Morrow & Umatilla Co Transportation Evacuation Plan: Phase I

Overall Assessment of Proposed Alternatives

Oscar Franzese
Barry Shumpert
John Sorensen

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OAK RIDGE NATIONAL LABORATORY

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Report Purpose

The objective of this report is to provide an overall evaluation of the proposed alternatives and improvements to the transportation network as described in the Transportation Evacuation Plan for the region surrounding the Umatilla Chemical Depot (UMCD) in Oregon.

From a public safety perspective, it is fortunate that large-scale vehicular emergency evacuations are very infrequent events. On the other hand, because of this low frequency there is a very small body of "lessons learned" from which to derive any meaningful guidance to assist during this type of traffic operations. Barring real life observations, one has to rely on laboratory experiments (mostly traffic simulation) to assess the impacts and benefits of traffic management strategies and transportation network improvements. For this specific purpose, the Oak Ridge National Laboratory (ORNL) developed the Oak Ridge Evacuation Modeling System (OREMS) for the Federal Emergency Management Agency (FEMA) and the U.S. Army Chemical Stockpile Emergency Preparedness Program (CSEPP). Other software systems exist that can complement the analysis performed using OREMS to evaluate, for example, the performance of signal coordination along an arterial or the operations of an interchange.

The Transportation Evacuation Plan for the UMCD area presents both physical and non-physical alternatives and improvements aimed, hopefully, at reducing the evacuation time and assuring public safety during an emergency evacuation. We believe that all the alternatives that deal with the physical environment have to be modeled, not to determine their absolute and true performance (the models cannot provide that since they are approximations to reality), but to have a sense of how well each proposed alternative behaves as compared to the other ones, and to find unforeseen problems that may arise from their deployment.

ORNL, SE Tech, IEM (Innovative Emergency Management), and more recently the Oregon Department of Transportation (OrDOT) have all conducted analyses to determine the feasibility of a vehicular evacuation for the population surrounding the UMCD. But only the latter has performed an evaluation of different traffic management strategies and alternatives for the proposed Transportation Evacuation Plan.

Due to time constraints, ORNL was not able to conduct any quantitative analysis of the proposed alternatives; we rely on the results reported by OrDOT (although with the caveats noted below), which we believe has performed an excellent modeling task. Instead, we provide in this report a qualitative assessment of the alternatives contained in the Transportation Evacuation Plan, which is based on our experience in assessment of emergency evacuation planning.

Description of the Area

The UMCD is situated in northern Morrow and Umatilla counties in northeastern Oregon (population 10,995, and 70,548, respectively[1]). The facility is located about three miles south of the Columbia River and four miles west of Hermiston, Oregon (pop. 13,154). The Depot occupies a roughly rectangular area of 19,728 acres with no on-post housing. The U.S. Army owns about 17,054 acres; the remaining acreage is covered by restrictive easements. The chemical storage facility site is located in the north central part of the facility, approximately one mile from the northern border of the installation, two miles from the eastern border, and 2.8 miles from the western border.

Figure 1 shows both the Immediate Response Zone (IRZ) and Protective Action Zone (PAZ) associated with the site. The PAZ boundary extends about 21 miles on the east, 18 miles on the west, 16 miles on the south, and about 20 miles due north of the chemical depot. There is also a Maritime Safety Zone (MSZ) covering approximately 46 miles along the Columbia River inside the PAZ.

The installation is encompassed by three major roads: Interstate 84/U. S. Highway 30 on the south, approximately three miles from the chemical storage area, Interstate 82 on the east, and U. S. Highway 730 on the north and west borders of the installation. Other important roads in the area are ORE 207 and U.S. Highway 395.

The nearest residential community to the UMCD is Irrigon (pop. 1,702) located approximately three miles north of the site. Other residential areas include Umatilla (pop. 4,978) to the north of the UMCD and within the IRZ; Hermiston (pop. 13,154) to the east and within the IRZ; Stanfield (pop. 1,979) and Echo (pop. 650) to the southeast and also within the IRZ; Boardman (pop. 2,855) to the west and within the PAZ; and Pendleton (pop. 16,354) to the east of the PAZ boundary. The Transportation Evacuation Plan covers all these cities and rural areas in between, except for the cities of Boardman and Pendleton (the latter is outside the analysis area and would not be evacuated during an emergency).

In the State of Washington, there are two sectors within the IRZ that lie north of the Columbia River in Benton County (pop. 142,475). There are two communities within these sectors that would be evacuated, which includes Paterson (pop. N/A) and Plymouth (pop. N/A). The PAZ in Washington is composed of three sectors, which are mostly rural.

[1] Population information from 2000 Census, U.S. Census Bureau, www.census.gov.

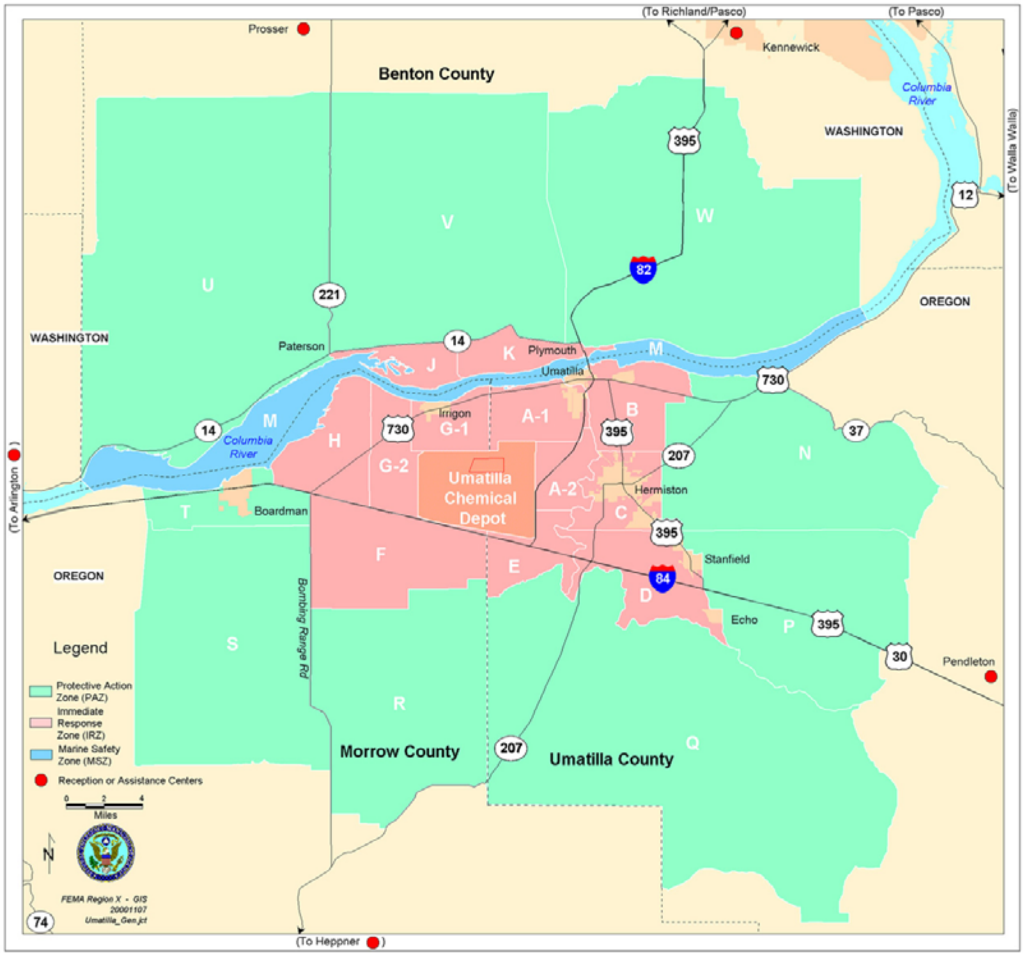

Figure 1. UMCD Emergency Planning Zones and Sectors (Source: CSEPP UMCD Web Site)

SCM Proposed Upgrades and Recommendations

SCM Consultants, Inc. has been contracted to develop the Transportation Evacuation Plan for the UMCD area. The firm finalized Phase I of the study which had as its main objective the determination of the evacuation routes that will allow for a safe and expeditious evacuation of the population in case of an accident or natural disaster at the UMCD that could cause the release of toxic gases to the atmosphere. Because of the Umatilla Community/Morrow County proposed maximum threshold of 2 hrs for the evacuation of 90% of the population at risk, the study also involved the identification of transportation improvements that would help make evacuation a feasible alternative.

SCM also conducted four stakeholder meetings in Hermiston, during the period June-September, 2002. The stakeholders included public safety and public works representatives from all the communities in the affected area, UMCD support, OrDOT, Oregon Department of Environmental Quality, Oregon State Health Department, Oregon Department of Emergency Management, Oregon State Police, FEMA, and the Red Cross.

Two sets of recommendations are included in the SCM Phase I Report. The first deals with physical improvements for the transportation network and necessary hardware for traffic operations during an emergency evacuation. Probable costs, within an order of magnitude, are provided for these improvements. The second identifies other physical improvements to the network, as well as other activities aimed at fostering interagency cooperation, personnel training, and public education. Costs and further analysis of these improvements are scheduled for Phase II.

Parallel to the SCM study, OrDOT conducted an extensive analysis using OREMS to identify potential bottlenecks during an emergency evacuation, as well as assessing the impacts of mitigation strategies and improvements in alleviating congestion. The costs of the majority of these improvements were not provided for this phase of the study.

The following two sub-sections briefly describe the improvements and recommendations provided by SCM and OrDOT.

SCM Recommendations

SCM recommendations are divided into two categories. The first one includes the improvements for which cost has been provided; the second one includes the remaining recommendations.

A.-Improvements with Probable Cost Provided (Phase I)

A.1.-Traffic Signals

Installation and coordination of traffic signals, and deployment of surveillance equipment (video cameras) within the affected area, with centralized control for both systems. The objective is to give more green time to major roads during an emergency evacuation.

In the near term (18 months to 3 years): install the signal linking and video camera monitoring equipment within the cities of Hermiston and Umatilla.

A.2.-Intersection & Roadway Added Capacity

Provide roadway and intersection improvements that increase capacity and flow in Hermiston and Umatilla. Proposed roadway capacity enhancements include upgrading Elm Ave (ORE 207) and Diagonal Road to at least three 12-foot wide lanes and 6-foot paved shoulders on both sides.

In the near term (18 months to 3 years): in Hermiston, upgrade (mostly lane widening, channelization, and drainage) the following intersections and roads: US 395 & Gladys; Elm Ave & Umatilla River Road; ORE 207 & Highland Ave; Hermiston Ave & 11th St (ORE 207); 1st St & Highland Ave; NE 7th St & Main; SE 7th St & Highland Ave; Diagonal Rd & Townsend & Hooker; Diagonal Rd & Punkin Rd; Rodeo and Fair Grounds; Soccer Field (near G. S. H.); Diagonal Road; and Wal-Mart Super Store Streets.

A.3.-Signage and Variable Message Signs

Install signs along evacuation routes; purchase changeable message signs to inform the public of traffic conditions during an emergency evacuation; purchase barricades to channelize traffic during an emergency evacuation.

In the near term (18 months to 3 years): install breakaway sign supports and signs in Hermiston, Irrigon, Umatilla, Stanfield, and Boardman; purchase 15 portable changeable message signs; purchase 75 barriers.

B.-Recommendations with no Probable Cost Provided (Phase II)

B.1.-Bridge Evaluation

Conduct a thorough assessment of the structural adequacy and condition of all bridges that are within the IRZ and PAZ, especially as related to seismic performance.

B.2.-OREMS Model Update

Update the OREMS traffic simulation model to reflect the designated evacuation routes, as well as signal and intersection improvements that have been already completed. Conduct another series of model runs to evaluate the performance during an emergency evacuation of the recommended improvements to roadways and intersections.

B.3.-Emergency Personnel Training

Train emergency traffic management personnel to conduct an emergency evacuation. These personnel should be appropriately equipped with HazMat suits and emergency response vehicles, including wreckers and other suitable equipment capable of moving disabled vehicles off the road as fast as possible.

B.4.-Public Education

Increase public education and awareness. Practice evacuation drills.

B.5.-Reverse Flow on Arterials

Implement reverse-flow traffic operations on selected arterials and two-way roads. Provide the appropriate training and public education.

B.6.-Interagency Cooperation

Foster and develop interagency cooperation for planning and traffic management. Acquire the necessary equipment to make this coordination possible during an emergency evacuation.

B.7.-Special Events and Special Installations

Further evaluate the already available and newly developed options to achieve a timely evacuation of special events and special installations and facilities in the area.

> *B.7.1.-Soccer Event:* Develop a policy regarding the maximum number of children that can participate at any given time and the availability of means of transportation for evacuations. Develop parking facilities in nearby areas to eliminate on-street parking.
>
> *B.7.2.-Fairgrounds:* Evaluate the feasibility of moving the fairgrounds to another location outside of the downtown area (e.g., to a property near the Hermiston Airport).
>
> *B.7.3.-Northwest Livestock Auction Ground:* Improve parking facilities and improve the intersection of Jordan Rd and Livestock Rd. Pave and widen Livestock Rd.

B.8.-Geographic Information Systems (GIS) and Real-time Traffic Information
Develop specific evacuation routes based on GIS mapping and real-time traffic management procedures.

OrDOT ETE Report

OrDOT conducted an extensive revision of the traffic simulation model developed in late 1998 by IEM, which was, at the time of the SCM study, the most up-to-date OREMS model available of the UMCD emergency planning area. The OrDOT technical personnel incorporated logical and necessary corrections to the available model that significantly reduced the evacuation time estimate (ETE), from more than 7 hrs to around 3 hrs. They also developed and analyzed improvements to the transportation network that further reduced this ETE, in some cases well below the proposed maximum threshold of 2 hrs for the evacuation of 90% of the at-risk population.

The alternatives studied by OrDOT are described below. They involve mostly added capacity at different intersections and road segments, as well as the assessment of reverse-flow operations on some arterials and contra-flow operations on the interstate freeways. These improvements were analyzed under both good and bad weather conditions. The results reported below are for good weather conditions; the OrDOT analysis showed that bad weather conditions would add an additional 15-20 minutes to the ETE, depending on the type of weather encountered. No cost estimation was included in the OrDOT reports; however, an estimation of the cost of some of the improvements analyzed by OrDOT was provided in the SCM's report.

C.1.-Do-nothing Alternative.
OrDOT revised the 1998 IEM model and re-assigned various turning movements to comply with the evacuation routes described in the SCM report, as well as adding several evacuation routes not previously defined in the UMCD network, with default geometric data. Also, all the scenarios modeled the evacuation of the entire IRZ and PAZ populations in Oregon.

Using 1990 Census population information, OREMS predicted that 95% of the total population would be safely evacuated in 125 minutes, and 100% in 167 minutes. With the 2000 Census population these figures were 180 and 241 minutes, respectively.

C.2.-Contra-Flow Operations on I-82
In this scenario all eastbound traffic on US 730 coming from Umatilla City is routed north on the I-82 southbound off-ramp (contra-flow operation), while all the westbound traffic on US 730 coming from McNary and Charleston is routed north on the I-82 northbound on-ramp (normal operation). This scenario significantly reduces the congestion on the US 730 mainline and ramps. The ETE is 183 minutes (2000 Census) and 139 minutes when the 1990 Census information is used. The 95% population evacuation is achieved in 135 and 105 minutes, respectively.

C.3.-Improvements on ORE 207
This scenario simulates the SCM recommended improvements for Elm Ave and Diagonal Ave (ORE 207) —i.e., a lane addition to increase the total number of lanes from 2 to 3. It is assumed that two of those three lanes will be used in the outbound direction, while the third lane will be kept open for emergency vehicles accessing the area. This added capacity could also be achieved (at a lower cost) by widening and

improving the shoulder on the outbound side, for temporary use during an emergency evacuation.

The predicted ETE for this scenario is 183 minutes (139 minutes) when using the 2000 (1990) Census population. To evacuate 95% of the population, OREMS predicted 135 and 105 minutes, when using the 2000 and 1990 Census data, respectively.

C.4.-Reverse-lane Strategy on US 395S

For this scenario, the multi-lanes on US 395 are reassigned such that this arterial operates with three outbound lanes and one inbound lane for emergency vehicles. OREMS output showed very little difference between this scenario and scenarios C.2 and C.3, indicating that the congestion problem is not directly related to the traffic flow on US 395, but to the bottleneck developed at the Stanfield interchange, where one lane is dropped producing a capacity loss on US 395 just before the I-84 eastbound on-ramp access. (Note: the improvement analyzed under this scenario was not included in the SCM's report.)

C.5.-Contra-Flow Operations on I-84

This scenario attempts to mitigate the bottleneck developed at the Stanfield Interchange (see C.4. above), allowing a contra-flow operation on the westbound lanes on I-84, such that half the traffic heading south on US 395 is routed east on the westbound interstate lanes and the other half crosses the overpass and is routed east on the eastbound lanes (normal operation) of I-84. This scenario also simulates a contra-flow operation for I-84 westbound, from the Oregon Trail Interchange west to a point outside the PAZ boundary, as well as a unidirectional flow on US 730, between the junctions of ORE 207 and ORE 37.

Using 1990 Census population information, OREMS predicted that 95% of the total population would be safely evacuated in 85 minutes, and 100% in 139 minutes. With the 2000 Census population these figures were 110 and 140 minutes, respectively. (Note: these improvements were not included in the SCM's report.)

C.6.-Double-lane On-ramp at the I-82 Umatilla Interchange

For this scenario, an additional dedicated lane is added to the on-ramp to increase the capacity for the traffic flow moving from US 730 onto I-82 northbound. The eastbound traffic on US 730 (from Umatilla City) is channelized to the left northbound on-ramp lane, while the westbound traffic (from McNary and Charleston) turns right onto the other on-ramp lane.

The simulation results show that this scenario performs similarly to scenario C.2., indicating that either improvement option is a worthwhile alternative from the standpoint of the ETE.

C.7.-Double-lane On-ramp at the I-84 Stanfield Interchange

In this scenario the two-lane, two-way overpass on US 395 that crosses I-84 is converted to accommodate a one-way multilane flow (lane reversal for the northbound lane on the overpass), and an extra lane is added to the eastbound on-ramp.

The results of this scenario did not show any improvement in the ETE or the evacuation time for the 95% of the total population. The reason for this is that the interstate already carries a substantial number of vehicles when the traffic from US 395 joins the eastbound traffic on I-84.

C.8.-Contra-flow Operation on the Entire I-84
This scenario differs from C.5. in that the contra-flow operation starts at the Ordinance Interchange. Both ways of the interstate operate as eastbound freeway segments to east of the interchange, while to the west of the Ordinance Interchange both ways of the interstate operate as westbound freeway segments. In this case OREMS predicts that it will take 105 minutes to evacuate 95% of the population, and 140 minutes to evacuate the entire IRZ and PAZ.

Assessment of Alternatives

Background
Similarly to other traffic planning and operational problems, vehicular emergency evacuation combines two basic components: the demand —represented by the population that needs to be evacuated— and the available capacity —represented by the topology and geometry of the transportation network, and the type of traffic control at each intersection. The objective of an emergency evacuation is to accommodate the demand to the available capacity of the transportation network such that the time to clear the area at risk is minimized. When assessing alternatives that could potentially help during an emergency evacuation, it is necessary to understand what influences the demand and the capacity, and how they interact during such an event.

The traffic demand is described by the geographical location of the population at the time the evacuation starts, the vehicle occupancy rate (VOR) —i.e., the number of person per vehicle—, and the departing time of the population. The background demand is also important, but it is possible to assume that only the traffic that is already on the network needs to be considered, while trips that have not entered the network from outside the PAZ at the start of the evacuation can be ignored. The assumption is that at the start of the evacuation, the PAZ will be cordoned and no traffic (except for emergency and law-enforcement vehicles) will be allowed to enter the area.

The three variables that characterize the demand (location, VOR, and departing time) play a very important role in the determination of the ETE. The way the congestion develops on the network is intimately related to the geographical location and distribution of the population. This geographical distribution and location varies with the time of the day, and day of the week, and therefore the congestion patterns that would develop on the network will be different for different days and times.

The VOR is a function of many variables, but time of day is perhaps the most important. During a working day one would expect the VOR to be lower (in general, we travel alone to our places of work) than during the night (a family at home will probably use one car to evacuate). Therefore, if an evacuation were to take place during the daytime more vehicles would be on the road. This higher demand in turn implies a higher level of congestion on the network, and most likely an increase in the ETE.

The departing time is represented by the traffic loading curves (see Rogers and Sharp, 1990). These cumulative curves indicate the proportion of the total at risk population that will attempt to load onto the transportation network by a specific time after the official call for evacuation. These curves vary by location. For example, the network within the IRZ is loaded at a much more rapid rate (90 minutes to mobilize 100% of the IRZ population) than the network within the PAZ (100% of the population is mobilized in 135 minutes). The evacuation time (100% of the population evacuated) can never be less than the time at which the last person leaves his/her home/place of work plus the time it takes to cross the PAZ boundary and reach the precautionary zone. This is also true for any other percentage of the population that one wants to consider.

The network capacity is described by the topology, or connectivity, of the network, the geometry of the streets and segments of freeways (e.g.; number of through lanes available to traffic, number of turning lanes, grade, lateral obstructions, acceleration and deceleration lanes, etc.), the type of traffic control at intersections (i.e.; signs or traffic signals), and the composition of the traffic (i.e.; percentage of trucks, percentage of other heavy vehicles).

Under regular (i.e.; day-to-day) traffic operations, congestion is classified as *recurring* when it is the result of a daily (e.g.; afternoon peak period) or periodic event (e.g.; a football game at the local stadium), or *nonrecurring* when it occurs only a certain percentage of the time at well-known problem locations (e.g.; double-parked trucks for pick up and delivery activities) or it occurs rarely at a specific site, and is due to a truly unusual event (e.g.; an accident on a street that normally has no problems). All these events result in either an increase in the demand or a reduction in the capacity, or both.

Congestion, therefore, arises when the demand exceeds the available capacity in the network. During an emergency evacuation the demand is far greater than during regular traffic operations and unless there is excess capacity in the transportation network, congestion will develop and delays will occur, ultimately increasing the ETE. Therefore, any physical improvement to the network that tries to decrease the ETE should focus on making available all the underutilized capacity of that network or adding extra capacity (of course, always taking safety under consideration). Alternatives that diminish the capacity of the network in some way will have little value for an emergency evacuation operation.

Evaluation of Proposed Improvements and Options

In this sub-section we present a qualitative evaluation of the recommend alternatives that form part of the UMCD Transportation Evacuation Plan. A description of these improvements, options, and courses of action can be found in the previous section (see *SCM Proposed Upgrades and Recommendations* on page 3 of this report).

I.A.1.-Traffic Signals

A traffic signal is a device that trades off delays for safety (although not strictly true in all cases). They reduce right-angle accidents and provide adequate time for pedestrians and vehicles to cross the intersection, but at the expense of increasing rear-end accidents and creating overall delay.

In order to accomplish their objectives, traffic signals have to stop the traffic flow on the main arterial to provide the right of way to the minor cross street at certain intervals of time. These intervals cannot be very large (they usually do not exceed 2 minutes), since otherwise the drivers waiting on the minor street will interpret the signal as malfunctioning and will attempt to cross the intersection, greatly increasing the risk of crashes.

As a vehicle approaches an intersection displaying a red signal the driver decelerates and stops either at the stop line or at the end of a queue. When the signal turns green the driver accelerates until the vehicle reaches its desired or maximum possible speed. The discharge process of the vehicles in the queue is controlled by the reaction times and desired acceleration rates of drivers, as well as the acceleration rates of the vehicles ahead. At the beginning of the green interval, the discharge rate at the stop lane starts to increase (interval Ls in Figure 2). After some time, the queuing vehicles reach a constant speed at the stop line and the discharge rate for the intersection approach reaches its maximum value, called the saturation flow rate (s). As the green interval ends the approaching drivers make a decision whether to continue across the stop line or stop. The departure rate starts to decrease and reaches zero as the red phase begins. Before the cross street is given the right of way an interval of about 1.5 seconds, during which all the approaches to the intersection are shown a red light, follows.

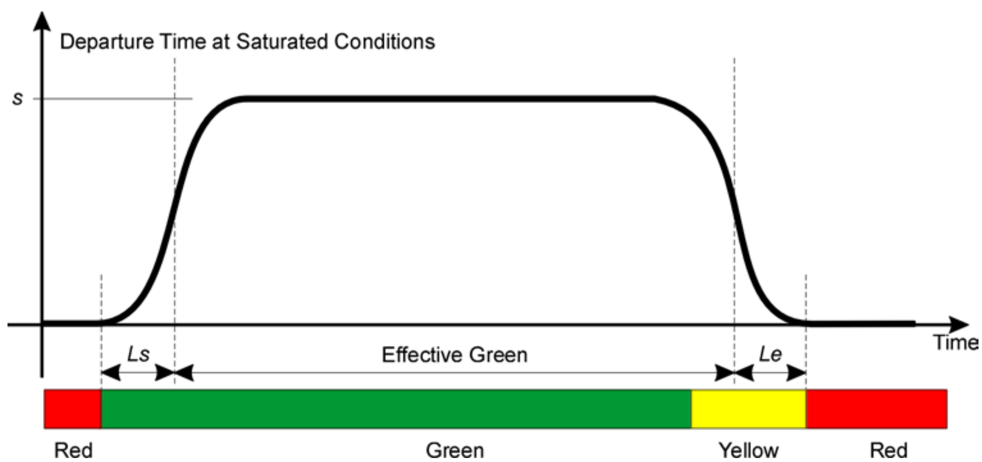

Figure 2. Departure Rates and Effective Green

This operation of an intersection controlled by a traffic signal introduces two types of delay: the start-up lost time —the time it takes to reach a constant speed after the approach has been shown a green—, usually 2.1 seconds/phase; and the change-interval lost time —generally a portion of the yellow plus all-red intervals— usually 1.50 seconds/phase. For instance, if a two-phase intersection has (2.10 + 1.50) = 3.60 sec lost time per phase and a cycle[2] length of 60 sec, it follows that the lost time per cycle is 7.2 sec, and that there will be 60 cycles in 1 hr. Then, the total lost time per

[2] A cycle is defined as one complete sequence of signal indications; a phase is the part of the cycle that is allocated to any combination of traffic movements receiving the right of way simultaneously during one or more intervals.

hour is 432 seconds (or more than 12% of an hour) during which no traffic is moving through the intersection.

Traffic signals generate other types of delay. Figure 3 shows a simplified model of queue formation for one approach at a signalized intersection operating below capacity. Vehicles arrive at the intersection at a constant rate of arrival indicated by the thick line on that figure. During the time the approach is shown a red phase, vehicles accumulate (a queue forms) on that approach, and when the green phase for the approach starts, the vehicles leave the intersection at a rate *s* (as discussed above) and the queue is dissipated by the end of the green phase. It can be shown that the length of the queue at any given time *t* is given by the segment *q(t)*, and that the area enclosed by the triangles in Figure 3 is the uniform delay (usually measured in veh-min or veh-hrs) experienced by the vehicles in the queue. A similar diagram (perhaps with different arrival and departure rates) can be constructed for the cross street approach.

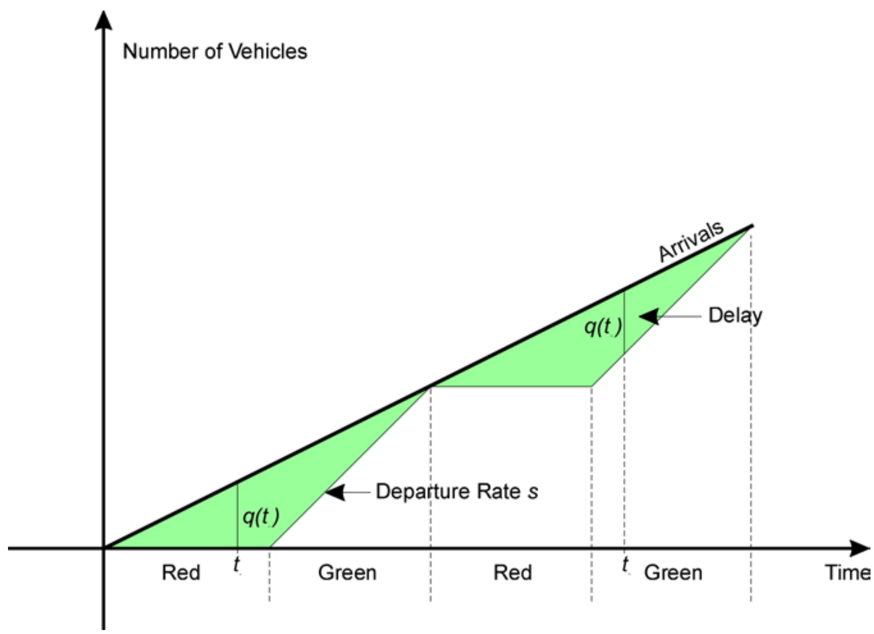

Figure 3. Cumulative Demand and Capacity for a Signalized Intersection

For oversaturated conditions (i.e., arrival rate larger than capacity), a condition very likely to develop in an emergency evacuation since the demand would increase considerably during such an event, Figure 3 is transformed to Figure 4.

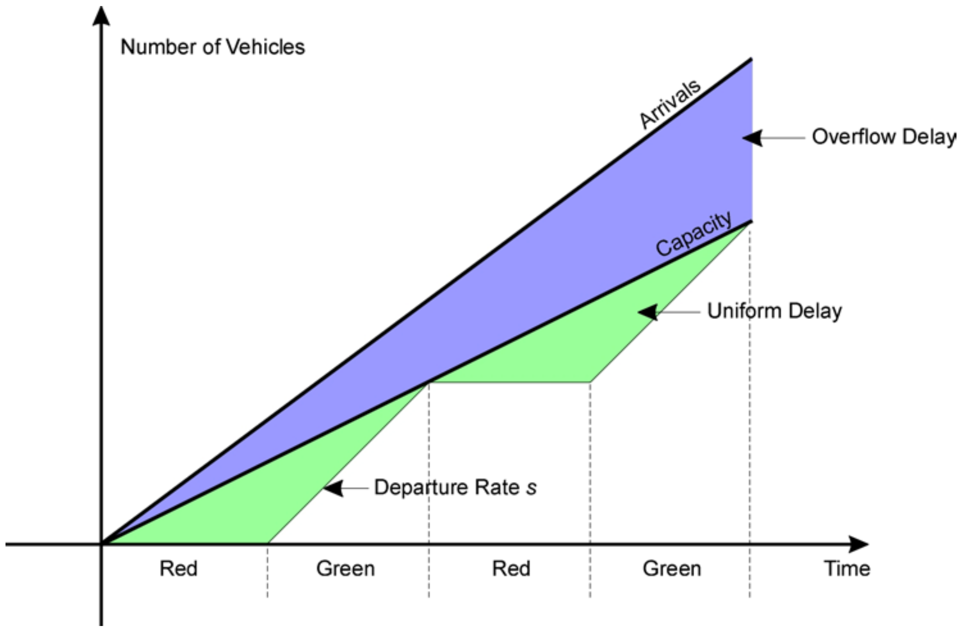

Figure 4. Cumulative Demand and Capacity for a Signalized Intersection under Oversaturated Conditions

Under these conditions the system (intersection) is in a non-equilibrium state, and the queue length increases cycle by cycle. The total delay has two components: uniform delay (green triangles between capacity and departure curves) and overflow delay (blue area between arrival and capacity curves). This overflow delay can be significant. Figure 5 shows the average delay per vehicle for different degrees of saturation (arrival rate over departing rate) and for oversaturation periods of 15 and 60 minutes (Neuburger 1971, Hurdle 1984). In an emergency evacuation it is very likely that the degree of saturation at some intersections would be high and that the oversaturation period would be long (more than 45 minutes based on the mobilization curves), resulting in very high average overflow delays. Therefore, traffic signals operating under these conditions are very likely to have a negative effect during an evacuation, by greatly reducing the throughput of the intersections that they control.

The above discussion centered around an isolated signalized intersection, which is the most benign situation. For signalized arterials, as congestion increases and intersections become saturated, queues begin to disrupt movements at upstream junctions. If oversaturation persists for any length of time (almost certain during an emergency evacuation) then the standard traffic signal coordination strategies have been found to exacerbate the problems caused by the "spillback" of queues into upstream intersections.

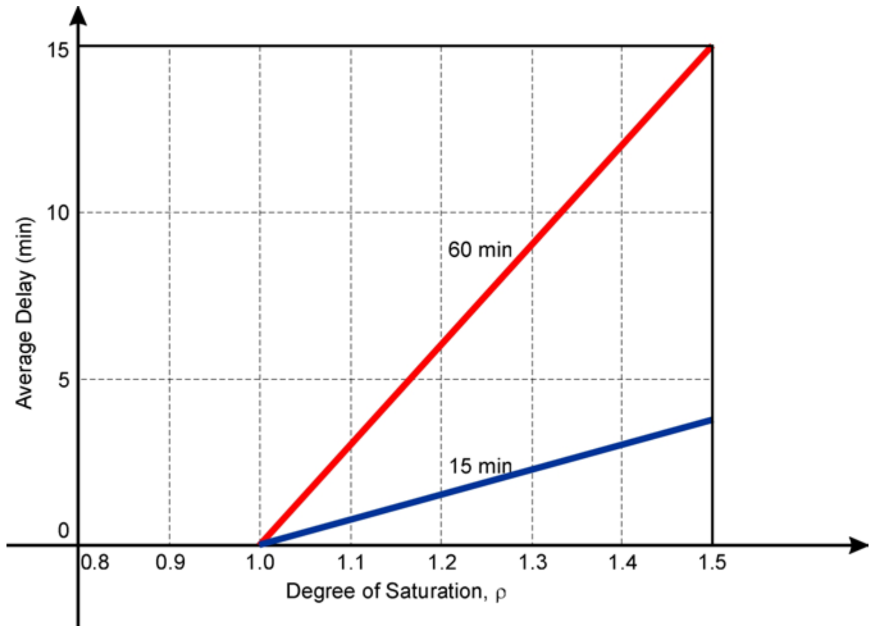

Figure 5. Average Overflow Delay for Oversaturation Periods 15 and 60 Minutes

Some signal coordination strategies for minimizing the impacts of disruptive queues have been devised. However, these strategies try to achieve "fairness" in the way the delays are distributed. During an emergency evacuation, that is not the main objective; the goal is to evacuate the population at risk in the minimum time. And this may imply that some drivers will have to experience significantly higher delays than other drivers.

Manual over-ride of the signals by traffic police at intersections is one solution used in several of the world's most congested cities, and many times here in the U. S. during major sport events, to manage traffic during periods of very high demand (see Mahalel et al, 1991). This is perhaps the best solution to handle the key intersections in the area we are analyzing.

Our suggestion is that a study be performed using a detailed traffic simulation model[3] (CORSIM, for example) to compare the performance of traffic coordination strategies against strategies that rely on manual operation of the traffic signals. The outputs generated by OREMS (e.g., demand as a function of time on the arterials where traffic signals and coordination are recommended in the SCM's study) would serve as inputs for the new model, together with the coordination strategies to be studied. This should be compared to a situation in which the traffic police give the green time to the main arterial for extended periods of time while flows on that arterial are high. Only the presence of the authority at the intersection will make it possible to assign these long green intervals; if this is done through a centralized computer, it is very likely that the signal will be disobeyed with increasing risk of

[3] While OREMS allows for modeling the evacuation of large geographic areas, it is not suitable for analyzing traffic strategies at a local level, such as traffic signal coordination.

crashes, and subsequent delays —a situation that must be avoided as much as possible during an emergency evacuation.

I.A.2.-Intersection & Roadway Added Capacity

As we have seen previously, congestion arises when the system is subjected to demands that exceed the available capacity. One of the remedies, of course is to provide more capacity. This type of improvements can be divided into two groups. The first one includes those alternatives aimed at adding new capacity to the transportation network (call it added capacity strategies, or ACSs), while the second tries to make use of excess capacity that is not being utilized or is underutilized (call it use of underutilized capacity, or UUC).

The SCM's and OrDOT's Reports propose both type of improvements. Under the ACSs, the SCM proposes to upgrade in the near term several intersections and roads in the Hermiston area. Some of these intersections were identified as critical intersections by OrDOT in a 2002 Report, while others were identified by SCM. ORNL did not receive any specific information regarding the process by which these intersections were selected, but the SCM's Report indicates that it involved both modeling (performed by OrDOT) for the selection of some of these intersections, and discussions with local authorities and local traffic managers for the selection of the remaining identified junctions.

The involvement in the selection process of people who know the network coupled with modeling activities to quantify the benefits of the proposed upgrades is the right approach. However, from reading the SCM's Report it is not clear that this process was used to select all the upgrades. As far as it is possible to determine, modeling of the impacts of some of these improvements under specific evacuation conditions (e.g., nighttime evacuation and no intersection in the area operating under traffic signals) was performed and showed that the improvements were worthwhile. Those included widening of ORE 207 north out of Hermiston to the junctions with US 395 and widening of US 395 between the junctions of ORE 207 and ORE 37. It is our recommendation that all other proposed improvements be modeled to determine their impacts during an emergency evacuation in the same way as those above, expanding the scenarios to cover also daytime evacuations.

Other improvements under the ACS category were analyzed by OrDOT with some of them showing great potential in alleviating the congestion during an emergency evacuation, and therefore reducing the ETE. Those included a double-lane on-ramp at the I-82 Umatilla Interchange and a similar upgrade at the Stanfield Interchange. The costs of these improvements need to be calculated to have a complete picture of their effectiveness.

OrDOT analyzed several improvements that fall under the UUC category. They included a reverse-lane strategy on US 395S, such that this arterial operates with three outbound lanes and one inbound lane for emergency vehicles; contra-flow operations on I-82; partial and total contra-flow operations on I-84; and new evacuation routes. All these improvements make available to outflow traffic underutilized capacity (i.e.; inbound lanes and new roads) in the network, with some of them producing impressive results. However, it is necessary to analyze the logistics and risks associated with these strategies very closely, specially the contra/reverse flow operations. For one thing, while the model points out the gains associated with the extra capacity made available by these alternatives, it does not give any indication of possible drawbacks.

Contra-flow operations demand extensive logistics and training, not only on the part of the authorities, but also from the public. When there is only a maximum of two hours to evacuate 90% of the population, there is no room for any mistakes. Just one crash on the contra-flow lanes due to somebody who entered the freeway the normal way could produce lane closures that would create severe congestion and delays which could wipe out any gains derived from the added capacity. The model is unable to produce this type of outcome, instead, it is the responsibility of the modeler to analyze and evaluate this type of situation.

It is our recommendation that contra-flow operations be used as the last resource. On arterials, one inbound lane should always be open not only to handle the emergency and law enforcement vehicles, but also to act as a fuse in case somebody mistakenly enters the arterial the normal way. On the freeways, this type of operations should be analyzed very carefully to determine if there is enough time to clear the traffic traveling on the contra-flow lanes, deploy the necessary barriers and signalization to route the traffic from the arterials to the freeway, and make sure that there is no way that somebody may enter the freeway the normal way.

Designating new evacuation routes also adds extra capacity and does this with minimum risks (as compared with contra-flow operation), specially if the number of locations at which they intersect is kept to a minimum. Their beneficial impacts in an emergency evacuation can be easily analyzed using OREMS (e.g., OrDOT included in their analysis some of the newly defined evacuation routes in the UMCD area). On the other hand, they increase the operations costs (more miles of roads need to be under surveillance) and also may require improvement costs (signage, and perhaps lane improvements).

The determination of the evacuation routes should also be a process that involves the local authorities and modelers, so that the greatest benefits are achieved. For example, the OrDOT analysis showed that a double-lane on-ramp at the I-84 Stanfield Interchange did not make substantial improvement to the ETE because the interstate was already carrying substantial traffic, while a contra-flow operation that redirected half of the traffic on US 395S, did. One alternative that may offer the same benefits, and does not require a contra-flow operation on I-84, is to designate the continuation of US 395S (i.e., Thielson Rd and further on Rieth Rd) as an evacuation route south of the Stanfield Interchange and allow half of the traffic to continue south and half to enter eastbound I-84. Another alternative would be to divert some of the traffic on US 395S to Feedville Rd (and further on Despain Gulch Rd) which exits 395 midway between Hermiston and Stanfield and connects to Highway 37 just north of Pendleton. While the benefits of these alternatives can be analyzed with OREMS, their feasibility needs to be decided in conjunction with the local authorities and stakeholders.

I.A.3.-Signage and Variable Message Signs

Because of the very short time available for an emergency evacuation, providing prompt information to the public plays a key role. Installation of signs along evacuation routes is a necessity to allow for an orderly evacuation. Changeable message signs (CMS) can also be very useful in keeping the public informed of traffic conditions during an emergency evacuation. Portable CMSs are very flexible, but the question is whether there is enough time (it has been proposed that 90% of the population should be evacuated in 2 hrs) to deploy them where they are needed. This needs to be evaluated.

Barricades to channelize traffic during an emergency evacuation are indispensable. Again, because of the short time available, the logistics of their deployment needs to be carefully studied and planned.

I.B.1.-Bridge Evaluation

Having such a short time to evacuate the population at risk, any potential loss of capacity in the network should be minimized. Bridges and overpasses are key components of the transportation network because alternative routes that bypass these structures may be very long, or even unavailable. Assessment of the structural adequacy and condition of all bridges and overpasses that are within the IRZ and PAZ should be conducted. The impacts of losing one or more of these structures during an emergency evacuation should also be modeled and analyzed to determine if evacuation is still a feasible alternative under such conditions.

I.B.2.-OREMS Model Update

OrDOT conducted an extensive revision of the traffic simulation model developed in late 1998 by IEM. The OrDOT technical personnel incorporated logical and necessary corrections to the available model. However, in some cases available information was eliminated.

For example, Figure 6 shows the definition in OREMS of a traffic signal at the intersection of Elm Ave and US 395 as coded by IEM. The top left inset shows the approaches to this intersection (north and south bound approaches on US 395 and eastbound approach on Elm Ave) while the arrows on the boxes numbered 1 to 6 in the middle of the picture indicate which approach has the right of way at the intersection at any given time. Evidently there is a conflict in phase 2 (box 2) between the US 395 southbound approach and the eastbound approach on Elm Ave (circled in red); both approaches are given the right of way at the same time. While if this situation existed in real life it would certainly cause crashes at this intersection, the model is unable to predict these outcomes (and in fact the intersection may behave better than if stop or yield signs were specified)[4]. OrDOT chose to eliminate the control at this intersection (and at all the others with traffic signals) and replace them with signs. This action produces better results (we have seen that in reality traffic signals degrade the throughput of an intersection, although they may be necessary for safety reasons). It is our recommendation that at least in the *Do-nothing Alternative*, the network be modeled as it is (i.e.; with all the existing traffic signal controllers specified).

[4] OREMS will give a warning if this type of situation arises, but it will accept it if the user insists.

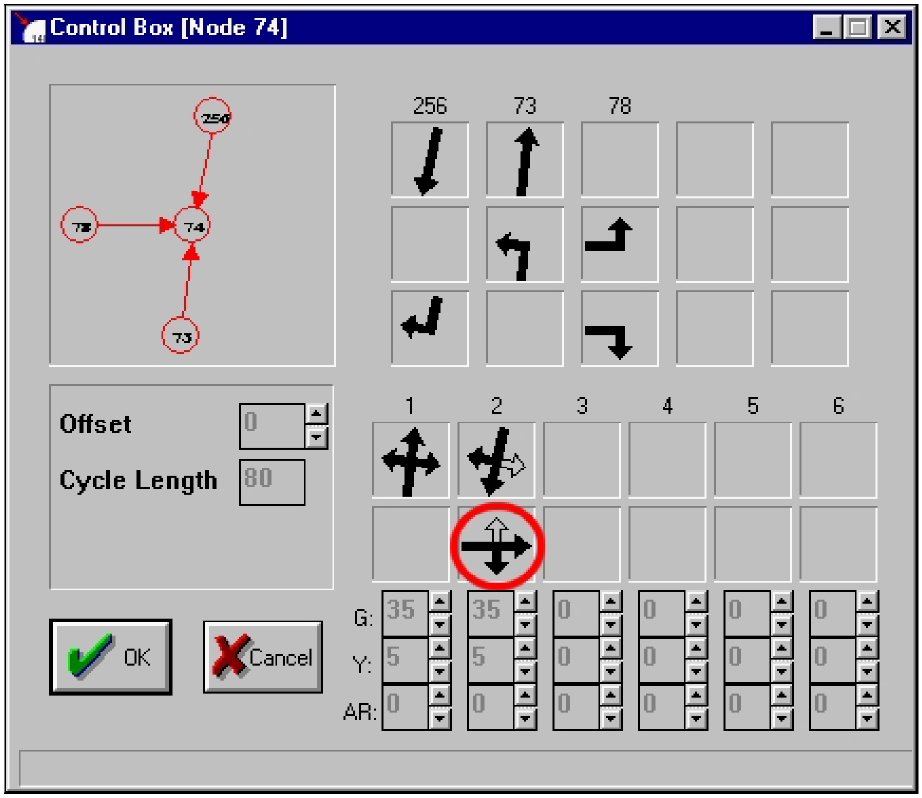

Figure 6. Intersection of Elm Ave and US 395

The models should also be revised to include all the improvements that have already been completed and, as suggested by OrDOT, some of the available roads in the network not included in the existing model, should be incorporated. Daytime evacuation scenarios should also be developed. In this case, a careful analysis of the VOR should be conducted to produce correct estimates of the expected demand during a daytime evacuation.

We also suggest that as a first approach the traffic assignment model included in OREMS be run to determine the optimal evacuation routes and to eliminate situations like the one illustrated in Figure 7. That figure shows the operations at the intersections of Butter Creek Rd & Elm Ave (node 77 inside the red circle) and at the intersection of Butter Creek Rd & Hartley Ave (node 252 inside the red circle), in which traffic on Elm Ave was routed south on Butter Creek Rd (left turn) and traffic on Hartley Ave was routed north on Butter Creek Rd (another left turn). It would have been better to direct the traffic on Elm Ave to the north and the traffic on Hartley Ave to the south (right turns are "less costly" than left turns and this will also eliminate conflicts at the intersection of Butter Creek Rd & Hartley Ave between the southbound traffic on Butter Creek and the eastbound traffic on Hartley Ave).

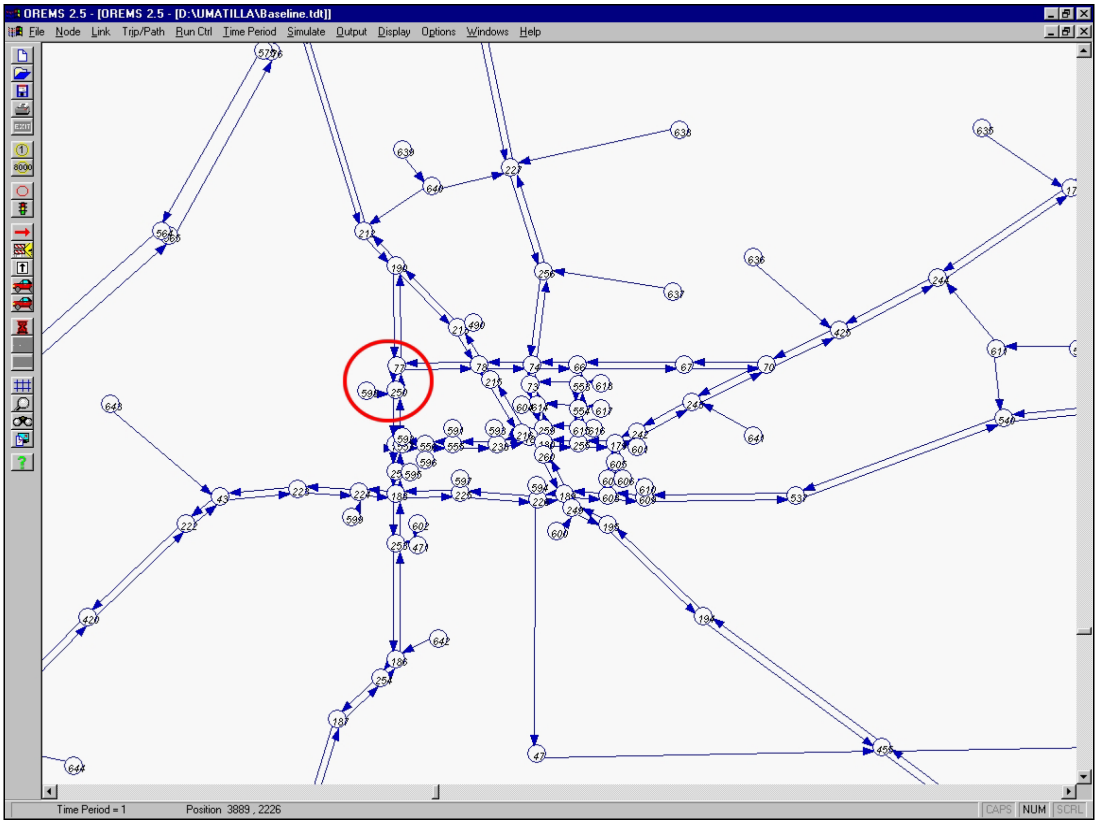

Figure 7. Intersections of Butter Creek Rd & Elm Ave (Node 77 inside the Red Circle) and Butter Creek Rd & Hartley Ave (Node 252 inside the Red Circle)

OrDOT identified some problems with the Evacuation SIMuation (ESIM) model provided with the currently available version of OREMS and they correctly and skillfully made the necessary model adjustments to be as close as possible to reality. ORNL is working on an upgrade of ESIM that has eliminated most of those problems. Particularly, it will be possible to model the interstate system with a freeway simulation model that would allow more control in defining the capacity of the lanes. The present version of the UMCD network should be revised to make use of these capabilities.

I.B.3.-Emergency Personnel Training and I.B.6.-Interagency Cooperation

These, together with public education, are key activities that need to be pursued to the full extent to assure a safe and orderly evacuation. In June 2000, less than one year after Hurricane Floyd, Federal Highway Administration (FHWA) organized a workshop to analyze the lessons learned from one of the largest emergency evacuations in US history. The stakeholders that participated in that workshop included Emergency Management agencies from several affected states, state DOTs, public safety agencies, FEMA, FHWA, state highway patrol, planning agencies, ORNL, and other institutions and agencies. The main conclusions were that the most pressing issues for a successful evacuation were interagency coordination, training, and communications.

We strongly support fostering and developing interagency cooperation for planning and traffic management, and the necessary training of the personnel that will be involved in an emergency evacuation.

I.B.4.-Public Education

Education of the population must be one of the highest priorities. An emergency evacuation can only proceed in an orderly manner if the population understands what is expected from them and what is that they can expect from such event.

It is very important to emphasize that an emergency evacuation is not a regular traffic operation. Although the vehicles the evacuating population will be driving will be the same they drive every day and the network on which these vehicles are driven will be almost the same, the objectives that the traffic network managers are trying to achieve are substantially different. For example, the population must understand that some of them will be experiencing unusual delays (much larger than in a normal day with heavy congestion), and need to know that while this would be a nuisance during a normal day, in an emergency evacuation it may be a necessity in order to assure the least evacuation time of the entire area at risk.

The critical importance of avoiding crashes should be emphasized to the public. During an emergency evacuation the network capacity will be stretched to the limit and anything that causes a loss of capacity (even a small accident) would produce very large delays (see Chin et al., 2001), with increasing ETE.

We have seen that the vehicle occupancy rate may have a great influence on the ETE since the demand is directly related to this variable. During a daytime evacuation, it would be very desirable to increase the VOR as much as possible[5]. One way of achieving this is carpooling, so people working at the same place evacuate with several colleagues using just one car instead of 2 or 3. This would require not only cooperation from the population, but also establishing the necessary logistics so the people who left their car behind can be reunited with their families and later on be able to re-enter the area. The benefits of carpooling can be easily analyzed with OREMS.

Also, through the use of OREMS, it will be easy to evaluate whether any efforts should be made in trying to change the mobilization curves through education (these curves describe a behavioral response of the population to the order to evacuate). Reducing the departure time may help reduce the ETE, but only in cases where the network is moderately congested or not congested. For a congested network, a reduction in the departure time may not reduce the ETE, and in some cases it may even increase it.

I.B.5.-Reverse Flow on Arterials

This type of improvement was discussed in *I.A.2* above.

I.B.7.-Special Events and Special Installations

Studies must be pursued to analyze the impacts of proposed alternatives and policies regarding soccer events, and the impacts or relocating the Fairground and the

[5] As explained before, during a working day one would expect the VOR to be lower (in general, we travel alone to our places of work) than during the night (a family at home will probably use one car to evacuate).

Northwest Livestock Auction ground. OREMS can be used to analyze the impacts in an emergency evacuation of the proposed alternatives.

I.B.8.-Geographic Information Systems (GIS) and Real-time Traffic Information
This is a worthwhile effort, but one that perhaps can only be achieved in the long term. We recommend an analysis of the feasibility of deploying a real-time traffic management system, to determine the costs of such a system and its benefits during an emergency evacuation.

Table 1 below summarizes the above discussion. The second column contains an evaluation of the level of potential benefits that the proposed alternatives, improvements, and courses of action shown in the first column could have on an emergency evacuation.

Table 1. Potential Impacts of Proposed Alternatives and Actions on Emergency Evacuation

Alternative/Action	Potential Impacts on Emergency Evacuation
I.A.1.-Traffic Signals	Potentially negative effects. Traffic control strategies need to be evaluated to determine effect on ETE.
I.A.2.-Intersection & Road Added Capacity	Potentially positive effects.
Added Cap.	In general, this type of alternative decreases ETE, if used where needed. All alternatives need to be evaluated under different scenarios (nighttime and daytime evacuation).
Use of Existing Cap.	Contra-flow strategies need to be carefully studied and planned (could have negative effects). Designation of additional evacuation routes could be beneficial.
I.A.3.-Signage and Variable Message Signs	
Signs	Positive effect.
Portable VMS	Positive effect; however logistics of deployment and time needed to deploy need to be studied and planned.
I.B.1.-Bridge Evaluation	Positive effect if can assure bridge integrity during an evacuation.
I.B.2.-OREMS Model Update	This action is needed to make possible the evaluation of proposed alternatives under all possible evacuation scenarios.
I.B.3.-Emergency Personnel Training	Positive effect.
I.B.4.-Public Education	Positive effect. This action is necessary in order to have an orderly evacuation.
I.B.5.-Reverse Flow on Arterials	Potentially positive effects. At least one inbound lane should remain open to inbound traffic.
I.B.6.-Interagency Cooperation	Positive effect. Interagency coordination has been identified as top priority in emergency evacuations.
I.B.7.-Special Events and Special Installations	Potentially positive effects. Need to be studied.
I.B.8.-GIS and Real-time Traffic Information	Potentially positive effects.

It should be emphasized that this is just a qualitative evaluation. A thorough evaluation and ranking of the proposed alternatives, improvements, and courses of action would require an assessment and quantification of all the benefits and costs that each alternative would bring. While the costs of any of them are somehow easy to quantify, the beneficial impacts of some of these alternatives —e.g.; public education, interagency coordination, training— are not. For those cases it is necessary to resort to indirect approaches (e.g., similar cases in other fields, expert opinion) to assess these benefits; for the others, models such as OREMS offer a way of determining the some of the impacts of the proposed alternatives on an emergency evacuation.

Other Evacuation Planning Issues

A successful evacuation is one that results in all people in the hazard area getting to safety before they receive a toxic chemical exposure. Accomplishing this goal depends only partially on the adequacy of the transportation network; it is also necessary to have plans and procedures that ensure quick and effective decision making and implementation.

To guide their response to a possible release of chemical warfare agent, the communities surrounding UMCD have developed the Integrated CSEPP Incident Response Action Plan for the Greater Umatilla Community and the Affected Municipal Jurisdictions (Revision 1, December 2001). This Incident Response Action Plan emphasizes shelter-in-place as the default protective action in the event of a Community Level Emergency. If a chemical agent release affects or is expected to affect off-post areas, shelter-in-place will be immediately recommended for the entire IRZ and PAZ. According to the plan, the Incident Commander (IC) in charge of the off-post response will then review initial modeling results, consult with the UMCD commander, and coordinate with appropriate elected and administrative officials. As a result of these actions, the Incident Commander may decide to recommend the evacuation of some or all areas. Additional guidance on evacuation is scheduled to be included in a future annex to the plan.

Recommendations for elements to be included in evacuation plans are listed in Appendix E of the CSEPP Planning Guidance, specifically in Guideline E.1.b. These recommendations include

- preparation of clear maps and written descriptions of evacuation areas and evacuation routes,
- identification of individuals authorized to determine when evacuation is needed and to issue an evacuation recommendation,
- development of procedures and assignment of personnel and resources for effecting evacuation traffic control, including extraordinary measures (e.g., use of shoulders or use of reverse-flow lanes),
- description of plans for timing the evacuation of different areas if a multi-stage evacuation is proposed,

- development of plans and procedures and assignment of resources and personnel for evacuating people without private vehicles or with mobility impairments, and

- methods to be used to handle vehicles that impede the evacuation because of mechanical problems.

Morrow and Umatilla counties appear to be addressing most of these recommendations as part of the process of evaluating the highway routes and traffic configurations that will result in the quickest evacuation of the risk area. Regarding the third bullet above, we recommend that all the alternatives and traffic management strategies be modeled under different scenarios (daytime evacuation, nighttime evacuation, good weather conditions, bad weather conditions, network capacity restrictions such as the collapse of a bridge, and other scenarios) to have a sense of how well each proposed alternative behaves as compared to the other ones, and to find unforeseen problems that may arise from their deployment. We recommend that all of these issues be incorporated into the evacuation annex of the Incident Response Action Plan.

It is further recommended that emergency planners give additional attention to the process by which an evacuation decision would be made and an evacuation recommendation would be issued to the public. The process described in the Incident Response Action Plan calls for the IC to engage in analysis and consultation after a chemical agent release to decide if evacuation is warranted. It seems questionable that these actions could be completed quickly enough (particularly considering the other demands on the IC's time during an emergency) to allow a successful evacuation (i.e., one that is completed before evacuees are exposed to toxic doses of chemical agent).

We recommend that the evacuation decision be studied during the preparedness phase with the goal of identifying the accident/weather scenarios which would lead to an evacuation recommendation. The key features of these scenarios could then be incorporated into a decision process that would facilitate quick decision making during an emergency. At the time of the release, the IC would, of course, be able to consider other factors that might modify the decision. However, the existence of a thought-out decision process would almost certainly result in quicker and more appropriate decisions regarding evacuation. It is recommended that all alternative ICs, the UMCD commander, and all relevant elected and administrative officials be involved in developing the decision process so that time-consuming "second guessing" is minimized at the time of an emergency.

Additional attention may also need to be given to public education efforts regarding evacuation. If the public in the vicinity of UMCD has been educated to regard shelter-in-place as the default protective action in the event of a chemical warfare agent release, they may be resistant to an unexpected recommendation to evacuate. Getting the quickest possible response to an evacuation order may require a public education effort that explains the situations when evacuation would be recommended and emphasizes the need for speedy compliance with the official recommendations.

References

Arnold, R., 2003, *UMCD Phase II, Task 4 – Error Analysis for UMCD Network*. Oregon Department of Transportation.

Arnold, R., 2003, *UMCD Phase II, Task 6 – Evaluating Model Results.* Oregon Department of Transportation.

Arnold, R., 2003, *UMCD Phase II, Task 6x – Additional Model Results.* Oregon Department of Transportation.

Chin, S., O. Franzese, D. Greene, H. Hwang, and R. Gibson, 2002. *Temporary Losses of Highway Capacity and Impacts on Performance*. ORNL/TM-2002/3. Oak Ridge, TN.

Hurdle, V. F. 1984. "Signalized Intersection Delay Model—A Primer for the Uninitiated," *Transportation Research Record 971* Transportation Research Board, National Research Council, Washington, D.C., pp. 96–105.

Neuburger, H. 1971. "The Economics of Heavily Congested Roads," *Transportation Research*, vol. 5, no. 4, p. 283–293.

Mahalel, D., Yehuda, G. and Shiftan, Y., 1991, "Manual Versus Automatic Operation of Traffic Signals," *Transportation Research Part A*, vol 25A, pp 121-127.

OREMS User's Guide. 1998. Oak Ridge National Laboratory. Oak Ridge, TN.

Rathi, A.K., F. Southworth, M. M. Vinagalla, and J.M. Jacobi, 1991, *Evacuation Time Estimates for Umatilla Depot Activity and Vicinity*, Prepared for the U.S. Department of the Army and the Federal Emergency Management Agency by Oak Ridge National Laboratory. Oak Ridge, TN.

Rogers, G. O., A. P. Watson, J. H. Sorensen, R. D. Sharp, and S. A. Carnes, 1990, *Evaluating Protective Actions for Chemical Agent Emergencies*, Oak Ridge National Laboratory. ORNL-6615. Oak Ridge, TN.

Rogers, G. O. and R. D. Sharp, 1990, *Protective Action Evaluator for Chemical Emergencies: A Users Manual*, Prepared for the Federal Emergency Management Agency by Oak Ridge National Laboratory. ORNL/TM-11594. Oak Ridge, TN.

SCM Consultants, "Transportation Evacuation Plan Phase I Interim Report", Second Draft, October 2002

Transportation Operations during Major Evacuations: Hurricane Workshop, FHWA, Westin Atlanta Airport Hotel, Atlanta, GA, June 26-28, 2000.

UMCD CSEPP Web Site: http://www.csepp.net/links/umatilla.htm