a high fire risk area. Both fire department personnel and homeowners have expressed concern for their safety, should a wildfire threaten their neighborhood. Before we discuss details of the simulation process, we need to discuss the assumptions under which this model and application was developed. First, it should be recognized that good data on small emergency evacuations does not exist. It is virtually impossible to collect traffic data in a residential neighborhood during an emergency evacuation without having a monitoring system deployed in advance. It should also be understood that the type of data normally collected in system monitoring and management falls short of the needs for data to fully characterize and model an evacuation event. Such characterizations include driver behavior under possible panic conditions, the degree to which the emergency overwhelms the environment (e.g. smoke limiting visibility), unusual driver behavior (e.g. leaving the roadway to cut across a landscaped lot), etc. This means that the issue of calibration is moot. That is, for all intents and purposes, calibration is not possible at the neighborhood scale for an evacuation event given the paucity of data. But a micro-scale traffic simulation model can be used under certain assumptions to estimate clearing time, for an emergency evacuation even when an accurate calibration is simply not possible. First, an orderly evacuation as modeled with a traffic simulation model (without driver panic) is likely to produce a neighborhood clearing time that is a lower bound on what might occur in the real event. The main reason for this is that accidents are more likely to occur when unpredictable behavior occurs. Accidents are the most likely element that will cause significant delay. Further, since environmental conditions like reduced visibility due to smoke is not added, simulated flow is likely to be faster and safer with less accidents. Thus, the simulation model can be used to estimate the best possible outcome. If the best possible outcome (as represented by clearing time to handle all vehicles leaving the neighborhood) is too high in comparison to the amount of time before an event like a wildfire overwhelms a neighborhood, then a major safety problem exists. If the opposite is true, then a neighborhood resident can have some degree of comfort that they will be able to safely leave if needed. The higher the estimated clearing time is under ideal conditions (e.g. no driver panic and no environmental restrictions) as compared to the time an event (like a wildfire) might overwhelm a neighborhood, the greater the possible problems in evacuation.

There are a wide variety of microscale simulation systems that have been developed to model traffic flow (e.g. see Smartest 2000). Some of these systems are stand alone modeling systems developed specifically for modeling traffic flow and others have been written as an application in a general purpose simulation system (e.g. THOREAU written in MODSIM (Glassco, et al. 1996). Although there are differences in capabilities in terms of available products, our choice was predicated in part by the California Department of Transportation (Caltrans). We developed a list of several possible candidates to use in this work. The Paramics software was one of the feasible candidates. Since Caltrans has deployed Paramics at each district office and wanted to have this simulation example available to districts, the Paramics software was used in this research. The remainder of this section specifies how the evacuation simulation was defined, in relatively general terms, as in most cases this type of model could be executed using one of several simulation products. Occasionally, Paramics specific issues are discussed, when important.

Typical microscale traffic simulation models simulate each vehicle with specific driving behavior. Each vehicle trip is modeled as a driver making a trip between an origin and a destination. The average number of trips made between origins and destinations are specified in advance for each origin-destination pair for each time period, where the interval of the time period can be specified as well (e.g. five minute, ten minute or fifteen minute time intervals). Each scenario is based upon a level of demand in terms of the number of vehicles leaving the neighborhood. For the work that we report here, we assumed that 30% of the demand leaves in the first 5 minutes, 50% leaves within the nest 5 minutes and 20% leaves within the next five minutes. For example, if an evacuation scenario was set up in which approximately 1000 cars were to exit the neighborhood, approximately 300 would begin their trip out of the neighborhood in the first five minutes, 500 in the next five minutes and 200 in the subsequent five minutes. Although this distribution could be changed, we defined this level of demand exertion with input and advice from neighborhood representatives. Such an event characteristic would be associated with a rather rapid acknowledgement of danger and taking care of last minute issues and then departing. For example, people may take their pets and gather a few belongings.

The MCN is depicted in figure 3, along with streets leading from the neighborhood. Foothill Road forms the southern boundary of the neighborhood. MCN is bordered on the west by Alamar Road. To the east, Mission Canyon Rd and Tunnel Road represent the boundaries. Exits for the MCN are depicted as the intersection at Mission Canyon and Foothill roads and Alamar and Foothill Roads. Eastbound traffic on Foothill Road beyond Mission Canyon Road is prevented as a road closure would be likely set up in the event of an evacuation (traveling further east along Foothill Road would be considered risky in the event of a wildfire). Traffic flow from Mission Canyon Road north of the Tunnel Road junction is depicted as an origin. This area is rather sparsely settled and may need to evacuate if the MCN needs to evacuate. Rather than depict this in minute detail, the demand from this area was handled as an aggregate flow. The destination zone associated with an evacuation is depicted in Figure 3, and represents westbound traffic on Foothill west of Alamar, Southbound traffic on Alamar just south of Foothill, and southbound traffic on Mission Canyon Road south of Foothill Road.

A major departure from most applications of a microscale simulation model is the spatial definition of an origin. Most transportation flow models are based upon the assumption that an origin-destination flow matrix exists between a set of transportation analysis zones (TAZ). TA Zones are generally defined as spatial entities of at least a few blocks to much larger areas, like a neighborhood. To represent the problem at a level of spatial detail that adequately characterizes the spatial distribution of demand within the neighborhood, we chose to define each household driveway as an origin for traffic flow.

For the MCN, there are 763 driveways or residential origins and one area origin (MCNorth) on Mission Canyon Road just north of the Tunnel Road junction as well as one destination zone. Together there are 765 zones. Traffic demand between each zone is specified in number of vehicles. Consequently the O-D matrix is 765 by 765, where most demands are set at zero. Flows from driveway zones to the exit zone were specified at specific levels (e.g. an average of 1 vehicle per household, an average of 1.5 vehicles per household, an average of 2 vehicles leaving per household, etc.). It should be recognized that some micro-scale simulation systems cannot handle an OD matrix that is nearly 800 by 800.

To characterize the road network, street elements were digitized in Paramics using air photos and a road network database. Elevations for the road network were taken from a elevation database that was provided by the Geology Department at UCSB. Elevations were accurate to less than a meter. Street slopes are needed as driver behavior changes when streets have a significant slope as well as curvature. Visibilities upon the approach to each intersections were considered key elements to represent relatively slow intersection approaches by drivers. All appropriate road intersection controls (e.g. stop signs) were coded as well as speed limits. In addition, common paths taken by drivers in the neighborhood were coded as preferred, as some street segments (although part of absolute shortest paths) were not typically chosen by drivers because they are steeper than many are comfortable using.

Paramics provides for dynamic information feedback on the part of drivers. For example, drivers can be given up-to-date information of shortest available routes (in terms of travel time) when departing from their driveway. Additionally, they can be given updated information periodically, so that they may balk after waiting in one queue and choose a different route. This option is called dynamic feedback. This type of information can help in reducing evacuation clearing time. The difference between having dynamic information updates and not represents the value added by having a special radio channel, broadcasting information so that the evacuation process can be speeded up, if some exits are available and under utilized. For the examples given here, we assumed dynamic feedback every minute to all drivers. We also selected driver behavior to be considerably more aggressive than the average driver.

Micro-scale simulation models that have been developed for traffic flow analysis do not simulate vehicles backing out of driveways. Often when drivers attempt such a maneuver, travel speeds along a street are low and traffic volume is low. It can be debated as to whether this is a needed capability in typical applications of such software (especially when modeling freeways and major arterials), however, this type of driving behavior can be important in modeling flow in a neighborhood, where most people typically back their cars out of the driveway and into the street. "Backing up and out of a driveway" can restrict traffic flow and significantly reduce street capacity. It would be desirable to simulate this action as well in an evacuation event. Any origin zone that generates traffic flow (in Paramics of other similar software) does so by simulating a vehicle moving into traffic going forward (not backing out into traffic). At first, this would seem to be a significant compromise in being able to model neighborhood evacuation realistically. However, modeling cars moving from a driveway and pulling forward into a street helps provide an estimate of the best possible performance of traffic flow in a neighborhood. Thus, if one wants to estimate the best possible clearing time, it would make sense to assume that cars pull forward onto the street from a driveway rather than back out into the street from a driveway. Further, it is recommended by the local fire department as well as the US Forest Service that in times of high fire risk, people should park in their driveways so that they can pull out onto the roadway instead of backing out. Consequently, this behavior is exactly what is recommended by educational literature.

In order to examine a broad scope of possible evacuation outcomes for the MCN, multiple scenarios were modeled. Each scenario represented a set of model assumptions. In modeling evacuation of the neighborhood, four principal variables were used:

1. The number of vehicles per household leaving the neighborhood: 1, 1.5, and 2 vehicles per household (even though car ownership per household is higher).
2. Opening an alternate exit: A dirt road that leads out of the neighborhood is currently closed. The neighborhood wanted to know what the impact of opening this road might have on evacuating the neighborhood.
3. Flow on Foothill Rd.: Foothill Rd. is probably the most important road in the entire network because every car must use it at some time in leaving the Mission Canyon neighborhood. If normal traffic is allowed on this road during an evacuation it will effect the clearing times.
4. Traffic Control: When traffic control is invoked, the critical intersections near the exits of the neighborhood are optimized. This involves converting some links to one-way with two lanes in each direction, and transforming intersections from a phase sharing system where cars take turns, to a system where traffic can move at all times. Such control is likely only when traffic control officers are present.

Using different values of the four principal variables, eighteen different scenarios were generated and modeled in our research. The results of the simulation is summarized in the next section

5. Results of the application to the Mission Canyon Neighborhood

For the different major characteristics underlying the evacuation simulation, eighteen different scenarios were defined, six each for different volume levels. Essentially, each scenario was based upon an assumed number of vehicles leaving each driveway, 1 car per driveway, 1.5 cars per driveway, and 2 cars per driveway. Even though car ownership per household may in many cases exceed 2 cars, we limited vehicles to at most 2 per household, as at any time during the day or night it is reasonable to believe that some fraction of the vehicles are not present. Also, since a demand level of 2 cars per driveway is large enough to create definite problems in a timely evacuation, higher levels would only exacerbate the problem. It is important to note that although the simulation model attempts to choose 2 departure times per driveway for such a simulation (i.e. 2 vehicles per driveway), such a level of demand is never exactly achieved as some driveways have zero vehicles departing, some have 1 vehicle departing and most have 2 vehicles departing. This discrepancy is caused by low OD volumes and the fact that the system is a stochastic model.

The results of the simulation runs are summarized in three tables, each concerning a given level of exit volume. Table 1 gives results of six evacuation scenarios involving 1 car leaving per driveway, Table 2 gives results for 1.5 cars leaving per driveway and Table 3 gives results for 2 cars leaving per driveway. For each scenario, the table gives the time taken for certain percentages of vehicles to clear the neighborhood and reach an exit. As an example, the first column in table 1 is associated with a scenario where the alternate ranch road is not open for evacuation traffic, some through traffic on Foothill Road is allowed to continue (note Foothill Road is a major corridor and closing Foothill Road to some through traffic would be difficult without appropriate levels of traffic control personnel), and no traffic control provisions at major exit intersections. For this simulation, it took approximately 21 minutes to clear the neighborhood. Note that for a similar scenario involving 2 vehicles leaving per driveway (Table 3), the clearing time was approximately 38 minutes, nearly double the amount of the 1 vehicle per driveway scenario. As this neighborhood is a similar size to the area within the 30 minute isochrone of the Oakland Hills fire, most would see that an evacuation would need to be accomplished safely within a shorter time than 30 minutes. It is easy to conclude that for several scenarios associated with minimal intervention, the estimated clearing time is too large and might lead to a disaster should an evacuation be needed.

An examination of the scenario results given in Table 1 2, and 3 suggest that traffic control at the critical intersections, providing for the additional ranch road exit, and controlling flow along Foothill Road, keeps evacuation clearing times at the lowest level for a given vehicle exiting volume per driveway. Overall, the results tend to suggest that a major evacuation problem exists without significant levels of intervention (i.e. traffic control) and education. First, education is needed so that neighborhood residents park their vehicles facing the street during high fire risk periods. Second, education is needed to convince residents that taking all of their vehicles may save some personal property, but may lead to loss of life (theirs or their neighbors). Without mitigating demand in terms of vehicles leaving the neighborhood during an evacuation event, this neighborhood is faces a serious risk of a disaster. Simply put, there is a chance that a fate similar to those who died in the Oakland Hills fire may befall those living in Mission Canyon. Finally residents can take action (e.g. clearing brush) that may mitigate the extreme conditions of a wildfire near their homes.

Figure 4 depicts several queues that form as vehicles attempt to leave the neighborhood. The simulation has now been used to demonstrate the problem to neighborhood residents as well as county employees using the graphical displays of Paramics. The results of this simulation along with considerable action on the part of the MC neighborhood homeowners association has been instrumental in convincing the county to initiate a door-to-door campaign to give people better information about evacuation and risk as well as schedule additional sheriff personnel for traffic management and patrol during weather events that trigger red flag alerts (i.e. weather and fuel moisture conditions that are associated with extreme high fire risk). These activities are a direct result of developing a better understanding of the potential evacuation difficulties that this neighborhood faces. The simulation model has also been instrumental in meetings so that a common understanding of what might happen can be visualized in real time.

6. Summary and Conclusions

In 1991, 25 people died while attempting to evacuate a neighborhood fire in a hillside neighborhood of Oakland, CA. While this event has piqued the interest of many people for safety, little if any work has been done to estimate evacuation risks at the neighborhood level. Previous work by Cova and Church (1997) and Church and Cova (2000) has led to an approach to estimate and map potential evacuation risk difficulty in terms of bulk lane demand. This report analyzes a neighborhood that was identified by Cova and Church (1997) that lies within a high fire risk area and also has a high value of bulk lane demand. This measure represents a ratio of exit demand to exit capacity. If bulk lane demand reaches 500 or more vehicles per exit lane, then clearing times can easily exceed 20 minutes or more. Once this level is reached, it is possible that the time taken by residents to clear the neighborhood is larger than the amount of time that an event such as a wildfire might overtake the neighborhood. This report presents details of a micro-scale traffic simulation model that was developed to analyze possible evacuation events for this neighborhood. Results of this model can be thought of as best case estimates for a given set of starting assumptions (i.e. characteristics of a scenario). Details of the simulation process have been presented along with results. The results suggest that without significant intervention policies, this neighborhood is at a significant risk of an evacuation disaster should a fast moving fire start close by.

A better understanding of what can be done for the neighborhood can be developed from results of the type of model presented in this report. First, it is important to encourage residents to use only the vehicles that they need, rather than attempting to save all of their cars from being destroyed. Evacuation clearing time can be significantly reduced by taking as few vehicles as possible and leaving the rest behind. This may make the difference between a safe and timely evacuation and a disaster with loss of life. Second, the simulation model can be used to help elevate awareness and educate both residents and county officials. With the aid of this program and persistent efforts on the part of neighborhood residents, county officials have developed plans to better educate residents and staff more personnel at time of greatest wildfire risk. Results of the simulation have also been used to bolster arguments by canyon residents for improving Foothill Road (State Highway 192), so that it can carry more traffic safely in the critical stretch between Mission Canyon Road and Alamar Road.

The results of this research give credence to communities using vulnerability mapping programs like that developed by Cova and Church coupled with a highly detailed evacuation analysis of vulnerable areas such as that presented in this report. This general approach can be used to: 1) identify areas of great risk, and 2) plan for the safety of the residents during an extreme event such as a wildfire. Either an evacuation plan can be crafted using the results of simulation or a plan for safe zones could be developed so that inhabitants need not risk their lives in attempting an evacuation. This general approach might also be useful in analyzing critical network elements and their role in public safety.

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Table 2: Evacuation clearing times for an average of 1 car leaving per driveway for the Mission Canyon neighborhood (results generated by Paramics)

Alternate Exit Open	No	no	No	yes	yes	Yes
Cars per Household	1	1	1	1	1	1
Flow along Foothill Rd.	Yes	No	No	yes	No	no
Traffic Control	none	Yes	None	none	yes	none
% of total vehicles cleared	time	Time	Time	time	time	time
50%	0:09:41	0:07:08	0:08:23	0:08:55	0:06:34	0:08:41
75%	0:14:27	0:10:15	0:12:04	0:14:10	0:09:42	0:12:41
90%	0:18:13	0:13:21	0:15:28	0:17:28	0:12:51	0:14:52
95%	0:19:51	0:14:45	0:16:44	0:18:33	0:13:45	0:16:01
100%	0:21:14	0:17:31	0:18:49	0:20:07	0:17:02	0:17:40
# vehicles cleared	time	Time	Time	time	time	time
200	0:05:07	0:04:50	0:04:57	0:04:48	0:04:11	0:05:16
400	0:09:34	0:07:33	0:09:14	0:09:12	0:06:57	0:09:34
600	0:14:06	0:11:27	0:13:41	0:14:27	0:10:24	0:13:53
800	0:20:53	N/A	N/A	N/A	N/A	N/A
1000	N/A	N/A	N/A	N/A	N/A	N/A
1200	N/A	N/A	N/A	N/A	N/A	N/A
1400	N/A	N/A	N/A	N/A	N/A	N/A
Average Number of Cars per minute	41.4	53.1	43.8	41.2	56.1	45.3

Table 2: Evacuation clearing times for an average of 1.5 cars leaving per driveway for the Mission Canyon neighborhood (results generated by Paramics)

Alternate Exit Open	no	no	no	yes	yes	yes
Cars per Household	1.5	1.5	1.5	1.5	1.5	1.5
Flow along Foothill Rd.	yes	No	no	yes	No	no
Traffic Control	none	Yes	none	none	yes	none
% of total vehicles cleared	time	Time	time	time	time	time
50%	0:13:08	0:08:01	0:11:54	0:11:56	0:07:50	0:11:29
75%	0:19:34	0:11:44	0:18:13	0:16:59	0:11:17	0:16:40
90%	0:24:28	0:15:36	0:22:53	0:20:53	0:14:34	0:19:52
95%	0:27:15	0:16:44	0:26:30	0:22:47	0:15:59	0:20:48
100%	0:30:27	0:19:01	0:29:10	0:24:57	0:17:51	0:23:03
# vehicles cleared	time	Time	time	time	time	time
200	0:05:00	0:03:38	0:04:59	0:04:41	0:03:45	0:04:42
400	0:09:17	0:06:15	0:08:51	0:08:34	0:06:01	0:08:32
600	0:13:36	0:08:46	0:13:13	0:12:13	0:08:29	0:12:29
800	0:17:45	0:11:30	0:17:39	0:15:45	0:11:01	0:16:22
1000	0:23:11	0:16:10	0:24:12	0:19:44	0:15:05	0:20:14
1200	N/A	N/A	N/A	N/A	N/A	N/A
1400	N/A	N/A	N/A	N/A	N/A	N/A
Average Number of Cars per minute	42.5	66.5	42.0	51.6	71.6	51.3

Table 3: Evacuation clearing times for an average of two cars leaving per driveway for the Mission Canyon neighborhood (results generated by Paramics)

Alternate Exit Open	no	no	no	yes	yes	yes
Cars per Household	2	2	2	2	2	2
Flow along Foothill Rd.	yes	No	no	yes	no	no
Traffic Control	none	Yes	none	none	yes	none
% of total vehicles cleared	time	Time	time	time	time	time
50%	0:17:27	0:09:14	0:15:43	0:15:09	0:09:06	0:13:48
75%	0:26:34	0:13:57	0:24:16	0:21:32	0:13:28	0:19:26
90%	0:33:26	0:18:08	0:30:25	0:26:42	0:17:05	0:23:42
95%	0:35:26	0:19:30	0:32:40	0:28:32	0:18:34	0:25:38
100%	0:38:32	0:23:36	0:34:58	0:31:39	0:21:28	0:29:09
# vehicles cleared	time	Time	time	time	time	time
200	0:04:40	0:03:31	0:04:43	0:04:38	0:03:30	0:04:38
400	0:08:35	0:05:58	0:08:47	0:08:24	0:05:37	0:08:24
600	0:12:49	0:07:59	0:12:59	0:12:10	0:07:43	0:11:47
800	0:17:37	0:09:57	0:16:55	0:15:39	0:09:50	0:14:57
1000	0:22:03	0:12:39	0:21:54	0:19:01	0:12:03	0:17:53
1200	0:26:56	0:16:01	0:26:53	0:22:28	0:14:54	0:21:21
1400	0:32:46	0:20:00	0:32:45	0:26:56	0:18:39	0:26:00
Average Number of Cars per minute	42.8	74.9	43.9	53.9	80.9	57.5

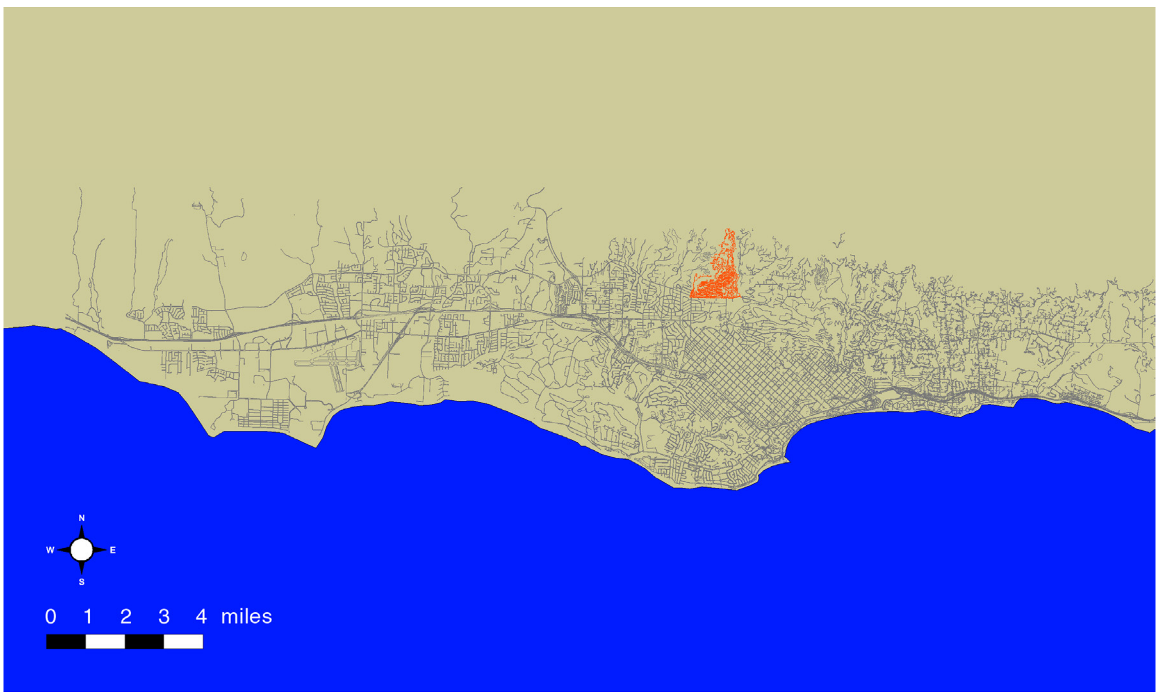

Figure 1: The Mission Canyon neighborhood depicted in Santa Barbara, California

Figure 2: House locations and street network of the Mission Canyon neighborhood

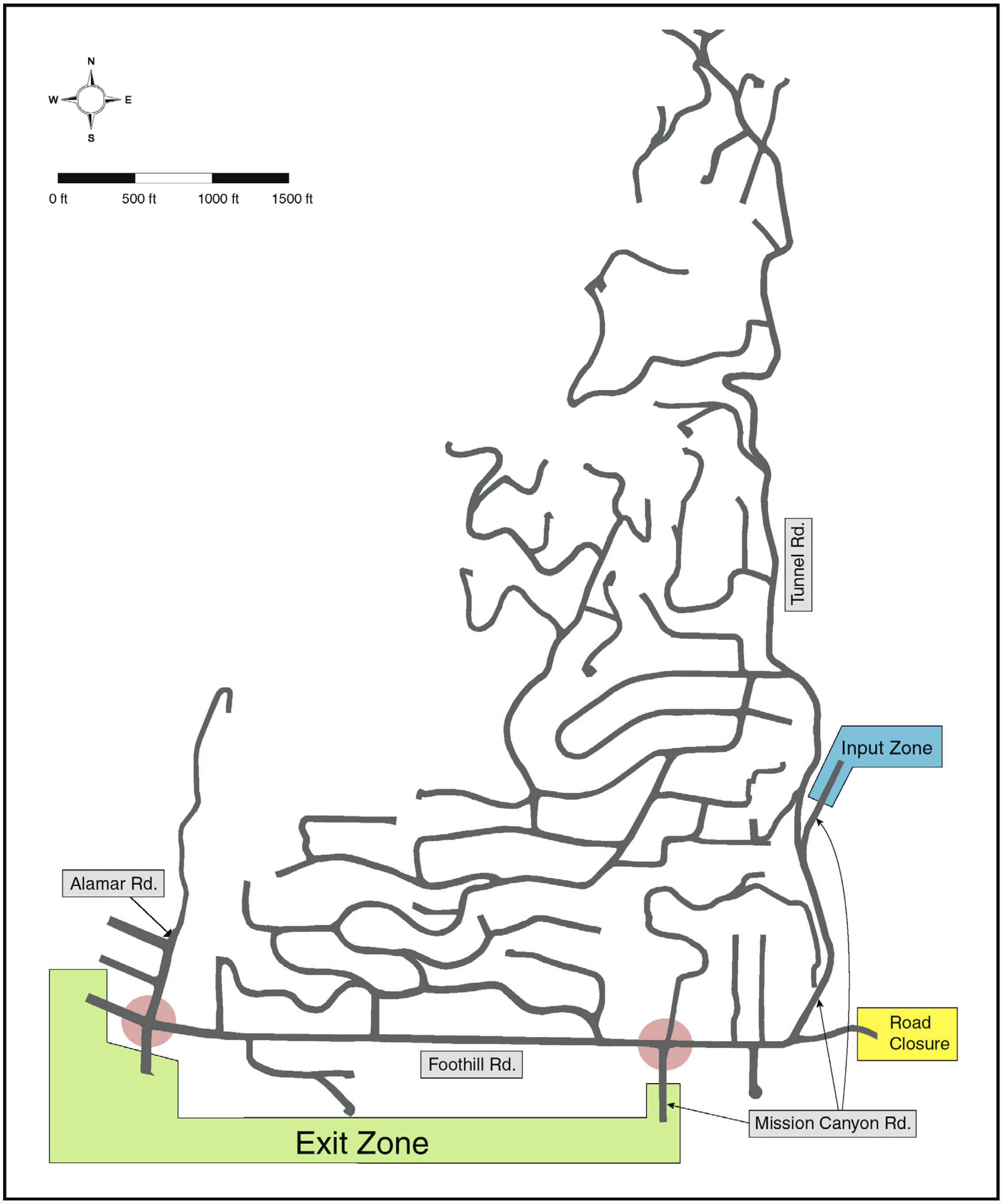

Figure 3: Major street intersections, exit zones, and road closure location for Mission Canyon

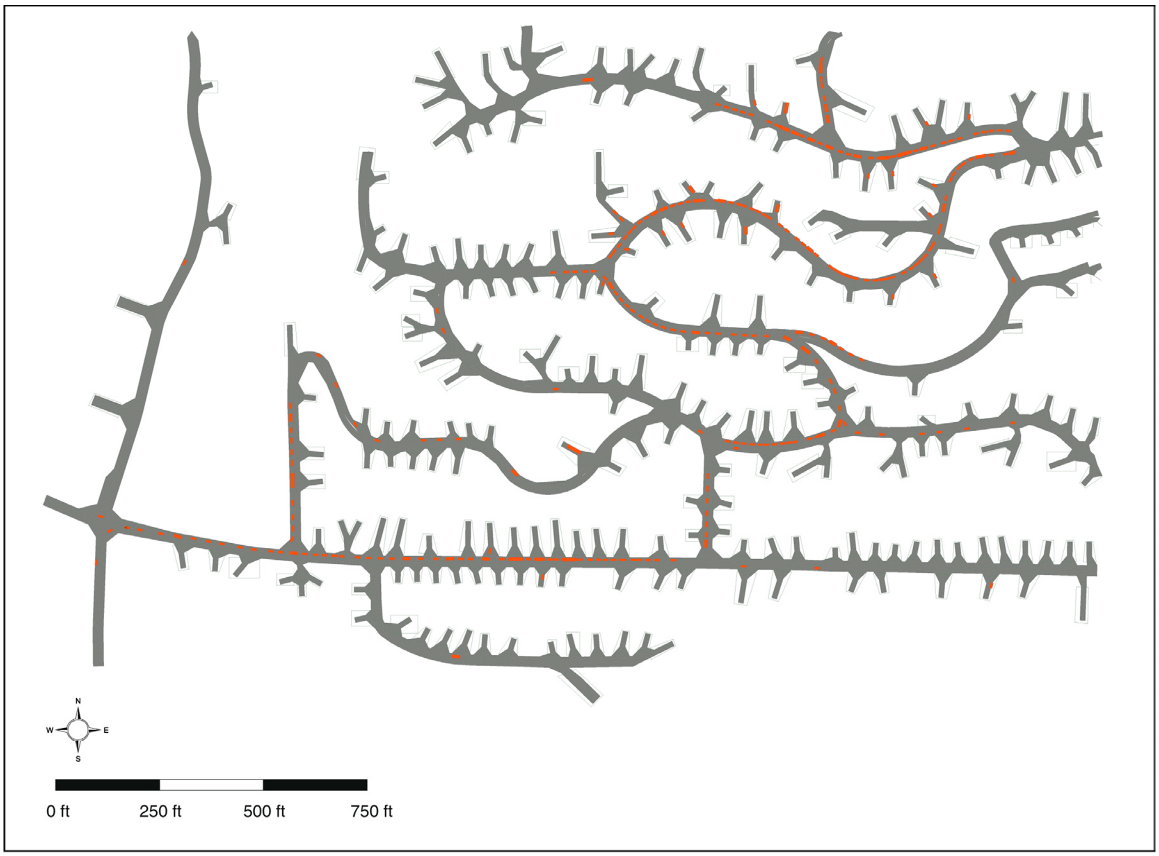

Figure 4: Congestion during a simulated evacuation event (Queues of cars can be seen in red).

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