The Test of Fire: A Comparison of Adapted Four-Step MPO Modeling Results and Planning Process Findings to Actual Experience

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ABSTRACT
In late 2010, the City of Colorado Springs and the Pikes Peak Area Council of Governments (PPACG) completed a cooperative wildfire evacuation planning process. The process was supported by simulation of wildfire evacuation scenarios using an adaptation of the PPACG's four-step travel model. The adapted model was used to assess times-to-evacuate, identify choke points, and develop traffic control plans for identified at-risk neighborhoods. Evacuation simulations used a worst-case scenario in which the wildfire event took place during the PM peak hour and affected households were included in both background commuter traffic and neighborhood evacuation traffic. Link-based hourly volume/capacity ratios were used as a metric to estimate times-to-evacuate and to identify egress bottlenecks. Route closures, route restrictions, no-entry restrictions and contraflow operations were evaluated as measures for inclusion in neighborhood-level traffic control plans.

On Tuesday, June 26, 2012, the simulated worst case became reality. Nearly 34,000 persons were evacuated during the event, more than half during the six hour period between 1530 and 2130. Before the wildfire was fully contained, 18,247 acres had burned, 347 homes and other structures had been destroyed, and 2 individuals had perished. That the no-notice, mandatory evacuation was as successful as it was can be attributed to extensive advance planning, the accuracy of modeled evacuation simulations and the effectiveness of the final traffic control plans. This paper examines how the model results were borne out by actual experience. Recommendations to improve no-notice evacuation planning from the perspective of "lessons learned" are also presented.

1 BACKGROUND

In the wake of recent increases in both planned and unplanned evacuations in the U.S. and internationally, increased attention has been directed on tools that can be used to prepare emergency responders for disaster. The literature includes a number of examples of Dynamic Traffic Assignment (DTA) microsimulation tools as well as tools that combine DTA with four-step and activity-based travel demand modeling applications [1,2,3,4,5,6]. These examples are generally applied to large urban areas and are designed to address large-scale notice evacuation for hurricane incidents. An exception to this is a paper by Noh, Chui, Zheng, Hickman and Mirchandari [7] that proposes a methodology for estimation of location and number of evacuees for short-notice evacuation, in this case for flash flooding. In many instances wildfire incidents pose an even higher level of complexity because they can not be predicted, may not be quickly identified and may be exceedingly fast-moving. These and similar incidents often require rapid, “no notice” evacuation. Regardless of the type of incident and the lead time involved, for each incident “the rubber meets the road,” that is, exit roadways are jammed with both responding and 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, the terrain, weather, and settlement patterns make wildfires the incident that occurs most often and must be addressed. Drought [8], rising temperatures and continued human settlement in the fire-prone ecosystems, dubbed the Wildland Urban Interface (WUI), have been cited as factors that have contributed to an increases in the incidence, size and destructive impact of wildfires in recent years. The July 2013 issue of *Planning* magazine cites a Colorado state forestry official’s estimate that a quarter of the state’s population living within WUI areas [9]. The second largest city in the state, the City of Colorado Springs fits or exceeds that profile. The full extent of the western city limits border the Pike National Forest and all neighborhoods located in the favored area lie within the WUI.

The 2002 Hayman Fire brought the wildfire threat to Colorado Springs into clear focus and signaled the need to put in place a management plan to support incident response including evacuations. The Hayman Fire still holds the distinction of being the largest wildfire in Colorado’s history. The fire impacted four counties, burning over 138,000 acres (52,650 hectares) immediately to the west and north of the Colorado Springs area. 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 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 primarily affected rural areas. However, the wildfires described above signal a change in this pattern. This changes occurred due to drought conditions, which produced extremely dry vegetation (fuel availability), placing Colorado’s urban areas increasingly at risk from wildfires.

2 PLANNING PROCESS AND MODELING RESULTS

The City of Colorado Springs’ response to recognized wildfire threat has been many-faceted and includes aggressive wildfire mitigation programs, personnel incident response training, and wildfire emergency response management planning. The planning efforts produced: a comprehensive Wildfire Mitigation Plan (WMP, 2001), the Colorado Springs Community Wildfire Protection Plan (CWPP, 2011, update to WMP) and the WUI Fire Evacuation Appendix to the Colorado Springs Emergency Operations Plan (2008, updated in 2012). The Colorado Springs Fire Department (CSFD) developed the WMP and CWPP update. The WUI Fire Evacuation Appendix was developed jointly by CSFD and the Colorado Springs Police Department Office of Emergency Management and includes model-supported traffic control plans that were developed with support of the Pikes Peak Area Council of Governments (PPACG).

The PPACG and their consultant team led development of the traffic control plans, ultimately using an adapted version of the MPO four-step model for screening-level analysis of evacuation constraints and iterative testing of traffic control strategies that were supported by expert panel review. Operational microsimulation, DTA and travel demand forecasting tools, as well as combinations of the two tools were considered as options to model evacuation performance and test traffic control strategies. Ultimately, several factors influenced the decision to adapt the MPO four-step model to support screening analysis of evacuation constraints and iterative testing of traffic control strategies. Either microsimulation or a DTA approach would have required that the team build new models, while the local MPO Travel model provided a readily adaptable tool to support this element of the plan. Perhaps more daunting was the added burden of defining evacuation population and location for new models. Indeed it was said in the aftermath of the Waldo Canyon Fire incident that the team had modeled an event for which you could not plan. Finally there was a clear understanding that no notice evacuation would produce saturated flow conditions that outstrip microsimulation model processing of traffic through the network. There really wouldn't be queues; there would be gridlock. The challenge then would be to maximize the capacity of egress routes (using contraflow) to allow more traffic to flow through evacuation routes in the shortest possible time and to restrict use of evacuation routes to evacuees (egress route restrictions/closures, evacuation area entry restrictions). The functionality of the MPO four-step model was well suited to these requirements. The model's GIS data base structure and mapping capabilities also offered essential functionality to support multiple scenario testing and expert panel operational screening of alternative traffic control strategies.

The 2010 model year scenario was selected for Fire Evacuation Analysis as it most closely represented the "existing condition" as far as population and employment. The PM Peak Hour time-of-day sub-model was selected to represent background traffic because it represented the worst case scenario for regional roadway network traffic congestion. Individual evacuation sub-areas were built within the PPACG model zone structure to represent eight districts (screening geography) within which were nested twenty-one neighborhoods at risk for wildfire. Together, these areas are identified as the WUI by the Colorado Springs Fire Department (CSFD) Wildfire Mitigation Plan.

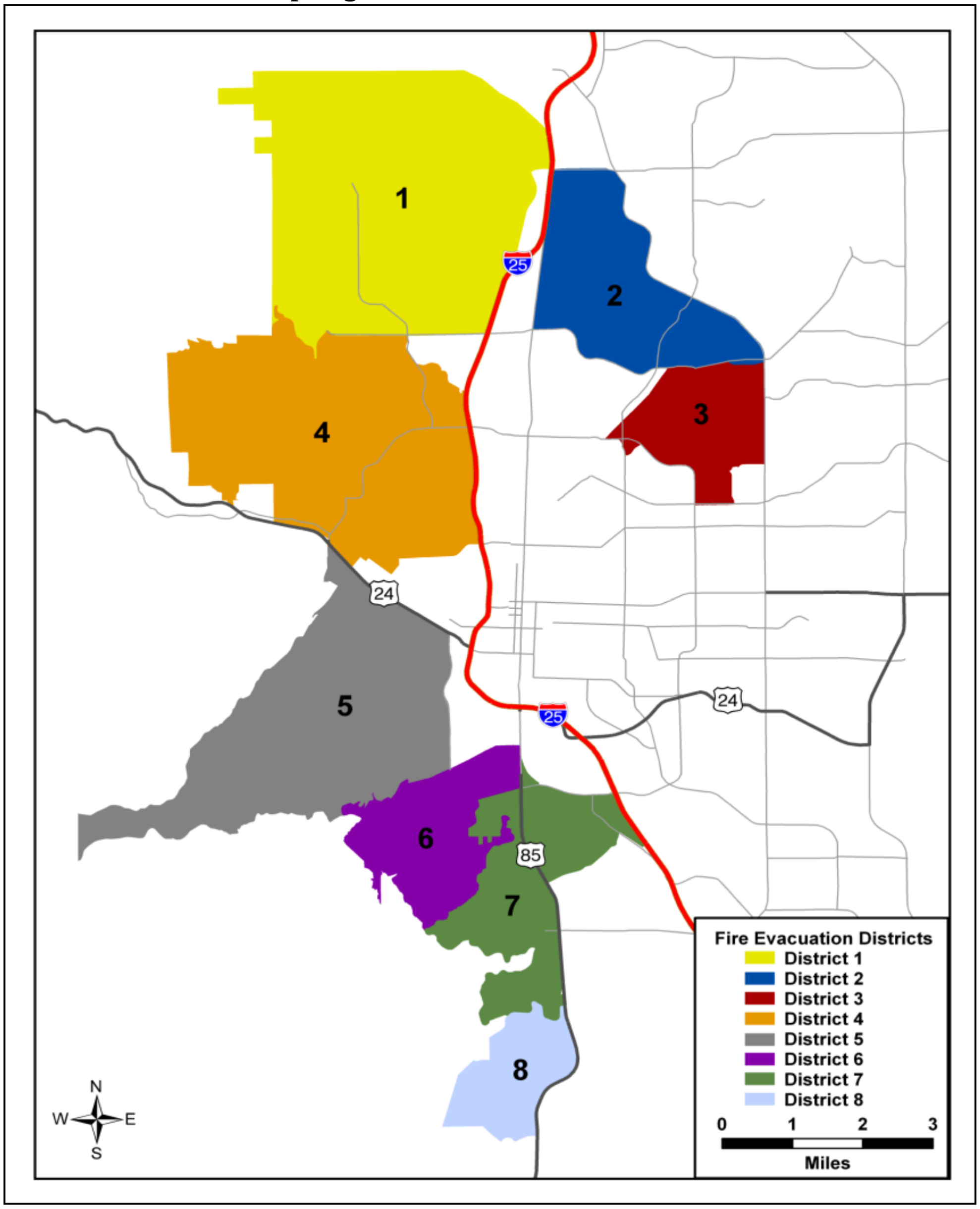
Figure 1 shows the general layout of the greater Colorado Springs area with the eight fire evacuation districts. These neighborhoods are all located in the interface between the relatively flat city streets and the beginning of the Rocky Mountains. There are limited access routes into and out of these neighborhoods, making them "islands" in highway network terms. Note also the presence of I-25 as a north-south facility with a limited number of east-west access points that are available to serve vehicles exiting from the western neighborhoods. First responders already knew that these intersections would be the first to back up during a wildfire evacuation. It must be noted also that in Colorado Springs, a city of over 500,000 persons, the remainder of personal business goes on as usual when a wildfire is in progress. A large majority of the homes and businesses lie in the flat eastern sections of the city and county. The people residing in these areas would be aware of a wildfire if one started, but would not necessarily change their activity patterns because of it. This fact means that in the case of wildfire evacuation, the emergency responders need to handle background traffic as well as the flow of evacuees from the areas in jeopardy.

A necessary piece is an approach or methodology that could take the typical demand peak hour and build a simple set of assumptions creating an evacuation traffic model. PPACG started by assembling a team of modelers and planners and conducting a listening session with the emergency responders. This step was important in that the PPACG could grasp the thoughts and needs of the emergency responders directly. Several "real-time" directives came out of that meeting including the need for:

- A set of fire evacuation districts, corresponding to the natural boundaries of fire influence zones.
- An intersection-focused approach, since intersections are the natural "pinch points" formed by outgoing evacuees, incoming responders, and background traffic.
- Contra-flow lane responses, particularly in the I-25 interchange areas.

- Evacuation traffic control plans with a focus on key evacuation routes including the I-25 interchange areas.

FIGURE 1 Colorado Springs Wildfire Evacuation Districts.



Some of the needs for wildfire evacuation response related directly to assigning personnel to key locations in real time. Given a fire in District 1, for example, police officers could be immediately dispatched to the critical intersections and begin evacuation traffic control. If establishing contra-flow traffic lanes was indicated, the material necessary for this activity, such as emergency lights, cones, and additional personnel, could be dispatched to the appropriate areas and staged for contra-flow operations. The district system and traffic assignment/simulation tools needed to conduct the fire evacuation modeling work are familiar to transportation planners and modelers. What was new was the opportunity to apply those tools in the service of larger ideas such as the protection of life, livelihood and property in Colorado Springs.

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.

Data Type	Characteristics or Attributes
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.

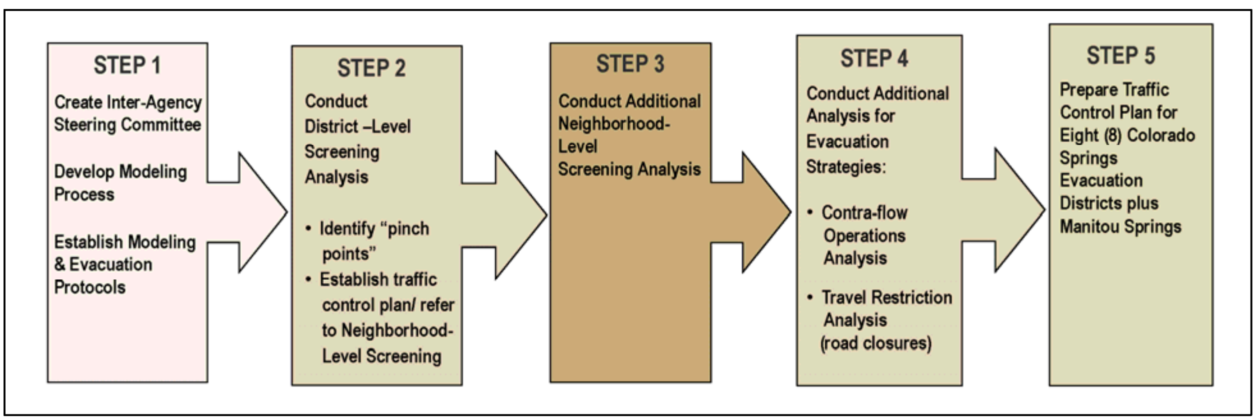
- **Scenario** – To begin planning, it is important to define the disaster scenario, both to focus the planning steps and to share the response personnel/responsibilities. This task is composed of “zone” building where zones may be understood as municipal jurisdictions, islands with a single escape point, at-risk watersheds, low-lying land, land in the path of a hurricane, or, in the case of Colorado Springs, a fire impact area. The scenarios are directly related to the type of disaster that is being faced. As an example, in Colorado Springs, evacuation planning scenarios were established for each of a set of fire evacuation districts. Each had a unique plan.
- **Demographic Data** – To continue planning, it is important to know the number of households who are in the impact zone. Knowledge of households includes having access to the number and age distribution of the persons in households, auto ownership levels, and the disabled population within households.
- **Land Use / Geography** – The land use of geographic components of the scenario building set is an important planning step. The local emergency response team knows the terrain, elevation, wind conditions / profile and any micro climates that may affect the definition of the scenario or the strategy to address it.
- **Road Network** – The highway network needs to be refined to the point of containing typical demand 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 important. In Colorado Springs, for example, I-25 has been closed for traffic incidents, and traffic diverted at the same (logical) north and south interchanges where a good north-south alternate route is available.
- **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. In Colorado Springs, the transit system was not utilized in the evacuation planning as the percentage of zero vehicle households is very small.
- **Special Facilities** – Knowledge of any institutional evacuation plans for schools, jails, nursing homes, hospitals and other are important to have. In Colorado Springs, the evacuation of institutional facilities was handled in a separate effort from household evacuation.

3 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.



3.1 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 developed based on consultation with emergency management personnel with oversight roles during the Boulder Colorado Fourmile Canyon Fire: official shelters (15%); the homes of relatives or friends (60%); hotels (15%); and out of the county to Denver or Pueblo areas (10%) [12,13]. 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 refugee zones 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 residents from their daily commute. 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 through 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.

3.2 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.

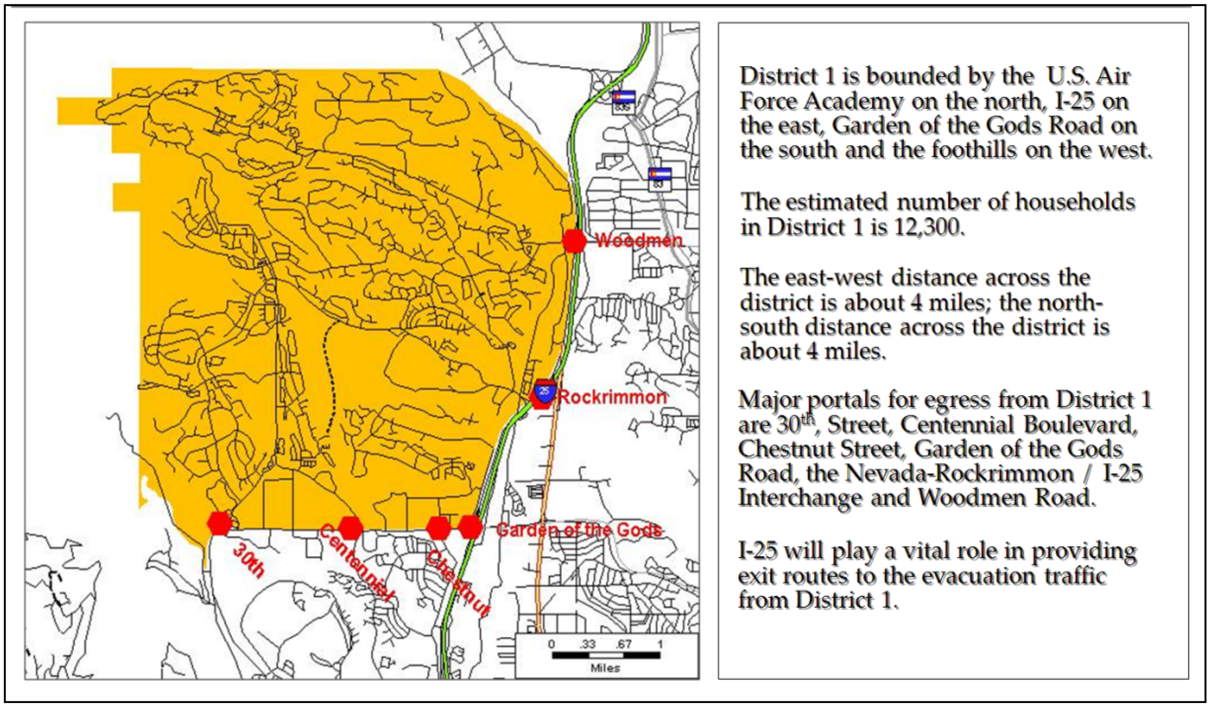


FIGURE 4 District 1 Evacuation and Background Traffic.

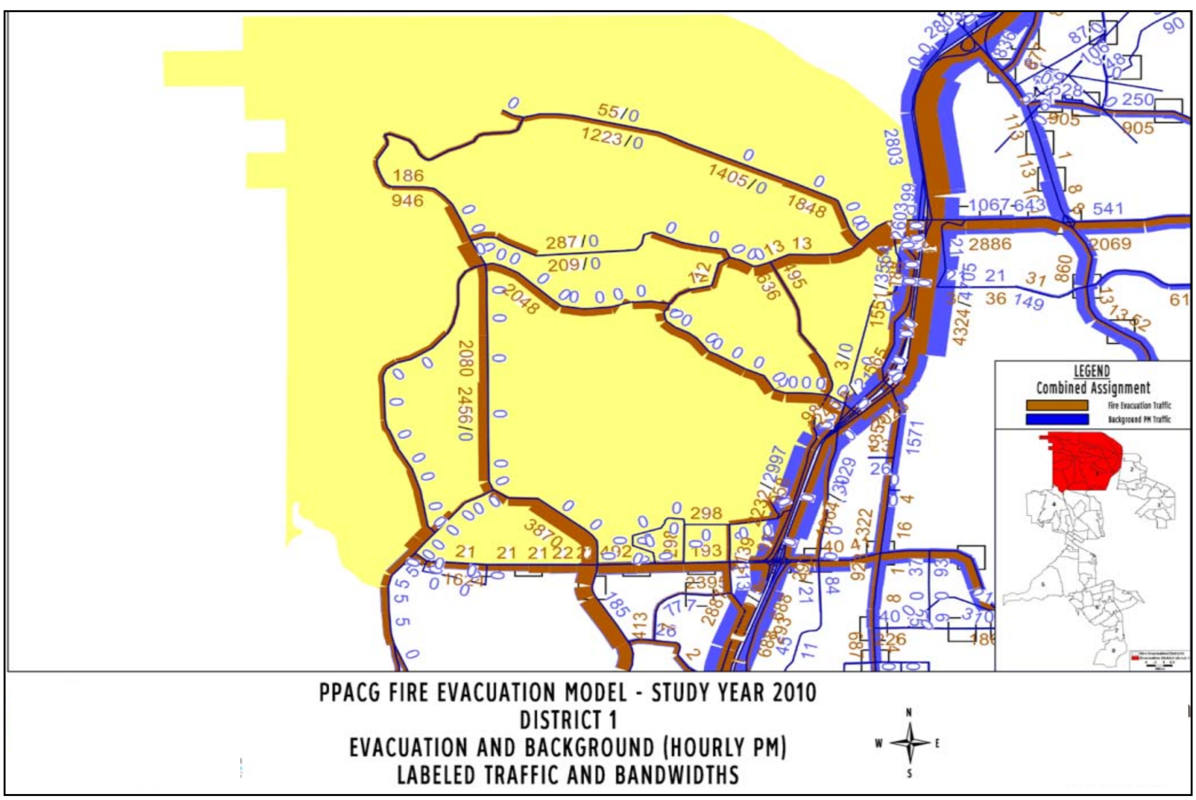
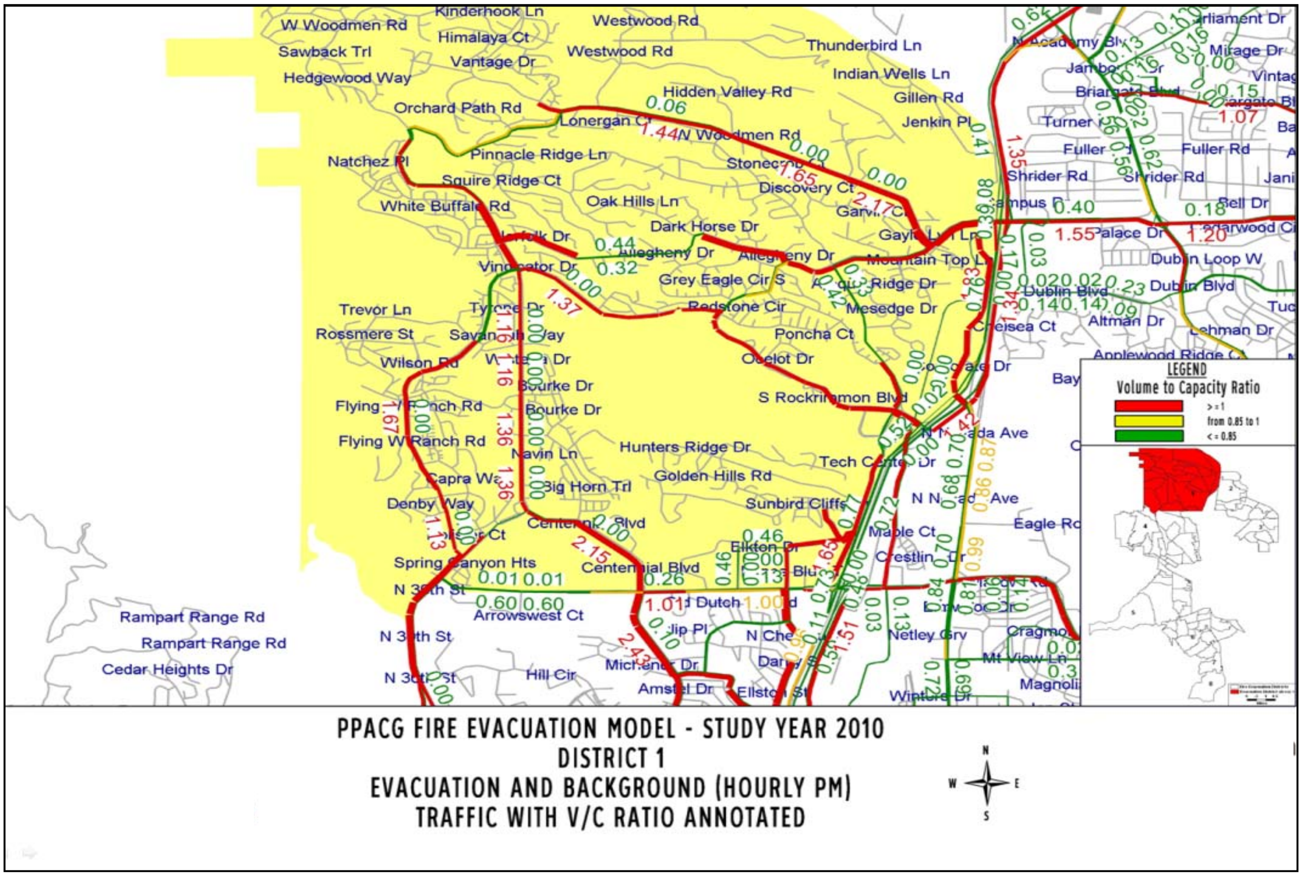


Figure 5 shows the result of the traffic bandwidth translated into volume/capacity ratios. As expected, many of the road segments have values well over 1.00 a rough indicator that they cannot clear during an average hour.

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.

3.3 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 6 Location of First Cut Neighborhoods.

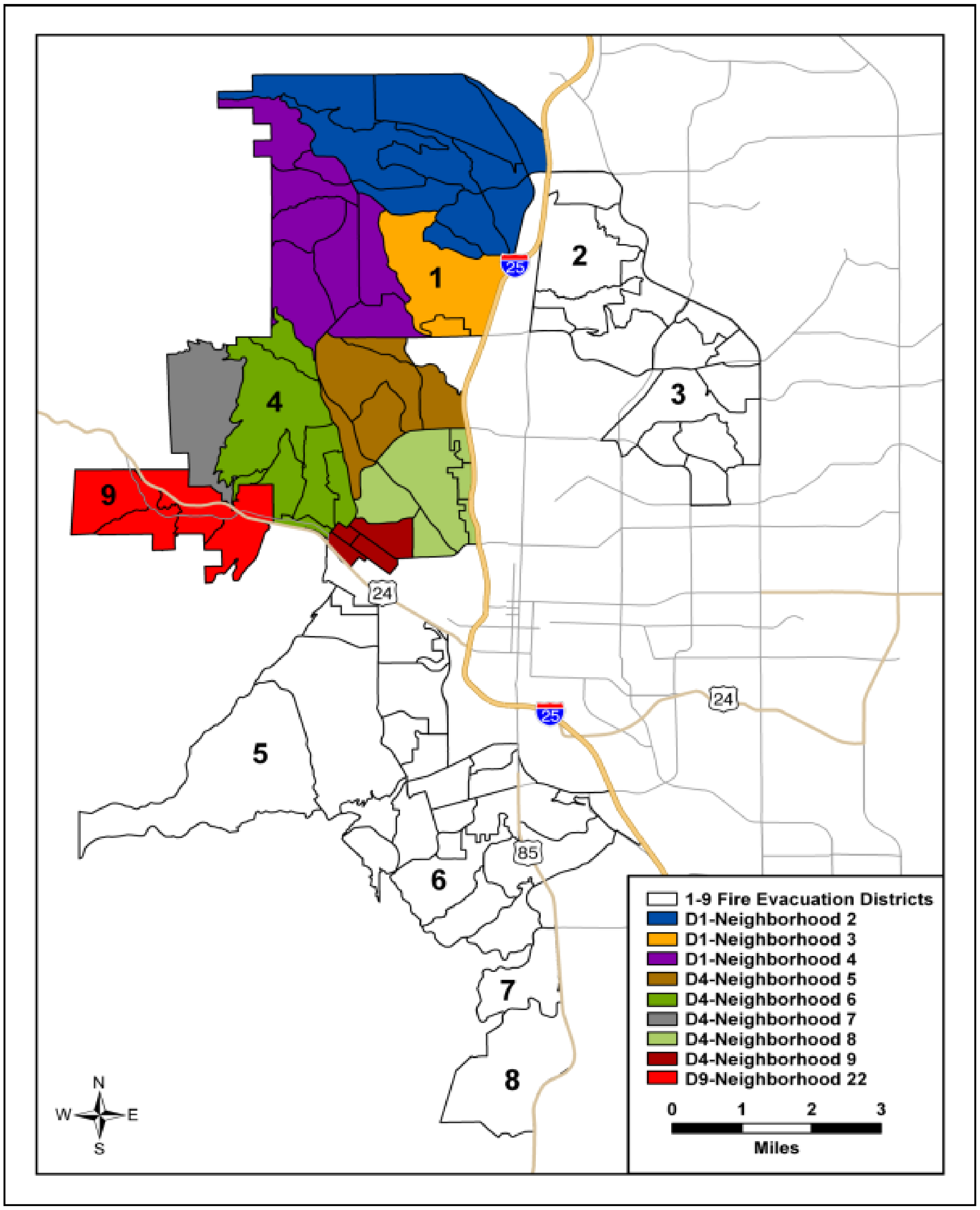
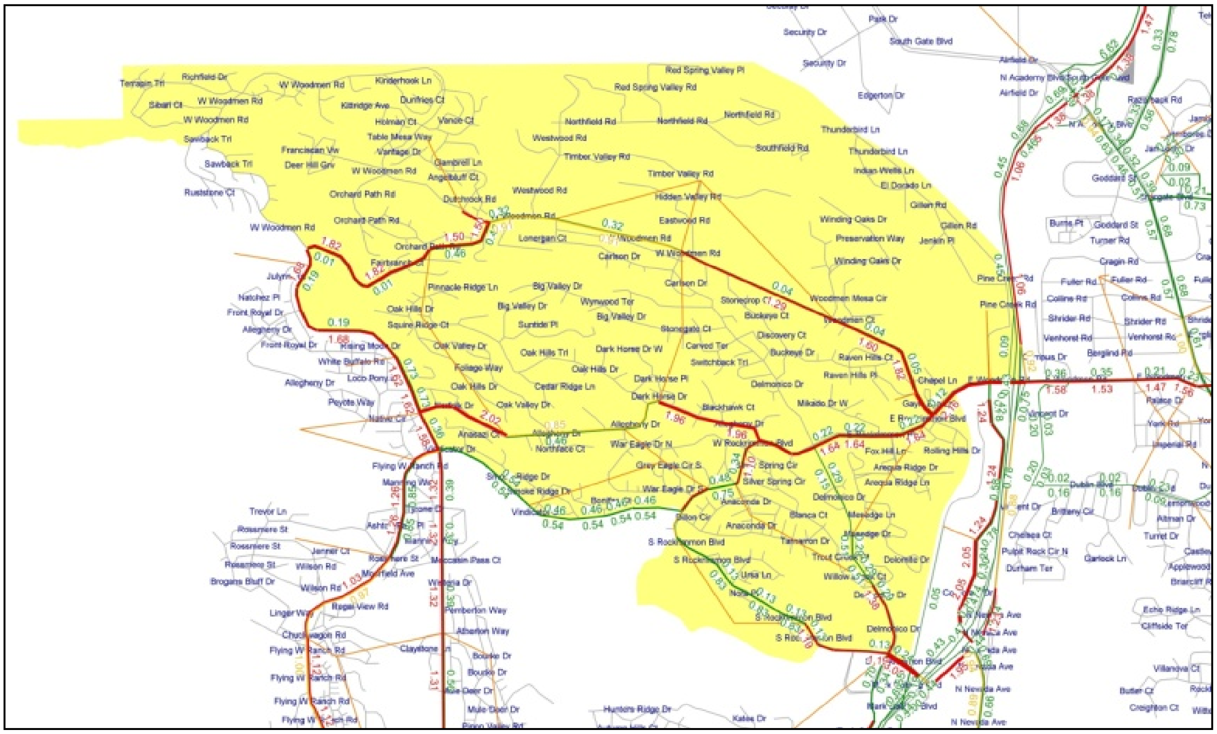


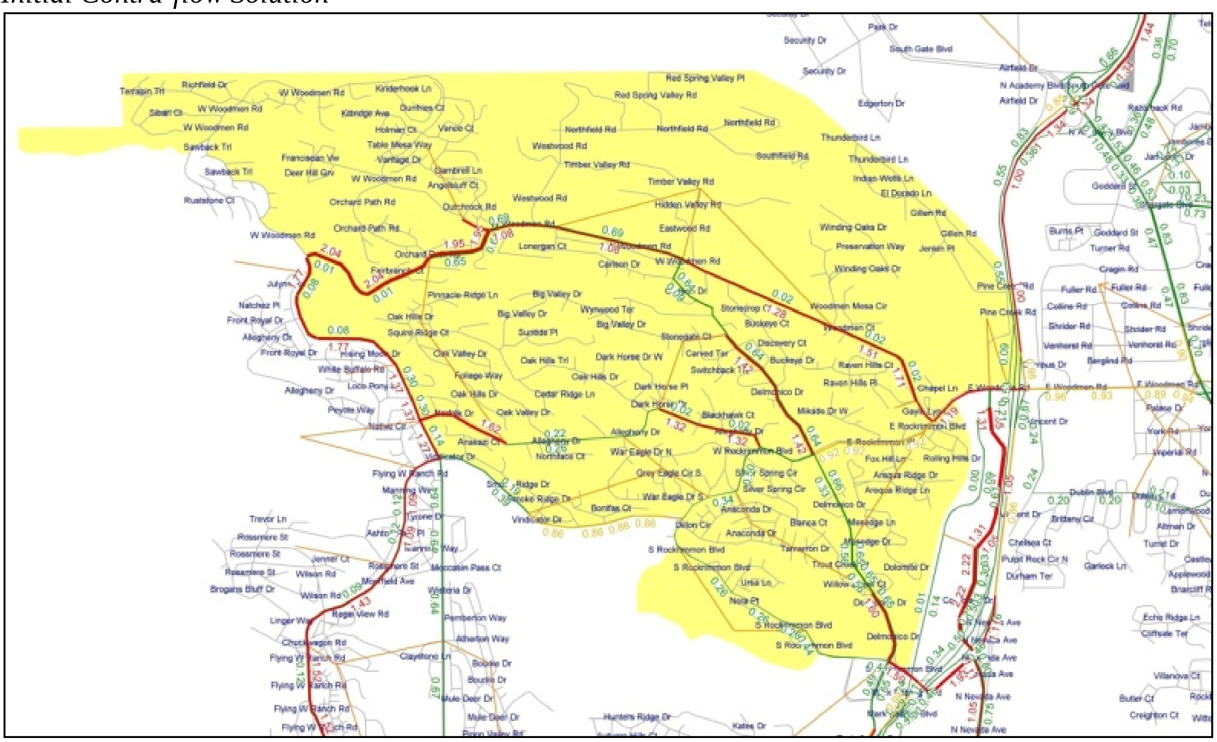
Figure 7 illustrates, in a three-image sequence, the process (baseline analysis, initial contraflow solution, final contraflow solution) used to develop traffic control recommendations when a "pinch point" is identified. Through iterative screening contra-flow options are tested: excess capacity is found 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.

FIGURE 7 Three-Step Contraflow Evaluation Process.

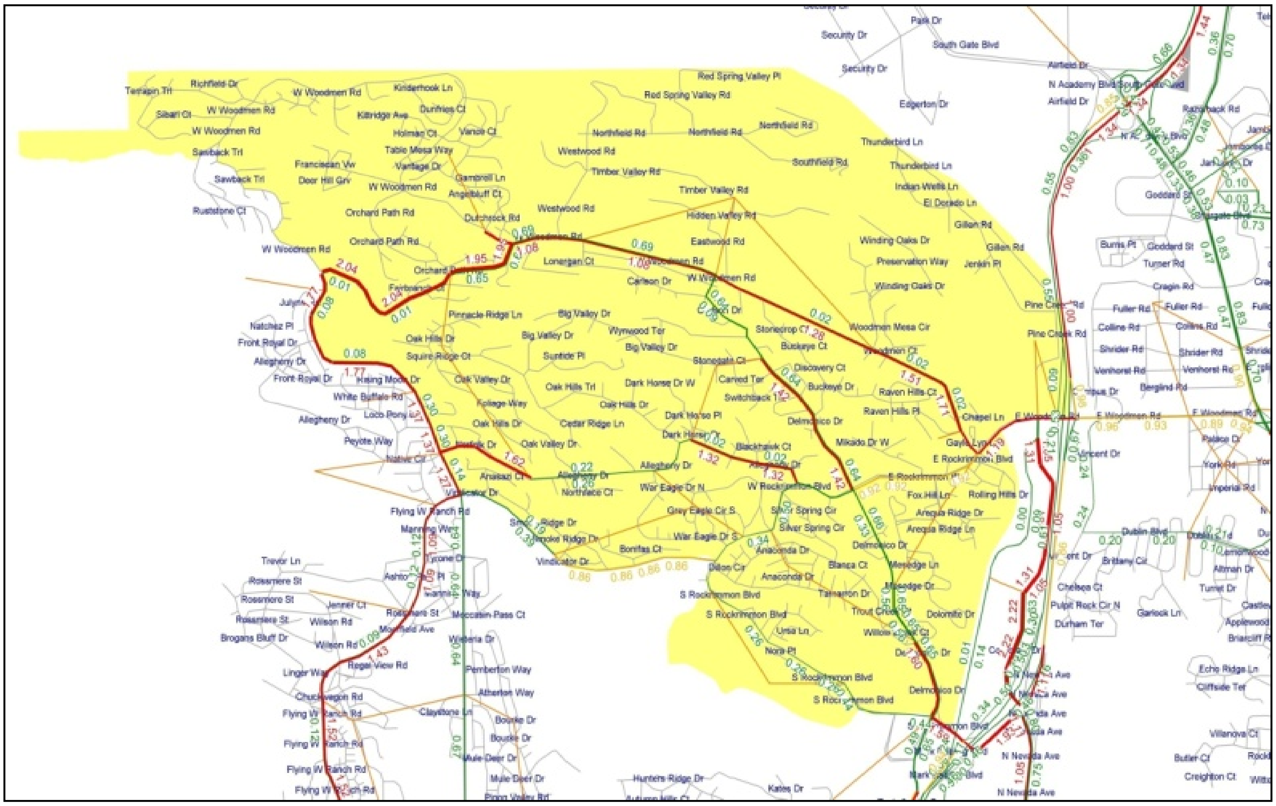
Baseline



Initial Contra-flow Solution



Final Contra-flow Solution



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/30th 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.

4 IMPLEMENTATION OF MODEL 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 emergency response 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 emergency responders, 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 emergency responders were 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 (see **Figure 8**), and is followed by larger scale detail maps (see example as **Figure 9**) using Fire Department map grid. 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.

FIGURE 8 Traffic Control Plan Key Map - District 1 Neighborhood 2.

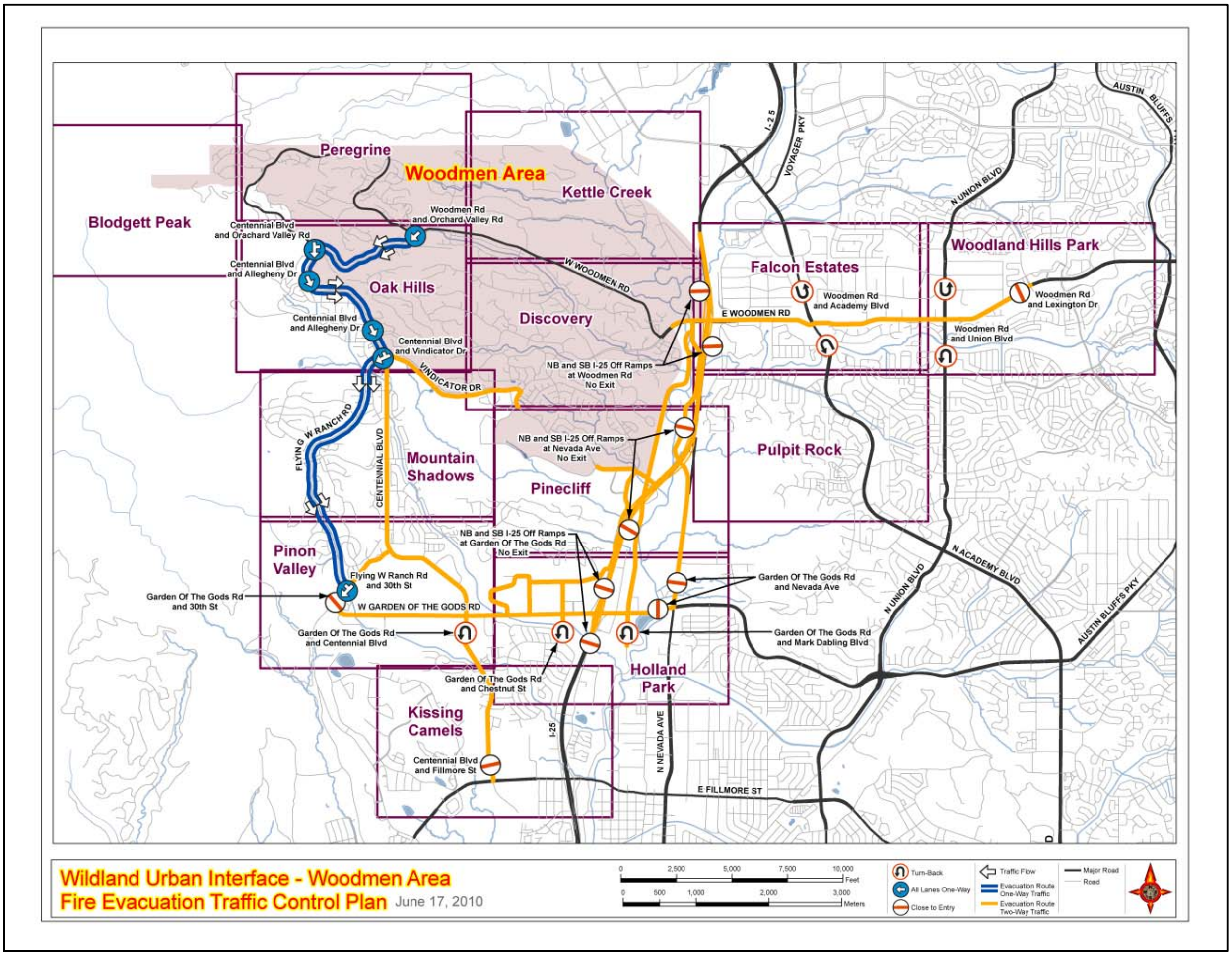
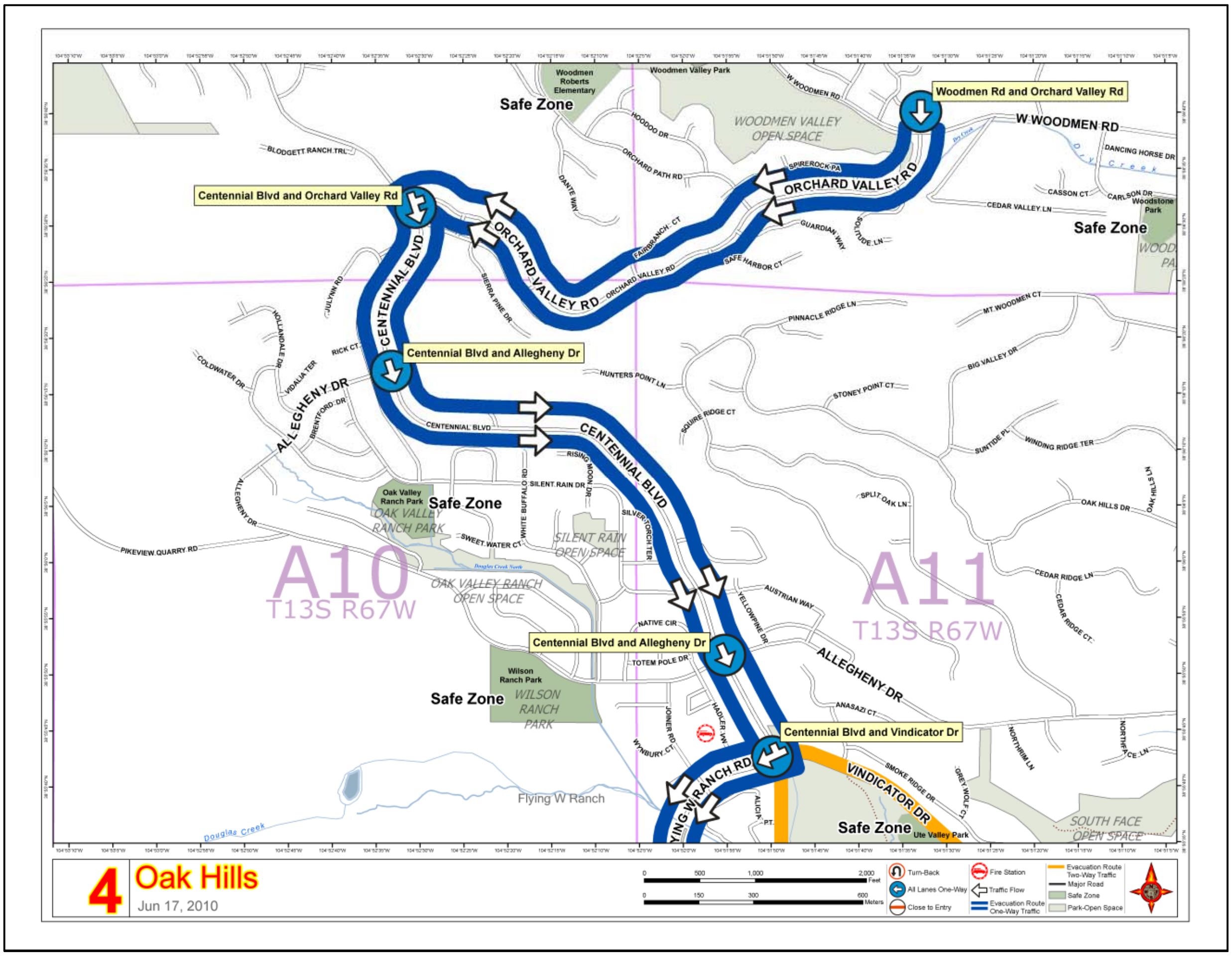


FIGURE 9 – Example Traffic Control Plan Grid Map – District 1 Neighborhood 2.



5 TEST OF FIRE – COMPARISON OF MODEL RESULTS VERSUS ACTUAL EXPERIENCE

On Tuesday, June 26, 2012, the simulated worst-case scenario that was modeled by the planning team became reality. The City of Colorado Springs' *Waldo Canyon Fire - Final After Action Report* [10] cites a convergence of conditions that began early in the afternoon of June 26th and culminated with the fire cresting the easternmost ridge of Queen's Canyon and raging through Wilson Ranch and the Mountain Shadows neighborhood, driven by 65 mph winds. In all, nearly 34,000 persons were evacuated for the Waldo Canyon Fire, more than half during the six hour period between 1530 and 2130 on June 26th. Before the Waldo Canyon Fire was fully contained, 18,247 acres had burned, 347 homes and other structures had been destroyed, and many others had been damaged. Tragically, two individuals lost their lives as a result of the fire.

At 1426 on the afternoon of June 26th, fire activity was reported in the Quarry above Cedar Heights. By 1500, converging winds combined with continued low humidity caused by the fire to develop a large column with a pyro-cumulus cloud on top, and at 1530 CSFD lookouts reported increased fire activity in Queen's Canyon. At 1608 fire was reported on east side of the most east-facing ridge of Queen's Canyon via CSFD radio. In response, an order for mandatory evacuation of Zone 3, including the Oak Valley, Peregrine and North Mountain Shadows neighborhoods, was requested at 1610 and commenced at 1624. As evacuation of Zone 3 continued, assisted evacuation (with 2 CSFD buses and 17 American Medical Response vehicles) of 103 patients from the Mount Saint Francis Nursing Center was initiated beginning at 1700. Staged evacuation of an area including WUI neighborhoods 2,3, 4 and part of neighborhood 5 was initiated on approximate two-hour intervals for the next six hours, with the final mandatory evacuation notice issued at 2146 for the Kissing Camels neighborhood.

As for the modeled worst-case scenario, the wildfire incident was a no notice event that took place during the evening peak hour commute. Surprisingly, residents went home from work and then evacuated from their homes; thus the intended double-count contingency was reality. Full traffic control measures, including ramps closures, no-entry and contraflow were implemented as modeled and included in the traffic control plans.

Because evacuation for the Waldo Canyon Fire included four modeled neighborhoods, and because the neighborhoods were evacuated incrementally as intermixed combinations of their parts, a precise comparison of model results encompassed to actual experience is not possible. As shown in **Table 2**, however it is possible to make a broad comparison of the individual modeled V/C ratios (Evacuation Times) for neighborhood sections to the implied Evacuation Time (based on duration of incremental evacuation stage) experience during the Waldo Canyon Fire event. For purposes of comparison actual time to evacuate was calculated as the elapsed time between initiation of evacuation of one zone and initiation of evacuation of the next zone in the phased evacuation sequence. Modeled time-to-evacuate was calculated as the modeled one-hour volume to capacity ratio multiplied by 60 minutes per hour. The comparison of estimated actual time-to-evacuate (E-Time) to the modeled time-to-evacuate demonstrated that, though seemingly naïve, the modeled one-hour link volume to capacity ratio proved to be a remarkably accurate metric of actual time-to-evacuate.

TABLE 2 Comparison of Modeled and Actual Times-to-Evacuate.

WUI Area	Location	Notice Type	Date-Time	E-Time[1]	V/C (E-Time)[2]	Count
D4-N6	Garden of the Gods	Notice: Mandatory	6/23 - 1410			Closed
D4-N7	Cedar Heights	Notice: Mandatory	6/23 - 1422			405
Part D1-N4	Zone 2: South Mountain Shadows	Notice: Voluntary	6/23 - 1458			1,875
D9	Manitou Springs	Notice: Mandatory Allowed to return 6/25	6/23 - 1930			4,000
Part D1-N4 Part D1-N2	Zone 3: Oak Valley, Peregrine, North Mountain Shadows	No Notice: Mandatory	6/26 - 1624	1:58	1.54 (1:32) 2.04 (2:02)	8,570
Part D1-N2	Zone 4: Mount Saint Francis Nursing Center	No Notice: Mandatory	6/26 - 1700			103
Part D1-N2	Zone 4: North Rockrimmon	No Notice: Mandatory	6/26 - 1822	2:12	1.71 (1:43)	10,660
Part D1-N2 Part D1-N3	Zone: 5 Southeast Rockrimmon	No Notice: Mandatory	6/26 - 1937		1.60 (1:36) 1.35 (1:21)	
Part D1-N4 Part D1-N3	Zone 6: Popes Valley, Pine Cliff, Woodmen Valley, Pinon Valley	No Notice: Mandatory	6/26 - 1950	1:56	1.54 (1:32) 1.35 (1:21)	6,770
				6:06		**26,103**
Part D4-N5	Zone 8: Kissing Camels	No Notice: Mandatory	6/26 - 2146		1.43 (1:26)	1,620
	Total Evacuated					**33,900**

Notes: 1) Actual implied time-to-evacuate as the time between issuance of the evacuation notice for that evacuation zone and that for the next zone evacuated. 2) Highest modeled link V/C ratio within the included modeled neighborhood section (conversion of hourly V/C ratio to time-to-evacuate).

6 CONCLUSIONS

Major strengths of the Colorado Springs response to the Waldo Canyon Fire that were identified by both the After Action Report [10] and a Wildfire Evacuation Planning Team Debriefing [11] include:

- **Planning**: CSFD, CSPD and CSOEM worked collaboratively with all City Departments (and the PPACG) for several years to develop policies, plans and procedures for a WUI fire. These plans were used in training and tested during emergency response exercises.
- **WUI Fire Evacuation Appendix to the Colorado Springs Emergency Operations Plan** (including traffic models and traffic control plans): The WUI Fire Evacuation Appendix to the Colorado Springs Emergency Operations Plan provides detailed information for the City on wildfire risk in the WUI as well as resources and plans for first responders to use during a WUI evacuation (including traffic control plans).
- **WUI "Up in Smoke" Exercises** (implementing model-based traffic control plans): The WUI Fire Evacuation Appendix to the Colorado Springs Emergency Operations Plan was further tested during the "Up in Smoke" WUI exercise series.

Will the west continue to burn? The incidence of wildfires has continued to grow in Colorado and throughout the mountainous west. This is in due to residential encroachment into vulnerable and relatively inaccessible areas, poor stewardship by outdoors enthusiasts, weather events (lightning), weather trends (dryer summers), mountain pine beetle and other insect infestations, 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 plan for wildfire evacuation.   The methodology and approach that was used to adapt the PPACG travel model for use in the Colorado Springs area for wildfire evacuation could easily be transferred to another region.

The key elements for success in developing the Colorado Spring the wildfire evacuation models and evacuation traffic control plans included consultation with the emergency community and heeding their advice, integrating local knowledge early and often, and understanding the strength and the limits of travel models. Adaptation of the MPO four-step model to assess times-to-evacuate, identify choke points, and develop traffic control plans for identified at-risk neighborhoods provided a cost-effective, "right-size" solution to the community's wildfire evacuation planning needs. The principle of Occam's razor holds that the simplest explanation is usually the correct one. In the case of evacuation road capacity assumptions, this principle proved true. Though seemingly naïve, the one-hour link volume to capacity ratio proved to be a remarkably accurate metric of actual time-to-evacuate.

REFERENCES

1. Lin, Dung-Ying, Naveen, Waller and Bhat. Evacuation Planning Using the Integrated System of Activity-Based Modeling and Dynamic Traffic Assignment. In *Transportation research Record: Journal of the Transportation Research Board, No. 2132*, Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 69-77.

2. Brown, Colby, White, van Syke and Benson. Development of Strategic Hurricane Evacuation-Dynamic Traffic Assignment Model for Houston, Texas, Region. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2137*, Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 46-53.

3. Cheng, Guangxiang, Wilmot and Baker. Dynamic Model for Hurricane Evacuation Planning. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2234*, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 125-134.

4. Ozbay, Kaan, Yazici, Iyer, Li, Erman Ozguven and Carnegie. Use of Regional Transportation Planning Tool for Modeling Emergency Evacuation: Case Study of Northern New Jersey. In *Transportation research Record: Journal of the Transportation Research Board, No. 2312*, Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 89-97.

5. Yuan, Fang and Lee. Improving Evacuation Planning with Sensible Measure of Effectiveness Choices. In *Transportation research Record: Journal of the Transportation Research Board, No. 2137*, Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 54-62.

6. Fang, Lei and Edara. Sensitivity of Evacuation Performance Estimates to Evacuee Route Choice Behavior. Presented at the TRB 2013 Annual Meeting. January 2013.

7. Noh, Hyunsoo, Chiu, Zheng, Hickman and Mirchandani. Approach to Modeling Demand and Supply for a Short-Notice Evacuation. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2091*, Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 91-99.

8. USDA U.S. Drought Monitor, July 3, 2012. Release Date: July 5, 2012. http://econintersect.com/wordpress/wp-content/uploads/2012/07/drought-map-us-03-July-2012.jpg

9. Best, Allen. In the Path of the Inferno. *Planning: The Magazine of the American Planning Association*, Vol. 79, No. 6, pp. 13-17.

10. City of Colorado Springs. *Waldo Canyon Fire, 23 June 2012 to 10 July 2012, Final After Action Report.* Release Date: 3 April 2013. http://www.springsgov.com/units/communications/ColoradoSpringsFinalWaldoAAR_3April2013.pdf

11. Meeting Notes: Wildfire Evacuation Planning Team Debriefing. Casper, Craig, Prather, Waters, Lupa and Paz de Araujo. January 31, 2013.

12. Benson, John. Fourmile Fire – A Look Back, *On Fire*, Boulder Mountain Fire Protection District, February 2011.

13. Burke, Caitlin, Steelman, Nowell, Bayoumi, Velez, Briefel, McCaffrey. Fourmile Canyon Fire Research Findings Summary. North Carolina State University, USFS Northern Research Station.