Regional Integrated Corridor Management Planning Final Report

A Project Developed by the Western States Rural Transportation Consortium

Prepared by

David Veneziano, Ph.D.
Research Scientist

Western Transportation Institute
Montana State University
PO Box 174250
Bozeman, MT 59717-4250

for the

State of California, Department of Transportation
Division of Research and Innovation

and

U.S. Department of Transportation
Research and Innovative Technology Administration

August, 2014

DISCLAIMER

The opinions expressed in this publication are those of the authors and not necessarily those of the California Department of Transportation, the United States Department of Transportation or Montana State University. Alternative accessible formats of this document will be provided upon request. Persons with disabilities who need an alternative accessible format of this information, or who require some other reasonable accommodation to participate, should contact Carla Little, Research Writer, Western Transportation Institute, Montana State University, PO Box 174250, Bozeman, MT 59717-4250, telephone number 406- 994-6431, e-mail: clittle@coe.montana.edu.

ACKNOWLEDGEMENTS

The authors wish to thank the California Department of Transportation (Caltrans) and the University Transportation Centers Program of the Office of Research, Development and Technology, Research & Innovative Technology Administration at the U.S. Department of Transportation for funding this research. The authors also thank the project steering committee, specifically Sean Campbell, Ian Turnbull and Ed Lamkin of Caltrans, Galen McGill of the Oregon Department of Transportation, Ron Vessey of the Washington State Department of Transportation and Jon Dickinson of the Nevada Department of Transportation for their assistance and oversight.

Revision History

Version	Description	Date
1.0	Draft	August, 2014
2.0	Finalized Report	October 2014

Table of Contents

Table of Figures

LIST OF ABBREVIATIONS

AADT – Annual Average Daily Traffic

Caltrans – California Department of Transportation

CCTV – Closed Circuit Television

CMS – Changeable Message Sign

COATS – California Oregon Advanced Transportation Systems

DOT - Department of Transportation

ECC – Emergency Coordination Center

EOC – Emergency Operations Center

EOP – Emergency Operations Plan

ESF – Emergency Support Function

FHWA – Federal Highway Administration

GIS –Geographic Information System

HAR – Highway Advisory Radio

HPMS – Highway Performance Monitoring System

ICM – Integrated Corridor Management

ICS – Incident Command System

ITS - Intelligent Transportation Systems

MPH – Miles Per Hour

NBI – National Bridge Inventory

NDOT – Nevada Department of Transportation

NIMS – National Incident Management System

ODOT – Oregon Department of Transportation

RETCO – Regional Emergency Transportation Coordinator

RWIS – Road Weather Information System

SOC – State Operations Center

TMC - Traffic Management Center

TOC – Traffic Operations Center

U.S. DOT – United States Department of Transportation

VMS – Variable Message Sign

WSDOT – Washington State Department of Transportation

WSRTC - Western States Rural Transportation Consortium

EXECUTIVE SUMMARY

Integrated Corridor Management (ICM) seeks to coordinate individual network operations between parallel facilities/routes, in order to create an interconnected system allowing cross network travel management. Traditionally, efforts to address congestion have focused on the roadway system (freeways, arterials, etc.), rather than an integrated approach, including between modes. However, these individual system components often serve routes that are parallel to one another, forming a corridor linking the same origins and destinations. This has presented the opportunity for operating and optimizing the entire system, specifically in an urban environment. To date, limited work has been performed examining ICM in a rural/regional context. Based on this, there was an interest by the Western States Rural Transportation Consortium (WSRTC) in exploring regional ICM in greater detail. Specifically, there was interest in establishing guidance and criteria to initiate, plan and develop a regional ICM plan. This work defined what regional ICM is, established the factors to consider when developing a regional ICM plan, and developed protocols and criteria for ICM deployment in a regional context. These were then tested by developing a high-level regional ICM plan for two routes in the WSRTC region.

The work consisted of a literature review that examined existing ICM efforts and related research, corridor-planning efforts in the WSRTC region, summaries of Emergency Operations Center (EOC) protocols and plans in each of the Consortium states, and a review of the United States Department of Transportation's ICM planning approach. This was followed by the development of the regional ICM planning approach and application of the planning approach to identifying alternative corridors for a primary route impacted by an event. Based on this work, a series of conclusions and recommendations were then developed for future applications and research.

The literature review confirmed that the primary focus of ICM initiatives and research to date has been on urban applications. In the limited cases where rural/regional ICM has been explored, efforts have focused on laying out a high-level approach to communications and emphasizing information sharing and dissemination. Neither the urban nor rural discussions had established a process for planning an ICM effort and most of the aspects of past work did not lend themselves to a regional usage. Similarly the U.S. DOT's ICM planning approach has not yet been adequately defined in any document. A review of existing EOC protocols and procedures found that a basic framework to support decision-making and operations under a regional ICM operation has been established in each WSRTC state. These protocols and procedures laid out a foundation for how operations could proceed when a regional ICM event occurred. Based on the findings of the literature review, it was concluded that the development of the regional ICM planning process would need to be made from scratch.

The next step for the work was the development of the general regional ICM planning framework. The definition of regional ICM was established, stating that "Regional Integrated Corridor Management is defined as the coordination of highway facilities across state and jurisdictional boundaries in a seamless manner to enable an interconnected system for long-distance cross-network travel in response to extended-duration events". Note that a true ICM approach includes all modes of transportation across a network. However, in many regional contexts, alternative modes, such as rail, transit, etc. are not feasible given the origin-destination pairs for many corridors.

The planning approach that was developed began with a group of entities/agencies identifying a need to address different events, conditions or scenarios that may occur along a primary highway corridor and may have a significant impact on mobility for an extended period of time. Stakeholders would identify an initial series of events, conditions or scenarios that may have an impact on these routes and that ICM could help address. The next step in the approach was to inventory existing highway assets and conditions. In this work, that inventory would be completed using GIS data to identify alternative routes and establish whether they are suitable for use in a regional ICM setting. These activities marked the end of the work pursed by this incubator project. Following evaluation of GIS data and any resulting recommendations, the selection of alternate routes to be used during ICM events would be made by all agencies involved in the process. Steps following this point address more detailed development of documents and agreements. This includes the development of Interagency Agreements, as well as detailed Concept of Operations and Requirements documents. The final steps of the regional ICM planning process entail the development of deployment/operation protocols.

Application of the planning process was made by identifying study corridors/routes of interest and the conditions that could impact them by the project Steering Committee. The demonstration corridors included U.S. 395 from Mojave, California to Carson City, Nevada, and SR 299 – U.S. 395 from Arcata, California to the junction of U.S. 395 and U.S 20 in Oregon. Based on these selected corridors, an inventory of highway assets along each was made using GIS data. This inventory collected relevant data that would support the identification of alternative routes, such as traffic, cross section element data, ITS elements and so forth, in the form of GIS shapefiles. Based on the route inventory, GIS route identification and optimization tools were used to determine alternative routes based on travel times, distance and capacity. The use of GIS in performing this task demonstrated its utility for automated analysis in evaluating road network data over a large geographic area in support of ICM planning activities. For the study cases examined, comparable alternative routes were identified in GIS that provided reasonable distances and travel times in the event that the study corridor was closed or had restricted traffic flow. The analysis approach demonstrated that a number of alternatives could be developed for presentation to stakeholders for discussion and selection as part of the larger regional ICM planning process in a quick and efficient manner.

Based on the findings of the work, a number of recommendations have been made. First, the datasets employed in this work were limited to those that were readily available. The result of this was a less detailed dataset was used in the analysis than would have been the case if the planning effort was limited to within one state's borders. It is recommended that data such as geometric features and signal timing plans be investigated in future research and/or planning efforts. Second, the approach demonstrated relied on recent/current information and trends (traffic levels). However, any potential ICM event will occur at some point in the future, and any future planning effort should incorporate future traffic projections developed from statewide (or in some cases within the overall region, urban-based) travel demand models. Finally, any pursuit of regional ICM planning in the future will need to extend beyond the planning phase discussed in this report and toward the development of interagency agreements and Concept of Operation and Requirements documents that allow for implementation to occur during an event. The content of those documents will rely on the event(s) and route alternatives identified during earlier planning steps.

1. INTRODUCTION

Integrated Corridor Management (ICM) seeks to coordinate individual network operations between parallel facilities/routes, in order to create an interconnected system allowing cross network travel management. The primary intent of ICM has been to address the congestion issues that plague urban areas. Traditionally, efforts to address congestion have focused on the roadway system (freeways, arterials, etc.), rather than an integrated approach, including between modes. However, these individual system components often serve routes that are parallel to one another, forming a corridor linking the same origins and destinations. This has presented the opportunity for operating and optimizing the entire system[1], which is the goal of ICM. The resulting improvement in traveler movement reduces travel times and impacts to the collective system, while increasing the reliability and predictability of travel.

To date, limited work has been performed examining ICM in a rural/regional context. Initial exploratory work was performed under the scope of the California Oregon Advanced Transportation Systems (COATS) Phase 3 project (1), with much of this work centered on the development of a web-based clearinghouse (which has since become the One Stop Shop for Traveler Information, http://oss.weathershare.org/). Based on this initial COATS-region work, there is an interest by the Western States Rural Transportation Consortium (WSRTC) in exploring regional ICM in greater detail. Specifically, there was interest in establishing guidance and criteria to initiate, plan and develop a regional ICM plan. This work would define what regional ICM is, establish the factors to consider when developing a regional ICM plan, and develop protocols and criteria for ICM deployment in a regional context. These would then be tested by developing a high-level regional ICM plan for two routes in the WSRTC region.

Project Background

This document presents the results of the development of an approach to Regional Integrated Corridor Management Planning in the form of an incubator project. The purpose of the project was to develop guidance and criteria for the initiation, planning and development of regional[2] Integrated Corridor Management plans. As outlined in the project work plan document (2), a series of eight tasks were completed during the project. These included:

- Project Management;
- Literature Review Update;
- Document Current ICM Planning Protocols;
- Document Current Emergency Operations Center (EOC) Protocols ;
- Develop Rural ICM Planning Protocols/Process;
- Route Inventory for Selected Rural ICM Corridor(s);
- Apply Developed Criteria to Study Route(s); and

[1] A true ICM approach includes all modes of transportation across a network. However, in many rural contexts, including that being discussed here, alternative modes, such as rail, transit, etc. are not feasible given the origin-destination pairs for many corridors. For the most part, there are no other modes across the study region that could provide an alternative for passenger and trucking movements. Therefore, the reason the reason that this study focuses on highways is that they are the only viable option in the region at this point in time.

[2] Note: in the context of the WSRTC states, the term “regional” largely refers to rural portions of each state and the terms regional and rural are used interchangeably.

- Final Report

This report documents the findings of these tasks. The project management task was ongoing throughout the course of the project and involved budgeting and reporting elements, which are not discussed in this report. The remaining tasks involved documentation of past ICM efforts, existing EOC protocols in each Consortium state, development of a framework for ICM planning in a rural context, and a general application of that framework through a route inventory and identification of route alternatives in the study area using study corridors identified by the project Steering Committee. Note that the demonstration was intended to be a high-level exercise given the exploratory nature of this project; detailed documents such as a Concept of Operations and Requirements were not proposed as part of the project work plan.

Research Objective

As stated, the intention of this investigation is to establish guidance and criteria to plan, initiate, and develop a rural ICM plan. The developed criteria would then be applied to two routes in the WSRTC region in order to test their practicality in a rural environment. As the focus of ICM is on the movement of persons[3] via alternative routes, this investigation will focus on highways only. Based on this highway-focused approach, the primary criteria to plan, initiate, and develop a rural ICM plan and apply it two study routes in the WSRTC region will demonstrate the process.

Expected Benefits

While not expected to address the severe congestion issues that urban ICM is focused on, rural ICM still offers several potential benefits. These benefits include improved goods movement, improved traveler safety, and improved throughput by better traffic management, as well as the provision of improved traveler information.

In terms of goods movement, the focus of rural ICM in keeping vehicles moving when a primary route is impacted would provide great benefits, as truck drivers would receive information (via Changeable Message Signs (CMS), Highway Advisory Radio (HAR), or Mobile Data Device, etc.) prior to reaching critical decision points. With this information, drivers can make a decision to continue on their original route or use the alternative route. In the event the truck maintains its original route, the driver will be better prepared for the potential of having to stop and can plan accordingly. In the event that the alternative route identified by an agency and communicated to the public is chosen, time and cost savings may be achieved, as the vehicle continues moving to its final destination, avoiding the delays present along the original route. By being able to keep moving, shipments avoid costly delays, while fuel consumption is reduced.

Traveler safety is expected to improve through the implementation of rural ICM plans as travelers will be provided with better information on which to base decisions with respect to continuing their trip, as well as decisions regarding lodging and other services. By receiving information about an impacting event in advance, travelers can find necessary services along their route in a timelier manner, as opposed to continuing with their trip and encountering a closure with no services available in the vicinity. As a result, travelers will avoid the potential for

[3] "Persons" is used at this point in the text, as ICM in general seeks to move people by multiple available modes (vehicle, transit, etc.). In a rural context, the most prevalent (and typically only) available mode is vehicular.

being stranded along a highway and requiring assistance from agencies that are already burdened by the impacting event.

A secondary safety benefit to travelers is that the provision of pertinent information regarding alternative routes may prompt travelers to take the recommended alternatives. In the case of a winter storm, for example, the recommended alternative route may be in better condition from a winter maintenance standpoint due to the storm's different level of impacts to those routes. By using the alternative route, travelers may be less exposed to roadway conditions that contribute to accidents. This is not to say that ICM in a rural environment will eliminate crashes, but it may play a role in reducing their number or severity.

Report Overview

This report is organized into five chapters. Chapter 1 has outlined the need for investigation into the development of a regional ICM planning approach. Chapter 2 presents a literature review that examines existing ICM efforts and related research, corridor-planning efforts in the WSRTC region, summaries of Emergency Operations Center protocols and plans in each of the Consortium states, and a review of the United States Department of Transportation's ICM planning approach. Chapter 3 discusses the development of a regional ICM planning approach and presents the approach that resulted from the work. Chapter 4 presents an application of the general planning approach to identifying alternative corridors for a primary route impacted by an ICM event. Finally, Chapter 5 presents conclusions and recommendations resulting from the overall work.

2. LITERATURE REVIEW

The initial task completed in the project work plan was a literature review. This review aimed to identify work performed to date on all aspects of ICM in the U.S. Much of the past and on-going work related to ICM has focused on various aspects of the U.S. DOT's Pioneer Sites effort. As expected, the focus of this literature has been on urban applications of ICM. The following sections provide a high level overview of the literature review findings.

ICM Efforts and Research

Various documents have discussed analysis, modeling and simulation of corridors as part of the U.S. DOT's ICM initiative (3, 4, 5). The initial sites that were selected as part of this effort included Dallas, Houston and San Antonio, Texas; Oakland and San Diego, California; Minneapolis, Minnesota; Seattle, Washington; and Montgomery County, Maryland. Concept of Operations (Con Ops) and Requirements documents for each of these sites were developed during the initial effort (3). Of the original sites, Dallas, Minneapolis and San Diego were then selected for analysis, modeling and simulation activities. The intent was to determine which combinations of ICM strategies will be most effective; to better understand the impacts and benefits of those strategies; and to identify problem areas, improve plan effectiveness, and guide correct investment decisions (6).

Aside from these documents that discuss the overall U.S. DOT ICM effort, literature related to specific sites has also been produced. Olyai summarized the planning work done in advance of the 2012 Dallas US 75 freeway corridor ICM deployment (7). A document compiled for the US-75 ICM corridor in Dallas presented high-level requirements, including functional and performance requirements (8). (A similar document was also developed for the I-880 corridor in Oakland, California (9).) Miller, et al. discussed the concept of operations and requirements developed for the I-15 Corridor ICM in San Diego, California (10). Johnson and Fariello discussed ICM concepts for medium sized urban areas based on the experiences of the Pioneer Site effort in San Antonio, Texas (11). Estrella, et al., discussed San Diego's experience in developing different aspects of their ICM as part of the Pioneer Sites effort (12). Cronin, et al., discussed the analysis, modeling and simulation of ICM strategies by the Dallas, Minneapolis and San Diego Pioneer sites (13).

Separate from the U.S. DOT's ICM Pioneer Sites, the Maricopa Association of Governments in the Phoenix, Arizona, area developed a Concept of Operations for an ICM system along I-10 (14). In June, 2010, the Niagara International Transportation Technology Coalition published system requirements for the Niagara (Buffalo, New York area) Frontier Corridor (15, 16). This included documentation of functional, non-functional and data requirements for an ICM initiative for the overall region (U.S. and Canada).

Other general urban ICM-related literature was also identified during the course of the review task that was not necessarily part of the U.S. DOT effort. Zhang, et al. developed a model of an integrated corridor management control system to manage traffic between a mainline freeway and a diversion route (arterial) in real time (17). Zimmerman, et al. discussed a methodology developed by the World Bank to apply ICM in growing Asian cities (18). While developed in an urban context, the steps outlined in the process - evaluate current and future near-term transportation problems, identify available transportation options and alternatives, evaluate individual options, select options to employ, and implement - bear further consideration for transfer to a regional ICM application. Alm, et al. developed a methodology for corridor management planning that took on a phased approach. It began with project scoping, followed by performance assessment, model development and scenario evaluation (19). A 2006 white paper by Berkley Transportation Systems discussed the methodologies and technologies appropriate for integrated corridor management operations (20). Chiu, et al. developed a simulation-based dynamic traffic assignment model that as of 2010 had been used for different analyses, including ICM corridor modeling (21).

Aside from urban ICM efforts, limited work and discussion has been performed in a rural context. The Integrated Tri-State Corridor Management System Initiative sought to improve center-to-center information sharing and exchange among traffic management and emergency response agencies in Caltrans Districts 2 and 3 (22), as well as neighboring areas in Oregon and Nevada. The project sought to develop a high level plan for center-to-center communications and build a foundation for a future integrated traveler information system, stopping short of implementation. The North/West Passage Corridor Transportation Pooled Fund Study examined ongoing standards development and methods for sharing, coordinating, and integrating traveler information across state borders (23). The primarily rural nature of the routes included in this corridor make the limited ICM efforts of this project of interest. The key aspect of interest from this study related to ICM is the development of an integrated traveler information and maintenance network.

ICM-Related Research

In addition to past and on-going ICM development and deployment efforts, other research of relevance has been conducted. Tanikella, et al., examined quantifying the benefits associated with the implementation of ICM strategies, with results indicating that reductions in travel time ranging from 20 to 27 percent were possible (24). Hamer, et al., examined the development and exploration of ICM strategies for Maryland's Coordinated Highways Action Response Team with a focus on operational improvements that could be made to facilities in the case of planned and unplanned network disturbances (25). Yang and Wei discussed the initial test of an integrated freeway and arterial data archiving system and its potential for supporting decision making of integrated freeway and arterial operations in Oakland County, Michigan (26). Quayle and Urbanik examined the process, challenges and lessons learned with building a micro-simulation model to determine whether such tools would be helpful in developing corridor level strategies for ICM in Portland, Oregon (27).

Zhou, et al., developed a simulation system that incorporated individual trip maker choices of travel mode, departure time and route in multimodal urban transportation networks (28). Alexiadis detailed ICM analysis, modeling and simulation (AMS) methodologies that were intended to serve as analytical approaches for assessing generic ICM corridors (29). Henry and Wendtland developed a series of Intelligent Transportation System (ITS) concepts for rural corridor management in Arizona (30). This work primarily included development of maps for key corridors and their alternatives, which showed ITS and other critical infrastructure that could be used to identify corridor-specific equipment and other needs to support traffic diversions.

Corridor Efforts in the WSRTC Region

An incident management plan and a winter response plan for the Siskiyou Pass area along Interstate 5 (I-5) in Northern California and Southern Oregon has been used with modifications for a number of years (31). The incident management plan consists of an operations guide providing brief, step-by-step procedures for the different phases of incident management for specific situations.

The West Coast Corridor Coalition has sought to address issues and chokepoints across jurisdictional, interest and financial boundaries (32). To address issues, a system-wide, regional approach is being pursued to plan and fund improvements across boundaries, fostering inter-agency cooperation.

The Cascadia Corridor initiative between Vancouver, British Columbia, and Eugene, Oregon aims to develop shared policy visions for transportation along the corridor. To this end, the focus of this effort in terms of corridors has been on the examination of how emerging technologies can ease congestion, improve travel times, increase capacity, and improve safety (33).

The I-80 Integrated Corridor Mobility project in Alameda and Contra Costa counties in California was the first full-scale deployment of active traffic management in the U.S. (34). The effort sought to improve travel time reliability; balance and stabilize traffic flow; better utilize existing capacity; and reduce incidents, crashes and emissions.

Literature Conclusions

As this brief overview of literature illustrates, the primary focus of ICM initiatives and research to date has been on urban applications. In the limited cases where rural/regional ICM has been explored, efforts have focused on laying out a high-level approach to communications and emphasizing information sharing and dissemination. Neither the urban or rural discussions have established a process for the planning of an ICM effort (i.e., identifying the steps from inception to deployment/application). ICM-related research has focused on data analysis and modeling to evaluate potential improvements, quantify benefits or simulate traveler behavior. Corridor-related efforts in the WSRTC region have primarily focused on identifying potential issues that may impact the system and addressing them cooperatively or through investments in improvements and technologies.

The primary conclusion that may be drawn from the literature review is that, while a good deal of work related to ICM has been completed at a number of levels, none of it has established a process that can be adapted for regional application. Furthermore, many of the aspects of work to date, while valuable in their contribution, do not lend themselves to a regional usage. For example, modeling and simulation are excellent tools to employ in an urban network to develop and compare scenarios and strategies, as ample support data is typically available. However, such modeling and simulation activities in a rural setting would be a challenge to employ given limited data and financial constraints. Consequently, based on existing literature, it would appear that the development of a process for planning regional ICM must be done from scratch. Such an approach must make use of the data that is presently available, recognizing that the collection and recording of additional data is not likely feasible, at least in the near term.

Emergency Operations Center Plans

This project task was performed to document current Emergency Operations Center (EOC) plans and procedures. Each of the WSRTC states has developed plans and/or procedures to address emergency scenarios on their respective highway networks. These plans and procedures represent a source of supplemental information that could be transferred or applied to the ICM planning process. When applying ICM to a regional context, this type of information will likely be necessary when considering long highway routes compared to the compact urban applications typically considered in the U.S. DOT's planning. The following sections summarize the primary findings of reviews completed on information from each WSRTC state.

California

Information specific to Caltrans regarding emergency operations activities is documented in the *State of California Emergency Plan* (35). Caltrans is tasked with assessing damage to the transportation system, providing engineering resources to other agencies when necessary, and establishing route priorities during recovery efforts. It also is tasked with coordinating state agency plans, procedures and preparations for route recovery, traffic regulation and air transportation.

The *California Catastrophic Incident Base Plan* summarizes events that have the potential for widespread impacts that would require coordination between multiple agencies both within and outside the state, particularly in coordinating transportation facilities to accommodate diverted traffic (36). The document outlines a concept of operations for facilitating such coordination. In California, counties manage Operation Area Emergency Operations Centers (EOCs), coordinate support and resources among local-level agencies. Regional EOCs coordinate with Operation Areas and manage the tasking of state agencies. The State Operations Center (SOC) coordinates the overall state response to the incident and serves as the link to Federal level and neighboring state agencies. During an incident, resources at all levels are integrated into incident command at the field level.

Finally, the Mineta Transportation Institute at San Jose State University developed an emergency management handbook that is pertinent to EOC practices and protocols specific to transportation (37). A key portion of the document discusses the roles and purposes of the Caltrans headquarters EOC. The document points out that the headquarters EOC is the coordination point for all department-wide disaster response activities (37). The headquarters EOC also ensures that Caltrans is coordinating with federal and local entities and verifies that the department's other essential functions continue during the event. Management with the local level is facilitated through the use of the Incident Command System (ICS) and the National Incident Management System (NIMS). The document also notes that many districts have their own EOC's, which typically handle normal, local event demands (floods, landslides, etc.). Typically, the relationship between the headquarters EOC and the local level is one of general coordination or support. Only as an event becomes regional does the headquarters EOC become involved in leading efforts. This would typically be the case in an event requiring an ICM response.

Nevada

Information on the Nevada DOT's emergency operations activities is outlined in the *State Comprehensive Emergency Management Plan* (38). NDOT is tasked with coordinating the state-level response to transportation infrastructure, transit and goods movement during incidents and disasters. Coordination and assistance are also provided to local entities and other state agencies requiring transportation capacity or capabilities in response to an emergency or disaster. Specific NDOT responsibilities outlined in the plan include:

- Provide for the coordination of transportation support;
- Maintain transportation routes to permit sustained flow of emergency relief;
- Support and assist law enforcement agencies in traffic access and control;
- Make available transportation assets during an emergency or disaster that are not generally available to other agencies to fulfill their mission
- Implement emergency functions including traffic control, hazardous materials containment response support, damage assessment and debris removal if needed;
- Assist state and local government entities in determining the most viable available transportation networks to, from and within the emergency or disaster area as well as regulate the use of such networks as needed; and
- Coordinate state-arranged transportation support, in cooperation with the Nevada Department of Administration (38).

NDOT emergency response operates at one of three levels, depending on the current statewide situation. Level 1 is normal operations, with the state Emergency Operations Center not being activated, as no special response is needed. Level 2 is the activation of the state EOC, with NDOT providing staff to support and coordinate all actions related to emergency response tasked to the agency. Level 3 response involves the activation of the DOT's Emergency Operations Center. At this level, the state's Incident Command System is put into use to ensure compatibility with other responding state department and agency data and communication sharing activities. During any level of event, recovery planning and operations are expected to begin as soon as possible to return the transportation system to normal operations.

Oregon

The state of Oregon's Emergency Operations Plan (EOP) lays out the roles and responsibilities of the Department of Transportation during emergency events (39). During such events, the role of the Oregon Department of Transportation (ODOT) is to close state highways and reroute traffic as needed. ODOT operates an Agency Operations Center in Salem (and five regional operations centers) that serves as the agency-wide coordination point for emergency response. Within the EOP, Section ESF1 (Emergency Support Functions) lays out the roles and responsibilities of ODOT during emergency events. These include:

- Coordinate transportation-related activities in support of the state Emergency Operations Plan;
- Work with other agencies as needed to determine the usable portions of the state transportation system, including roads and bridges, railroads, transit systems, and motor carrier facilities.
- Work with local road authorities and the Federal Highway Administration (FHWA) to implement the Federal-Aid Highway Emergency Relief (ER) program for federal-aid highways in Oregon.
- Coordinate and control emergency highway traffic regulation in conjunction with the Oregon State Police (OSP), Oregon Military Department and the FHWA.

- Maintain liaison with the Oregon Chapter of the Association of General Contractors and construction and equipment rental companies.
- Work with the Oregon aviation authorities in regard to aviation-related response activities, including the use of state owned airports.
- Conduct aerial reconnaissance and photographic missions, as requested, provided resources are available.
- Provide transportation-related public information and mapping support to the Governor's Office, the Oregon Emergency Coordination Center (ECC), or the lead state response agency, in addition to the public information and mapping support work done within ODOT, during response and recovery activities.
- Coordinate with the U.S. Department of Transportation Region 10 Regional Emergency Transportation Coordinator (RETCO) or designee, to obtain federal transportation support.

ODOT is also responsible for coordinating with the Oregon State Police for road closures, traffic redirection and other functions in line with OSP's mission. However, details on the approach to these responsibilities are not presented in the document.

Washington

WSDOT's emergency operations information is outlined in three documents. The first is the state's Emergency Support Function (ESF) 1 – Transportation document that is part of the Comprehensive Emergency Management Plan (40). The second document is the DOT's Emergency Operations Plan (41). The third document is the Regional Transportation Recovery Annex, which serves as a catastrophic disaster coordination plan (42).

The ESF document establishes the responsibilities of the DOT during emergencies, disasters and hazardous conditions. WSDOT headquarters coordinates all WSDOT emergency management activities. Six regional offices (Seattle, Spokane, Tumwater, Vancouver, Wenatchee, and Yakima) handle field operations in their area during emergencies.

WSDOT's Emergency Operations Plan provides further information on operations in an emergency where coordination between agencies is required (41). The document lays out WSDOT's roles in preparing for and responding to emergencies. Broadly summarized, this consists of various phases. The preparedness phase entails training and exercises to prepare for emergency events and scenarios; identifying hazards, critical infrastructure and key resources; and planning for the continuity of operations during an event. Mitigation is also an ongoing activity to reduce or eliminate risks before an event occurs. The response phase of an emergency includes the initial mobilization related to the event, including notification, situation and damage assessments; referral to the Standard Operating Procedures that are relevant to the event; activation of the EOC; reporting; and field operations. Finally, the recovery phase restores the affected area and infrastructure to its previous condition.

One section of the Emergency Operations Plan of particular interest to the ICM effort outlines the details and procedures for developing detour routes:

- Region Traffic Engineer(s) coordinates selection of detour routes, which during an emergency may need to be developed in a short time frame. The general approach utilized is:

- Contact local jurisdictions and jointly agree on a process.
- Gather data (maps, plans, roadway and roadside inventory information, etc.).
- Identify preliminary detour routes utilizing the selection criteria. [Note, the selection criteria are not outlined in the EOP document.]
- Drive detour routes to identify and record issues and features that could affect detour traffic.
- Determine acceptance of route by the local jurisdiction(s).
- Revise preliminary detour routes as needed.
- Identify areas of concern such as route capacity, fuel availability, overhead clearances, railroad crossings, weight restrictions, residential areas, tight turns, temporary traffic control device needs, grades, speed zones, choke points, advanced signage locations, safety concerns, etc.
- Identify commercial vehicle restrictions.
- Identify routes that are closed to hazardous materials and other specific loads.
- Determine if there are restrictions needed for travel during certain time periods.
- Compile draft plan for review by the Region Traffic Engineer(s).
- Work on agreements with any local agencies with jurisdiction over roads where traffic will be diverted (41).

Once routes have been identified, the EOP outlines how they are implemented. This includes development of an implementation plan that discusses restrictions, signage locations, procedures for putting a detour route into operation, and other agencies with whom to coordinate. WSDOT coordinates with other agencies throughout the detour via the regional EOC. There must also be communications between the field and the EOC, with information passed along to WSDOT headquarters via the regional EOC.

The Regional Transportation Recovery Annex addresses transportation recovery after major transportation disruptions requiring multi-agency coordination (42). In the Annex, the process begins with short-term coordination, where agencies share situational awareness, coordinate with partner agencies, establish and implement detours and identify mid- and long-term actions that need to be taken. Short-term coordination occurs within the first 72 hours following an event. Mid-term actions consist of managing transportation demand, establishing additional alternative routes, implementing multi-modal solutions, prioritizing repairs and other activities to assist in recovery. Monitoring and re-evaluating progress continues during this phase, which begins within the first hours of an event and can extend weeks or months. Long-term actions are permanent measures that return the transportation to pre-event or better condition. Actions during this phase include establishing long-term priorities, making temporary repairs, formulating new projects as needed and monitoring recovery progress, among other activities.

While multiple agencies are a part the actions laid out in the Annex, WSDOT plays a key role. Specific responsibilities of WSDOT assigned under the Annex include:

- Coordinate transportation-related missions in support of recovery efforts.
- Prioritize and/or allocate transportation resources and recovery efforts.
- Conduct damage assessment to the state transportation facilities.

- Determine the usable portions of the state transportation system and coordinate emergency highway traffic regulations with other appropriate agencies.
- Reconstruct, repair and maintain the state transportation system.
- Coordinate with Washington State Patrol for traffic control.
- Coordinate maritime, aviation and rail recovery with respective lead federal agency.
- Inspect infrastructure and prioritize repairs on the state transportation network.
- Provide highway rerouting information to redirect traffic or keep traffic moving.
- Provide assets such as barricades, road signs, variable message signs, and pavement markings for implementing detours and other changes in traffic patterns.
- Institute traffic changes such as High Occupancy Vehicle, High Occupancy Toll, congestion pricing or reversible lanes.
- Restore state transportation system connectivity and re-establish ferry system operations (42).

In line with disruption scenarios, the Annex indicates alternative routing plans should be developed. These are done by working groups and planning teams that examine base information on the transportation network to identify facilities impacted by different closure scenarios. Factors to consider during the process include traffic levels, emergency needs, economic impacts of an event, route redundancy and ease of repair. Based on scenarios and potential closures, alternative routing plans are developed by examining level of service maps to identify alternatives that can accommodate additional traffic without reaching congestion levels.

Emergency Operation Center Conclusions

Based on the review of existing EOC protocols and procedures, a basic framework to support decision-making and operations under a regional ICM operation has been established in each state. These protocols and procedures differ in some respects, but in general, they lay out a foundation for how operations would proceed when a regional ICM event occurred. The primary conclusion that can be drawn from this portion of the review is that there would be a need to develop a more coordinated set of protocols and interagency agreements between states/agencies to facilitate multi-state ICM operations. The development of such a coordinated set of protocols and procedures will be integrated into the overall regional ICM planning process, discussed in later sections of this report.

Review of the U.S. DOT ICM Planning Approach

Interestingly, no specific document has been produced that lays out the steps involved in ICM. Rather, one must review various pieces of information presented on the U.S. DOT's ICM website (43). While this information provides background on the components of ICM, it does not lay them out in a step-by-step manner. Consequently, the conclusion must be drawn that there is no set procedure or steps for establishing and applying ICM, aside from the general phases of ICM employed at the U.S. DOT's Pioneer Sites. These phases include:

- Phase 1: Foundational Research – identifying current corridor management practices in use and development of generic guidance such as a concept of operations to guide potential applications.
- Phase 2: Corridor Tools, Strategies and Integration – model, simulate and analyze ICM strategies for sites and test various standards, interfaces and management schemes.

- Phase 3: Corridor Site Development, Analysis and Demonstration – field deployment and evaluation of ICM at Pioneer Sites.
- Phase 4: Outreach and Knowledge and Technology Transfer – Develop resource guidance documents and materials that aid in ICM implementation.

These phases are logical in establishing a general approach to ICM (particularly research and initial application), but they do not present a plan that can be readily transferred and adapted.

Aside from the discussion of these phases, only a limited amount of supplemental discussion related to the strategies that should be employed in ICM have been laid out by the U.S. DOT effort. These primarily consist of the following:

- Information sharing and coordination between agencies, including collection of real-time data and development of data sharing platforms, as well as coordinated responses to events;
- Coordinated operations to improve efficiency, including coordination of signals to accommodate traffic shifts, as well as signal preemption for emergency vehicles;
- Facilitation of cross-network shifts by disseminating alternate route information and promoting shifts via traveler information streams; and
- Planning for operations through data archiving and modeling, planning response activities, and coordinating construction and maintenance activities (43).

Although these strategies provide initial guidance for aspects of ICM that should be considered during the planning process, they do not themselves represent an approach or steps to the ICM planning process. Once again, those interested in carrying out ICM planning, either in a rural or urban setting, are left to determine their own direction.

One final avenue of discussion laid out by the U.S. DOT effort is a generic set of ICM needs. While these needs have been developed with an urban context in mind, they serve as useful considerations for a regional perspective as well. ICM needs include:

- Information sharing and coordination across systems;
- Optimization of supply and demand for transportation services in a corridor;
- Decision support tools to support ICM;
- Information on what affects route, mode and travel time decisions;
- Analysis and prediction of system performance for planning and real-time operations (44).

Once again, these points do not represent a planning process or steps to implementing ICM in any context. Rather, they provide a series of items that should be taken into account during the course of any ICM planning effort. In reviewing this list, one must bear in mind that it has been developed in an urban context; some of its aspects, such as what may affect mode selection, do not necessarily apply to a regional application.

The conclusion that may be drawn from the review of the U.S. DOT's ICM planning approach is that it has not yet been adequately defined in any document. The original intent of the work was to transfer different aspects of the process for use in planning regional ICM. Consequently, that prospective approach, which would have been developed for an urban context, cannot be transferred to a regional application. While the ongoing U.S. DOT effort will ultimately produce guidance documentation, it has not yet reached the point of doing so. Based on this observation, those interested in ICM have some discretion in how to plan and implement it. In short, the U.S. DOT hasn't developed a step-by-step approach to ICM to date that can be directly transferred and applied to a regional context. Rather, a process for the ICM planning process that can be applied in a regional context needs to be developed from scratch.

While many of the considerations identified by the urban ICM process are applicable in a regional context, the development of the regional ICM planning approach will need to take on a different approach in some respects. For example, when considering rural corridors across multiple states, the issues being addressed, the routes employed and their capabilities/capacities need to be considered at the outset. Detailed ICM planning (including the development of Concept of Operations and Requirements documents) should only begin after routes have been evaluated for their suitability to host traffic reroutes/detours. If a route(s) cannot accommodate shifts in traffic, it does not make sense to develop more detailed plans and interagency agreements. Similarly, even if routes are available to facilitate ICM-related traffic shifts, they may still require additional infrastructure, such as ITS field elements, to support operations. Consequently, such aspects must be accounted for in developing the regional ICM planning process. The outline for that proposed process is presented in the following sections.

Chapter Summary

The literature review conducted in support of this work found that the primary focus of ICM initiatives and research to date has been on urban applications. In the limited cases where rural/regional ICM has been explored, efforts have focused on laying out a high-level approach to communications and emphasizing information sharing and dissemination. Neither the urban or rural discussions have established a process for the planning of an ICM effort. Corridor-related efforts in the WSRTC region have primarily focused on identifying potential issues that may impact the roadway system and addressing them cooperatively or through investments in improvements and technologies.

The primary conclusion that may be drawn from the literature review is that, while a good deal of work related to ICM has been completed, none of it has established a process that can be adapted for regional application. Furthermore, many of the aspects of work to date do not lend themselves to a regional usage. Consequently, based on existing literature, the development of a process for planning regional ICM must be developed from scratch. The approach must make use of the data that is presently available, recognizing that the collection and recording of additional data is not likely feasible, at least in the near term.

Based on the review of existing EOC protocols and procedures, a basic framework to support decision-making and operations under a regional ICM operation has been established in each state. These protocols and procedures differ in some respects, but in general, they lay out a foundation for how operations would proceed when a regional ICM event occurred. The primary conclusion that can be drawn from this portion of the review was that there would be a need to develop a more coordinated set of protocols and interagency agreements between states/agencies to facilitate multi-state ICM operations. The development of such a coordinated set of protocols and procedures would be integrated into the overall regional ICM planning process as part of interagency agreements and related documents.

Finally, it can be concluded that the U.S. DOT's ICM planning approach has not yet been adequately defined in any document. Consequently, the approach developed for an urban context cannot be transferred to a regional application. Based on this observation, those interested in ICM have some discretion in how to plan and implement it. In light of this, the development of an approach that is tailored to a regional context can be pursued, and that is the focus of the next chapter.

3. DEVELOPMENT OF REGIONAL ICM PLANNING PROCESS

One central aspect of this project was to define what regional ICM is and to develop a planning process/criteria to apply when evaluating rural corridors and identifying prospective alternatives. Consequently, the criteria developed focused on the highway mode, as this mode dominates the regional (rural) transportation network. Future rural ICM work should examine other modal alternatives; however, that work was beyond the scope of this project.

At present, the U.S. DOT's ICM initiative has developed general guidance regarding overall planning. Components of that ICM planning process include:

- Concept Generation
- Corridor Inventory (note, this is not a defined step of the process but has been identified while developing this scope of work)
- Systems Engineering Management Plan
- System Conception
- Requirements
- ICM High Level Design (Architecture)
- ICM Detailed Design
- Procurement
- Implementation and Deployment
- Operations and Maintenance/Evaluation
- Configuration Management (45)

Recall that this process has been developed with an urban application in mind. Consequently, during the course of the project discussed here, it was necessary to remove some of these components as well as modify or add others in order to be applied to a rural context. This becomes evident in the following sections as the regional planning process is laid out.

Definition of Regional ICM

In order to establish the regional ICM planning process, the definition of regional ICM must first be established. Phase 1 of the U.S. DOT ICM effort has defined ICM as "the coordination of individual network operations between adjacent facilities that creates an interconnected system capable of cross-network travel management. For the purposes of this work, much of this definition applies to a regional application as well. Regional ICM also seeks to promote an interconnected system to facilitate cross-network travel. While the ICM definition presented above does not explicitly mention it, that cross-network travel occurs between different jurisdictions and over shorter distances within a denser geographic region than a regional application might entail. Consequently, a specific definition of regional ICM might be as follows:

- Regional Integrated Corridor Management is defined as the coordination of highway facilities[4] across state and jurisdictional boundaries in a seamless manner to enable an

[4] Recall that a true ICM approach would include all modes of transportation across a network, but in the rural context discussed here, highways are the only viable option in the region at this point in time.

interconnected system for long-distance cross-network travel in response to extended-duration events.

Based on this definition, the aim of regional ICM is to facilitate traffic diversions along alternative routes/corridors in response to various impacting events, such as weather, major construction, major incidents/crashes, and so forth. These impacting events are typically of an extended duration, spurring the need to facilitate the continued movement of traffic via alternative routes. In the regional context, alternative corridors will typically cover long distances, spanning multiple jurisdictional and state boundaries. Consequently, regional ICM addresses more than just the needs of localized detours in a rural area; it seeks to facilitate a continuous flow of traffic over long distances when a major event has the potential to impact a primary route.

Given the definition of regional ICM, the factors that should be considered in the development of plans and applications can be identified and discussed. This aspect of the work is discussed in the next section.

Factors to Consider

In developing the approach to regional ICM planning, a number of factors need to be considered. Foremost among these is the need for regional ICM itself. If there is a need for a regional ICM, whether it is to address issues related to weather, large scale construction, major disasters or incidents, or other events, then various factors that can impact or influence regional ICM throughout its planning and execution must be considered. This section presents and discusses these factors, which are further considered in the development of the planning process itself. Note that this list is by no means comprehensive; rather, it is expected to grow and evolve as further discussions occur in the future.

Establishing the need for regional ICM is an important first step that will guide and shape the subsequent planning process. In a broad sense, it can be concluded that yes, there is a need for regional ICM to address impacting events or conditions across broad corridors that span multiple states or jurisdictions (far larger than most urban ICM plans cover). The need for ICM to address such conditions warrants the development of a planning approach for regional use. In a narrow sense, it must be determined whether ICM is necessary to address a specific event, condition or scenario in a specific region or for a specific corridor. If the necessary infrastructure (i.e., alternative routes) exists between two endpoints that can accommodate traffic diversions, then regional ICM is also warranted in a narrow sense. Of course, that corridor must first be identified, and the various stakeholders must come to an agreement that regional ICM is a topic they should discuss.

It is also important to determine when regional ICM should be considered. The use of regional ICM will entail a significant amount of resources (staff, financial, infrastructure, etc.) to plan and implement. Consequently, the events, conditions or scenarios that it would address need to be carefully identified and selected. The use of regional ICM is not appropriate or easy to justify for every situation. However, when a major reconstruction activity or weather event (e.g., blizzards on mountain passes) is expected, then the implementation of regional ICM may be considered. The specific event, condition or scenario sets should be discussed among the stakeholders involved with the corridor under consideration.

The mention of stakeholders raises another factor for consideration: coordination and interagency operations. In pursuing plans for regional ICM across multiple jurisdictions and routes, multiple parties and facilities will be involved and impacted. Consequently, the regional ICM planning process will need to consider the development of interagency agreements and protocols to guide the implementation and operation of ICM when it is employed.

Regarding the primary route being impacted and the alternative routes used for diversion, the capacity and suitability of the existing infrastructure should be considered, as should current and periodic activities (construction) that could impact the suitability of diversion routes if ICM were implemented. Existing infrastructure should be examined to determine how much additional traffic can be handled, where existing bottlenecks might be located, and what ITS infrastructure and field elements are available along all routes that can aid traffic management and provide drivers with information in advance of decision points. Additionally, the events, conditions or scenarios that warrant the use of regional ICM will typically occur suddenly, necessitating deployment of the ICM in a short timeframe. All of these elements should be considered and addressed throughout the planning process.

Communication and information dissemination are also important considerations. Between agencies, data sharing is becoming less of an issue, particularly as more web-based data sharing platforms come online. These tools allow agencies to monitor what is occurring at their counterpart agencies in near real time, irrespective of geographic scope. However, disseminating information to the driving public directly impacted by the ICM event remains a challenge. Adequate infrastructure, such as Variable Message Signs (VMS), HAR and even static metal signage that support the overall ICM plan must be present and functional in the field. These provide drivers with information in advance of decision points and along alternative routes. Improvements and expansion of web-based traveler information, particularly websites such as One Stop Shop (http://oss.weathershare.org/), provide an additional approach to information dissemination that extends beyond traditional jurisdictional borders.

As these factors indicate, development of a regional ICM planning process must account for unique considerations separate from those encountered in an urban environment. The rural context can provide limited parallel routes to facilitate shifts, and in most cases, no alternative modes (compared to urban environments with transit). The limited staff and financial resources that may be available for agencies to devote to the development and pursuit of regional ICM also must be considered. This requires a straightforward approach to regional ICM planning (and eventually, deployment) that is less data intensive compared to its urban counterpart.

Criteria and Protocols for Deployment

When pursing the development and implementation of regional ICM, there is a need for established criteria and protocols to guide the process. Criteria refers to the development of metrics that indicate that regional ICM is something that can be employed to address an event, condition or scenario along a primary corridor. Criteria include whether long-duration impacts to a primary route are possible, if alternative routes of sufficient design and capacity are available for diversion, whether existing/potential bottlenecks along the diversion routes can be addressed, whether the support infrastructure (field elements, interagency communications, etc.) exist to support ICM, and whether there is consensus among all stakeholder agencies that ICM should be pursued.

Consideration must also be given to protocols, both new and existing, for the planning and deployment of regional ICM. In terms of new protocols, it will be necessary for agencies to agree to coordinate efforts during ICM operations and develop interagency agreements to this end. In employing ICM across large geographic distances and across jurisdictions, there may be a need to revise some existing emergency response protocols at individual agencies to ensure uniformity of actions. Part of the ICM planning process should include an approach to address these needs. However, it can also be expected that in many respects, existing protocols can remain in use or even employed at other agencies (if a best practice is identified during a review of protocols).

Finally, the deployment of regional ICM during an event, condition or scenario must also have established protocols. The development of these protocols must be incorporated into the overall planning process. To some extent, guidance and discussion related to deployment exists through the various reports and documents generated by the U.S. DOT ICM effort. Specifically, such information is presented on the U.S. DOT's Integrated Corridor Management website (43) under the "ICM Knowledgebase" portion of the site. As the U.S. DOT site work progresses, it is expected that additional documents and guidance will become available.

Approach

By examining existing literature, reviewing existing EOC protocols, defining regional ICM, identifying factors to consider, and establishing general criteria and protocols to address/incorporate, a proposed regional ICM planning process was developed. This process has been developed in a manner that takes into account the broad geographic and jurisdictional scope that will be present for most rural applications. It also attempts to address the limited financial and staff resources that may initially be available to devote to planning regional ICM. In essence, the planning process laid out in Figure 1 seeks to first identify the need and applicability of regional ICM at a high level, followed by more detailed development of documents such as the Concept of Operation, Requirements, Interagency Agreements and General Protocols. The approach presented here is an initial outline and is expected to be modified based on discussions and subsequent input. This approach proposed for the regional ICM planning process is discussed in further detail in the following paragraphs.

The regional ICM planning process, illustrated in **Figure 1**, begins with a group of entities (this may be as small as two parties) identifying a need to address different events, conditions or scenarios that may occur along a primary corridor and may have a significant impact on mobility for an extended period of time. The extent of the corridor can range from compact (covering only a few counties) through broad (covering multiple states). Regardless, the initial step in the regional ICM planning process is for a group of individual entities to recognize that there may be a need to address an issue or issues and then to bring together a larger group of stakeholders from the geographic area for a group discussion. Stakeholders may include, but are not limited to, DOTs, state and local police, local fire departments, general state and local government entities, EOC leadership, TMC/TOC staff, and local or county public works staff.

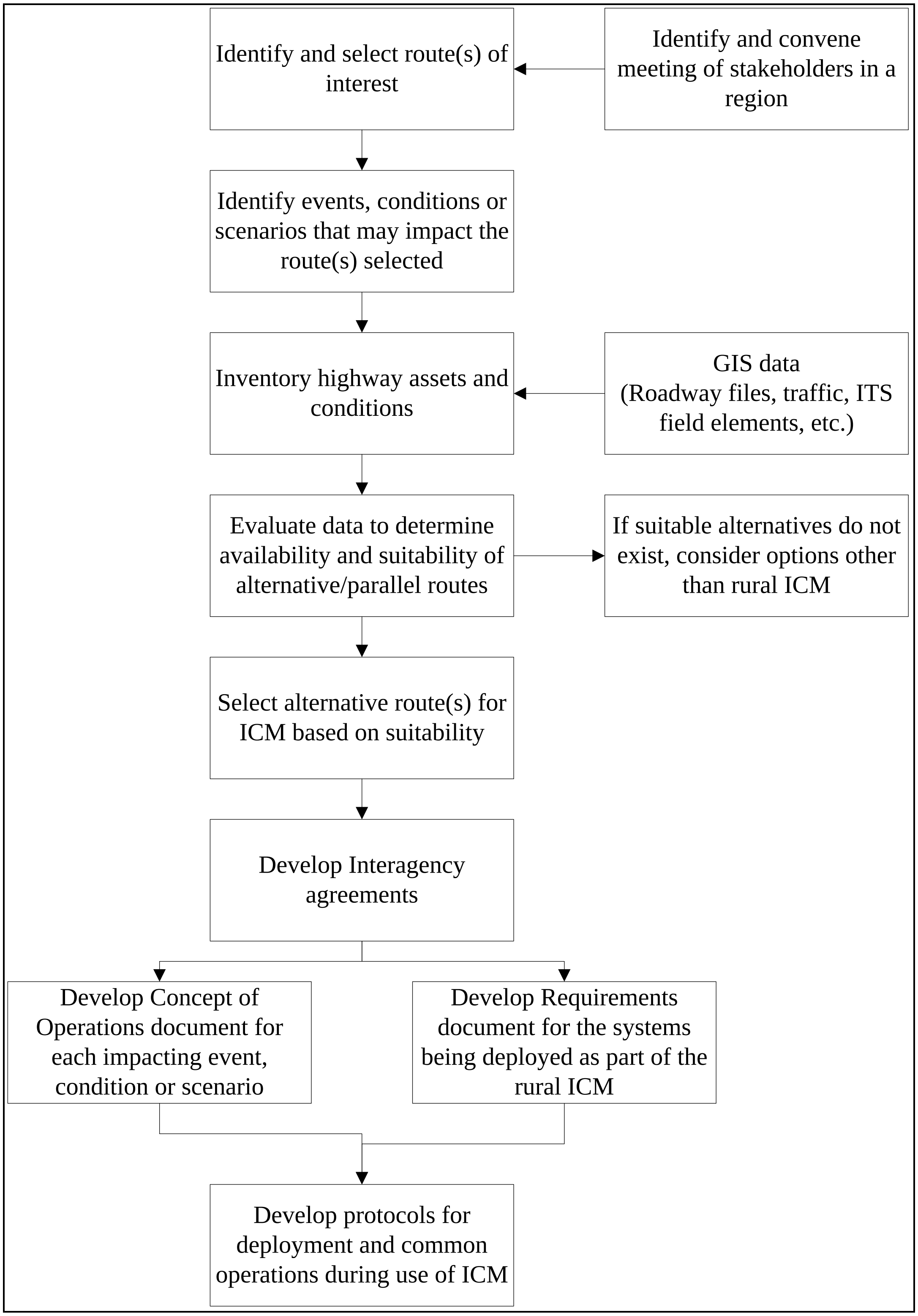

Figure 1: Flowchart of regional ICM planning process

Once a meeting of stakeholders is convened, the routes of interest (both those which may be impacted as well as those that can serve as alternates) should be discussed. As part of this meeting, stakeholders should identify an initial series of events, conditions or scenarios that may have an impact on these routes and that ICM could help address. This identification, while shown as a separate step in the flowchart, can occur within the meeting, as well as afterward as new impacts are identified by stakeholders. Regardless, the purpose of these steps is to identify routes and impacts and to develop consensus that ICM is an approach to addressing those impacts in a manner that keeps long-distance traffic moving along alternative routes or corridors.

Once routes have been identified at a high level, the next step in the approach is to inventory existing highway assets and conditions. This step of the process seeks to identify whether alternative routes exist (beyond the extent to which stakeholders have already identified potential alternatives) and establish whether these alternatives can handle increased traffic due to diversions from the primary route. It is envisioned that such an analysis would be performed by one lead entity (e.g., a DOT district or regional office) to address the limited funding and staffing available from rural entities. The intent of this step is not to develop sophisticated models, but rather to identify alternate routes and establish whether they would be suitable for handling increased traffic when a regional ICM plan would be deployed.

The next step would be to use Geographic Information Systems (GIS) data to identify alternative routes and establish whether they are suitable for use in a regional ICM setting. This data would include roadway attribute files (typically containing pavement types, traffic volumes and other data), location of ITS field elements, intersection attributes, and so forth. GIS data would be processed to establish whether routes identified as prospective alternatives would be suitable for ICM use in terms of design (i.e., gravel roads are not acceptable to handle diverted traffic) and capacity (extra capacity available to absorb diverted traffic). If such routes are not present or identified, then the planning process should conclude that regional ICM is not the best strategy to consider, and alternative approaches or practices should be evaluated. The intent of this step, which will be further developed through continued work beyond this white paper, would be to establish how such data may be used and to develop criteria that should be considered in determining when a route(s) can be used in regional ICM plans.

Following evaluation of GIS data, the selection of alternate routes to be used during ICM events would be made. The criteria that would be employed in selecting alternative routes could include:

- Potential for an impacting event, condition or scenario to occur which will reduce or eliminate the present capacity of a primary route from handling traffic for an extended period of time (e.g., greater than 24 hours).
- Availability of alternative routes with appropriate designs and features (i.e., paved).
- Adequate capacity to handle at least some traffic diverted from the impacted route (i.e., is the alternative route under design capacity at present.).
- Presence or absence of bottlenecks or other features that could impact throughput.
- Availability of ITS field elements to convey real-time information to vehicles and to provide ICM/Transportation Management Center (TMC)/Transportation Operations Center (TOC) managers with real-time performance data.

- Availability of adequate services (gas stations, grocery stores, hotels) along a route. For the purposes of this work, the existence of communities of significant size (5000+ residents) would be used as a proxy for the presence of such features (as GIS files do not typically exist to provide detailed business data).

Within the context of this project and the data that was available, the work focused on the identification of impacting events, design features of available routes, adequacy of those available routes (capacity) and available ITS field elements. Note that within the scope of the current project, identification of route alternatives was the point where work concluded.

Steps following this point address more detailed development of documents and agreements that were beyond the scope of an incubator project setting. For completeness, however, a brief discussion of the remaining planning steps is provided in the following sections.

Before progressing to the development of detailed documents and plans, it would be feasible for Interagency Agreements to be developed and signed. This should only occur if all agencies agree that pursuit of regional ICM will be beneficial and they are willing to devote the necessary resources to the effort, both in additional planning and deployment. This will also help to ensure that there is support and resources for the development of the more detailed documents that will follow, particularly in terms of staff and finance.

Once the ICM routes have been selected and agreements signed, the next step is to develop detailed Concept of Operations and Requirements documents. These steps should be completed collaboratively by different stakeholders, although one agency should take the lead in development for coordination purposes. The Concept of Operations (ConOps) lays out what the regional ICM plan will do during a specific event, condition or scenario. Depending on the number of impacts that are expected along a corridor, more than one ConOps document may need to be developed. The ConOps will outline the specific practices and procedures that are recommended for an event, condition or scenario – particularly ones that result in a long-term closure of the primary route. The Requirements document for a regional ICM will discuss what data would be acquired and used in deploying and managing ICM, from what agencies it will be acquired, how it will be presented, and other specifics related to the data-sharing and management. The Requirements document will also provide a preliminary blueprint to guide the development or deployment of infrastructure or other needs related to the regional ICM. As a result of the ConOps and Requirements documents, all stakeholders will be aware of what may be required in pursuing deployment of ICM in a rural setting.

The final steps of the regional ICM planning process entail the development of deployment/operation protocols. This step involves the development of guidance documents to aid in deploying and operating the regional ICM plan when an event, condition or scenario occurs. The documentation would cover aspects such as the setup of alternate route signage, the deployment of staff in the field, and coordinated management of operations across jurisdictions. This documentation should serve to establish the process for initiating, operating and shutting down regional ICM operations.

Chapter Summary

This chapter has outlined the development of a regional ICM planning process approach. The approach begins with a group of entities (this may be as small as two parties) identifying a need to address different events, conditions or scenarios that may occur along a primary corridor and may have a significant impact on mobility for an extended period of time. Stakeholders identify an initial series of events, conditions or scenarios that may have an impact on these routes and that ICM could help address at this initial point in the process. Once routes have been identified at a high level, the next step in the approach is to inventory existing highway assets and conditions. This would be done using Geographic Information Systems data to identify alternative routes and establish whether they are suitable for use in a regional ICM setting. Following evaluation of GIS data and any resulting recommendations, the selection of alternate routes to be used during ICM events would be made by all agencies involved in the process. Steps following this point address more detailed development of documents and agreements. This includes the development of Interagency Agreements, as well as detailed Concept of Operations and Requirements documents. The final steps of the regional ICM planning process entail the development of deployment/operation protocols. The development of these documents and eventual deployment are not the focus of the current project and is not discussed in this report.

4. ALTERNTATIVE ROUTE IDENITIFCATION PROCESS

Unlike urban ICM applications, regional applications of ICM can often be characterized by a lack of alternative routes or parallel modes. Rather, routing in response to a particular event can entail significant vehicle diversions to alternative routes that may or may not be readily identified. Alternative routes through rural areas may not necessarily have the capacity to accommodate additional traffic, or, if they can, may require changes to signal timing plans, necessary ITS infrastructure, adequate signage and so forth to address potential diversions. Regardless, such routes must first be identified, and potential limitations present on them must be accounted for.

At first glance, one may assume that studying a general map such as those provided by Google Maps could yield an alternative set of routes that could be used in ICM. In some cases, this could be done, albeit in a general sense. Study of such maps could provide those involved in planning the ICM an idea of prospective routes that could be investigated for inclusion, but beyond this high-level identification, the suitability of those routes cannot be established. Rather, more detailed analysis is required to establish the suitability of prospective routes based on different aspects, including, but not limited to:

- Overall travel distance and time compared to affected route.
- Suitability of route to handle additional traffic.
- Impacts of additional restrictions.

To take such factors into consideration, Geographic Information Systems provide a useful analysis platform. Most transportation agencies use GIS packages from different vendors so there is a familiarity with such tools for staff. Many of these software programs provide a mechanism that allows a user to identify routes based on blockages, features (length, travel time, restrictive features such as congestion or bridge restrictions) and other factors that can be translated into costs or time. GIS analysis completes the highway asset inventory and data analysis/route identification steps of the ICM planning process. Of course, other approaches to asset inventory, identifying alternate routes and so forth exist, such as spreadsheet analysis, paper maps, etc. For this work however, GIS was the preferred approach given its data processing and mapping capabilities.

The following sections discuss the collection of data and the application of GIS analysis to the overall ICM planning process in identifying prospective routes for restrictive events. The text discusses the overall process employed in such a manner that it can be used in any formal ICM planning processes in the future. The work does not provide specific recommendations for alternative routes that should be used during a specific event. Rather, the work presented in this chapter represents the demonstration of the general process up to the point of selecting those alternative routes.

Approach

The approach taken was to demonstrate the use of GIS on routes identified by the WSRTC steering committee. To this end, the committee members nominated two prospective routes. The first route was U.S. 395 from Mojave, California northward to Carson City, Nevada. The route has few alternatives when impacted by activities such as construction, and is also located in an area where volcanic activity could occur. The second route identified by the committee was California State Route 299 eastward from Arcata, California to its intersection with US 395 and then northward on U.S. 395 to its intersection with U.S. 20 in Oregon. This route passes through mountainous areas which are susceptible to fires, land and rock slides and weather events.

With these two study routes identified, the next step in the process was to acquire the data necessary to identify prospective alternate routes based on length, travel time, capacity, availability of ITS infrastructure, etc. This required a data collection effort that is discussed in the next section.

Inventory of Data and Assets

All of the respective states that the study routes pass through maintain various GIS databases. At the most basic level, the primary GIS data of interest to this work were roadway files. In general, it was expected that these files would provide basic information such as number of lanes, pavement type, traffic volume, speed limit and so forth. This information would then be used to eliminate roads that were not suitable alternatives for detouring traffic, such as gravel roads, residential streets, etc. The information would also be used to determine whether sufficient capacity would be available to absorb diverted traffic from the study routes.

During the course of obtaining the roadway shapefiles from California, Nevada and Oregon, it was found that each state had constructed their databases and shapefiles using different fields. This would not necessarily be an issue, provided that in general the primary fields that were needed, such as number of lanes, were present in each database. If the necessary fields were present in each database, then they could be merged together and provide a unified dataset for analysis. Unfortunately, the existing state datasets did not share even basic fields in common. For example, the Oregon DOT maintains separate shapefiles for roadway geometry, Annual Average Daily Traffic (AADT), pavement type, and pavement width which did not share a common field identifier by which they themselves could be linked. The Nevada DOT and Caltrans shapefiles lacked information on traffic volumes. Individually, the roadway data for each state was adequate, if missing some important components; however, when examining corridors crossing state lines, this data could not be combined to provide a seamless network dataset.

In order to address the issue of having a common file for roadways in the three state region, alternative data sources were sought. During the course of that search, it was found that data from the Highway Performance Monitoring System (HPMS) had been incorporated into shapefiles (46). The HPMS is a national program that inventories information for all federally-funded public road mileage annually. The shapefiles were developed for each state, but provided a series of datasets that could be merged together to provide one complete file. The HPMS data contained elements needed for ICM analysis including AADT, functional classification and number of lanes. While pavement type and width were not provided, it was assumed that given the nature of the routes that the HPMS inventories, all were paved (asphalt or concrete) and generally had lane widths exceeding 11 feet. One additional point to note is that the most recent year of data available was 2012, and this was used for the analysis presented here.

In addition to roadway information, similar data was collected for bridges using National Bridge Inventory (NBI) text files that contained spatial coordinates (47). This data provided information on bridges in each state that had weight or height restrictions associated with them. These bridges would pose an issue for rerouting traffic from the study corridors. As such, bridges which presented such restrictions were included in the later analysis as posing an added cost to the particular segment they were located along. For the purposes of this work, bridges with a posting value of 4 or less indicated a weight restriction, while bridges with an over or under clearance of less than 4.3 meters were height restrictive, with both of these thresholds established by NBI guidance.

ITS field element data is essential to redirecting traffic, providing guidance along alternative routes and monitoring conditions along various routes. In light of this, the availability of ITS elements, namely CMS signs, Closed Circuit Television Cameras (CCTV) and Road Weather Information Stations (RWIS) stations was of interest. While the presence or absence of such features was not directly considered when the route analysis was performed, a visual identification along the prospective routes identified by the program would still prove useful when considering what route(s) should be selected. The three study states did not have publicly available shapefiles for these respective elements. However, the location of these features was known through other research efforts, and this information was developed into the necessary shapefiles using coordinate data (48, 49).

Aside from this data, two other data elements were of interest but not crucial in demonstrating the ICM planning process during the course of this work. The first data element would be long range transportation plan estimates for future traffic volumes. This information would be of interest in order to accommodate for future increases in traffic when identifying prospective alternate routes. It is possible that future traffic along a given route or segment might eliminate it from being a useful alternative at some point in the future. As a result, that route or segment should be accounted for when identifying prospective alternatives in the present. Such data was not readily available in a format that could be used in this work; consequently, the route alternatives identified were generated for the present day scenario only.

The second data element of interest was data related to signalization along roads in the study area. This data would include the presence/location of signals, as well as general timing information (such as the maximum length of green time per cycle that a respective route might receive). Such information is not maintained in a shapefile format by any of the study states (nor indeed by most agencies). The acquisition of such data from individual agencies and coding of that data into a GIS-usable format, even for information as basic as coordinate locations, was beyond the scope of this work and in itself represents a significant effort. As a result, signalization data such as presence and maximum green time was not considered during the course of this work. However, this information is of great importance when considering the impacts that rerouted traffic might have under an ICM scenario, and the development of such a database and its inclusion in route analysis should be investigated further in the future.

With the requisite data acquired, the next step of the process was formatting. This would provide a common, unified dataset which could be used for route identification and analysis. However, the data itself required clean-up before it could be considered usable for route identification and analysis. The approach involved in this process is discussed in the next section.

Data Formatting

The initial step in assembling the unified dataset covering the area of each study route was to format and prepare the necessary datasets. For the U.S. 395 corridor, this consisted of merging together California and Nevada road shapefiles, while California and Oregon road shapefiles were merged for the S.R. 299-U.S. 395 corridor. These abbreviated areas were merged in order to provide a more compact study area and routes for later evaluation. Conceptually, the merging of three separate shapefiles joins them together into one, unified file, as shown in Figure 2.

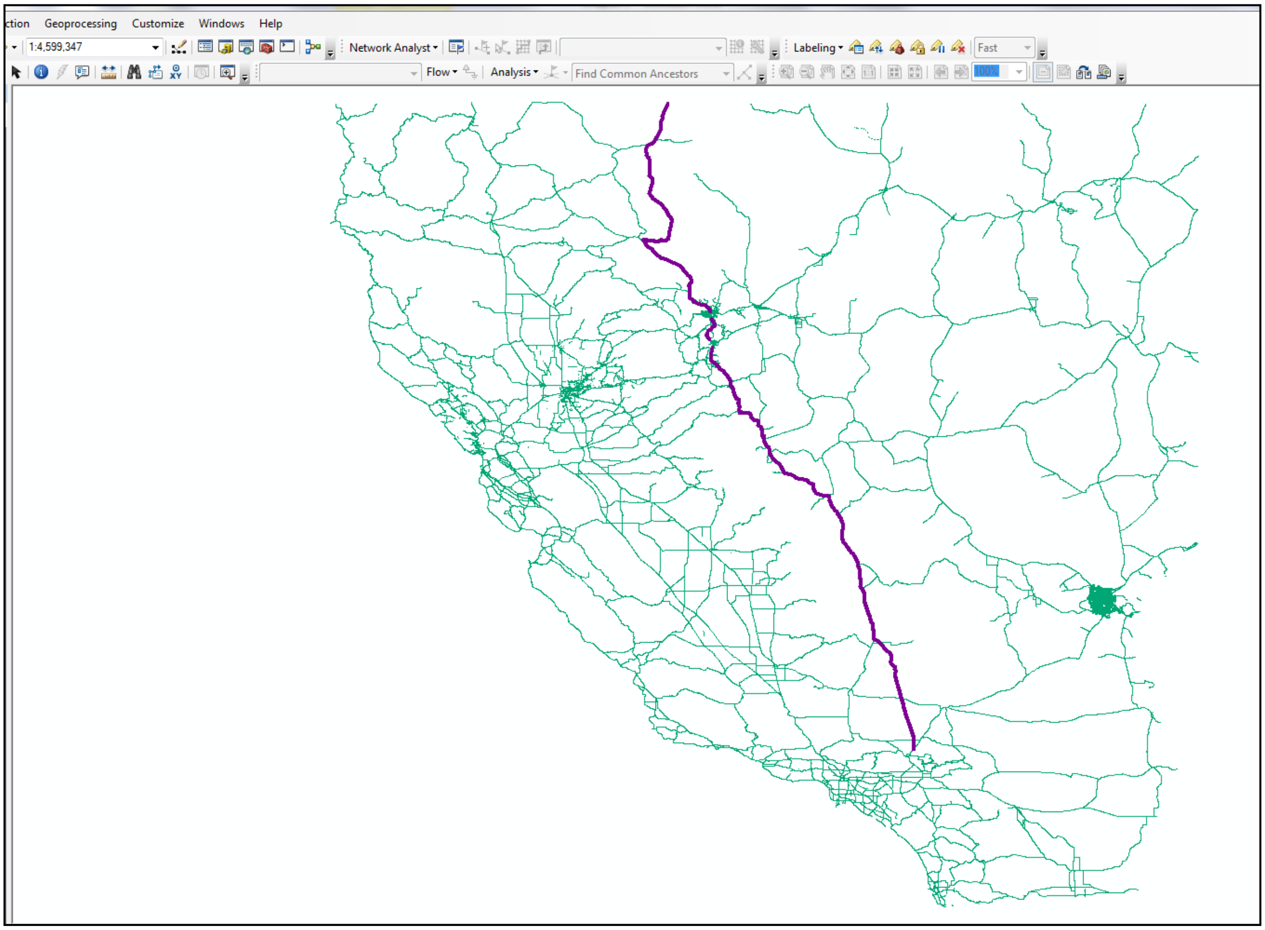

Figure 2: Merged road shapefile for the U.S. 395 corridor

Once the road shapefiles were merged for each of the study routes/regions, additional files were created to incorporate bridges (weight and height restrictions) and ITS elements. In creating these files, the primary concern was ensuring that they were projected in the same coordinate system as the road shapefiles (Geographic Coordinate System World Geodetic System 1984, or GCS_WGS_1984). To address this, the files were converted from one project system to another when there were conflicts using GCS_WGS_1984 coordinates for all shapefiles. In addition to projections, the creation of the bridge shapefile focused on only those structures that presented height and/or weight restrictions in order to pinpoint only those locations that would present an issue under an ICM scenario. The project file resulting from these early steps is presented in Figure 3.

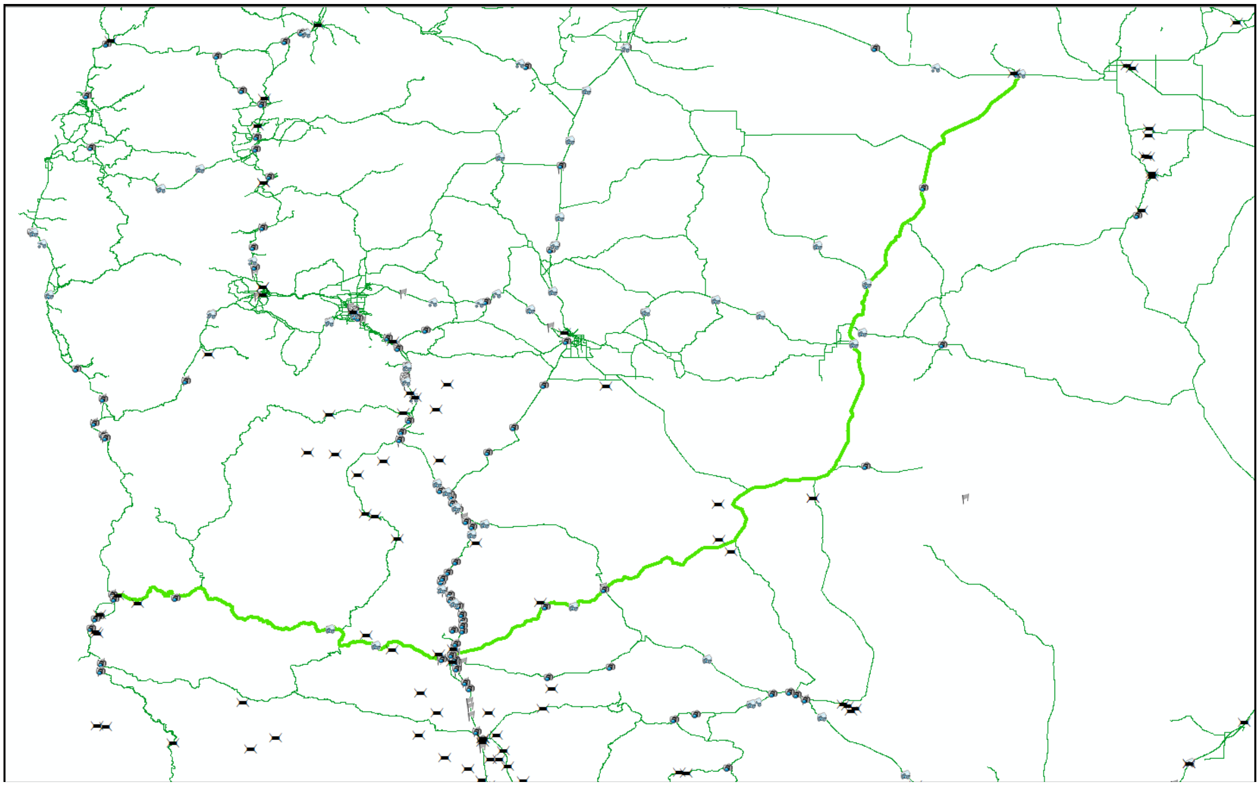

Figure 3: Final set of shapefiles for the S.R. 299-U.S. 395 study corridor

At this point, all of the files available for consideration in the analysis had been formatted, and the initial attempt to identify alternative routes was performed. This involved creating a network file that assigned costs (time) to each roadway segment in order to identify the shortest path(s) when evaluating the network. The creation of this network is discussed later in this section, for reasons discussed in the following paragraphs.

During the initial attempts to identify alternative routes using the initial networks that were created, it was observed that no routes, including the direct U.S. 395 corridor, could be identified by the program between Mojave, California and Carson City, Nevada. Upon further investigation, a reference document (50) indicated that shapefiles of roadway segments can have gaps between line segments that do not necessarily appear unless the location has been magnified to a high degree. In examining the study area data for each route, it was discovered that such gaps existed both at the borders between states as well as on the road networks within each state. Such gaps are largely the result of digitizing errors when developing the line segments. This was the cause of the inability to identify paths over long distances between endpoints and required correction.

To address the gap issue, a process called integration had to be performed. Integration removes the gaps between segments or intersections where they exist based on a tolerance specified by the user. In the case of this work, a high tolerance value (25 feet) was used to ensure that significant gaps between segments would be identified and corrected. GIS facilitated the integration process by examining each road segment and determining if another segment lay within a specified distance and connects those segments when they fall within that distance of one another. The integration process run on each road shapefile for the study areas effectively addressed the issue, and the roads between and within each state were effectively connected as a unified network.

Once the issues with gaps had been addressed, it was next necessary to add respective time fields to the road shapefile. These time fields were based on posted speed limits for each route compared to the length of the respective segment. Unfortunately, the HPMS data used to create the road shapefiles for the regions did not have speed limits for each segment included as a data field. The files did contain functional classification data for each segment, so it was possible to assign a general speed limit based on that classification. For the purposes of this work, routes classified as interstates were assigned a speed limit of 70 miles per hour (mph), major arterials a speed limit of 55 mph, minor arterials a speed limit of 45 mph, and locals and collectors a speed limit of 35 mph. While these speed limits are general and it is admitted that they would not always match the speed limit posted in the field, they did facilitate analysis for the purposes of this demonstration. Speed limits and the calculated travel times for each segment were added as new fields into the shapefile.

In addition to travel time, another field was added to account for the potential for an alternative route to accommodate a shift of traffic from the primary route. This was done by assuming that the highest hourly AADT value of the primary route that would have reduced traffic flow or be closed was added to the alternate segment during the highest AADT hour for that road. The motivation was to identify whether the capacity of that alternative road would be exceeded at any point by adding more traffic during its highest hour of traffic. AADT were determined by using the assumption of Caltrans' HPMS manual that this peak was 6 to 8 percent of total AADT for freeways and 9 to 15 percent for non-freeways (51). A value of 1,700 vehicles per hour per lane was used to establish roads that were exceeding capacity, based on Highway Capacity Manual guidance (52). Routes that exceeded this value had an additional cost added when the network was later analyzed.

Formatting of the various datasets was completed at this point. The next step was the development of a network dataset. This dataset was a conversion of the existing roadway shapefiles for each of the study corridors in a manner that stores the connectivity of the source features from the original file. In other words, the network dataset identifies locations, such as intersections or interchanges, where a vehicle can enter or leave a specific path. This connectivity is crucial in the context of identifying alternative routes for a corridor, particularly in ICM analysis. The following section discusses the analysis of the network in identifying alternative routes to the study corridors using an overall ICM approach.

Analysis

Using the two study routes discussed in the "Approach" section, the next step in the process was to identify route alternatives. This portion of the analysis can answer a number of different questions, including what is the shortest path between two points (distance or time), which routes can serve a specific location (business analysis) and what alternative routes are available if a primary route is blocked in one or more locations. In the case of ICM, this latter feature is useful in identifying what alternative paths are feasible if a primary route is blocked in one or more locations. To identify alternative routes, different start and stop points for a primary route along with barriers along that route were added to the analysis. The stops are specified by the user as the beginning and end points of the study corridor in the case of ICM. Barriers allow the user to specify points where a restriction may be encountered. Point barriers represent locations that represent a restriction or an added cost, such as a bridge-related weight limit. Line barriers are restrictions that prevent connectivity (traffic flow) beyond a specific location. Similarly, polygon restrictions are entire areas where a path cannot be followed. Polygon barriers are especially useful in ICM analysis in eliminating entire areas from consideration and speeding up analysis when identifying alternative routes. With this background, a specific discussion of the analysis for each of the study routes can proceed.

U.S. 395

Recall that the U.S. 395 route could be impacted by construction and possibly volcanic activity. To account for these potential obstructions, the focus of the analysis was on restricting traffic from proceeding on different segments by using the line barrier restriction. The restrictions used in this evaluation are general; the precise location where a restriction is placed would depend on the specific event being addressed. For example, if construction was being performed in the middle of the U.S. 395 route, then restrictions would need to be placed following junctions with major cross routes in order to divert traffic before it reaches the work zone.

In identifying alternative routes for U.S. 395, three types of restrictions were used. Point restrictions were added using the bridge restriction shapefile. Line restrictions were added at two points within the U.S. 395 corridor to represent construction. These restrictions redirect all traffic, presenting a worst-case scenario for rerouting. In reality, it is likely that U.S. 395 would remain open to at least limited traffic (perhaps single lane through the work zone) and the complete AADT on that segment would not need to be redirected. Regardless, for the purposes of demonstration, these line restrictions illustrate a completely closed scenario.

Finally, polygon barriers were used to restrict the consideration of roads that would be well outside of a logical distance for diversion. For example, when looking at rerouting traffic from U.S. 395, it is unrealistic to consider sending that traffic as far away as Las Vegas or along the Pacific coast. Still, depending on the nature of the evaluation, it is not feasible to simply eliminate these routes when creating the roadway shapefile or network dataset, since a need for them could conceivably arise during the analysis. However, for the purposes of this demonstration, their exclusion via polygon barriers was preferable in order to generate reasonable route options. A screen capture of the complete project, including the different restrictions, is presented in Figure 4.

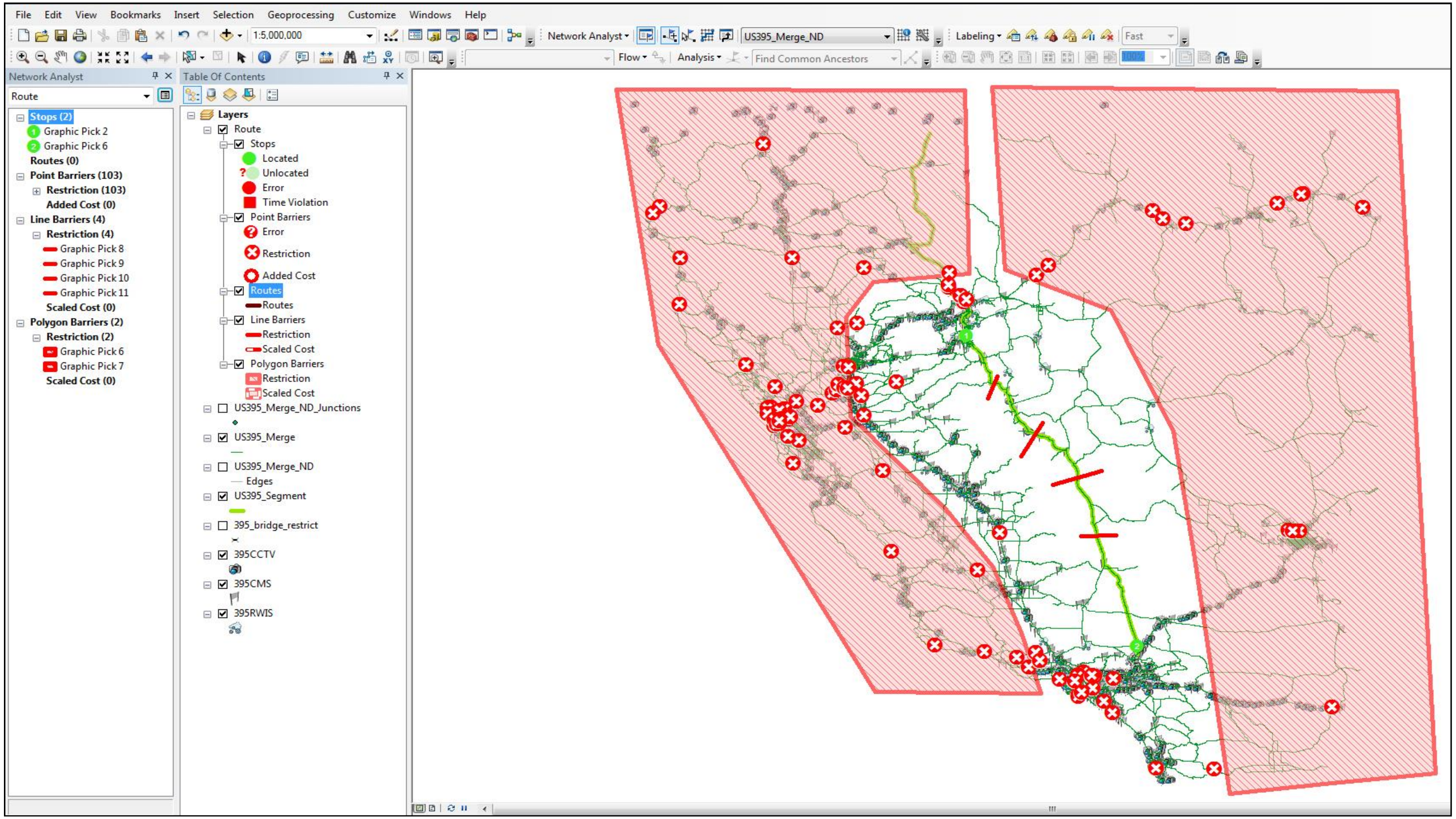

Figure 4: U.S. 395 project file with restrictions added

The result of the network analysis based on the restrictions displayed in Figure 4 is presented in Figure 5. As this figure illustrates, the alternative route that was identified by the program uses a portion of U.S. 395 at each end, relying heavily on routes to the west of the corridor primarily in California. From the south, the alternate route consists of SR. 178 and SR. 58 into Bakersfield, then SR. 33, SR. 198 and SR 41 and SR 49 northward, and finally SR. 88 eastward, rejoining U.S. 395 south of Carson City. The route length was 567 miles between the endpoints and an estimated travel time of 11 hours and 2 minutes. Interestingly, this is far longer than the 343 miles and 5 hour and 46 minute travel time via the U.S. 395 corridor.

In looking at the map, the initial question one might raise is why was I-5 not part of the route between Bakersfield and at least Fresno? The answer to this is that a bridge restriction along I-5 was present. As a result, the analysis excluded this portion of the route in favor of a path that did not have such a restriction. Additionally, some segments of I-5 were characterized as exceeding capacity when diverted traffic from U.S. 395 was added. For the sake of demonstration, the bridge restriction on I-5 was removed and line barriers were added to guide the program in identifying I-5 as part of the alternative corridor, as illustrated in Figure 7.

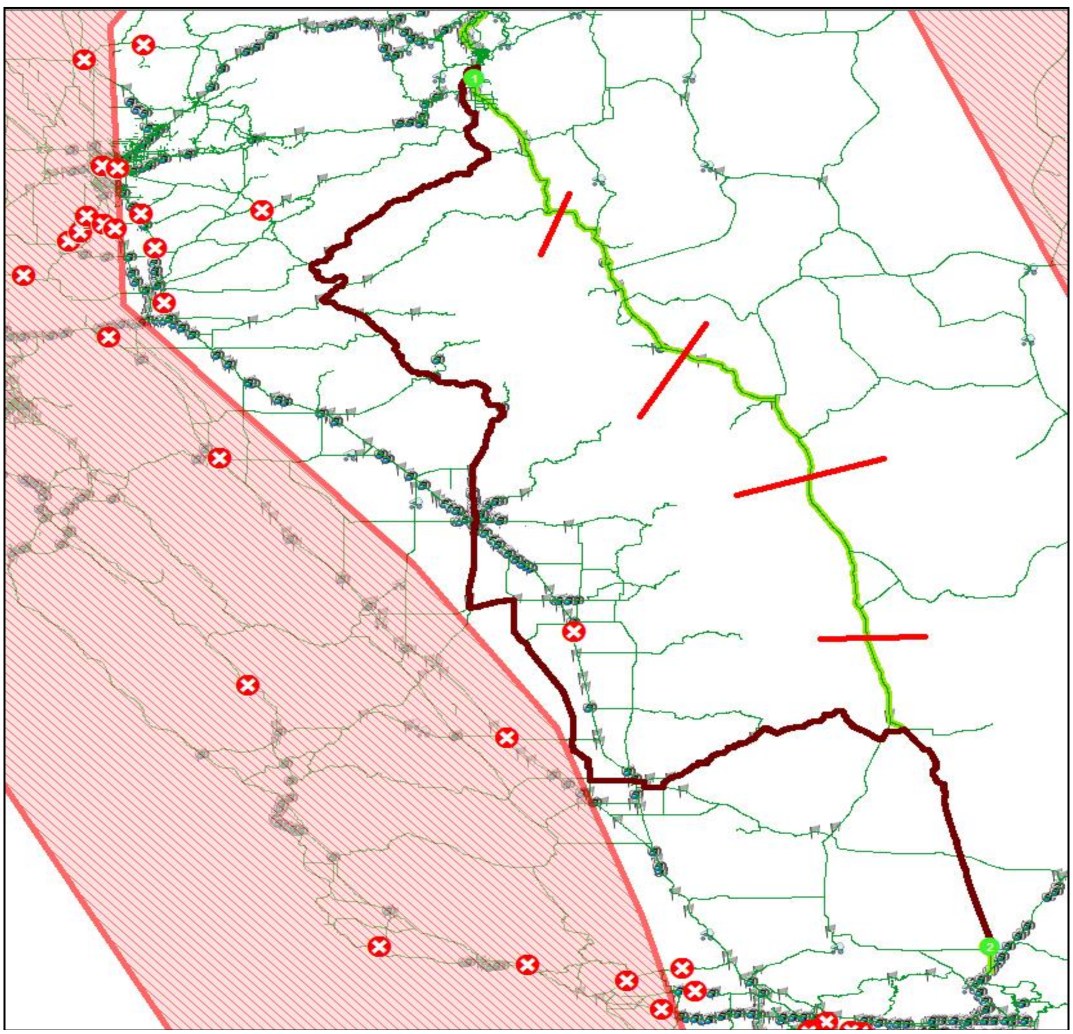

Figure 5: Alternative route identified for U.S. 395 corridor

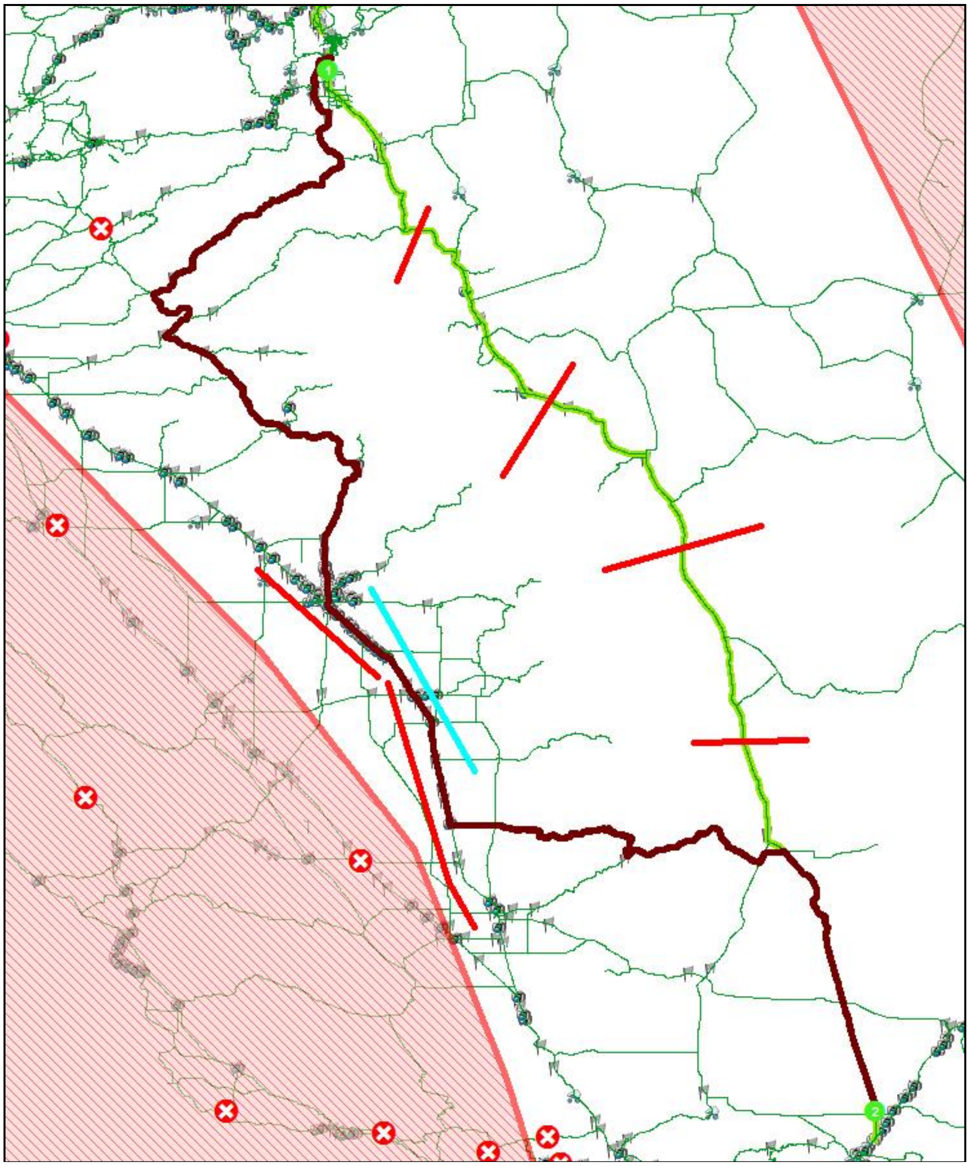

Figure 6: Alternative route for U.S. 395 corridor incorporating I-5

As the figures illustrate, aside from the I-5 segment, very few points along the alternative corridors identified are host to ITS deployments. While this should not exclude the routes from consideration, it does identify a key gap that would need to be addressed if an ICM plan was developed and eventually deployed to address the impacts of construction on U.S.395. For example, portable VMS would need to be deployed at various locations along the route to provide guidance to drivers. Additionally, temporary CCTV camera installations would also need to be considered.

As one would expect, a number of alternative routes could be created via the process of adding, moving or removing restrictions. As a result, only the routes laid out in the prior paragraphs are presented within this discussion. The intent here has been to outline how GIS can be applied to identify an initial alternative route(s) for the U.S. 395 corridor to address construction. Recall that volcanic activity could conceivably restrict traffic over a more significant portion of the corridor, as well as on neighboring routes. In this case, the use of point and line barriers is not necessarily the best approach to guiding traffic to alternative routes. Instead, a different mechanism is needed to eliminate wider portions of geography from consideration. To do this, the use of a polygon restriction covering the study route and neighboring roads will be demonstrated. Additionally, the use of a line barrier to focus the program on identifying prospective alternative routes is also employed.

As Figure 7 indicates, the route identified by the analysis is largely comprised of I-5. From south to north, the roads identified as an alternate to the U.S. 395 corridor include SR. 178 west to Bakersfield, I-5 north to the Stockton area, and then SR.88 east to the point where it intersects U.S. 395. The route length was 513 miles between the endpoints and an estimated travel time of 8 hours and 53 minutes. The bulk of this route is instrumented with ITS deployments, although SR. 178 and SR. 88 would require deployment of portable devices in the event of an ICM deployment. The route itself is free of bridge restrictions, although issues such as grades and restrictive curvature may be present on portions, particularly the SR. 88 segment.

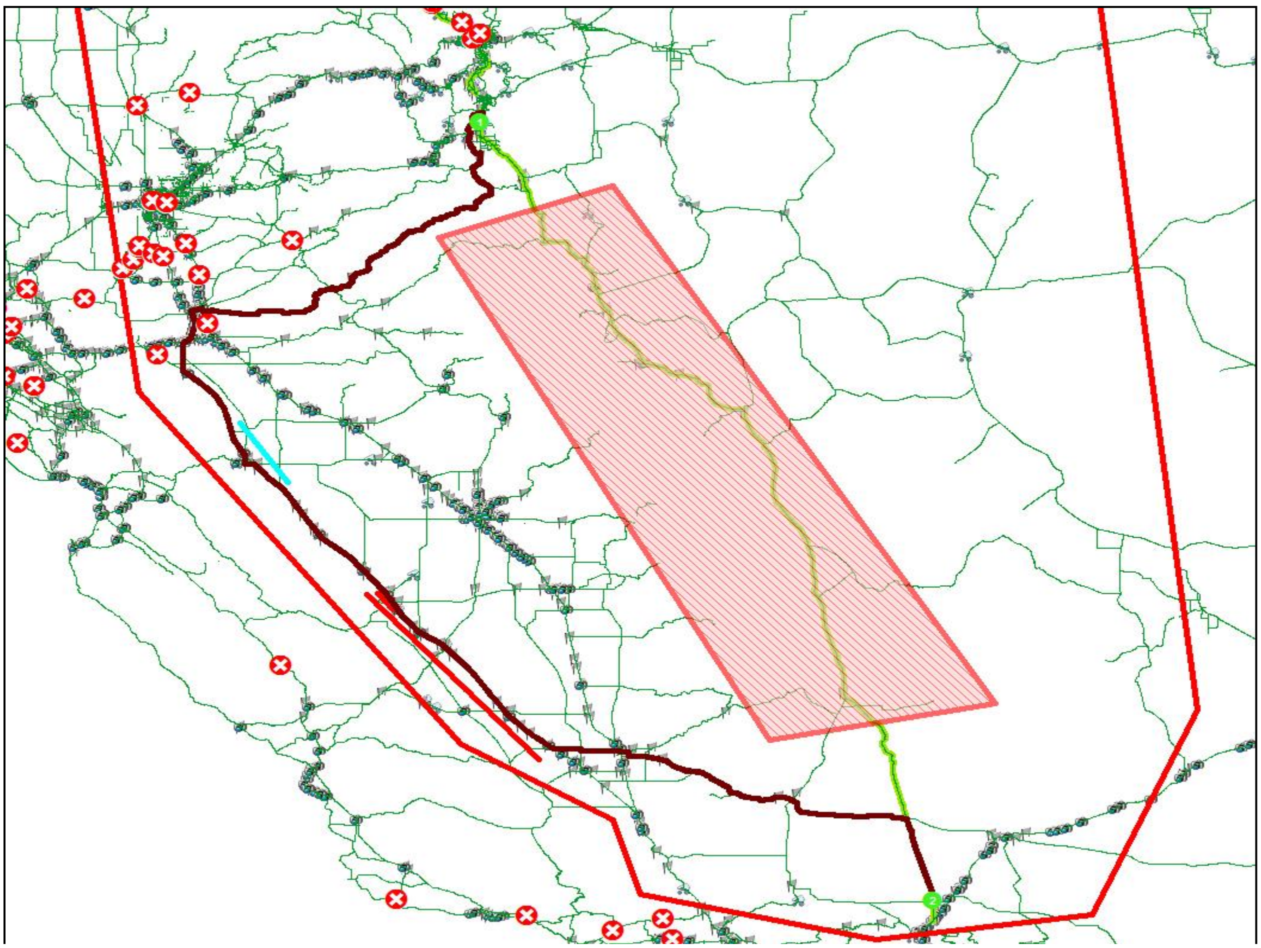

Figure 7: Alternative route identified for volcanic scenario, U.S. 395 corridor

One interesting aspect to point out is that the use of an alternative approach in setting up restrictions led to a different routing than was identified in the road construction example. This underscores the iterative nature of identifying routes that would likely be employed when developing ICM plans for rural corridors. As the approaches to identifying and incorporating restrictions and barriers changes, so too do the routes that the program will identify. If additional information is taken into account, such as terrain and grades, further iterations of a route would also likely occur.

SR299 – U.S. 395

The second route identified as being of interest was California State Route 299 eastward from Arcata, California to its intersection with US 395 and then northward on U.S. 395 its intersection with U.S. 20 in Oregon. The challenges faced on this route are related to weather, rock slides and fires. These types of events can occur at varying points along the corridor, with rock slides and weather being located in the more mountainous portions of the route near and inland from the Pacific coast and fires occurring in different locations inland.

For the first case examined, consider that a storm in the Northern Coast Range and Klamath Mountains has produced a number of rock slides that have essentially closed SR. 299 as a through route between Arcata and Redding. To do so, two line barriers are used at either end of this portion of the corridor to represent that closure. For this case, also assume that SR. 36, directly to the south of SR. 299 has also been affected by slides.

To identify alternative routes for SR 299 in this area, two types of restrictions were used. Point restrictions were added using the bridge restriction shapefile. A line restriction was added at the center of the corridor to replicate a closure of the entire route. This restriction would redirect all traffic, presenting a scenario for rerouting where portions of SR 299 may be available for travel. Conceivably, polygon barriers could have also been employed in this scenario to narrow the range of alternative routes available for analysis; however, their use was not viewed as necessary in this case given the limited route options already present between the endpoints. A screen capture of the complete project, including the different restrictions, is presented in Figure 8.

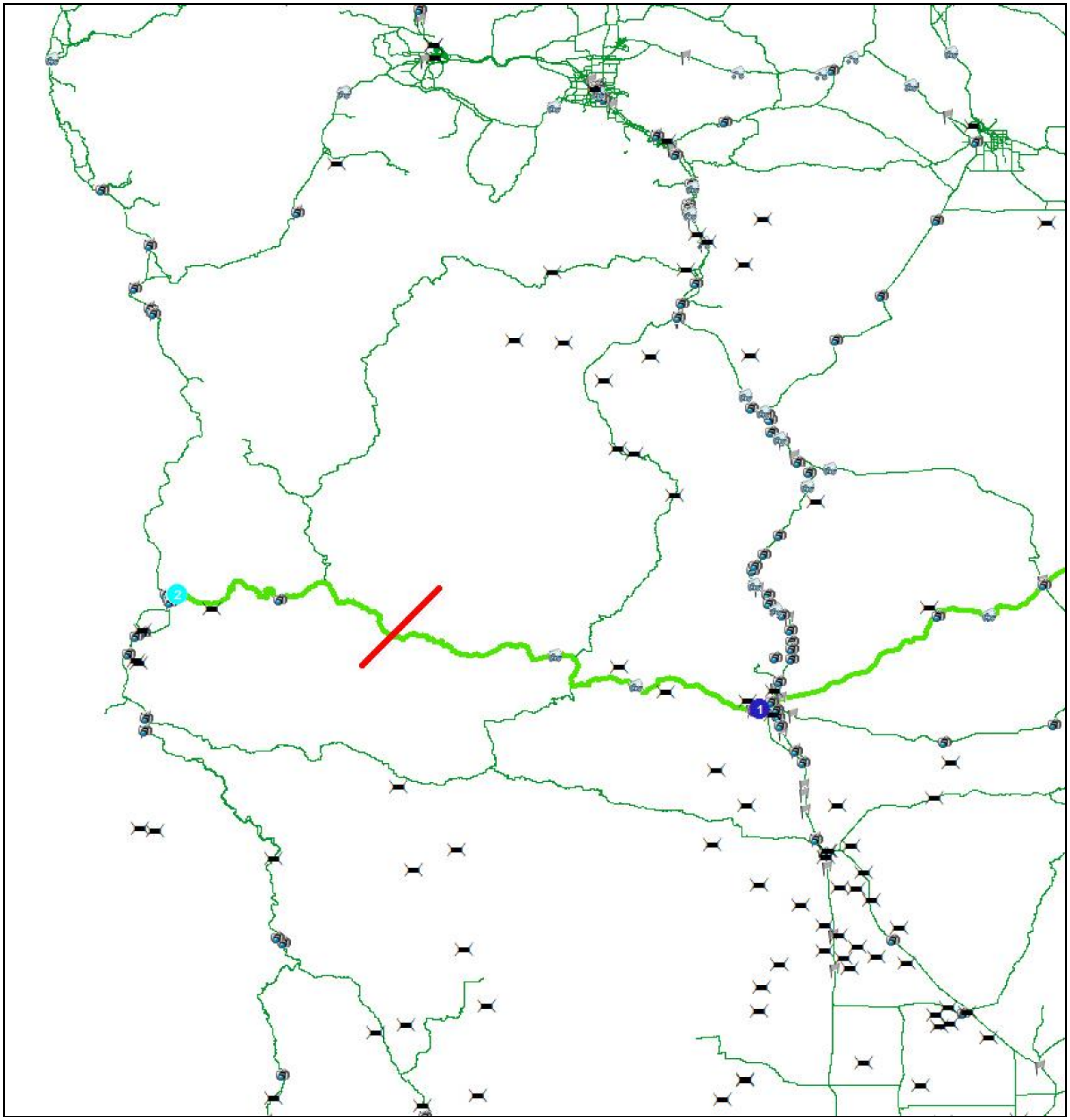

Figure 8: SR 299 rock slide project file with restriction added

The initial network solution identified by the program was a route from Arcata using U.S. 101 south to its junction with SR 36, then SR 36 eastward to the junction with SR 3, and then SR 3 northeastward to its junction with SR 299, which is then the remainder of the route to Redding. This route is illustrated in Figure 9. The total length of the route is approximately 176 miles and requires a travel time of 3 hours and 45 minutes. This is a significant increase over the SR 299 route, which be 134 miles and require 2 hours and 43 minutes of travel time. As the figure illustrates, the alternative route is lacking on ITS elements, similar to the SR 299 route. However, this could be addressed through the use of mobile CMS and CCTV devices, as needed.

While this is a viable alternative in the event of a rockslide, the route is also likely to have been affected by the same storm that caused the initial rock slides on SR 299. In light of this, an alternative scenario was also developed using a polygon restriction to limit travel in the mountainous areas of the region.

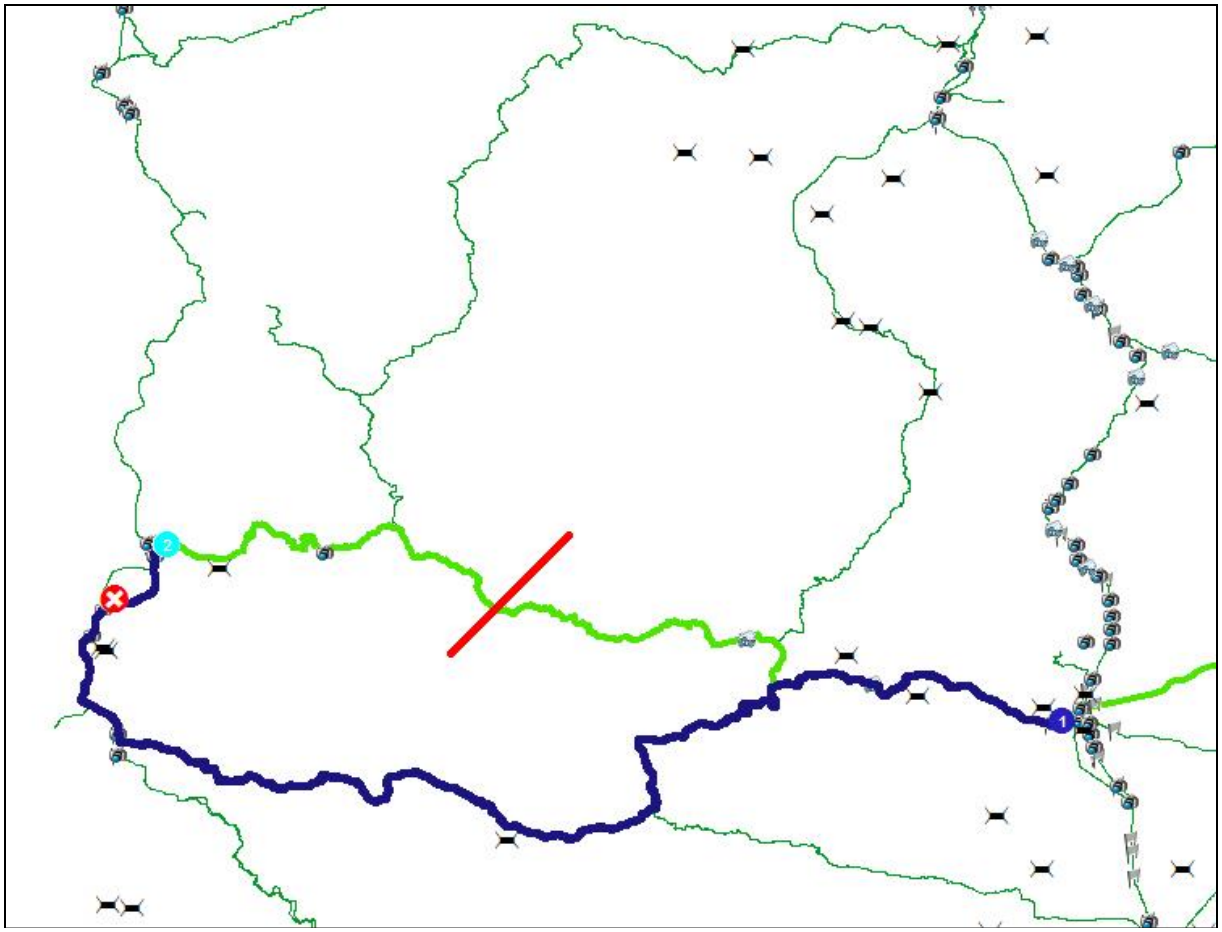

Figure 9: Initial route identified for rock slide scenario, SR 299 corridor

The polygon approach to restricting travel is depicted in Figure 10. As illustrated, a broad area and several prospective roads have been designated as areas that should not be considered for alternative routes. In this case, the routes that are available for consideration are further to the North and South of the restricted area.

Based on the polygon restriction, the analysis identified the alternative route presented in Figure 11. As the figure indicates, the alternative route identified takes a northerly path in order to proceed from Arcata to Redding. The route consists of U.S. 101 north from Arcata to Crescent City, then U.S. 199 northeast to Grants Pass, Oregon, where I-5 is then taken south to Redding. The I-5 portion of the route is heavily instrumented with ITS devices, while the U.S. 101 and U.S. 199 portions would require temporary deployments or future build-outs to assist in an ICM reroute scenario. The total length of the route is 336 miles and requires a travel time of 6 hours and 23 minutes. This travel time, when compared to the initial alternative route for the corridor, underscores the impact that multiple closures to parallel routes could have in the area. It also highlights the advantages of undertaking an initial investigation of prospective ICM routes in order to identify their appropriateness and what may be needed to prepare those routes to meet the increased traffic demands during a reroute.

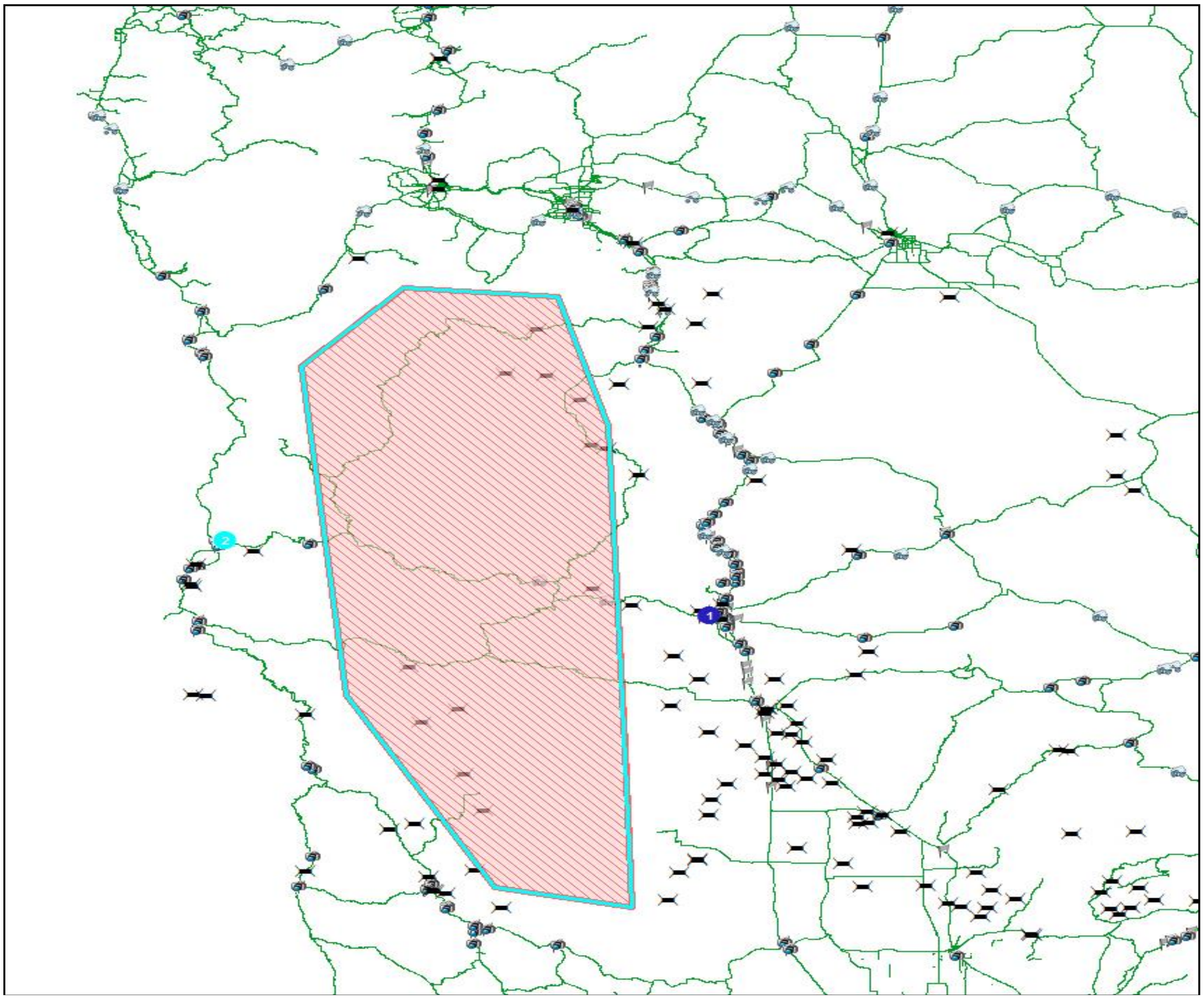

Figure 10: Polygon restriction, SR 299 corridor

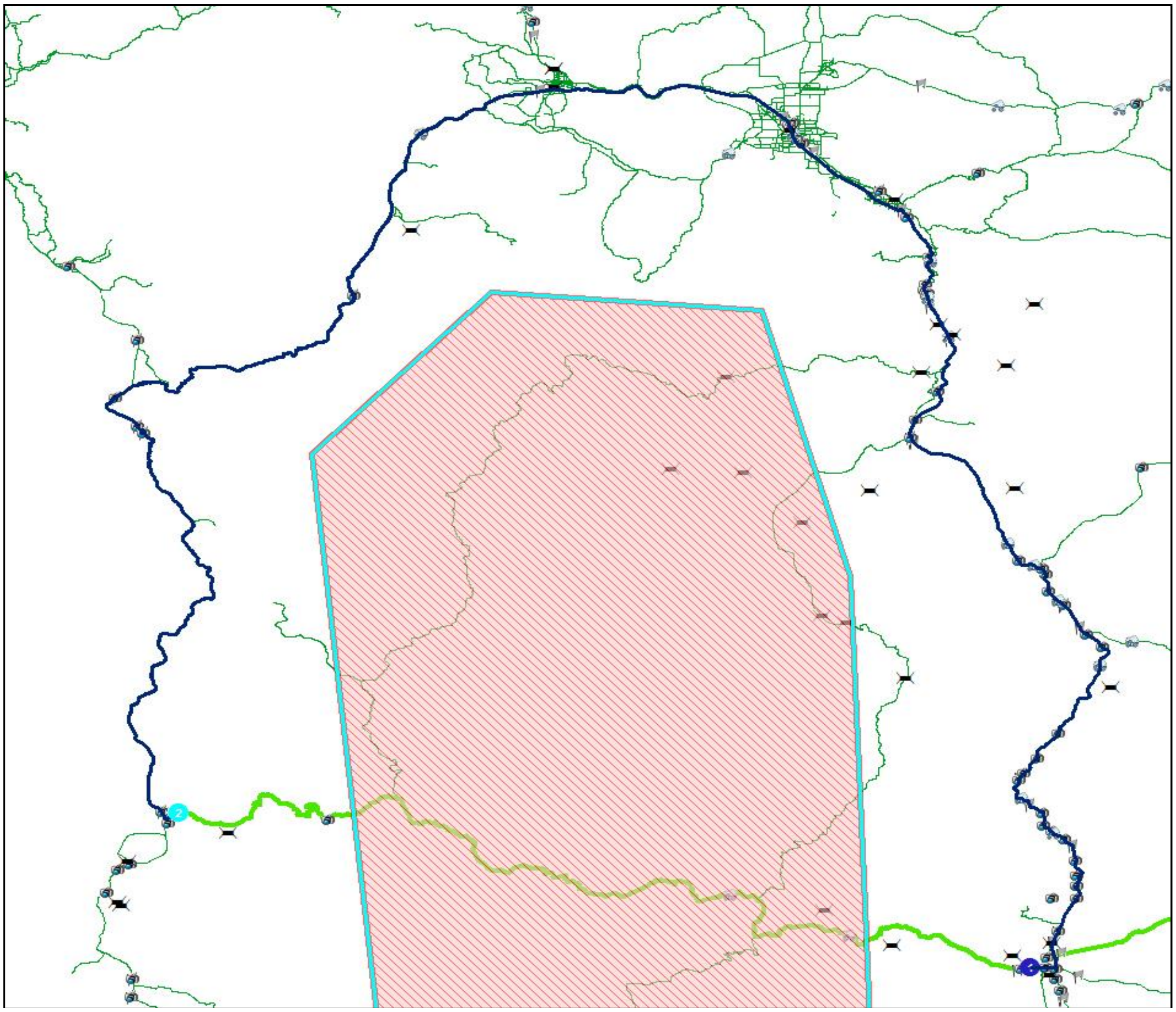

Figure 11: Alternative route identified for rock slide scenario, SR 299 corridor

The second ICM scenario considered here was the potential for a portion of the SR 299 – U.S. 395 corridor to be impacted and potentially closed by fire activity. In this case, the corridor endpoints would consist of the junction of U.S. 395 and U.S. 20 to the north (in Oregon) and Redding, California in the south. For this scenario, a polygon restriction was employed to represent an entire area impacted by fire activity. This restriction limited the available roads for the analysis to consider when identifying alternate routes. The restriction employed in this scenario is presented in Figure 12. As the figure illustrates, the northern portion of the study corridor consisting of U.S. 395 is largely unaffected, and it was expected that this portion of the corridor would be identified by the program as being part of an alternative route.

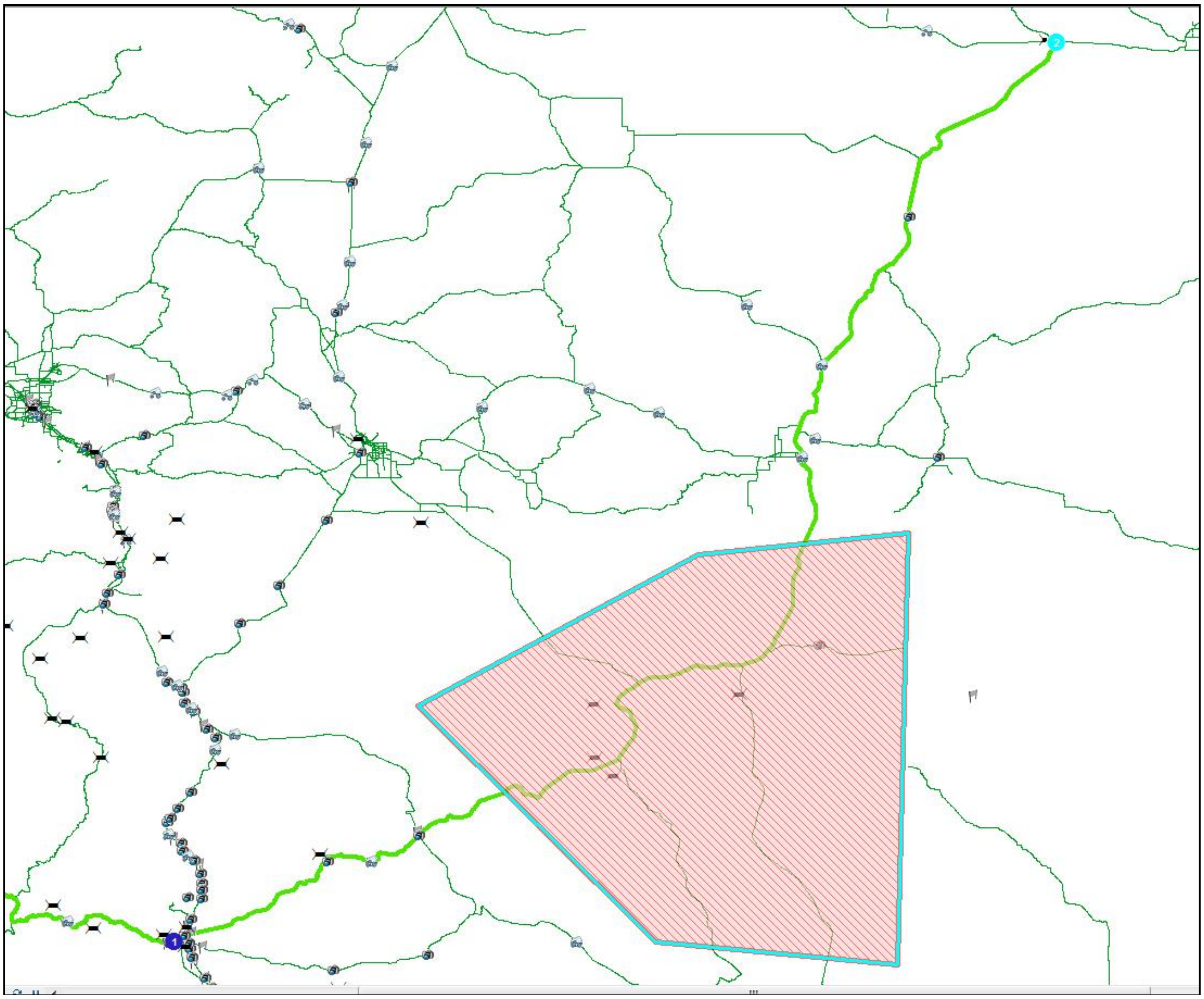

Figure 12: Restriction for fire scenario, SR299-U.S. 395 corridor

Figure 13 illustrates the alternative route identified by the analysis based on the fire restriction that was employed. The route consists of U.S. 395 south from the junction with U.S. 20, OR 140 west from Lakeview, Oregon to Klamath Falls Oregon, U.S. 97 south to its intersection with I-5 and then I-5 south to Redding. The total length of the route is 350 miles and has a travel time of 6 hours and 11 minutes. In this case, the alternative route is only slightly longer from both a time and distance perspective (314 miles and 5 hours and 41 minutes for the SR 299-U.S. 395 corridor). Overall, the corridor has only a few ITS deployments (aside from the I-5 segment) with CCTV in California and RWIS stations in Oregon. Any reroute scenario would require additional deployment of ITS devices in support of ICM efforts.

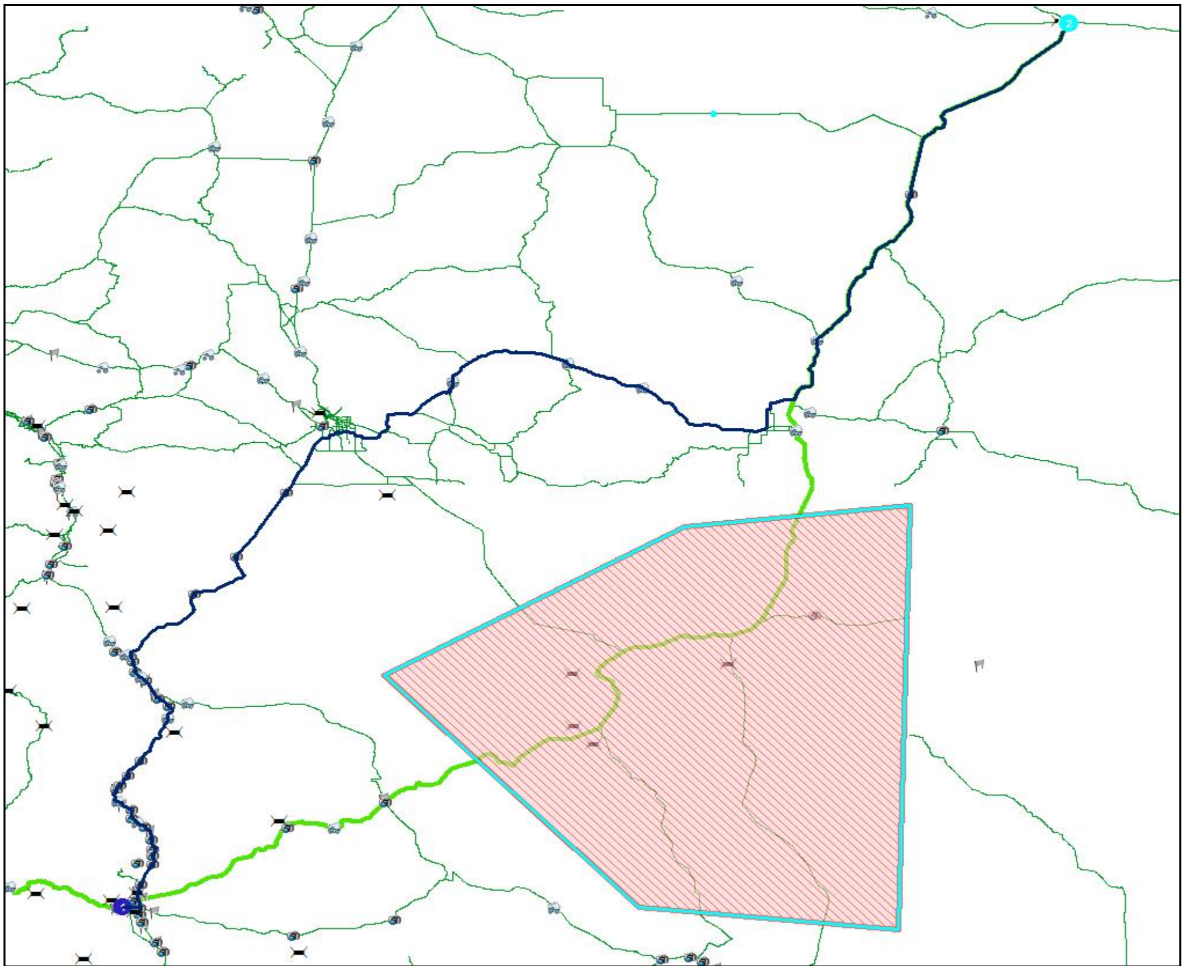

Figure 13: Alternative route identified for fire scenario, SR 299-U.S. 395 corridor

A review of the northern section of the corridor, specifically the U.S. 395 portion, shows that a similar fire-related closure would require a more extensive alternative route. To consider the impacts that a fire or other closure would have on the northern portion of the route, specifically U.S. 395, another polygon restriction was developed. This restriction is presented in Figure 14. Once again, Redding and the junction with U.S. 20 in Oregon remain the endpoints of the affected corridor.

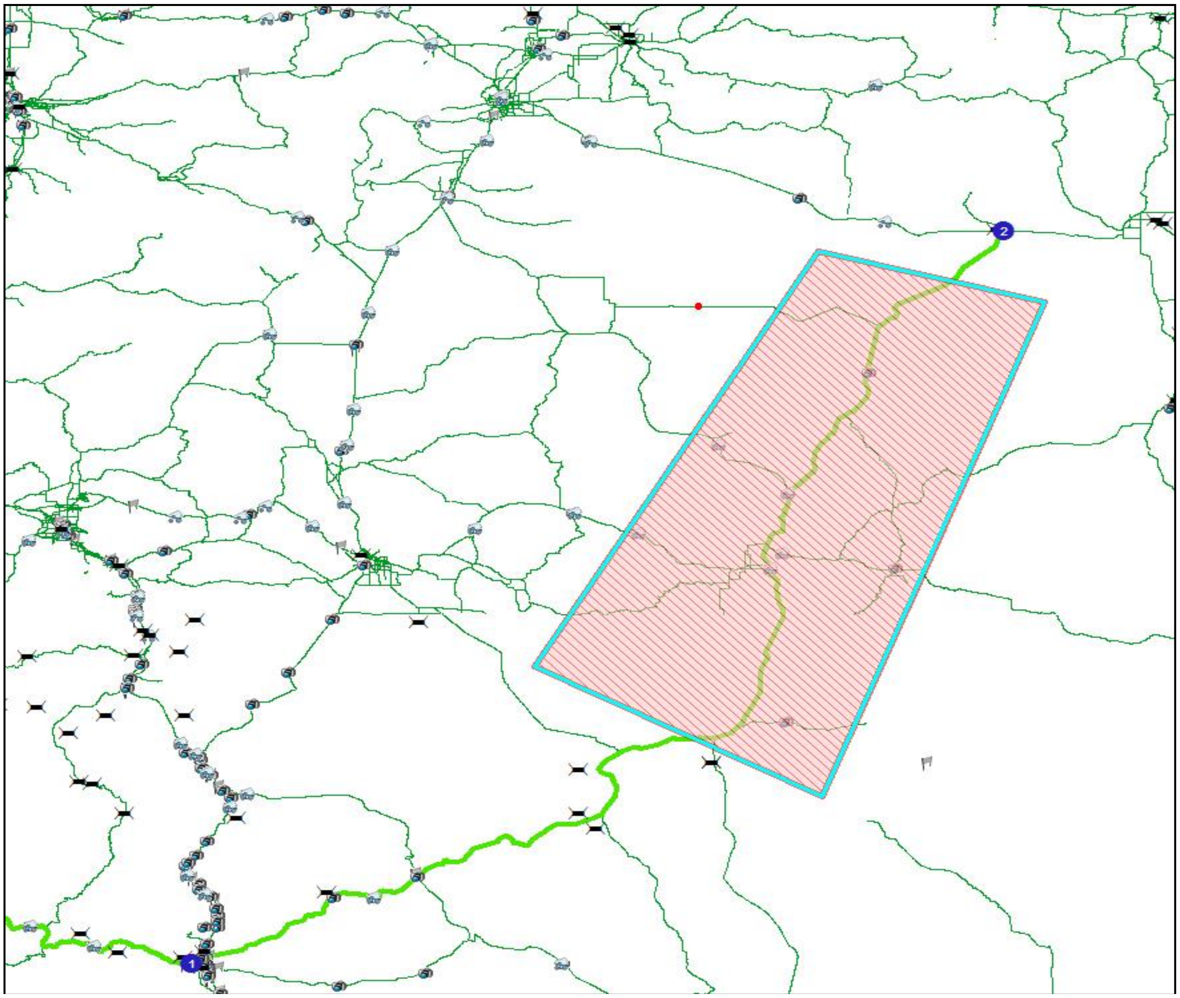

Figure 14: Restriction for fire scenario, U.S. 395 segment

The alternative routing identified by the analysis consists of I-5 north from Redding to the junction with U.S. 97 in Weed, California, north on U.S. 97 from Weed to Bend, Oregon, where the route intersects U.S. 20, which is used for the remainder of the trip east. The overall route is displayed in Figure 15. The length of the route is 377 miles and has a travel time of 6 hours and 20 minutes. This once again compares favorably to the SR 299-U.S. 395 corridor, which has a distance of 314 miles and a travel time of 5 hours and 41 minutes. The alternative corridor is instrumented with ITS deployments along its length, providing a good start in terms of support infrastructure for implementing a prospective ICM plan.

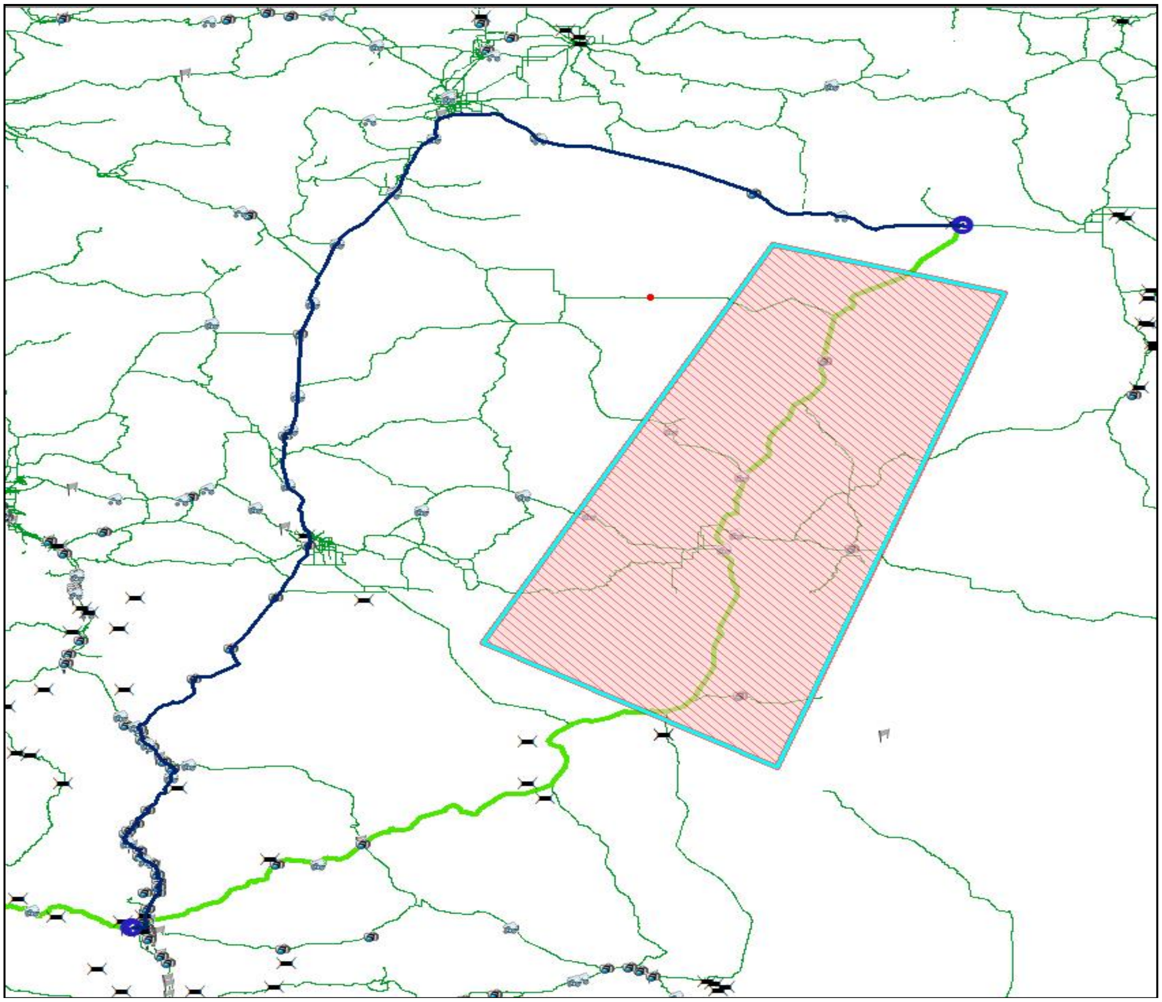

Figure 15: Alternative route identified for fire scenario, U.S. 395 segment

As these examples from the SR 299-U.S. 395 corridor have illustrated, the use of GIS to identify multiple prospective alternative routes along the same corridor based on events or restrictions in different locations is straightforward. In general, the alternatives identified were comparable in terms of length and travel time to the SR 299-U.S. 395 corridor. However, the travel time estimates do not factor in the delays that could arise from adding more traffic from the impacted route to the alternative route. Estimating these delays is difficult outside of the development of a detailed simulation model that can incorporate vehicle distributions along a road segment during a given time of day. While all traffic that would normally travel the original route will not be diverted, as some vehicles are completing local trips, it can be assumed that all through and a majority of long-distance traffic would use the alternative route, which would make an impact. However, the overall intent of these cases has been to demonstrate the initial approach and tools that can be used in planning for an ICM event rather than conducting simulation models of traffic flows.

Discussion

The use of GIS is viewed to be the preferred approach to identifying prospective alternative routes for ICM events in that such a platform allows different datasets to be employed together to depict route restrictions, identify appropriate infrastructure (ITS deployments, bridge capacity, etc.) and optimize the routing process. In the context of the case studies outlined in this chapter, the GIS approach has been presented as one which is transferable to similar corridors to address a number of different scenarios within an ICM planning context. Of course, the routes identified in these examples would ultimately be affected (along with other potential routes) by the exact nature of the event, its precise location, the limitations of alternative routes and the volumes and impacts that diverted traffic would have on other portions of the system. Information such as travel demand models would begin to address this knowledge gap, but at present, there is no straightforward means of incorporating such information from disparate sources into a unified dataset for evaluating ICM alternatives over a multi-state region.

While the approach discussed here can be considered semi data-intensive, many prospective data elements were not employed in light of the incubator/demonstration nature of the project. For example, while information on aspects that have a restrictive affect on rerouting traffic such as bridge restrictions, was incorporated, other elements, such as traffic signal locations and timing plans were not available for use. In reality, such datasets do not exist in a GIS-friendly format, and the development of such a database over a large, multi-state area would represent a significant project in itself. Still, such information, along with data on prospective vehicle speeds when passing through local communities, would provide a better indication of the delays and resulting cost from a time perspective that would be encountered along a given path.

Another critical item that can have a large impact on the selection of a routing is roadway curvature. However, determining such data and placing it into a GIS format would be a challenge. To some extent, this might be addressed through the presence of restricted speed limits at such locations. However, the HPMS datasets employed in this work did not include such specific information. Ideally, a more detailed GIS file would have segments broken down by the length covered by a respective speed limit.

Finally, GIS has the ability to incorporate elevation data that can serve as an added cost consideration. Elevation data are especially of interest for alternative routes that could see an increase in truck traffic during an ICM event. These vehicles could be expected to travel slower on grades, impacting the travel time for other vehicles on the route. In some cases, a route may be inappropriate for such vehicles in the absence of climbing lanes or pull offs to allow faster vehicles to pass. Elevation data suitable for incorporation into the work discussed here were not identified, although in general, such data for each of the states discussed here is available, and future efforts should investigate the use of this element in greater detail.

In light of these points, it is important to stress that the approach outlined in this chapter can be adjusted in terms of the datasets incorporated and the various restrictions and costs that can be factored in for a particular route if or when such data becomes available in the future. The approach serves as a useful means to quickly identify alternative routes based on an initial set of criteria, such as travel times, distances, bridge restrictions, ITS deployment presence and so forth. Once these initial routes have been identified, then further consideration could be made to factors such as roadway curvature or signal timings that may not (at present) be available in a

GIS format. If these factors present a restriction or cost to a certain route, then that restriction or cost could be incorporated into the GIS project through the addition of a point barrier or cost, polygon restriction, etc.

The end result of the GIS analysis portion of the ICM planning process is the identification of feasible alternative routes to divert traffic onto during an ICM event. Once appropriate routes have been identified, the process moves on to discussion and agreement between agencies of whether such routes should be used during an ICM event. That discussion would ultimately lead to the development of interagency agreements, which are beyond the scope of this incubator project.

Chapter Summary

This chapter has provided a general overview of the process for using GIS data to identify alternative routes to address events within the overall regional ICM planning process framework. The general planning approach developed in Chapter 3 was applied by first identifying study corridors/routes of interest and the conditions that could impact them. These routes and impacts were identified by the Steering Committee. The first corridor was U.S. 395 from Mojave, California to Carson City, Nevada, which could be impacted by construction and volcanic activity. The second corridor was SR 299 – U.S. 395 from Arcata, California to the junction of U.S. 395 and U.S 20 in Oregon. This corridor could be affected by weather and wildfire activity. Based on these selected corridors, an inventory of highway assets along each was made using GIS data.

GIS data used in the inventory and analysis consisted primarily of shapefiles from the Highway Performance Monitoring System, which provided information such as segment length, number of lanes, AADT and functional classification. Further work with this data allowed for the development of fields for calculation of travel time on a respective road segment and capacity when diverted traffic from the primary route was added to a prospective alternative segment. Additional GIS data included the location of ITS elements along all roads in the study area, which was used to identify corridors where instrumentation was already present. Finally, National Bridge Inventory shapefile data was used to identify restrictions along segments when weight or height limits might be present. Once acquired, the data was formatted to present a unified dataset for analysis with the GIS platform.

The highway network evaluated in the dataset was already determined to be appropriate for consideration from a pavement surface standpoint by nature of being part of the HPMS dataset, which includes National Highway System segments only. Based on the route inventory, GIS route identification and optimization tools were used to determine alternative routes based on travel times, distance and capacity. The use of GIS in performing this task demonstrated its utility in evaluating road network data over a large geographic area in support of ICM planning activities. In the absence of such a platform, entities would need to coordinate efforts to first identify prospective alternative routes and then evaluate their suitability by some set of common metrics.

While the GIS analysis did demonstrate the overall regional ICM planning process from the prospective of identifying alternative routes, it did have limitations from the standpoint of data. Additional data of interest, namely roadway geometrics (e.g., curve radius) and signal timing plans were not available in a GIS format (let alone a unified database at a state-level for signal timings). This prevented the use of such data to identify further restrictions or delays along each route segment. Elevation data also play a role in identifying limitations on one corridor versus another, particularly for heavy vehicles. Data that were suitable for inclusion in this incubator project were not identified during the course of the work. In all of these cases, future work should examine how such data elements can be developed (geometrics and signal timings) and incorporated (all items) into the overall data analysis component of the planning process.

In summary, the work discussed in this chapter demonstrated the feasibility of using GIS in the regional ICM planning process for route inventory and alternative route identification purposes. For the study cases examined, comparable alternative routes were identified in GIS that provided reasonable distance and travel times in the event that the study corridor was closed or had restricted traffic flow. The use of GIS allowed for different restrictions to be put into place not only on the primary corridor of interest, but also on other routes, segments or even regionally that might need to be excluded from consideration. The analysis approach discussed here can provide a number of alternatives that can ultimately be presented to stakeholders for discussion and selection as part of the larger regional ICM planning process.

5. CONCLUSIONS AND RECOMMENDATIONS

Integrated Corridor Management seeks to coordinate individual network operations between parallel facilities/routes, in order to create an interconnected system allowing cross network travel management. The primary intent of ICM has been to address the congestion issues that plague urban areas. To date, limited work has been performed examining ICM in a rural/regional context. In light of this, there was interest by the Western States Rural Transportation Consortium to explore regional ICM in greater detail. Specifically, there was interest in establishing guidance and criteria to initiate, plan and develop a regional ICM plan. This work would define what regional ICM is, establish the factors to consider when developing a regional ICM plan, and develop protocols and criteria for ICM deployment in a regional context and then test them for one or two routes in the WSRTC region. The following sections discuss the overall conclusions and recommendations that resulted from the overall research effort.

Conclusions

The literature review conducted in support of this work confirmed that the primary focus of ICM initiatives and research to date has been on urban applications. In the limited cases where rural/regional ICM has been explored, efforts have focused on laying out a high-level approach to communications and emphasizing information sharing and dissemination. Neither the urban or rural discussions have established a process for the planning of an ICM effort. The primary conclusion that may be drawn from this is that, while a good deal of work related to ICM has been completed, none of it has established a process that can be adapted for regional application. Furthermore, many of the aspects of work to date do not lend themselves to a regional usage. Similarly the U.S. DOT's ICM planning approach has not yet been adequately defined in any document. Consequently, the approach developed for an urban context cannot be transferred to a regional application. A review of existing EOC protocols and procedures found that a basic framework to support decision-making and operations under a regional ICM operation has been established in each state. These protocols and procedures differed in some respects, but in general, they lay out a foundation for how operations would proceed when a regional ICM event occurred. Consequently, based on the overall review work performed, the development of a process for planning regional ICM must be developed from scratch. The approach must make use of the data that is presently available, recognizing that the collection and recording of additional data is not likely feasible, at least in the near term.

Based on the review work completed, which showed that no clear approach to a regional ICM planning process had been established, a general framework for such an approach was developed. Prior to that development, the definition of regional ICM was established, stating that "Regional Integrated Corridor Management is defined as the coordination of highway facilities across state and jurisdictional boundaries in a seamless manner to enable an interconnected system for long-distance cross-network travel in response to extended-duration events." The approach began with a group of entities (as small as two parties) identifying a need to address different events, conditions or scenarios that may occur along a primary corridor and may have a significant impact on mobility for an extended period of time. Stakeholders would identify an initial series of events, conditions or scenarios that may have an impact on these routes and that ICM could help address. Once routes have been identified at a high level, the next step in the approach is to inventory existing highway assets and conditions. In this work, that inventory would be completed using GIS data to identify alternative routes and establish whether they are suitable for use in a regional ICM setting. These activities marked the end of the work pursed by this incubator project.

Following evaluation of GIS data and any resulting recommendations, the selection of alternate routes to be used during ICM events would be made by all agencies involved in the process. Steps following this point address more detailed development of documents and agreements. This includes the development of Interagency Agreements, as well as detailed Concept of Operations and Requirements documents. The final steps of the regional ICM planning process entail the development of deployment/operation protocols.

Application of the developed planning process was made by first identifying study corridors/routes of interest and the conditions that could impact them. These routes and impacts were identified by the Steering Committee. The demonstration corridors included U.S. 395 from Mojave, California to Carson City, Nevada, and SR 299 – U.S. 395 from Arcata, California to the junction of U.S. 395 and U.S 20 in Oregon. Based on these selected corridors, an inventory of highway assets along each was made using GIS data. This inventory collected relevant data that would support the identification of alternative routes, such as traffic, cross-section, ITS elements and so forth in the form of GIS shapefiles.

Based on the route inventory, GIS route identification and optimization tools were used to determine alternative routes based on travel times, distance and capacity. The use of GIS in performing this task demonstrated its utility in evaluating road network data over a large geographic area in support of ICM planning activities through an automated analysis. For the study cases examined, comparable alternative routes were identified in GIS that provided reasonable distance and travel times in the event that the study corridor was closed or had restricted traffic flow. The use of GIS allowed for different restrictions to be put into place not only on the primary corridor of interest, but also on other routes, segments or even regionally that might need to be excluded from consideration. The analysis approach provided a number of alternatives that could ultimately be presented to stakeholders for discussion and selection as part of the larger regional ICM planning process.

Recommendations

Based on the work completed during this incubator project, a few recommendations can be made. First, being that the work was a proof-of-concept effort, the datasets employed were limited to those that were readily available. For example, HPMS roadway shapefiles were used instead of the roadway shapefiles because the files shared a common set of fields from state to state. A detailed effort would have been required to reconcile the different shapefile data files present in each state's individual shapefiles. The result of this was that a less detailed dataset was used in the analysis than would have been the case if the planning effort was limited to within one state's borders. While the basic information used in the analysis, such as AADT, number of lanes and functional classification, was present in the HPMS data, other items that may have been of interest such as pavement widths, shoulder presence, etc., were not. Such information could have been useful in developing a cost or restriction field based on the safety adequacy of a road segment, and the integration of such information should be investigated in the future.

In addition to the limitations of the roadway shapefiles, additional data that would have been of use to the work was not available in a shapefile format. Specifically, data such as geometric features (primarily curve radius) and signal timing plans do not exist in a format that can be readily transferred into a GIS-compatible format. Indeed, in many cases such information is kept in a paper or pdf format that would require development of a GIS database from scratch. This would represent a significant investment in time and financial resources and was beyond the scope of this work. Still, it might be of interest in a future effort to examine, on a small, localized scale, the development of such datasets. This would provide a better understanding of the time and financial resources that would be required on a regional scale. Given the geometrics and signal timings play a central role in the efficiency and safety of one alternative route versus another, the use of such data in future planning efforts is necessary and warrants investigation.

Finally, in terms of data, it is also recommended that an appropriate elevation dataset be identified for use in factoring in the effects of grades on travel along alternative corridors in future efforts. Such datasets are currently available, but it is not clear which would be the best to consider when accounting for the impacts that grades may have on different aspects of travel time, especially on routes where adequate passing lanes may not be present to accommodate an increase in traffic. These aspects of terrain and elevation should be examined in the future as well.

Secondly, the planning approach that has been developed and demonstrated here relies on current information and trends (traffic levels). This was the result of using data from sources such as the HPMS which incorporate past observations of traffic data. However, any potential ICM event will occur at some point in the future, and it is likely that traffic volume at that point in time will have grown compared to past or present observations. In light of this, any future planning effort would ideally incorporate future traffic projections developed from statewide (or in some cases within the overall region, urban-based) travel demand models. The use of such information would better represent the conditions that would be present in the future during an ICM event. Unfortunately, during the course of this work, datasets that provide such information in a format that could be readily transferred into a GIS shapefile were not identified. Future work should examine how information from travel demand model efforts can be incorporated into the existing roadway shapefiles being used for analysis or the development of standalone shapefiles that can be considered when identifying route alternatives. This will be a challenge given that any travel demand model data will not directly correspond to the roadway segments present in existing shapefiles.

Third, any pursuit of regional ICM planning in the future, whether from a research or field application perspective, will need to extend beyond the planning phase discussed in this report and toward the development of interagency agreements, Concept of Operations and Requirements documents that allow for implementation to occur during an event. The content of those documents will rely on the event(s) and route alternatives identified during earlier planning steps. In the absence of any published guidance from the US DOT's ICM efforts, it is likely that such documents will need to be developed from scratch when considering a regional context. Collectively, all of the aspects of the approach discussed in this report will require agency buy-in before any significant effort towards development of ICM plans can begin.

6. REFERENCES

1. Veneziano, David, Douglas Galarus, Shaowei Wang, Daniell Richter and Nishadhi Nikalandawatte. Integrated Corridor Management in the COATS Region: Overview and Concept of Operations. Western Transportation Institute, September 2009.

2. Veneziano, David. Rural Integrated Corridor Management Planning – Work Plan. Western Transportation Institute, March, 2011.

3 Alexiadis, Vassili. Integrated Corridor Management Analysis, Modeling and Simulation Results for the Test Corridor Report. United States. Department of Transportation, Washington, D.C., June, 2008, 117 pp.

4 Alexiadis, Vassili. "Integrated Corridor Management in the U.S. – Analysis, Modeling and Simulation.". 14th International IEEE Conference on Intelligent Transportation Systems. Washington, D.C., October 5-7, 2011, pp. 218-223.

5 Cronin, B., S. Mortensen and D. Thompson. Integrated Corridor Management. ITE Journal, Vol. 78, No. 5, 2008, pp. 40–45.

6 Sheehan, Bob. "Integrated Corridor Management (ICM) Overview." Transportation Research Board Joint Operations Committee Mid-Year Meeting, Las Vegas, July 18-21, 2011.

7 Olyai, Koorosh. "Integrated Corridor Management – US 75." Transportation Research Board Joint Operations Committee Mid-Year Meeting, Las Vegas, July 18-21, 2011.

8 Dallas Area Rapid Transit (DART). High-Level Requirements for the US-75 Integrated Corridor in Dallas, Texas. FHWA-JPO-08-046EDL14426, U.S. Department of Transportation, Washington D.C. April 2008.

9 Oakland Pioneer Site Team. System Requirement Specification for the I-880 Corridor in Oakland, California. FHWA-JPO-08-047EDL14427, U.S. Department of Transportation, Washington D.C. March 2008.

10 Miller, Mark and Alex Skabadonis. San Diego I-15 Integrated Corridor Management System: Stage II (Analysis, Modeling and Simulation). UCB-ITS-PRR-2010-9, California Partners for Advanced Transit and Highways, University of California, March, 2010, 63 pp.

11 Johnson, Josh and Brian Fariello. Integrated Corridor Management Concepts for a Medium Sized Urban Area – Lessons Learned from San Antonio. Proceedings: 15th Annual World Congress on Intelligent Transportation Systems, New York City, November, 2008. 10 pp.

12 Estrella, Alex, Bruce Churchill and Mark Miller. Integrated Corridor Management: The San Diego Pioneer Site Experience. Proceedings: 15th Annual World Congress on Intelligent Transportation Systems, New York City, November, 2008. 11 pp.

13 Cronin, Brian, Steve Mortensen, Robert Sheehan and Dale Thompson. Integrated Corridor Management. Public Roads, Vol. 74, No. 3, November/December 2010.

14 Kimley Horn and Associates. "I-10 Integrated Corridor Management System Concept of Operations." Maricopa Association of Governments, Phoenix, August, 2007.

15 Eng-Wong, Taub and Associates and Bergmann Associates. NITTEC Transportation Operations Integrated Corridor Management Requirements Document. Niagara International Transportation Technology Coalition, January, 2010, 65 pp.

16 Masters, Phil. Regional Traffic Management in an International Context (Presentation). Proceedings 90th Annual Transportation Research Board Meeting, Washington D.C., January 2011.

17 Zhang, Li, Jizhan Gou and Minzhou Jin. "A Model of Integrated Corridor Traffic Optimization." Proceedings 91st Annual Transportation Research Board Meeting, Washington D.C., January 2012.

18 Zimmerman, Sam, Said Dahdah and Wei Wang. "Integrated Corridor Management for Urban Transport." Proceedings 91st Annual Transportation Research Board Meeting, Washington D.C., January 2012.

19 Alm, Eric, Virginia Lingham, Hamed Benovar, Xuegang Ban and Lianyu Chu. "An Integrated Methodology for Corridor Management Planning." Proceedings 87th Annual Transportation Research Board Meeting, Washington D.C., January 2008.

20 Berkley Transportation Systems. Integrated Corridor Management. Berkley Transportation Systems, September, 2007, 7 pp.

21 Chiu, Yi-Chang, Eric Pihl and Nick Renna. A Simulation Based Dynamic Traffic Assignment Model for Corridor/Regional Operational Planning Analysis. Presentation to the Michigan Department of Transportation, Lansing, August 11, 2010.

22 Kimley-Horn and Associates and California Center for Innovative Transportation. Integrated Tri-State Corridor Management System: Final Report. California Department of Transportation, May, 2007.

23 North/West Passage Work Plan. http://www.nwpassage.info/about/workplan.php. Accessed 6 November, 2012.

24 Tanikella, H., B. Park, B. Smith, and M. Best. Assisting the Benefits of Implementing Integrated Corridor Management Strategies. American Society of Civil Engineers, Proceedings: Ninth International Conference of Applications of Advanced Technology in Transportation. 2006, pp.774–779.

25 Hamdar, S. S. Eisenman, and H. Mahmassani. Evaluation of Operational Strategies for Integrated Corridor Management. Proceedings 85th Annual Transportation Research Board Meeting, Washington D.C., January 2006.

26 Yang, Q. and H. Wei. Data Archiving Testing and Initial Analysis in Supporting GLITS I-75 Integrated Corridor Project. Proceedings 87th Annual Transportation Research Board Meeting, Washington D.C., January 2008.

27 Quayle, S. and T. Urbanik. Integrated Corridor Management: Simulation Model Conversion between VISUM and VISSIM. Proceedings 87th Annual Transportation Research Board Meeting, Washington D.C., January 2008.

28 Zhou, X., H. Mahmassani, and K. Zhang. Dynamic Micro-Assignment Modeling Approach for integrated Multimodal Urban Corridor Management. Transportation Research Part C, Vol. 16, No. 2, 2008, pp. 167–186.

29 Alexiadis, V. Integrated Corridor Management Analysis, Modeling and Simulation (AMS) Methodology. U.S. Department of Transportation, Washington D.C. March 2008.

30 Henry, Micah and Michael Wendtland. ITS Concepts for Rural Corridor Management. FHWA-AZ-07-615, Arizona Department of Transportation, Phoenix, September, 2007.

31 Cuelho, E. and A. Kalinowski. The Siskiyou Pass Traveler Information and Incident Management Early-Winner Project. Western Transportation Institute, April 2004.

32 Cambridge Systematics. West Coast Corridor Coalition Trade and Transportation Study: Executive Summary. Washington Department of Transportation, February, 2008.

33 Cascadia Corridor. http://www.cascadiaproject.org/hubscorridorsandgateways/corridors.php Accessed November 21, 2008.

34 Minoofar, Cyrus, Anush Nejad and Habib Shamskhou. The I-80 Integrated Corridor Mobility (ICM) Project. Proceedings: 15th Annual World Congress on Intelligent Transportation Systems, New York City, November, 2008. 12 pp.

35 California Emergency Management Agency. *State of California Emergency Plan*. California Emergency Management Agency, Sacramento, July 2009. 190 pp.

36 Governor's Office of Emergency Services. *California Catastrophic Incident Base Plan: Concept of Operations*. Governor's Office of Emergency Services, Sacramento, September 2008. 60 pp.

37 Edwards, Frances and Daniel Goodrich. *Handbook of Emergency Management for State-Level Transportation Agencies*. Mineta Transportation Institute, San Jose State University, February 2010. 124 pp.

38 State of Nevada. *State Comprehensive Emergency Management Plan*. State of Nevada, Carson City, January 2014. 245 pp.

39 Ecology and Environment Inc. *State of Oregon Emergency Operations Plan*. Oregon Emergency Management, Salem, September 2010. 122 pp.

40 Emergency Management Division. *Washington State Comprehensive Emergency Management Plan Emergency Support Function 1 - Transportation*. Washington State Emergency Management Division, Olympia, July 2007. 499 pp.

41 Office of Emergency Management. *Emergency Operations Plan*. Document M 54-11.01, Washington State Department of Transportation, Olympia, May 2011. 312 pp.

42 Washington State Department of Transportation. *Regional Transportation Recovery Annex*. Washington State Department of Transportation, Olympia, February 2011. 241 pp.

43. Research and Innovative Technology Administration. Integrated Corridor Management. United States Department of Transportation, Washington, D.C., Undated. Available at: http://www.its.dot.gov/icms/

44. Hill, C. and J. Kaiser. Integrated Corridor Management (ICM) Initiative: Surveillance and Detection Requirements for Arterial and Transit Networks. United States Department of Transportation, Washington, D.C., November 2008.

45. Federal Highway Administration. Integrated Corridor Management Systems Program Plan. United States Department of Transportation, Washington, D.C., 2006. Available at: http://www.its.dot.gov/icms/workplan.htm.

46. Federal Highway Administration. HPMS Public Release of Geospatial Data in Shapefile Format. United States Department of Transportation, Washington, D.C., Undated. Available at: http://www.fhwa.dot.gov/policyinformation/hpms/shapefiles.cfm

47. Federal Highway Administration. 2013 National Bridge Inventory ASCII Files. United States Department of Transportation, Washington, D.C., 2013. Available at: http://www.fhwa.dot.gov/bridge/nbi/ascii.cfm?year=2013

48. Richter, Daniell, Shaowei Wang and Douglas Galarus. WeatherShare Phase 2 Final Report. Western Transportation Institute, Montana State University, Bozeman, December 2009.

49. Galarus, Douglas, David Veneziano, Daniell Richter, Kelvin Bateman and Leann Koon. Western States One-Stop Shop for Rural Traveler Information: Research on Clarus System Data. United States Department of Transportation, Federal Highway Administration, Washington, D.C., September 2011. 104 pp.

50 Jensen, Jeffery. ArcGIS Network Analyst Data Prep Tutorial. Department of Civil and Environmental Engineering, University of Nevada, Las Vegas, 2011. Available at: https://faculty.unlv.edu/jensen/CEE_468/modules/NetworkAnalyst/pdf/ArcGISNetworkAnalystDataPrepTutorial.pdf

51 California Department of Transportation Division of Transportation System Information. Highway Performance Monitoring System: Instructions for Updates. California Department of Transportation, Sacramento, April 2007. 58 p.

52 Transportation Research Board. Highway Capacity Manual, 2010. Transportation Research Board of the National Academies, Washington, D.C., 2010.