

**Adapting a Four-Step MPO Travel Model for Wildfire Evacuation Planning:  
A Practical Application from Colorado Springs**

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## **Abstract**

In the wake of a number of planned and unplanned evacuations that have taken place throughout the U.S. in recent years, the need for applied transportation planning and modeling in the area of emergency evacuation strategy has never been stronger. In this paper, the authors explain how an MPO traffic model was adapted for use as a wildfire evacuation planning tool and how the analysis results were put into active use by the emergency response community of Colorado Springs. Addressed are model inputs and assumptions, emergency scenarios, traffic control strategies, shelters or destinations of evacuees, and evacuation time frames. On the model side the authors address networks, household auto ownership assumptions, evacuee shelter locations, group quarters, road capacity, transit use, contra-flow assumptions, background traffic, and the next step of moving the evacuation model results to a actionable tool for use by emergency responders. The authors also show they utilized a year-long collaboration with the heads of the fire and police emergency response in Colorado Springs and how feedback from these groups improved evacuation response planning. While the emergency evacuation model was developed and refined for western mountainous cities like Colorado Springs that have residential areas in very dry foothill-type terrain, the approach has value for other areas of the west as well as flat areas where planned evacuation may take place.

## 1 Introduction

In the wake of planned and unplanned evacuations in the U.S. and internationally, there is a focus on tools that can prepare emergency responders to effectively manage disaster response. The transportation sector is critical to disaster response and recovery in that transportation infrastructure provides the means to move first responders, such as firefighters, into place, and paves the way for civilian evacuation. Each type of disaster is different in that it may be driven by air, water, fire, mudslide, disease or the act of a determined person; however each disaster is alike in that “the rubber meets the road,” that is, exit roadways are jammed with people departing in motorized vehicles. Without planning, localized or regional traffic gridlock can occur and place evacuees, as well as responders, in jeopardy.

In Colorado Springs, terrain, weather, and settlement patterns bring the threat of wildfire into sharp focus. The history of wildfire in the Colorado Springs area includes an increasing number of examples, the best known among these the September 2002, Hayman fire. The Hayman fire holds the distinction of being the largest wildfire in Colorado’s history. Extremely fast moving, in its first day the Hayman fire burned 60,000 acres (24,300 hectares). Hundreds of forestry officials and firefighters fought the Hayman fire that ultimately burned over 138,000 acres (52,650 hectares) immediately to the west and north of the Colorado Springs area. The fire caused nearly \$40 million in damages, burned 600 structures (including 133 homes), and forced the evacuation of 5,340 persons. Before the Hayman fire, wildfire incidence had been confined to rural areas. Recent examples signal a change in this pattern; drought conditions have produced extremely dry vegetation (fuel availability) that has placed Colorado’s urban areas increasingly at risk from wildfires.

## 2 Initial Response

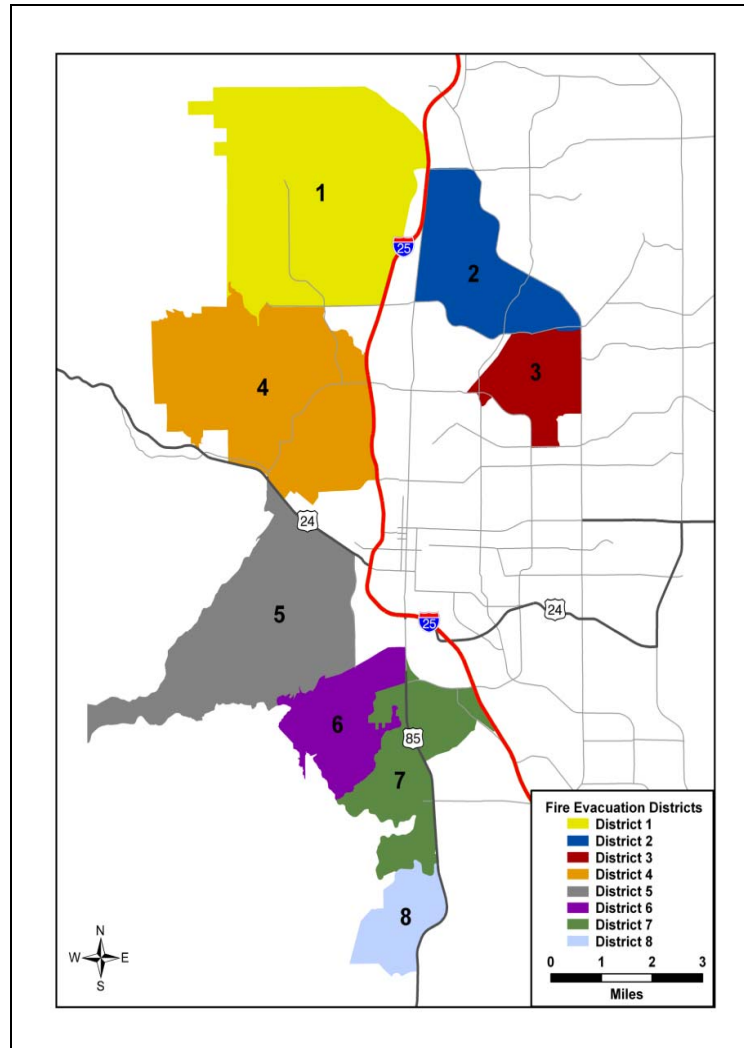
The City of Colorado Springs’ response to increased wildfire threat included development of a wildfire emergency response management plan. The Colorado Springs Office of Emergency Management, with the support of the Police Department and Fire Department undertook development of the plan, which required identification of wildfire evacuation logistics, including: evacuation protocols, communication/notification procedures, evacuation routes, and traffic control/staffing plans.

Identification of a tool that could provide a clear understanding of both the magnitude of evacuation traffic and the capacity of the roadway network to handle that traffic was essential to the planning effort. A literature search was conducted to identify an appropriate evacuation simulation tool. For the demands of the Colorado Springs planning process, the body of references suggested that a macro model such as the regional travel demand model might be adapted for stand-alone use or paired with mesoscopic simulation for increasingly detailed analysis. Meso and micro level simulation and travel demand forecasting tools, as well as combinations of the two tools were also considered, and advantages and disadvantages were weighed. Ultimately, stand-alone use of an adapted version of the regional travel demand model was pursued as an adequate approach that could be accomplished within the identified budget

**Figure 1** shows the eight fire evacuation districts within the general layout of the greater Colorado Springs area. The identified Wildland Urban Interface exists at the interface between the relatively flat city streets and the beginning of the Rocky Mountains. There are limited access routes into and out of these areas, making them “islands” in highway network terms. I-25, the City’s single north-south freeway facility, has limited east-west access points available to serve

evacuating traffic. Because of this, first responders knew that the adjacent I-25 interchanges would be taxed during a wildfire evacuation. They also knew that background traffic, and how to handle that traffic, would be of concern. Colorado Springs is a city of over 500,000 persons. A large majority of the homes and businesses lie in the flat eastern sections of the city and county. While people residing in these areas would be aware of a wildfire if one started, they would not necessarily change their activity patterns because of it. This fact meant that emergency responders would need to handle/restrict background traffic, as well as the flow of evacuees from the affected areas, during a wildfire incident.

**Figure 1: Fire Evacuation Districts in Colorado Springs**



The 2010 model year scenario from the PPACG Travel Model was selected for fire evacuation analysis as most closely representing the “existing condition.” The PM Peak Hour time-of-day sub-model was selected to represent background traffic because it represents the worst case scenario for regional roadway network traffic congestion. Model versions for individual evacuation sub-areas were built within the PPACG model zone structure to represent eight districts (screening geography) within which are nested the twenty-one neighborhoods identified as the Wildland Urban Interface by the Colorado Springs Fire Department (CSFD) Wildfire

Mitigation Plan as at risk for wildfire. Additional foundational modeling assumptions were established with input from a standing Technical Steering Committee established to support the project. These baseline assumptions included: evacuation protocols, expected evacuee sheltering destination distribution, and available traffic control options. “Real-time” directives that came from the steering committee included:

- Shelter in place locations/policies
- contra-flow operation guidelines
- Evacuation area entry/reentry policies
- Emergency access requirements
- Special needs population evacuation protocols
- Off-site sheltering locations/capacities

### 3 Data Needs for Evacuation Models

**Table 1** organizes the data needs for planned or unplanned evacuations. A brief discussion of each topic provides better means of understanding the Colorado Springs methodology:

**Table 1: Data Needs for Evacuation Models**

<b>Data Type</b>	<b>Characteristics or Attributes</b>
Scenario	Impacted area, notice vs. no-notice, impact on transportation network and resources
Demographic Data	Automobile ownership, number of households, number of persons and age distribution of households, auto ownership levels, disabled representation within households
Land Use/Geography	Geographic characteristics of the focus area, terrain, elevation, wind conditions/ profiles, micro-climate
Road Network	Roadway geometrics, number of lanes, free flow speed/speed limits, other roadway characteristics for microscopic model
Traffic Control	Intersection control, signal preemption/emergency operation, route closures, traveler information system, contra-flow, route guidance and other ITS deployment
Background Traffic	Background (non-evacuating) traffic volumes
Evacuation Plan/Strategy	Designated evacuation routes, evacuation rate depending on hazard nature/type and evacuation order type, staged evacuation, time frame, shelters/reception centers, notification means
Evacuee Behavior	Mobilization time, activity sequence, vehicle occupancy rate
Assisted Evacuation Information	Transit routes, schedule, and capacity for transit-dependent evacuees
Special Facilities	Evacuation information (populations, procedures) for schools, jails, nursing homes, hospitals and other.

- **Scenario** – Disaster scenarios are built as a basis for analysis and evacuation planning. These scenarios identify the area/zone to be evacuated, where zones may be understood as municipal jurisdictions, islands with a single escape point, at-risk watersheds, low-lying land, land in the path of a hurricane, or a fire impact area.
- **Demographic Data** – To continue planning, it is essential to know the number of households included within the impact areas/zones. Knowledge of households includes:

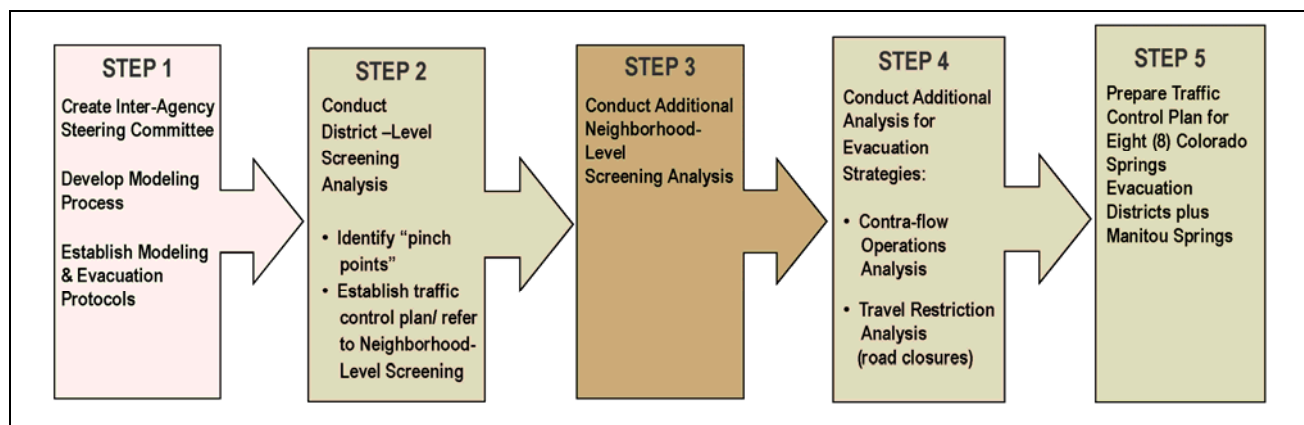
the number and age distribution of the persons in households, auto ownership levels, and special needs population within households.

- **Land Use/Geography** – Land use/geography of the evacuation zone and surrounding area is important to scenario building and alternatives analysis. The local emergency response team knows the terrain, elevation, wind conditions/profile and any micro climate conditions that may affect scenario definition or evacuation strategies.
- **Road Network** – The highway network scenario component must include capacity defining attributes such as number of lanes, speed limit, turn bays, and shoulders.
- **Traffic Control** – Knowledge of the highway network should be extended to include understanding of traffic signal devices, any signal plan, contra-flow capability, route closure protocol, traveler information system, route guidance and other ITS deployment in the impacted area.
- **Background Traffic** – Knowledge of background (non-evacuating) traffic volumes is an essential scenario component.
- **Evacuation Plan/Strategy** – A temporal aspect comes with this consideration. There may be known and designated evacuation routes which have previously delivered an evacuation rate depending on the nature of the hazard. As an example, hurricane evacuations in coastal cities may well have a multi-day time frame. The evacuation order type must also address where the evacuees are requested to remove themselves to. What shelters/reception centers are available to them? Finally, what is the means of notification of a mandatory evacuation?
- **Evacuee Behavior** – The temporal aspect is extended with this consideration. The mobilization time (which is tied to the safety of the evacuees), the activity sequence, and the vehicle occupancy rate enter the equation here.
- **Assisted Evacuation Information** – Knowledge of transit routes and schedules and the potential carrying capacity for transit-dependent evacuees is needed.
- **Special Facilities** – Knowledge of any institutional evacuation plans for schools, jails, nursing homes, hospitals and other are important to have.

#### 4 Methodology

The team understood the problem posed by the City of Colorado Springs and began the process of establishing a methodology. There are five main conceptual steps in the process as shown in Figure 2.

**Figure 2: Modeling and Screening Process**



#### 4.1 Model Run Mechanics

The evacuation model steps were appended to the official PPACG 2010 travel model run. The reason for this step is that the integrity of the model run could be transferred to the evacuation steps. The zonal data such as population and autos available, and network data such as the PM traffic results were right at hand. If a 2010 network or socioeconomic change was contemplated, the entire 24 hour model could be re-run and the new PM auto trip table would be available. In most cases the evacuation add-on steps, a final 40-50 commands, were run alone. These steps followed this general flow:

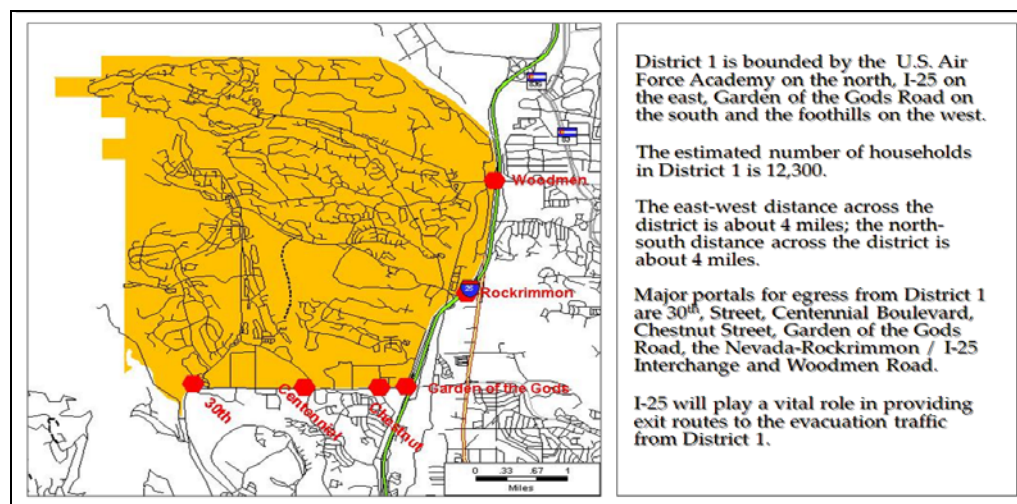
- **Trip Generation/Distribution of Evacuation Traffic** - Prepare the households for an evacuation model run. Use the U.S. Census 2000 auto ownership data to estimate household vehicles present for evacuation. The household was assumed to be full (i.e. everyone home from work or school) establishing the worst case scenario. The trip attractions (evacuee destinations) were agreed upon by the study team: official shelters (15%); the homes of relatives or friends (60%); hotels (15%); and out of the county to Denver or Pueblo areas (10%). The households where 60% of the evacuees go to are not keyed by family or friend connections, but developed using established household totals and a gravity model. The PPACG hotel database by TAZ proved useful since 15% of people are expected to use a hotel. Once out of the affected area, evacuees are not permitted to return, meaning that most traffic in the affected area is effectively one-way. Only emergency vehicles are permitted into the affected Fire Evacuation District. A set of candidate refuge zones (evacuee destinations) also had to be generated for each district to prevent illogical movements.
- **Implementation of Background Traffic Destination Restrictions** – The PM Peak Hour sub-model was generally allowed to function as if there was not a wildfire event. That is, no attempt was made to remove evacuees from their daily compute. Thus the integrity of the PM Peak sub-model as worst-case background traffic was preserved. According to established protocols, however, no one would be allowed to enter the evacuation areas during a wildfire event except emergency responders. In addition access to destinations to the west of the foothills, wildfire source and spread areas would also be restricted. These realities were handled by limiting the trip destinations allowed for background traffic.
- **Preparation of the Evacuation Network** – The PPACG model network was set to a one-hour PM capacity. Background traffic, in the form the existing PM all-purpose vehicle trip table was assigned to the network together with the evacuation trip table using a multi-class assignment procedure. The threads were kept separate. The travel demand software, like many of them, would not perform an assignment if access was removed from even one zone in the region. Centroid connector links were an important element in the network preparation; they had to be maintained even if access to the evacuation area was prohibited. Although background traffic destinations within evacuation areas had been eliminated, review of initial assignment results revealed some instances of non-evacuation travelers (background traffic) cutting across affected evacuation zones. This phenomenon was handled by limited use of turn prohibitors applied at the entry portals to the affected areas. Some trial and error was necessary to blend the realities of evacuation to the demands of travel models.
- **Initial Screening Level 1** – With modeling protocols in place the first level of modeling and screening ready for testing. District level runs and screening were completed for the 8 Colorado Springs Fire Evacuation Districts. The volume to capacity (V/C) ratio was

used as a performance measure with time-to evacuate target of 1 hour (V/C ratio less than or equal to 1.0). While this is a rough metric, it is understandable and immediately provides a guide to the “hot spots”. The beauty of the multiclass assignment is that the V/C ratio can be calculated for either class of traffic or for the sum of the two. A GIS mapping atlas was developed as a tool to generate a stakeholder review and comments. An example using District 1 is show below.

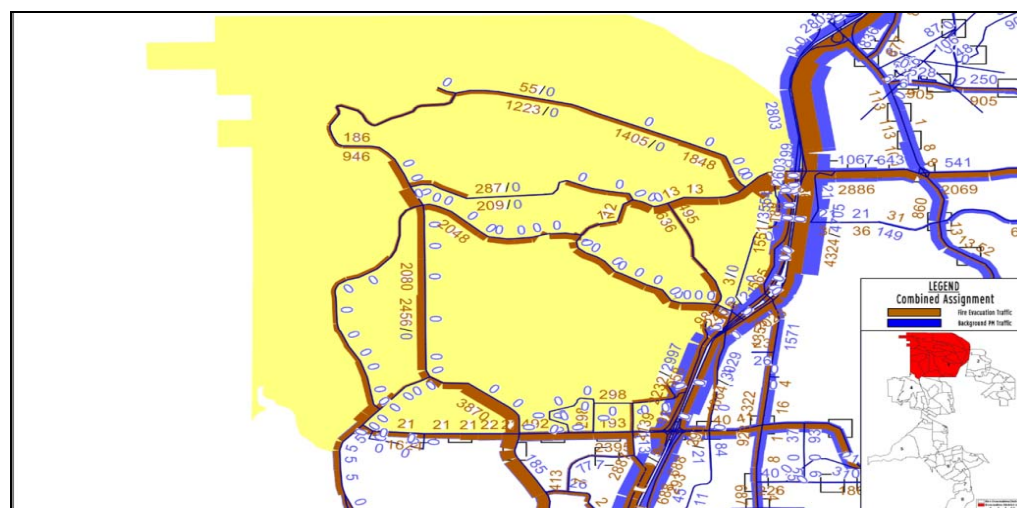
#### 4.2 Initial Screening at the District Level

**Figure 3** shows the main characteristics of the district including the area, number of households and major portals with detailed street network shown in the background. **Figure 4** shows the assigned model network with both evacuation and PM background traffic shown in bandwidth plots. The model network is much less detailed. Note that there is little “pass-through” traffic in District 1.

**Figure 3: District 1 Characteristics**



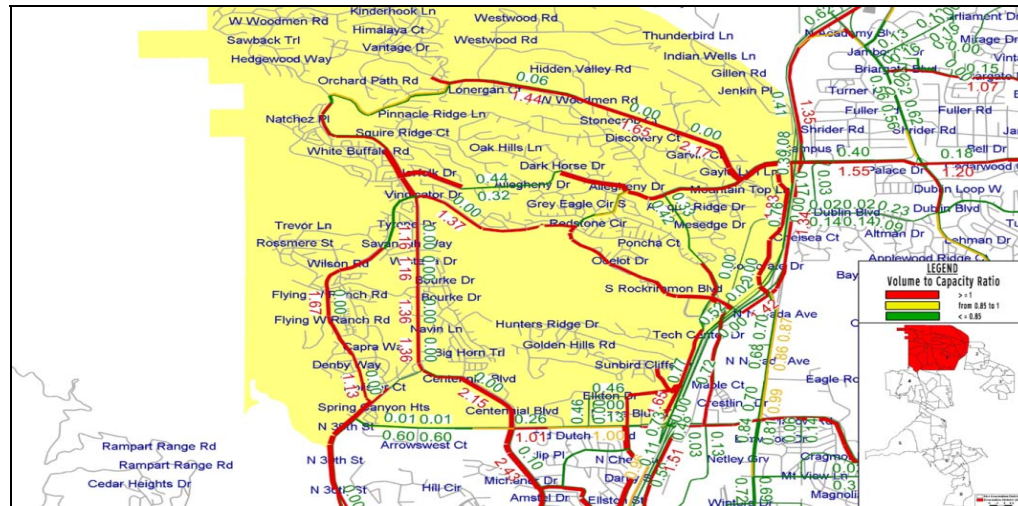
**Figure 4: District 1 Evacuation and Background Traffic**





**Figure 5** shows the result of the traffic bandwidth translated into volume/capacity ratios. As expected, many of the road segments have values well over 1.00 a rough indicator that they cannot clear during an average hour.

**Figure 5: Volume/Capacity Ratio of Evacuation and Background Traffic**



District 1 is an example of a district that did not attract pass-through traffic. The reason is that the shortest path does not flow through this district; instead it follows I-25. A look at the configuration of the other districts (Figure 1) will show that some of them will get pass-through traffic. They needed to receive network edits with turn prohibitors at the entry portals that would not allow illogical movements such as driving into an area that is on fire. The initial screening at the district level also brought forward the need to break the districts into smaller units. This decision was not a modeling concern. The local terrain and street network drove the district and neighborhood boundary setting. The emergency officials knew well where the “natural” fire boundaries lay and which portals would need to be monitored. District 1 is made up of three distinct neighborhoods based on the roadway configuration: North “Cap”, Southwest, and Southeast. These three are physically separated by terrain and thus fire would not spread easily from one to the other.

### 4.3 Neighborhood Screening

Neighborhood screening for fire evacuation was the next step. **Figure 6** shows the location of the nine neighborhoods that were the focus of the first round of detailed application. The blue north “cap” of District 1 will be shown as an example of the next step of analysis.

**Figure 7** illustrates in a two-image sequence the process used to develop traffic control recommendations when a “pinch point” is identified. Through iterative screening contra-flow options are tested: excess capacity is found at one or more of the portals, though in the opposite direction, network edits are performed to free up and use the excess contra-flow capacity, and the volume/capacity is recalculated. The outcome is a given – traffic congestion is moved away from the evacuation area and there is a reduction in the overall time to clear the neighborhood. Note that the traffic is posted on the outgoing highway segment only. The opposite direction is added to it in order to ramp up the lanes available to exiting traffic.

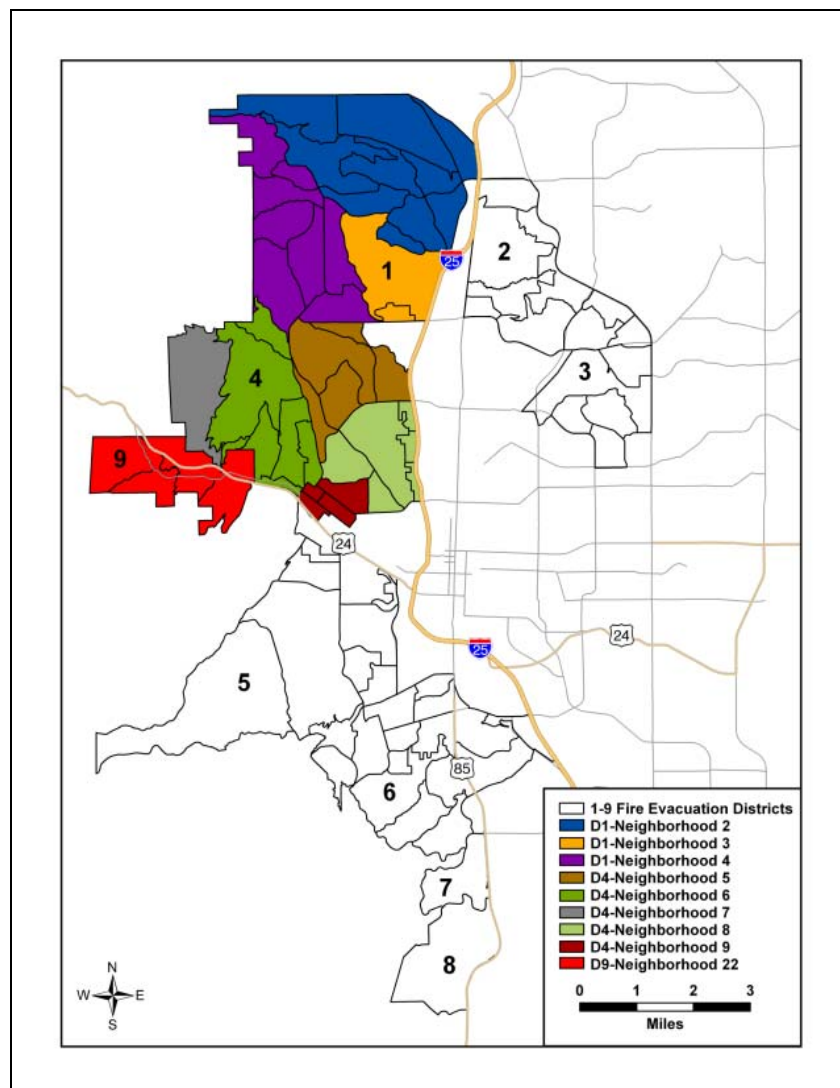
Contra-flow operations in District 1 Neighborhood 2 were tested in varying scenarios involving selected facilities, ranging from a single roadway segment to the majority of the major street

network within the neighborhood. The most effective combination, shown below as part of the final Traffic Control Atlas involved:

- Westbound/southbound contra-flow on Orchard Path/Centennial Boulevard between West Woodmen Road and Allegheny. Eleven access points must be controlled.
- Southbound contra-flow on Flying W Ranch Road/30<sup>th</sup> Street between Vindicator Drive and Garden of the Gods Road. 14 access points must be controlled.

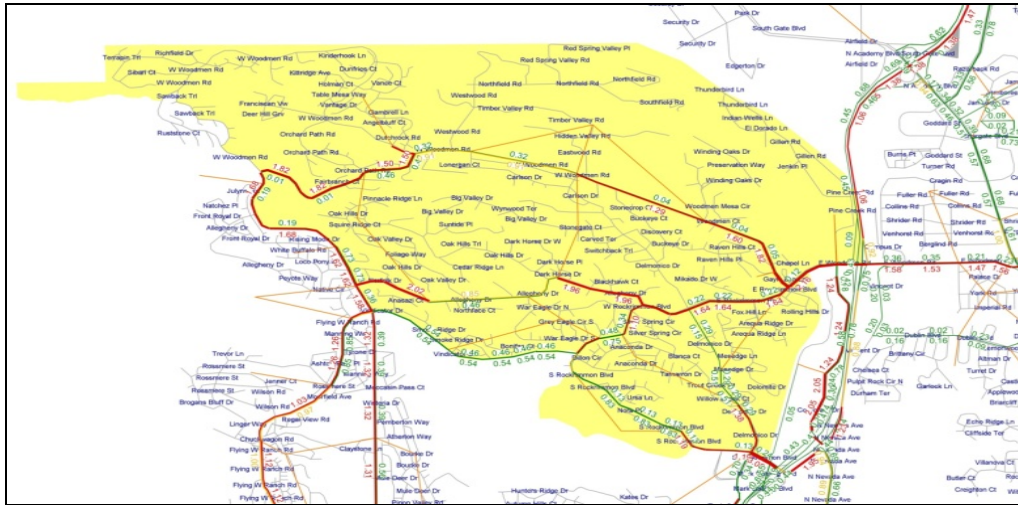
It should be noted that contra-flow operation was an extraordinary strategy needed for only the most constrained neighborhoods. It did not replace baseline strategies including: restriction of egress routes to evacuation traffic only and prohibition of entry into the evacuation area by non-responder traffic.

**Figure 6: Location of First Cut Neighborhoods**

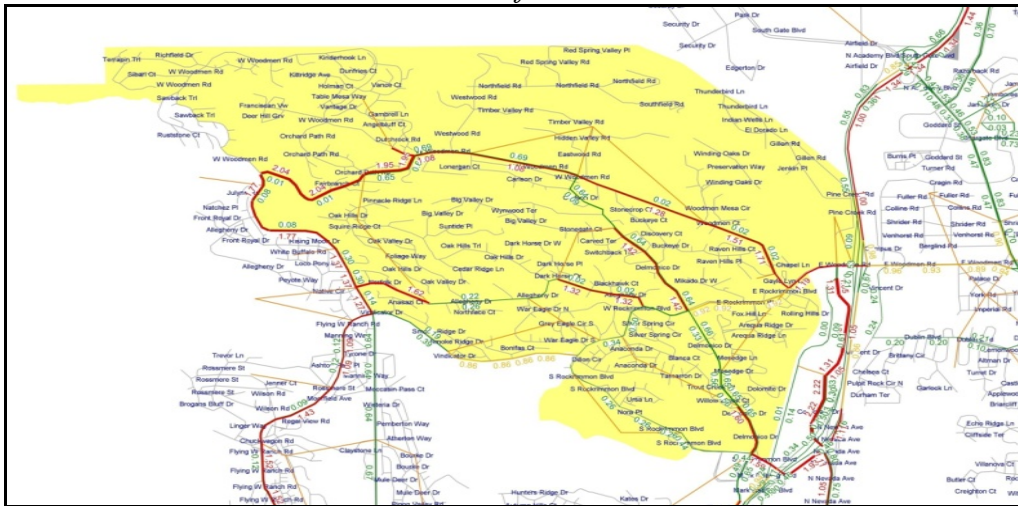


**Figure 7: Example Evolution of a Contra-flow Solution**

*Baseline*



*Final Contra-flow Solution*



## 6 Implementing Modeled Findings

The evacuation travel model, conducted at the neighborhood level, provided actionable information for planned evacuation. While the results were based on a set of assumptions and the known scaling issues of travel models such as centroid connector locations, continuing involvement of the Colorado Springs planning team provided needed local knowledge and expertise to compensate for known regional model shortcomings. The results of the iterative modeling process provided to the emergency community of Colorado Springs an actionable traffic-based scenario that had been tested and is known to be the optimum. Once the final traffic control strategies were approved by the Colorado Springs planning team, the project moved to the implementation phase. A hardcopy Traffic Control Manual was deemed the most effective way to implement the final evacuation traffic control strategies. The quick availability of the hotspot exit portals locations, names of the streets and traffic control protocols would be invaluable in meeting the challenges of rapid response to wildfire events, and could be most effectively conveyed through hardcopy manuals. A B-size operations manual was already



carried in emergency responder vehicles, so this would be a familiar tool. The Colorado Springs planning team was actively involved in shaping the format and content of the manual. They dictated, size, colors, icons and map grid to be used. The final Fire Evacuation Traffic Control Plan field atlas includes a section for each evacuation area in which a key map shows the overall traffic control plan, and is followed by larger scale detail maps (see example as **Figure 8**). The scale and nomenclature already used by the Fire Department in their field operations map books are used for consistency. The symbols on the traffic control plan, such as turn back or contra-flow can be readily translated into a required number of emergency personnel at specific locations. Again, the traffic control plans have a scientific basis and provide an objective means of handling a planned evacuation.

## 6 Conclusions

Will the west continue to burn? The incidence of unplanned wildfires may grow in Colorado and throughout the mountainous west due to residential encroachment into vulnerable and relatively inaccessible areas, poor stewardship by outdoors enthusiasts, weather events (lightning), weather trends (drier summers) and arson. It may also be that there are fewer financial resources to fight fires as cities and counties pull back from or charge a fee for providing a wide variety of services, including fighting fires where human life is not at stake. Regardless of where the future leads, it is cost-effective to use valuable resources to prepare a planned evacuation plan. The methodology and approach that was used to adapt the PPACG travel model for use in the Colorado Springs area for fire evacuation could easily be transferred to another region.

The key elements for success in the fire evacuation models were consulting with the emergency community and heeding their advice, integrating local knowledge early and often, and understanding the strength and the limits of travel models. The true measure of success is that the fire evacuations atlases are a permanent feature in Colorado Springs emergency planning and when implemented can assist in saving lives and protecting property.

**Figure 8: Traffic Control Plan Key Map/Grid Map - District 1 Neighborhood 2**

