I-70 RURAL IVHS

CORRIDOR PLANNING AND FEASIBILITY ANALYSIS

NEEDS ASSESSMENT

DOT

Colorado Department of Transportation

DE LEUW, CATHER & COMPANY

Engineers and Planners • Denver

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EXECUTIVE OVERVIEW

OBJECTIVES

- Assess Technological and Institutional Needs
- Apply Technologies to User Needs
- Define Institutional Barriers
- Document the Analysis

PROCESS

- Analyze Transportation System Characteristics
- Assess Mobility, Safety, Information, and Communications Resources
- Apply Advanced Technology Solutions
- Report the Results

SOURCES

- CDOT ITS Program Office; Regions 1,3,6
- Colorado State Patrol
- Local Governments
- FHWA Colorado Division; Region 8
- Transportation Service Providers
- Local Communities and Organizations
- Recreation/Tourism Interests
- Emergency Response/ Enforcement Organizations
- Commercial Vehicle Operators

Scope: Identify and assess the needs of those who operate and maintain and support the surface transportation systems on the corridor. Contacts should include. but not be limited to, maintenance and traffic personnel in CDOT Regions I and 3, the Colorado State Patrol (CSP), local governments, the Colorado Tourism Board [defumct as of project notice-to-proceed--voters elected, in November 1992, to stop program finding], corridor transit companies, ski and recreational organizations, local chambers of commerce, local residents, and the traveling public.

No committee structure is defined Although CDOT will provide the names of representatives from each of its disciplines, participation from other outside agencies will be less certain. Education of potential participants to the opportunities and benefits of IVHS technologies may be needed. Development and approval of committee(s) and other organizational structure(s) to suit the study methodology is expected.

The task will include the assessment of the potentialfor implementation of 25 identified IVHS features:

1. *additional variable message signs on westbound in advance of the Loveland Pass exit, eastbound in advance of Floyd Hill exit, Dowd Junction, Vail Pass, and other needed locations;*
2. *upgrades of computer equipment to provide better automatic message handling of the new and existing message signs along the corridor;*
3. *sensor-actuated environmentaI warning and predictive systems for ice, snow, and high winds at numerous locations along the corridor including, but not limited to, Dowd Junction, Vail Pass, FIoyd Hill, and Glenwood Canyon;*
4. *automatic avalanche and rock slide warning systems for road maintenance crews and travelers at high-hazard locations;*
5. *an initial cellular reporting program, to be expanded as coverage of the corridor becomes complete;*
6. *public cellular-based roadside telephones in remote locations;*
7. *corridor courtesy patrols;*
8. *Glenwood Canyon and Eisenhower Tunnel-based control centers for ITS along the corridor;*
9. *real-time traveler information links to facilities provided by the Colorado Tourism Board [now defunct];*
10. *"intelligent" rest areas;*
11. *a transit/rideshare site adjacent to the Morrison interchange with real-time road information, transit schedules, and weather information;*
12. *other intermodal [multi-modal] ties to public transportation systems (including recreation-specific buses) along the corridor;*
13. *the inclusion of HOV lanes/ramps at locations where future congestion leveIs may warrant widening;*
14. *the placement ofportable message signs and highway advisory radio units at strategic locations throughout the corridor for use in incident management;*

15. *road and weather information distribution via privately supported information kiosks at airports, various ski areas, via cable TV, and other media;*
16. *retrofit of lighting and reflective coatings of both bores of the Twin Tunnels to reduce accidents and improve capacity;*
17. *remote controlled bi-directional lane controls for the Twin Tunnels to provide increasedcapacity through a 3:1 [lane] split;*
18. *remote video surveillance of the Twin Tunnels and approaches, Genesee to Morrison exit, Dowd Junction, Vail Pass and Floyd Hill for faster accident detection and response;*
19. *model the benefits of automatic median barrier relocation equipment creating a 3:2 [3:1] lane split near Idaho Springs with a filled median;*
20. *traveler information links with the CSP [Colorado State Patrol} and commercial traffic reporting agencies;*
21. *digital AM, FM, or pager-based radio sub-carrier traffic message channels;*
22. *data and communications links to the CDOT-sponsored trafflc operations center;*
23. *data and communications links with the CSP;*
24. *satellite or earth-basedpersonal radio mayday systems; and*
25. *other potential ITS features identified during the needs assessment.*

The needs assessment will be summarized in a report format.

Deliverable: ***Needs Assessment Report***

The Needs Assessment process for the I-70 Rural IVHS Corridor Planning and Feasibility Analysis enabled definition and assessment to validate technological solutions for the I-70 West Corridor. Additionally, userneeds were examined with respect to transportation and the institutional barriers that can deter implementation of ITS to solve system-wide and area-specific problems.

During activities for the Needs Assessment phase, numerous ITS solutions for potential implementation were scrutinized, based on:

- the user needs;
- the potential that each technology holds for inclusion in the evolving national architecture;
- data gathered from the Information Search task; and
- field surveys and stakeholder outreach processes.

Involvement by relevant stakeholders included:

✓ the CDOT ITS Program Offtce and Engineering and Planning Regions;
- the Colorado State Patrol;
- local governments;
- Colorado tourism and resort industry associations;
- economic development organizations and chambers of commerce;
- enforcement, safety, and emergency services districts;
- public transportation service providers;
- recreational/resort area representatives groups;
- broadcast and printed media organizations;
- a few local citizens and travelers; and
- private sector organizations and businesses.

The national ITS Planning Process, adopted by the FHWA, begins with problem formulation and system definition processes. During the initial planning phases, the FHWA guidelines call for an inventory of the existing transportation system to establish ITS composition and the composition of ITS subsystems, including all information pertaining to the available resources and the operating environments. The system definition can then be used to identifyl deficiencies and opportunities; to create a vision of the desired transportation system; and to develop a list of the functional and technological system requirements to achieve the envisioned system and begin the implementation process. The Needs Assessment fulfills these early planning activity guidelines.

The assessment of needs concentrated on the following system wide goals:

- safety measure applications;
- congestion reduction;
- mobility improvements;
- enhanced economic productivity;
- energy efficiency;
- environmental quality; and
- public image.

Focusing on the above goals, the evaluation of inventory of the existing technologies deployed within the I-70 West Corridor, included:

- variable message signs (VMS);
- environmental sensors;
- highway advisory radio;
- microwave communication systems;
- cellular telephone antennas;
- ✓ automatic vehicle location systems; and
- ramp metering.

Aspects of the existing transportation system that emerged as potential areas for improvement opportunities included measures related to:

- weather/weather-related conditions;
- roadway conditions/symptoms;
- ✓ safety;
- information sources;
- communications;
- traveler mobility;
- organizational structure; and
- institutional barriers.

A thesis, prepared as a part of a graduate Master's degree program in Transportation Engineering at the University of Colorado at Denver, is appended to the Needs Assessment document. It compiles and reports on the results from databasing historical traffic volumes along I-70 (from permanent traffic counters located between Denver and Frisco) into a Geographic Information System (GIS). Spatial queries, made within the GIS, identify graphically, hot spot congestion and link travel times.

The Needs Assessment presents the findings of a thorough feasibility -analysis of several ITS technologies and applications considered for implementation. These technologies and applications are related to the following ITS features:

✓VMS;
✓ sensor-actuated environment;
- cellular telephone;
- call boxes;
- corridor courtesy patrols;
- regional traffic operations centers;
- real-time traveler information;
- mass transportation;
- other intermodal ties;
- high occupancy vehicle infrastructure;
- incident management;
- roadway delineation;
- lane controls; and
- video surveillance.

The analysis and documentation focuses on the ability of each of the above ITS applications to respond to user needs throughout the I-70 West Corridor. It additionally addresses how technologies support various ITS user service functional requirements. Corresponding to the functional areas organized for ***the I- 70 Rural IVHS*** study, needs were assessed in relation to the following categories:

- commercial vehicle operations;
- communication systems;
- data collection/aggregation;
- education/training;
- emergency response;
- environmental/economic impact;
- institutional issues;
- public/private partnerships;
- public transportation/alternate modes;
- safety/warning;
- traffic management/operations; and
- traveler information.

The technologies to support the functional areas are thoroughly described ***in the Information Search Memorandum.*** The specific application of those technologies to the transportation needs and problems within the I-70 West Corridor are evaluated in this Needs Assessment report.

Assessment of the institutional barriers associated with the development and operation of transportation systems within the I-70 West Corridor relied on an examination of the organizational structure of the agencies and organizations pertinent to implementation of an ITS program for the Corridor. The overview identifies the intra-agency and inter-agency program needs, and outlines the institutional barriers associated with each, including policy, financing, legislative, and cooperative matters.

The Needs Assessment explores the need for public/private partnerships for the I-70 West Corridor ITS implementation, with respect to cost/revenue-sharing, risk/liability, information exchange/ownership, policy/rules/regulations, and legislative action. Emphasis is placed on the assessment of the local, regional, intrastate, and interstate users needs.

Based on the technologies and institutional actions identified in this report, a wide range of projects and programs are identified in the Early Action Projects and Corridor Master Plan documentation. The recommendations in these reports reflect the solutions to specific transportation problems and needs, and not simply an application of advanced technologies just because they are available.

The Needs Assessment report evaluates the results of the ***Transportation Needs Survey,*** conducted to solicit perceived and real issues and problems identified by stakeholders within the I-70 West Corridor. The responses to ***the survey,*** summarized in ***the Information Search Memorandum,*** provide an overview of the prevailing expectations for transportation and level of knowledge of ITS, supporting development of the ***Business Plan and Marketing Strategy*** and ***the Corridor Master Plan.***

NEEDS ASSESSMENT

SECTION I

INTRODUCTION

SECTION I INTRODUCTION

PURPOSE

Determining the needs of a transportation system, both physical and institutional, is critical to the identification and development of solutions which will most efficiently resolve the systems deficiencies. Any attempt to develop an Intelligent Transportation System (ITS) program for the I-70 West Corridor must be predicated by the identification of system deficiencies and a search for ITS initiatives which result from and satisfy these needs.

The companion document, ***Information Search Memorandum,*** documents known transportation-related problems that degrade the operational performance within the I-70 West Corridor study area, delineated on the east and west from Denver and Glenwood Springs. Institutional and organizational concerns, affecting transportation within the Corridor are also documented. ***The Information Search Memorandum*** reports on available ITS technologies that have reasonable applicability for implementation.

The ***Needs Assessment*** task resulted in the evaluation of relevant transportation system and institutional needs throughout the I-70 West Corridor, recommending specific ITS technologies and strategies that are appropriate to address corridor-wide and area-specific needs.

The ***Needs Assessment*** task documentation for ***the I-70 Rural IVHS*** study assesses the validity of the technological and institutional needs of those agencies and organizations that operate, maintain, and support surface transportation systems within the I-70 West Corridor. The results of the ***Needs Assessment*** provides the basis for recommendations documented ***in the Corridor Master Plan,*** recommending ITS strategies, programs, and projects as short-, medium- and long-term solutions to I-70 West Corridor needs. While corridor-specific needs are identified and evaluated to date, they should be continually reexamined and updated in the future.

The purpose of an ITS needs assessment is not to perform detailed traffic/transportation operational and capacity analyses, but rather to examine those analyses performed by others in conjunction with the transportation systems inventory (physical and organizational). The end result is an assessment on how ITS technologies and applications can supplement or serve alone as a solution(s) to recurrent needs and/or problems, setting the stage for developing a strategic, system-wide plan for the area and systems being examined (the ***Corridor Master Plan).*** The needs assessment for the I-70 West Corridor serves this purpose.

BACKGROUND

The ***Needs Assessment,*** as the second task in a series of activities to validate deployment of ITS applications throughout the I-70 West Corridor, is detailed herein as a reference and companion to the following project documentation:

- ***Information Search Memorandum--survey*** and identification of system needs, both physical and institutional as well as identification and investigation of available ITS technologies having relevance to the I-70 West Corridor.

- ***Early Action Projects Executive Summary and*** Appended-detailed summaries for specific early action projects recommended for design and deployment within the I-70 West Corridor, including a preview of future ITS projects for medium- and long-term implementation;

- ***Business Plan/Marketing*** Strategy--recommended actions to support implementation of ITS initiatives through organizational and management strategies, including financial, marketing, and partnership opportunities; and

- ***Corridor Master Plan--the*** guidance document for deployment of an integrated Intelligent Transportation System for the I-70 West Corridor. As a working document, the Plan recommends strategies and actions to implement system-wide andproject-specific applications to meet the ITS goals and objectives of the responsible Colorado Department of Transportation (CDOT) Engineering Regions (1,3, and 6).

PHYSICAL DESCRIPTION

Interstate 70 (I-70) is the east-west backbone for surface transportation in Northwest Colorado. The corridor, in addition to I-70, is comprised of ten State Highways and U.S. Routes that provide alternate as well as primary access to towns throughout the region:

- U.S. Route 6 (US 6) runs intermittently parallel to I-70, serving as a frontage road and providing alternate access along certain segments of I-70.

- State Highway 470 (C-470) travels south from I-70 to Denver's southern suburbs, connecting to Interstate 25 (I-25).

- State Highway 26 (SH 26) runs parallel to C-470 immediately west of the Hogback formations (foothills), from I-70 south to Morrison Road.

- State Highway 119 (SH 119) provides primary access to the gaming towns of Black Hawk and Central City from US 6 in Clear Creek Canyon.

- US. Route 40 (US 40) provides access to the City of Golden (west of the Hogback) as well as primary access to Winter Park and further west to Steamboat Springs from the Empire junction at I-70.

- State Highway 9 (SH 9), from the Silverthorne/Dillon area along I-70, travels south, providing primary access to Breckenridge, and north connecting with SH 40 in Kremmling.

- State Highway 91 and U.S. Route 24 (SH 91 and US 24) both provide access to Leadville from I-70 at Copper Mountain and Dowds Junction, respectively.

- State Highway 13 1 (SH 13 1) provides alternate access to Steamboat Springs from I-70 at Wolcott.

- State Highway 82 (SH 82) provides primary access to Carbondale, Basalt and Aspen from I-70 at Glenwood Springs, while connecting with State Highway 133 (SH 133) and U.S. Route 24 (US 24).

The I-70 West Corridor, from Denver to Glenwood Springs (Figure I-l, Study Area), serves vehicular travel for numerous communities and recreational areas throughout the northwest region of Colorado. The heavily traveled roadways within this transportation corridor are classified as rural and mountainous facilities, mostly characterized by steep grades and sharp curves.

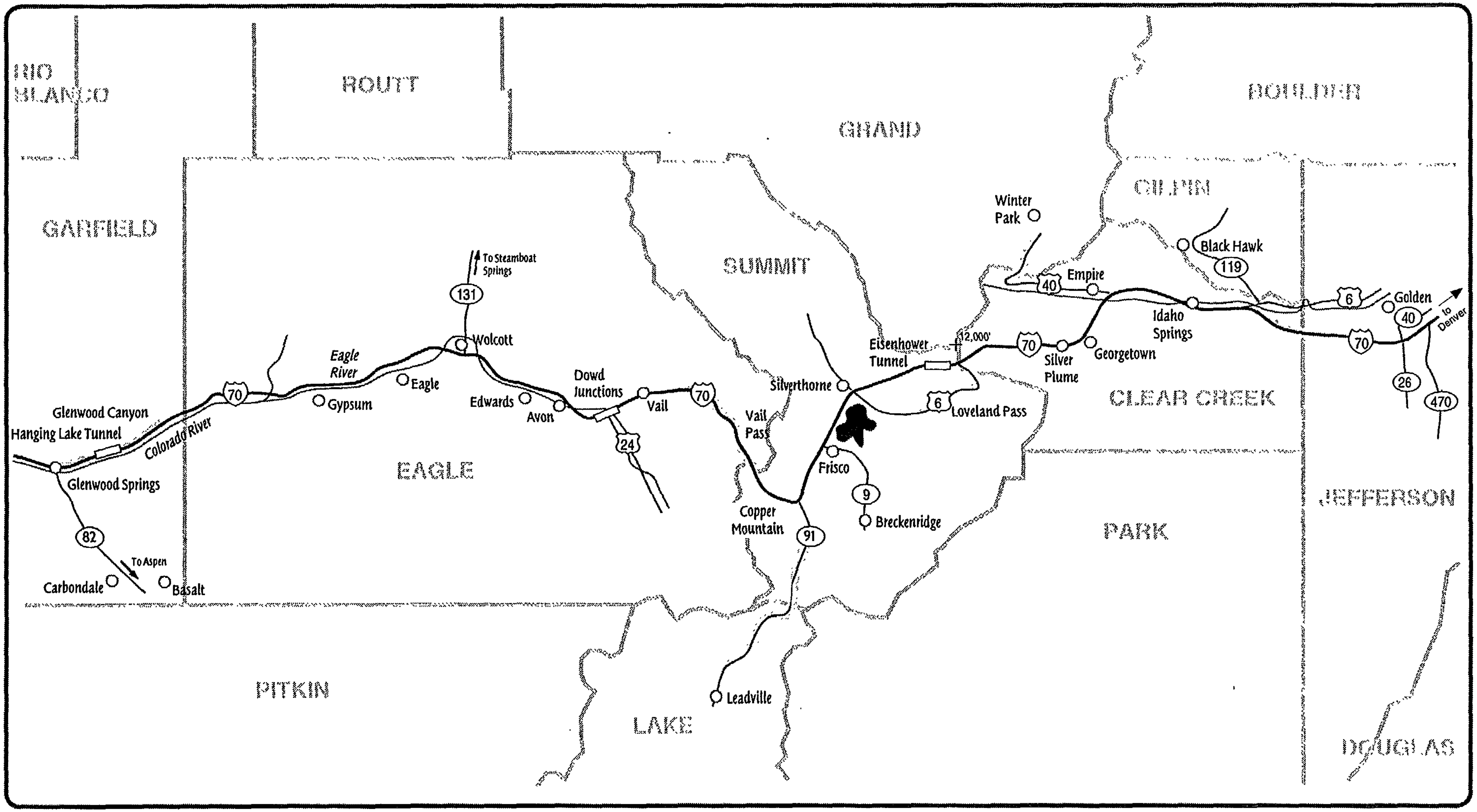
Many governmental jurisdictions and special interest groups are stakeholders in transportation along the I-70 and associated state, county, and local facilities. The carrying-capacity for large volumes of mixed vehicular traffic with minimal negative impact to the surrounding environment is of primary importance to all stakeholders.

From the C-470/I-70 interchange west of Denver in Jefferson County, at an elevation of 6000 feet, I-70 enters Mount Vernon Canyon as a six-lane facility, traversing 6 to 8 percent grades as it heads west into the Rocky Mountains. The Hogback, a geologic formation along the Front Range, establishes the demarcation of the foothills from the Denver metropolitan area valley.

Residential communities; scenic overlooks; historical, paleontological, and archaeological sites; and business/commercial activities attract commuters and travelers to this 12.5 mile segment of the corridor. Access to the towns of Golden, Evergreen, Morrison, Black Hawk, and Central City, and other northern Front Range communities intersect I-70 in this area via US 6, US 40, SH 26, and C-470. Prior to leaving Jefferson County, I-70 intersects with State Highway 74 (SH 74) at the Genesee Interchange.

Entering Clear Creek County at 7500 feet, I-70 narrows to a four-lane facility, dropping toward the canyon between Smith and Floyd Hills and the Santa Fe and Saddleback Mountains in the Arapaho National Forest. At the bottom of the grade, US 6 interchanges with I-70, providing alternate access to Black Hawk and Central City via SH 119. Idaho Springs, an historic mining town nestled in Flirtation Peak canyon, lies approximately 8 miles from the Clear Creek/Jefferson County line. I-70 winds through the canyon approach, then cuts through the mountainside via the l/4 mile long Twin Tunnels.

Climbing out of the Idaho Springs canyon, I-70 begins a steep and twisting 15 mile ascent toward Georgetown and Silver Plume, passing the towns of Dumont, Downieville, and Lawson, reaching 8500 feet at the US 40 interchange. US 40 continues west to Empire and toward its climb toward



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I-70 RURAL IVHS

NEEDS ASSESSMENT

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Study Area

Figure I-1

Berthoud Pass on the Continental Divide, providing access to Winter Park, Steamboat Springs, and other recreational areas in northwest Colorado. I-70 turns south through Empire Pass toward Georgetown, at 9000 feet. At Georgetown, I-70 turns south, climbing toward a 10,000 foot elevation and Silver Plume.

I-70 continues a 12-mile westward climb toward the Continental Divide and 11,000 feet, serving the towns of Graymont and Bakerville before intersecting with US 6. US 6 heads south over Loveland Pass, providing an alternate route over the Divide for over-height and hazardous cargo-carrying commercial vehicles.

I-70 travels through the Eisenhower/Johnson Memorial Tunnel, an approximate 2 mile passage through the Continental Divide, delineating Clear Creek and Summit Counties. Exiting the west tunnel portal and turning southwest, a six-lane I-70 bends and descends for 10 miles, along 6 to 8 percent grades, into the Dillon Reservoir valley, serving the towns of Dillon, Silverthome, and Frisco in Summit County. The valley flourishes with summer and winter recreational activities. Access to Keystone and the ski slopes via US 6; south to Breckenridge and Leadville via SH 9; and north to Kremmling and Steamboat Springs via SH 9 make this activity center an important travel hub.

I-70, a four-lane divided freeway, begins another 11.5 mile ascent into the White River National Forest and the Eagles Nest Wilderness, continuing south through Officer's Gulch, before turning west at the junction of SH 9 1, leading to Fremont Pass. I-70 veers west then north to Vail Pass at 10,666 feet and enters Eagle County. West of Vail Pass, I-70 continues a 13 mile up and down, winding travel path, generally northwest, then west into the Vail Valley at 8200 feet. About 3 miles southwest of Vail, I-70 intersects with US 24 (heading southeast to Leadville) at Dowds Junction, where it turns northwesterly and parallels the Eagle River and the Southern Pacific (formerly Denver & Rio Grande Western)/Amtrak passenger train route. The I-70 descent into the. Eagle River Valley, at approximately 7500 feet, serves the towns of Avon, Edwards, Wilmor, and Wolcott.

Local routes intersect this 15 mile stretch of I-70, providing access north to Steamboat Springs via SH 13 1 and south along county roads into the White River National Forest. West of Wolcott, I-70 enters the Red Canyon, a generally straight and flat 15 mile passage past the town of Eagle to Gypsum. US 6 parallels I-70 throughout this stretch. I-70 continues west for 9 miles, at an approximate elevation of 6200 feet, toward Dotsero and the confluence of the Eagle and Colorado Rivers before entering Garfield County and Glenwood Canyon.

Entering Glenwood Canyon and Garfield County, I-70 winds sharply along a new four-lane elevated and cantilevered facility for 13 miles. It passes through the Hanging Lake Tunnel and provides access to numerous recreational and rest area facilities along the Colorado River. Exiting the canyon to the west, I-70 enters the City of Glenwood Springs, at about 6000 feet, famous for many summer recreational activities. Connections, in Glenwood Springs to SH 82, provide access to the towns and recreational areas of Carbondale, Basalt, Snowmass, and Aspen.

I-70 RURAL IVHS

NEEDS ASSESSMENT

SECTION II

SYSTEM NEEDS

SECTION II SYSTEM NEEDS

An assessment of the physical and organizational inventory of corridor-wide problems and needs (documented in the companion ***Information Search Memorandum)*** revealed 6 major areas that greatly affect transportation system performance. These are:

- weather/weather-related conditions;
- physical roadway characteristics;
- safety;
- information sources;
- communications; and
- traveler mobility.

Further evaluation of each problem/need, related to these areas, enabled a global analysis to determine how ITS might apply and produce partial or whole benefit to solving a particular problem or need or group of related problems/needs. By examining each of these areas, the relationships between the problems and needs within the I-70 West Corridor, as a system, were tied to the system-wide goals to:

- increase safety;
- manage and reduce congestion;
- improve mobility;
- enhance economic productivity;
- alleviate energy-use inefficiencies;
- emphasize environmental quality; and
- ✓ heighten positive public perception.

WEATHER/WEATHER-RELATED CONDITIONS

The I-70 West Corridor is subject to adverse weather and weather-related conditions that create hazardous travel conditions. The affects of weather result in safety and congestion problems that have potential to be alleviated if travelers can be advised of impending conditions in ample time to make alternate trip-making decisions. Table II-1 pinpoints specific focal areas within the I-70 West Corridor where weather and weather-related conditions affect travel and system performance.

Weather Systems. Weather systems develop suddenly and frequently throughout the entire I-70 West Corridor. These storms can produce conditions of poor visibility, high winds, cold temperatures, snow, ice, and rain and result in hazardous driving conditions. Approximately 40% of the traffic accidents on I-70 between US 40 and the town of Glenwood Springs from December 1,199O to March 3 1,1995, occurred in the presence of rain or snow. An even larger 60% of the total accidents occurred on wet, snowy, or icy roadways, indicating that not just weather systems create

TABLE&I
WEATHER/WEATHER-RELATED FOCUS AREAS

WEATHER SYSTEMS	ROADWAY ICING	AVALANCHE & ROCK/MUD SLIDES	HIGH WINDS	FIRES
- Accidents + I-70: C-470 to Floyd Hill Frisco to Eagle - Road Closures + I-70: Floyd Hill Georgetown Frisco Copper Mountain Vail + US6: Loveland Pass - Lack of Information + At Corridor Entrances + Along Routes	- Accidents + I-70: Frisco to Eagle Floyd Hill Dowds Junction Glenwood Canyon - Slowing/Delays + Tunnel Approaches Twin Tunnels Eisenhower + Steep Grades C-470 to Floyd Hill Idaho Springs to Silver Plume Eisenhower to Silverthome Frisco to Eagle Loveland Pass Berthoud Pass McClure Pass Independence Pass Rabbit Ears Pass + Sharp Curves Floyd Hill to Idaho Springs Glenwood Canyon SH Mountain Passes	- Road Closures + I-70: Floyd Hill Georgetown Frisco Copper Mountain Vail Straight Creek Glenwood Canyon Glenwood Springs West + US6: Loveland Pass + SH 40: Berthoud Pass	- Accidents + I-70: Floyd Hill Georgetown Vail Pass Dowds Junction Glenwood Canyon	- Road Closures + Forest Entire Corridor + Vehicular (Brake/ Engine Failures; Altitude-Related) Within Tunnels On Steep Down-Grades

driving hazards but the resulting conditions can also be a partial cause accidents. Weather-related accidents occur throughout the entire corridor. In particular, they accounted for a slightly higher percent of the accidents on I-70 between Frisco and Eagle.

Between January 1990 and March 1995, I-70 experienced 9 road closures due strictly to poor visibility and adverse weather. These road closures occurred at Vail, Georgetown, Floyd Hill, Copper Mountain, and Frisco. The State Highways within the I-70 West Corridor experienced 22 road closures due to poor visibility and adverse weather between these dates. US 6 recorded the majority of these closures, at Loveland Pass.

Weather systems create problems when operations and maintenance personnel, motorists, and transit carriers, unaware of existing or potential weather conditions, proceed into hazardous areas unprepared. Currently there is inadequate real-time weather information available to motorists to avoid such situations.

Roadway Icing. Roadway icing is a weather-related condition, occurring when wet roadways are subject to freezing temperatures. Preferential roadway icing occurs throughout the corridor at various locations. Icy roadways result in traction problems for vehicles. Motorists traveling at unsafe speeds over these areas can quickly lose control of their vehicles, often resulting in accidents.

Between US 40 and Glenwood Springs from December 1, 1990 to March 3 1, 1995, more than 35% of the total accidents on I-70 occurred under icy conditions. Icy road accidents occur throughout the corridor, as to be expected, but account for a larger percent of the accidents on I-70 between Frisco and Eagle. On I-70 between Frisco and Vail Pass icy conditions were present during 55% of the recorded accidents, the highest percent of the corridor. Other locations for icy conditions include Floyd Hill, Dowds Junction, and Glenwood Canyon.

Icy conditions are extremely dangerous in the corridor's tunnels. Ice can form as far as 1,000 feet into the tunnel portals. Lack of shoulders, minimal width travel lanes, and restricted access increase the potential danger of icy roadways within the tunnels.

Preventive and continual maintenance should be applied to areas experiencing temperature conditions susceptible to roadway freezing. In order to apply preventive maintenance in an efficient manner, weather and roadway conditions throughout the corridor, especially at overpasses, tunnels and historically ice-prone locations, should be monitored. Motorists need to be warned of icy conditions in advance so they can proceed with caution.

Avalanche and Rock/Mud Slides. Characteristic of a mountainous region, the I-70 West Corridor is highly susceptible to avalanche and rock/mud slides. These natural disasters can adversely affect travel conditions in several ways. Falling debris can block travel lanes, resulting in lane and/or road closures. The threat of an avalanche alone can be so great that a lane or entire roadway will be closed so maintenance crews can blast to invoke a slide. This works to eliminate or reduce the potential danger. Motorists unaware of the conditions ahead can crash into debris on the travel lanes. Lastly, debris can directly collide into a vehicle traveling through the corridor.

Avalanche danger occurs throughout the winter and spring months, dependent on snowfall amount and the instability of snow depth. Rock/mud slide conditions occur predominantly during the spring months as snow melt begins. These conditions are common each year in the southern Colorado mountain areas (Durango, Alan-rosa, Wolf Creek Pass), and particular in the northwest and central mountain areas through which I-70 and other major state highway routes (US 6, SH 40, SH 82) traverse.

I-70, within the study area, has been closed six times since 1990 because of avalanche or rock/mud slides in the areas of Vail (2), Georgetown (l), Copper Mountain (l), Frisco (1) and Straight Creek

(1). During this period, there have also been 28 road closures on State and US highways resulting from the effects of avalanche and rock/mud slides. US 6 at Loveland Pass was closed 25 times alone.

By measuring the seismic and/or acoustic activity, avalanche and rock/mud slide conditions and occurrences can be detected. If avalanches and rock slides are identified before they occur, they can often be averted or minimized. Therefore, it is important to detect avalanche and rock slide warning signs in order to apply timely preventive measures. When an avalanche or rock slide does occur, it is important to quickly identify the location of the occurrence, provide aide to any injured persons, alert approaching motorists of the danger, and remove the debris from the roadway.

High Winds. High winds are continually present throughout the I-70 West Corridor. High winds do not only occur during adverse weather conditions. Often clear, sunny days can be plagued by high gusts of wind. High winds can force vehicles to swerve into adjacent lanes, off the roadway, or even to tip over. Powerful gusts are a particular problem for high profile vehicles. Twenty percent of the corridor's annual traffic consists of commercial vehicles, most of which are high profile vehicles.

High winds are most prevalent in the Georgetown area as well as Floyd Hill, Vail Pass, Dowds Junction, and Glenwood Canyon. To reduce the threat of wind gusts, vehicles must reduce their travel speeds and proceed with caution. High winds need to be identified so that the vehicle operators can receive advanced warning of the dangerous conditions ahead.

Fires. The I-70 West Corridor crosses mountainous forest lands. Potential for forest fires to come in close proximity to a roadway exists. As a forest fire approaches a roadway, heavy smoke can create hazardous visibility conditions and unsafe air quality. If the fire reaches the roadway, the flames themselves can become a threat.

Forest fires can occur throughout the corridor, most commonly during dry summer seasons. Forest fires can be ignited naturally by lightening, deliberately by an arsonist, or unintentionally by unsafe campers or forest personnel attempting a controlled bum to reduce undergrowth.

Automobile fires pose a second type of threat from fire throughout the I-70 West Corridor. The high altitude and steep grades of I-70, coupled with the problems associated with automobiles that are not properly maintained, frequently result in engine fires. Automobile fires are severely compounded when they occur within one of the corridors tunnels. There are about 10 fires per year in the Eisenhower tunnel alone. Tunnel fires are difficult to detect in a timely manner and can quickly generate smoke and gasses.

Early detection of fires, both forest and automobile, and efficient response, is critical to protect the safety of corridor travelers. To ensure efficient response to corridor fires, response efforts should be coordinated between the many operating agencies which respond to fires within the I-70 West Corridor.

ROADWAY CHARACTERISTICS

Roadway elements, such as steep grades, sharp curve, lane widths, little or no shoulder areas, and poor line-of-sight visibility can predispose travelers to potential accidents. Within the I-70 West Corridor, such hazardous roadway characteristics result from the extreme topography of the area in which the Interstate is located. Table II-2 highlights the focal problem areas related to roadway characteristics.

TABLE II-2
ROADWAY CHARACTERISTICS FOCUS AREAS

GEOMETRICS	SPEED	LIGHTING	MARKINGS
- Steep Grades + I-70: Genesee Floyd Hill Eisenhower Tunnel Vail Pass - Horizontal/Vertical Curves + I-70: Floyd Hill Vail Pass Glenwood Canyon - Corridor Tunnels + Eisenhower Tunnel + Hanging Lake Tunnel + Twin Tunnels	- Steep Grades + I-70: Genesee Floyd Hill Eisenhower Tunnel Vail Pass - Sharp Curves + I-70: Floyd Hill to Idaho Springs + Glenwood Canyon	- Low Ambient Light + Roadway Geometry + Pavement Markings + Roadside Delineators + Roadside Obstructions - Unlit Areas + Corridor-Wide Roadway Geometry Pavement Markings Roadside Delineators Roadside Obstructions + Within Tunnels Twin Tunnels	- Within Tunnels + Debris Accumulation - Roadway Surfaces + Snowpack Cover + Debris Accumulation

Geometrics. Roadway geometrics pertain to the physical proportioning of a highway. This includes horizontal and vertical curves, lane widths, cross sections, grades and shoulders. Physical proportioning is limited throughout the I-70 West Corridor by the topography. The resulting roadway geometrics demand a high level of driver attentiveness and skill to safely traverse the corridor.

The same steep and sustained grades that make it possible for I-70 to traverse the Rocky Mountains cause numerous problems for motorists. Some of the more intense grades include Genesee, Floyd Hill, the Eisenhower Tunnel and Vail Pass. These grades can cause engine overheating, brake failure and excessive/slow speeds.

Horizontal and vertical curves are located throughout the corridor. Curves can cause motorists traveling to fast to lose control of their vehicle. Curves are difficult to recognize at nighttime or during poor visibility conditions and can reduce sight distance. Sight distance is a particular problem when a traffic accident or stalled vehicle cannot be identified by approaching motorists in time to stop or avoid the wreckage. This often results in multi-car accidents. Areas that have experienced sight distance problems on I-70 are Floyd Hill, Vail Pass, and Glenwood Canyon.

The tunnels located throughout the corridor, particularly the Eisenhower, Hanging Lake, and Twin Tunnels are characterized by minimum lane widths, no shoulders, restricted access and low light. This results in motorists reducing there speeds to travel through the tunnels. During peak periods this reduction in speed can result in congestion in the areas preceding the tunnel entrances. Restricted access throughout the tunnels makes vehicular breakdowns inside of the tunnels extremely dangerous.

As traffic increases on the I-70 West Corridor, roadway geometrics will become an increasing safety concern. Motorists need to reduce their speed when sight distance is reduced. Proper warning to this effect as well as real-time warnings to hazards not in sight will reduce this problem. Better roadside delineators and brighter roadway lighting is also necessary to reduce the hazards of roadway geometrics.

Speed. Excessive vehicular speeds are a concern on any roadway. The extreme weather-related roadway conditions and roadway geometrics increase this concern for the I-70 West Corridor. Icy roads, wind gusts, and sharp horizontal and steep vertical curves, located throughout the corridor, demand slower, more cautious traveling speeds.

Grades create speed problems for both ascending and descending vehicles. Steep and/or long upgrades do not only affect the performance of heavy vehicles, but also the performance of automobiles. Trucks and large buses, as well as some compact and sub-compact automobiles, are under-powered and/or affected by altitude (lack of oxygen) to climb long, steep grades, particularly at Floyd Hill, the Eisenhower Tunnel approaches, and Vail Pass. Other vehicles that can maintain and surpass the speed limit are frequently obstructed in their progress by slower-moving vehicles.

Conversely, steep downgrades cause vehicles to attain fast/unsafe traveling speeds quickly, often before the driver realizes it. Trucks and large buses must gear down to maintain control at lower speeds. When a varying mix of vehicle types are present, large speed differentials result, creating a potential for accidents and/or congestion. The problem is compounded when slow-moving vehicles attempt to pass slower moving vehicles, restricting the speed in all lanes.

Often motorists are unaware that they are traveling at unsafe speeds. Adverse weather can create poor roadway conditions, reducing the safe speed limit. Motorists often drive under the assumption that the static posted speed limit is a safe traveling speed, when in fact their speed must be reduced during adverse conditions. Driver inattention is often a human factor that creates the potential for incidents, potentially severe, particularly at higher, unsafe speeds.

Identification of vehicle speeds for the purpose of alerting motorists traveling at excess speeds can reduce accidents. Motorists could also be alerted to the presence of slow-moving vehicles ahead. If legislation is modified, speeding citations could be mailed to those motorists caught on video traveling in excess of the speed limit.

Lighting. Roadway lighting is a particular concern during dusk, dawn, and nighttime hours. As ambient light levels decrease, sight distance decreases as well. Roadway geometrics, signage, delineators, and obstacles in the roadway can become difficult to detect in low light conditions. Vehicle headlights are not always sufficient during rain or snow to adequately illuminate the travel way ahead.

Roadway lighting is not provided in many of the rural sections of the corridor. High risk, high accident areas, such as those that have numerous sharp, reversing curves, should be illuminated to delineate edges of travel way and lane separations.

Lighting within the tunnels during daylight hours is intended to simulate outside conditions. In bright sunlight, some travelers eyes do not adjust to the light levels quick enough. This results in slowing and/or braking, setting the stage for potential rear-end or side-swipe collisions if following motorists are not prepared to reduce their speed as well.

Markings. When pavement markings for travel, turn, and merge lanes and shoulders can no longer be identified or when roadside delineators cannot be seen, travel safety is compromised. Pavement markings are often compromised on all roadways within I-70 West Corridor during the winter months when snow accumulates and covers the striping and roadside delineators. Multiple lanes are often reduced by one lane as motorists, unable to identify exact lane locations and roadway edges, default to a more secure distance laterally between vehicles. This effectively reduces the capacity of the roadway, compounding any congestion problems that already exist.

Additionally, road debris and snow can accumulate on the roadways, particularly within the tunnels, reducing the brightness of the roadway markings. Special roadway delineation applications can compliment regular roadway markings, alerting motorists to changes in the roadway geometrics.

SAFETY

The safety issues facing the I-70 West Corridor are unique to a rural corridor, with special concerns for wildlife intrusions and remoteness. Increased safety measures can reduce the number of incidents (and injuries and fatalities), allowing people to feel more at ease while traveling. Increased safety also reduces the economic loss resulting from accidents, which is estimated nationally at 2% of the Gross National Product. Table II-3 illustrates the foal areas within the I-70 West Corridor where safety concerns are prevalent.

TABLE II-3 SAFETY FOCUS AREAS			
ROADKILL	**INCIDENT RESPONSE**	**TRAVELER INFORMATION**	**TRAVELER ASSISTANCE**
- Animal/Vehicular Conflicts + Big-Horn Sheep: US-40 - Georgetown + Deer: Eagle to Glenwood Springs	- Traffic Accidents + I-70: Genesee Frisco to Eagle Floyd Hill Dowds Junction Glenwood Canyon - Avalanche & Rock/Mud Slides + I-70: Floyd Hill Georgetown Eisenhower Tunnel Approaches Vail Pass Straight Creek + US 6: Loveland Pass + us 40: Berthoud Pass Rabbit Ears Pass + Other State Highways McClure Pass Independence Pass - Inaccessibility + For Emergency Crews + For Removal/Clean-Up	- Lack of Information + Advisories + Warnings Throughout Corridor and at Corridor Access Points	- Calls for Help - Personal Security Throughout Corridor

Roadkill. A rural corridor mandates the coexistence of nature and humans. Deer, elk and Big-Horn sheep are common throughout the I-70 West Corridor. Between December 1, 199O and March 3 1, 1995,291 traffic accidents on I-70 between US 40 and Glenwood Springs involved wild animals. Six other accidents involved domestic animals. Areas along I-70 with the largest percent of accidents involving animals are between Eagle and Glenwood Springs and between US 40 and Georgetown. Deer are most prevalent on I-70 between Eagle and Glenwood Springs while the Georgetown region possesses a large population of Big-Horn sheep.

Animal/vehicular conflicts can result in major property damage to automobiles, personal injury, and costly clean-up and removal. In the past, efforts to keep animals off of the roadways have proven to be expensive, unsightly, and ineffective. The most efficient manner to reduce animal/vehicular conflicts is **to** warn motorists of nearby animals and recommend lower traveling speeds. Static signs displaying this type of information tend to be ignored, because usually there are no animals in sight so after a number of passes, motorists subconsciously disregard the warnings. Methods to detect wildlife entering rights-of-way, so that warnings can be conveyed to travelers via dynamic signage, are ITS applications that have good potential to resolve these problems and needs.

Incident Response. Emergency notification systems are basically non-existent within the I-70 West Corridor, except within the jurisdiction of the Eisenhower and Hanging Lake tunnel complex operations. In a rural area, incident response is not always immediate as incidents are not usually detected/reported in a timely manner. A motorist experiencing difficulties must attempt to contact authorities using a personal cellular telephone, if one is available and reception permitting, or travel to an available public telephone to call for help. In reporting the incident, the motorist must identify or approximate the incident location based on natural features or mile markers. If the motorist is incapacitated, emergency notification relies on passing motorists.

Incident response is directly related to motorist safety. The more quickly emergency response teams can administer aid to a victim, less severe the consequences result. Within the I-70 West Corridor, emergency responders are taxed for time in responding to incidents. Incident response programs can speed up this process. The high volumes of traffic along I-70 also require timely incident response programs. It is proven that for every one minute saved in responding to and clearing an incident, four minutes are saved in reestablishing the typical level of service (LOS) for the roadway.

When accidents are detected/reported, emergency crews must sometimes travel great distances to locate and arrive at the scene. It is critical to identify incidents as soon as possible to allow for emergency response travel times. Incidents should be removed from the roadway as soon as possible, in order ‘to resume full roadway capacity. The Denver metropolitan area has adopted “move it/remove it” legislation enabling removal of vehicular obstruction from the travel lanes as quickly as possible. Ideally, vehicles involved in an incident would be moved, not just off the roadway, but out of sight of the roadway, to reduce continued congestion resulting from driver “curiosity”.

Avalanches and rock slides often result in complete closure of I-70. As a result, incident management activities will impact a wide geographic area, and the technical and personnel requirements will be similarly dispersed. The rugged terrain of the I-70 West Corridor, and the remoteness of some areas at which incidents may occur, make it difficult to reach the scene of traffic accidents and hazardous material spills if vehicles leave the immediate corridor right-of-way. Incident management planning thus must include contingencies for unusual conditions, and the potential need for specialized equipment to access the site. Maintaining communication channels between the engineering personnel responsible for planning, and the incident management personnel who handle unpredicted incidents, will alert the emergency personnel to particular trouble spots and needs, and their input will aid in developing an appropriate maintenance-of-traffic or operations plan.

Equipment and labor should be focused on high incident locations, such as I-70 from US 40 to Floyd Hill, Dowds Junction, Vail Pass, and the corridor tunnels, during periods peak travel times (holiday weekends; Friday and Sunday evenings). Response plans, involving the efforts of multiple jurisdictions, should be predetermined and implemented immediately upon incident detection/confirmation. Response plans can improve emergency vehicle dispatching as well as routing.

Incidents also include planned events which create traffic problems. These events can include special festivals in a corridor town or major ski weekends. These events can create an inordinate amount of traffic over a given duration. Information regarding these events needs to be disseminated to allow travelers to make informed decisions on their routes and travel times. Additionally, response plans should be formulated and enacted for these events.

Traveler Information. As previously noted, weather, traffic accidents and congestion in conjunction with limited access, limited sight distance, multiple tunnels and high traffic demands require that accurate real-time advanced warning be provided throughout the I-70 West Corridor. A sensor-actuated environment used in conjunction with expert systems can determine hazardous ice, snow, high wind, avalanche, and rock slide conditions and flag potential incidents throughout the corridor. Warnings should be provided on existing and potential conditions at entrances to the corridor and periodically throughout the corridor. Advanced warnings will allow motorists to modify their routes or traveling times, increasing safety and reducing congestion.

Traveler Assistance. The I-70 West Corridor has areas of little or no civilization, and can undergo extended periods of low traffic volumes. Stranded motorists cannot always rely on being able to walk to the nearest town for help or for good Samaritans to pass by. Motorists need a means by which they can call for help or report an incident. Although there are call boxes in the corridor, they are too infrequent and not always reliable. The radio call boxes in Glenwood Canyon have never worked properly and need to be replaced by cellular call boxes. Cellular telephone coverage has expanded to provide decent coverage of the I-70 West Corridor. The I-70 West Corridor needs a network of call boxes, initially at rural interchanges and throughout rural areas, to increase driver safety in the event of an accident or breakdown.

INFORMATION SOURCES

There are two distinct functional areas where information sources are needed: data collection and processing to provide operations and traveler information, and education and training to describe and promote the benefits of ITS as an alternative and/or component of transportation system improvements. For ITS to perform at their full capability within the I-70 West Corridor, there must be interconnectivity among ITS elements and interaction between the responsible agencies and communities. Information sources must exist at the national, state, regional and local levels. Table II-4 identifies the necessary components to ensure that reliable data **is** available.

National. As Colorado ITS projects develop and begin to rely on national interaction, demanded by such projects as an automated Port of Entry, national compatibility will become an increasing concern. The USDOT ITS National Program Plan (NPP) serves as a comprehensive user-oriented planning reference which outlines the research, development, testing, and other activities necessary to achieve and support deployment of ITS within the framework of a nationally compatible, intermodal system. The National Program Plan addresses the role of the federal government and

TABLE II-4
INFORMATION SOURCES FOCUS AREAS

NATIONAL	CLEARINGHOUSES	STATE PUBLIC INFORMATION OFFICES	REGIONAL	LOCAL
- Compatibility + USDOT National ITS Program Plan 6 US DOT National Architecture	- Information Dissemination + Internet/World Wide Web Sites: US DOT ITSAmerica Bureau of Transportation Statistics State DOT Home Pages	- ITS Education + Publications + Outreach Programs - Traveler Information Dissemination + Public Information Officers + Road Condition Reports/Hotlines	- Infonation Hubs + Transportation Management Systems + Private Industry/ Media - Coordination + Transportation Engineering and Planning Entities + Transportation Improvement Plans and Programs + Service Providers	- Transportation System Users + County/Municipal Governments + Business/Resident Communities + Special Interest Groups - Information Providers + Chambers of Commerce + Media

public/private partnerships in facilitating ITS deployment and identifies the critical planning, marketing, education, and coordination tasks which must be undertaken nationwide. The National Program Plan identifies and fully defines the ITS services and functions that can be included in the I-70 ITS Implementation Plan, to serve the needs, priorities, and market forces of the I-70 West Corridor.

With the goal of establishing a national ITS architecture which meets the needs of many different stakeholders by mid-1996, the System Architecture Development Program was initiated. Of the four alternative architectures being researched through the Program, a unifying national architecture will emerge. The national ITS architecture will have an “open” configuration to ensure nationwide compatibility over the long term, to permit phased implementation, to encourage competition among suppliers, to establish industry standards, and to provide the flexibility that will facilitate system evolution over time. It is critical that the ITS applications deployed within the I-70 West Corridor be consistent with the national architecture, to ensure that the Corridor does not become an isolated ITS that does not accommodate inter-regional travel.

The US DOT is also in charge of overseeing the development of national standards for the data-intensive computer and communication systems required for ITS deployment. Standards will facilitate the compatibility and interoperability of systems. Various standards are being developed by organizations such as the American Society for Testing and Materials (ASTM), Electronic Industries Association (EIA), Institute of Electrical and Electronics Engineers (IEEE), Institute of Navigation (ION), Institute of Transportation Engineers (ITE), National Electrical Manufactures Association (NEMA), Telecommunications Industry Association (TIA), and the Society of

Automotive Engineers (SAE). Continued involvement through these societies is necessary to establish proper standards.

The national standards and system architecture will support the important requirement for information sharing across state boundaries and other jurisdictions, such as port-of-entry, weather, road closure, and hazardous material tracking information. The tourism industry has a vested interest in providing accurate traveler information relating to recreational activities, such as skiing or camping, to potential visitors from other states. A nation-wide information search is needed to determine what information is available and what is additional information is desired. Once information has been located, sharing agreements and communication links need to be established.

Clearinghouses. Disseminating information is an integral part of ITS. Agencies must be able to alert travelers as well as other agencies of transportation problems and solutions.

Information clearinghouses can be used to distribute transportation information locally, regionally, nationally and even globally. Information clearinghouses utilize centralized databases and computer systems that can be accessed in a variety of ways. One such clearinghouse is the Internet's World Wide Web (WWW). A variety of transportation information is currently available on the WWW, including real-time traffic reports for Seattle, Los Angeles, Houston, and San Diego on the Texas Transportation Institute home page (http://herman.tamu.edu); and real-time congestion levels for the Chicago metro-land area (http://mana.eecs.uic.edu:800l/GCM/GCM.html). Additionally, clearinghouses can be linked with Traffic Operations Centers to share information, locally, regionally, nationally, and globally.

State Public Information Offices. Public support can make or break ITS projects. To insure public support of ITS, the public needs to be informed of the possible ITS technologies available and the benefits that ITS can provide. The public needs to be able to readily access transportation information.

Public Information Offices are responsible for providing the public with transportation-related information. Public Information Offices need to have access to a variety of corridor information. . Information including congestion, accidents, incidents, road and weather conditions, expected travel times, and alternate routes. As liaisons to the public, Public Information Offices need to be familiar with the advanced technologies deployed within the I-70 West Corridor. Additionally, the Public Information Offices should initiate public outreach programs to promote ITS and educate the general public on the benefits of ITS.

Regional. ITS subsystems create a wealth of information. This various information is most efficiently collected and processed centrally within a region. An integrated ITS architecture ensures that like data is screened and processed similarly and output is handled consistently. It ensures that parameters and algorithms are the same for data received from different data sources and outgoing messages are consistent throughout a region.

Transportation management systems (TMSs) are needed to serve as focal points for area-wide data collection, data processing, information dissemination, demand management, incident management, and fleet management. Existing systems within the corridor are currently operated and maintained by the CDOT Engineering Region within which they are located. For example, the central control units for the existing variable message signs (VMS) and SCAN systems were originally operated by the CDOT Engineering Regions. (Currently, efforts to integrate the SCAN systems are underway, and Region 1 has delegated control of I-70 West Corridor VMSs within their jurisdiction to Colorado's statewide interim Traffic Operations Center.) The field infrastructure within the corridor will be linked through a distributed network of integrated control hubs having sufficient computing power to utilize the data for real-time Advanced Traffic Management Systems (ATMS) and Advanced Traveler Information Systems (ATIS) applications. Centrally maintained dynamic databases will be available to multiple end users, including the CDOT operation and maintenance personnel, the traveling public, emergency response services, police, the media, and other operating agencies. The interconnect between facilities will enable a statewide information exchange, data processing, and seamless transportation system operations.

The responsible transportation planning and engineering regions need area-wide coordination to achieve successful ITS implementation. Problems and activities need to be identified throughout the corridor and appropriate actions determined on a corridor-wide basis.

The CDOT Engineering Regions are responsible for the majority of operation and maintenance' activities that occur within the corridor. Animal/vehicular clean-up and motorists assistance draws maintenance crews away from their required duties. The ITS applications and services implemented within the corridor should be designed to minimize operational and maintenance requirements. Additionally, remote collection of roadway condition data, such as icing and amounts of deicing chemicals applied to roadway surfaces, will allow maintenance crews to operate more efficiently.

Maintenance sections within the Engineering Regions can provide information schedules on road construction and maintenance operations. The Engineering Regions also need to coordinate traffic control and incident response strategies and plans throughout the corridor. Use of coordinated Geographic Information Systems (GIS) will also aide in traffic management and incident response plan development. GIS need to be set up and developed through a corridor-wide effort to ensure compatibility.

Local. County and municipal governments are concerned about congestion during peak travel seasons, both in the winter and summer, that reduces the local quality of life and damages the environment. Congestion results from incidents and high traffic volumes and is compounded in corridor towns by lack of knowledge regarding available parking, County and city governments throughout the corridor can use real-time traffic information to dispatch local emergency and police units, prepare hospital emergency rooms for incoming traffic accident victims, direct motorists to available parking, and implement traffic control strategies.

Organizations like chambers of commerce, need to provide information regarding local business and resort area activities visitors. Information on special events; business/resort/recreational area operating hours/seasons; and available transportation will help to promote the local economy. Resorts and businesses can help to reduce the peak hour traffic, and thus reduce congestion, by encouraging off peak trips and public transportation for corridor travel. Local business and resorts can be a source of funding for area traveler information kiosks, VMS, and highway advisory radio (HAR) systems, as well as sponsors of components of many ITS projects and programs.

COMMUNICATIONS

The major component of ITS infrastructure is a reliable communications system. The corridor communications system represents the single element that can dictate the success or failure of ITS implementation within the I-70 West Corridor. Adequate and reliable communications, for both data and voice processing, are critical. Communications between operating agencies and users are also crucial. Table II-5 summarizes the areas of focus for communications within the I-70 West Corridor.

TABLE II-5
COMMUNICATIONS FOCUS AREAS

SYSTEMS / EQUIPMENT	USER INTERFACE
- Capacity, Data Integrity, and Coverage + System Requirements and Upgrades + Two-Way Data, Voice, and Video Communications	- Information Sharing 6 Transportation Management Systems + Colorado State Patrol + Emergency Service Providers + Operating Agencies + Regional/Local Service Providers + Other Information Sources - User Cooperation + Inter- and Intra-Agency + Between Agencies and their Constituencies

Systems/Equipment. The existing communication systems, used throughout the I-70 West Corridor for data and voice transmissions, include leased telephone lines, microwave, and digital trunked-radio. Leased lines do not provide adequate capacity, voice/data integrity, and coverage to support current communications needs. The State microwave system requires line-of-site transmission--existing microwave tower installations cannot provide complete and continuous coverage within the I-70 West Corridor. Implementation of digital-trunked radio communications systems by CSP and CDOT is a recent effort to provide more complete and comprehensive coverage. As new data-intensive ITS applications are deployed, capacity, integrity, and coverage constraints and limitations will intensify.

New communications systems and upgrade of existing systems are needed to sustain ITS within the I-70 West Corridor. Upgrades need to support all methods and devices to gather, share, and disseminate real-time information. Two-way data and video communications are needed between control centers and field devices. Voice and data communications are needed throughout the corridor to support inter-agency coordination and administrative functions. The communications system must include provisions for future system expansion and technological developments.

User Interface. Successful implementation of ITS within the I-70 West Corridor depends on the availability of accurate, reliable information. The communications infrastructure must facilitate information sharing between Transportation Management Systems, operating and enforcement agencies, emergency and regional/local (public works, transit) service providers, and other information sources (national compatibility, clearinghouses, public information offices). A dependable, non-capacity constrained communications infrastructure and associated processing systems are needed to support multi-jurisdictional information sharing functions. Links must be provided to interconnect the following agencies and organizations, at a minimum:

- CDOT Engineering Regions (Operations and Maintenance; Headquarters and Field Offices, including Tunnel Control Centers);
- Colorado Transportation Management System;
- Colorado State Patrol;
- Department of Revenue, Ports of Entry Division;
- Municipal and County Governments;
- Local Law Enforcement and Fire Districts;
- Emergency Service Providers (Hospital, Ambulance, Paramedics, Special Response Teams, Tow Operators)
- Transit Service Providers (Public and Private)
- Commercial Traffic Reporting Services
- Media (Select Television/Radio Stations--potentially print media services)
- Colorado Incident Management Coalition
- Any Other State/Regional/Local ITS Organizations Responsible for Management/ Administration of ITS Programs Within the Corridor

To fully realize this goal, agencies must work together to establish protocols and ensure data conformity and hardware/software compatibility. Data conformity will ensure that consistent, coordinated systems and codes are used. Alias tables need to be developed to translate data that is not consistent.

Cooperation is a relevant part of communications. Agencies must transcend their internal and external differences. Competition for limited funds, the need for autonomy, and “business as usual” each create conflict that is neither productive nor solution-oriented. The ability to communicate respective problems and needs and keeping an open mind to other conflicting problems and needs opens the door to more effective communications. Team dynamics are utmost.

Agencies need to be responsive to their constituents. Likewise, those constituents must recognize that regional and other organizational needs (particularly economic) are equally important as local quality of life. In example, many of the local constituents within the I-70 West Corridor perceive that truck-related accidents are the primary cause of safety and congestion problems. They believe that if all commercial vehicles are restricted from using I-70 that most travel problems will disappear. The state and regional impacts of such an action would be devastating to Colorado's economy if goods cannot be shipped within and through the State via I-70. Open communications and developing trust can help respective constituencies recognize, logically (not emotionally), how and what trade-offs can be negotiated to satisfy the needs of all users at acceptable levels.

TRAVELER MOBILITY

The purpose of a transportation network is to allow for the efficient and effective movement of both goods and people. This can be accomplished via roads, rail, trails, and air; using automobiles, motorcycles, trucks, vans, buses, bicycles, trains, transit vehicles (heavy and light rail), airplanes, horses and other pack animals, and on foot. The institution of publicly-owned and -operated transportation systems has relegated overwhelming freedom of mobility, creating a pervasive perception that individual, unrestricted mobility is an inalienable right. The consequences on the environment, quality of life, ability to maintain the "perfect" system (resource allocation including funds, staff, materials, and equipment), and social and economic vitality are far-reaching. Table II-6 describes the mobility areas requiring focus within the I-70 West Corridor.

TABLE II-4
TRAVELER MOBILITY FOCUS AREAS

DELAYS	TRAVEL MODES
- Incidents + Vehicular Accidents + Animal Conflicts + Stranded Travelers - Weather/Environment + Visibility + Natural Disasters - Physical Conditions + Substandar/Treacherous Roadway Geometry + Lack of Alternative Services (Transit, Rail, Air) / Volumes + Increased Recreational Usage + Commercial Vehicle Usage + Population Growth	- Private Automobiles _+ Information-Advisories/Warnings + Reasonable Alternate Mode Travel Choices - Commercial Vehicles + Seamless Passage + Credential/Freight Enforcement + Productivity/Efftciency/Safety - Shuttles/Buses/Vanpools/Carpools/Other Transit + Schedule Availability/Reliability + Passenger Comfort/Security/Convenience/Accessibility + Travel Freedom + Travel Time + Multi-Modal Transfer Centers - Air Travel + Ground Transportation Choices + Location and Capacity + Intermodal Freight Transfer - Passenger Rail + Available Corridors + Capital and Operating Costs (Farebox Revenues and Subsidies) - Bicycles/Equestrians/Pedestrians + Safety (Remote Areas/Interface with Motorized Vehicles) + Trail Congestion

Delays. As traffic volumes on a roadway near or surpass the roadway capacity, or in the event of an incident, roadways become congested. Traffic volumes throughout the I-70 West Corridor are currently increasing at a current rate of five percent per year. Traffic volumes are significantly greater on the eastern end of the corridor near the Denver metropolitan area. I-70 at the Genesee Interchange recorded a 1994 average daily traffic count (ADT) of nearly 50,000 vehicles per day, with the average ADT in July over 61,000 vehicles per day. The Eisenhower tunnel handles a lesser yet still significant 21,000 vehicles per day (as determined by the 1994 ADT). Traffic volumes at the towns along the corridor, such as Vail and Glenwood Springs, create pockets of high ADT. Traffic volumes are greater during the summer months than the winter months.

To accommodate peak period traffic levels, CDOT has implemented a manual reversible lane program through the Eisenhower tunnel. This manual operation entails significant labor and requires long set-up and take-down periods. It can be significantly improved and automated with today's technologies. In the Glenwood Springs area, there is morning and afternoon urban cornmuter congestion has proven to be significant enough for CDOT maintenance to adapt its schedule around these peak periods.

Incidents include traffic accidents, natural disasters, hazardous material spills, adverse weather, special events, etc. The most common incident is the traffic accident. An average of 1,300 accidents per year occur on I-70 between US 40 and Glenwood Springs. Since 1990, I-70 between Floyd Hill and US 40 has possessed the highest number of accidents per mile. The Vail region, from Vail Pass to the town of Vail has possessed a similarly high accident frequency.

Incidents can result in blocked travel lanes and even closed roadways. Fewer travel lanes reduces roadway capacity predisposing the facility to congestion. Incidents can also result in congestion when they are off the travel way but still in view of passing motorists. Curiosity causes motorists to slow down to look at any wreckage, emergency vehicles or just about anything bent, broken, or bloody.

Incidents within the tunnels are a particular problem. Stalled vehicles are the cause for nearly two stoppages per day. In the past there have been as many as 14 stalls in 45 minutes within a tunnel. In such an event the tunnels must be completely closed due to the increased risk of fire.

Congestion due to high traffic volumes can be relieved by either increasing the capacity or decreasing the number of vehicles traveling the corridor. Increased ridership of public transportation and high occupancy vehicles (HOV) will reduce traffic volumes. If incidents are quickly identified and cleared from the travel lanes, traffic flow would be less disrupted. The tunnels, in particular, need to be monitored closely for incidents. Travel demand management programs should be implemented throughout the corridor at congestion prone locations.

Travel Modes. The current emphasis in transportation, to alleviate congestion and improve environmental quality, is to encourage alternative travel modes other than individuals singularly occupying and using one vehicle. A wide variety of alternative travel modes can be offered within the I-70 West Corridor, given adequate funding and political/community will.

Private automobiles are the most popular mode of transportation. The -high number of private automobiles traversing the I-70 West Corridor compounds congestion problems. Traveler frustration increases exponentially with congestion; increasing vehicle miles of travel translates into a potential for more incidents; and more pollutants are emitted into the environment as the number of vehicles increases.

Better informed motorists, with more information on incident locations, weather conditions, traffic volumes and travel times, parking availability, and public transit schedules, will be able to select better routes, delay trips, or select other modes of travel. Efforts need to be made to reduce vehicular-related pollutants and control roadway run-off from seeping into the environment. Motorists need to be encouraged to make trips at less congested times and/or utilize other modes of travel.

Commercial vehicle operators need to carry goods as quickly and safely as possible through the I-70 West Corridor. Terrain and weather exacerbate this need. Commercial vehicles are regulated by the State to ensure, safe transport as well as collect necessary fees that are applied to maintaining roadway surfaces and enforcing use of the facility.

From an operating agency perspective, commercial vehicle regulation enforcement can be time-consuming and labor intensive. Operators often abuse equipment and shipment mandates (donning tire chains when roadway surfaces are slippery; hazardous material cargo passage through the tunnels) because the actions are time consuming (longer trips reduce economic productivity when shipments are not delivered on time).

Commercial vehicle safety is a major problem in the I-70 West Corridor environment. Steep downgrades burn out braking systems, resulting in run-a-way trucks and potential accidents. Accidents may result in hazardous material spills requiring special emergency response mechanisms. Accidents may involve other vehicles, resulting in personal injury and property damage that require immediate emergency response actions. Oversize vehicles (height and weight) and those carrying hazardous materials are re-routed around tunnels to avoid clearance problems and potential fire hazards. This results in inconvenience and loss of productivity to the trucking industry.

Automation of credential processing and commercial vehicle monitoring at ports-of-entry have been proven to eliminate unnecessary vehicle stops; improve enforcement and inspection efficiency; and reduce paperwork and labor. Targeting commercial vehicles for safe speed compliance is being evaluated.

Public transportation is historically underutilized within the I-70 West Corridor. This mode of transportation can be targeted to increase its desirability. Traveler information can be used to promote mass transit. Better access to public transportation as well as more information to routes and schedules can increase public transportation ridership.

Providing shuttle, van, and bus schedule information at multi-modal transfer centers and park-and-ride lots near corridor access points has potential to increase public transportation ridership and reduce automobile use of the roadway facilities. Transfer centers and park-and-ride lots would, most likely, be regularly used by travelers if alternate mode options are available.

Most travelers are concerned with personal schedule restrictions, comfort, and reliability of public transportation. Again, the imposition on personal freedom makes them more unwilling to use alternative modes of travel. Visitors, particularly out-of-state recreationalists, carry specialized equipment and bags that are a nuisance to transport. Car rental is highly preferred over shuttle services.

Amtrak passenger rail service and the Winter Park Ski Train are popular services for recreational travelers with a specific destination (Glenwood Springs hot springs and the Winter Park Ski Area). Additional services of this nature can be promoted and successful if capital and operating costs can be funded and the ticket price is reasonable.

Commuter/passenger rail systems have been proposed for many recreational areas in Northwest Colorado, including along I-70. Studies show that, if adequate ridership can be achieved, a system may be operated without loss, if subsidized. Proponents believe that if the service is available, it will be used. Rail operators (Union Pacific, Burlington Northern) are interested in operating commuter and/or passenger rail service if it can be profitable.

Denver International Airport (DIA), located northeast of the Denver metropolitan area, is a major origin for visitors traveling to destinations in the I-70 West Corridor. Air passenger service is available to the Eagle County Regional Airport (Vail area), Sardy Field (Aspen area), and the Yampa Valley Regional Airport (Steamboat Springs area). Ground transportation is required from the airports to final destinations, the Eagle and Yampa areas requiring relatively longer ground transport distances.. Multi-modal transfer centers would be needed at the airports to encourage mass transit use. Automobile rentals are the most common form of ground transportation used. Providing traveler information at airports (road conditions, available ground transportation options) have been identified as appropriate resources to help travelers make more informed decisions about ground transportation options.

There are many bicycle routes throughout the I-70 West Corridor. Bicycles are generally used as a recreational mode of transportation. Information along the bicycle route is sparse. Lack of grade separations from other vehicular traffic increases the danger to bicyclist from potential conflicts. Pedestrian trails are available, generally as recreational hike or walking trails within municipal and resort areas and within the national forest and park confines.

I-70 RURAL IVHS

NEEDS ASSEESMENT

SECTION III

TECHNOLOGY OPPORTUNITIES

SECTION III TECHNOLOGY OPPORTUNITIES

Many ITS-related technologies and applications of those technologies to transportation are available and being developed continuously. The research, development, and manufacturing markets are evolving very rapidly. Based on the system-wide ITS goals established for the 1-70 ***Rural IVHS*** study, the 25 specific features identified in the Scope of Work for this, study, and the 6 system needs categories identified and detailed in ***Section I. System Needs*** of ***this Needs Assessment*** report, the following existing technologies, and any applicable advances in those technologies as of January 1996, were evaluated:

- variable message signs (VMS);
- environmental sensors;
- highway advisory radio (HAR);
- microwave communications systems;
- cellular telephone;
- automatic vehicle location systems; and
- ramp metering.

These technologies were assessed with respect to ITS services and applications that have potential to respond to and/or resolve the universe of transportation system-related problems, needs, and concerns identified by all stakeholders within the I-70 West Corridor. Very generalized applications, such as "installing computerized traveler information kiosks at rest areas," led to the development and selection of the specific project sets identified in ***the Early Action*** documents and ***the Corridor Master Plan.***

Any ITS applications reviewed during the Needs Assessment process, and recommended herein for potential application within the I-70 West Corridor, were selected based on the technological information researched and documented in the companion report, ***Information Search Memorandum.*** It is important that the reader and user of ***I-70 Rural IVHS*** study documents recognize that ITS applications and technologies emerge and change the shape of the future almost daily. The recommendations (or portions thereof) in this and companion documents may become obsolete overnight. A specific ITS technology or application should be researched for any new advances (the emergence of any new technologies/applications that may meet a need more thoroughly should also be investigated) prior to design and implementation of a recommended project or program.

The relationships between the ITS applications identified in the 1-70 ***Rural IVHS*** study Scope of Work and the technology opportunities discussed herein are shown in Table III-l. The relationships between the technology opportunities discussed in this section and the system needs which they fulfill (identified in Section II, System Needs), are matrixed in Table III-2.

TABLE III-l ITS TECHNOLOGY CATEGORIES	
NEEDS ASSESSMENT TECHNOLOGY OPPORTUNITY CATEGORY	**I-70 RURAL IVHS STUDY SCOPE OF WORK ITS APPLICATION/FUNCTIONAL AREA**
Data Dissemination Systems	2.2.1 Additional VMS
Sensors/Detectors	2.2.3 Sensor-Actuated Environment 2.2.4 Automatic Avalanche
Cellular-Based Systems	2.2.5 Cellular Reporting Program
Call Boxes	2.2.6 Public Roadside Telephones
Courtesy Patrols	2.2.7 Corridor Courtesy Patrols
Traffic Operations Centers	2.2.2 Upgrade Computer Equipment 2.2.8 Tunnel Control Centers (TCC's)
Traveler Information	2.2.9 Real-Time Traveler Information Links 2.2.10 Intelligent Rest Areas 2.2.15 Road/Weather Information Distribution 2.2.20 Traveler Information Links 2.2.21 Subcarrier Traffic Message Channels
Mass Transportation	2.2.11 Transit/Rideshare Services 2.2.12 Other Intermodal Tiks
HOV Infrastructure	2.2.13 HOV Lanes/Ramps
Incident Management	2.2.14 Incident Management 2.2.24 Mayday Systems
Roadway Delineation	2.2.16 Lighting/Reflective Coatings
Lane Controls	2.2.17 Bi-Directional Lane Controls 2.2.19 Automatic Median Barriers
Video Surveillance	2.2.18 Remote Video Surveillance
Communications	2.2.22 Links to TCC's 2.2.23 Links to CSP
Other ITS Applications	2.2.25 Other Potential IVHS Applications

TABLE III-2 *MAPPING OF TECHNOLOGY OPPORTUNITIES TO SYSTEM NEEDS*						
NEEDS ASSESSMENT TECHNOLOGY OPPORTUNITY CATEGORY	**I-70 WEST CORRIDOR SYSTEM NEEDS**					
	Weather	**Roadway Characteristics**	**Safety**	**Information Sources**	**Communications**	**Traveler Mobility**
Data Dissemination Systems	✓	✓	✓		✓	✓
Sensors/Detectors	✓	✓	✓	✓	✓	✓
Cellular Telephone			✓	✓	✓	
Call Boxes			✓	✓	✓	
Courtesy Patrols			✓		✓	✓
Traffic Operations Centers	✓	✓	✓	✓	✓	✓
Traveler Information	✓	✓	✓	✓	✓	✓
Mass Transportation					✓	✓
HOV Infrastructure		✓				✓
Incident Management			✓	✓	✓	✓
Roadway Delineation	✓	✓	✓			
Lane Controls		✓			✓	✓
Video Surveillance			✓	✓	✓	✓
Communications	✓	✓	✓	✓	✓	✓
Other ITS Applications	✓	✓	✓	✓		✓

DATA DISSEMINATION SYSTEMS

Variable Message Signs. The primary function of a variable message sign (VMS) is to convey travel-related information. VMS are typically placed prior to points of decision for motorist information. Conventional VMS placement in urban areas attempts to advise the motorist of an alternate route around congestion, an incident, or construction activity. The I-70 West Corridor, however, has few alternate parallel routes for route diversion, In addition, the traffic patterns differ from that of an urban freeway. High volumes of recreational travelers and commercial vehicles are unique characteristics of the I-70 West Corridor. This mix creates distinctive peak periods, requiring special traffic management measures that focus on the needs of the recreational and commercial travelers and the alternatives available within the corridor to resolve resulting transportation-related problems.

VMS are commonly proposed for traffic management and control strategies. As stated previously, the I-70 West Corridor has little or no parallel alternate routes to divert traffic. However, many of the municipalities and resorts have more than one access from I-70. These access points are typically miles apart. Providing advanced advisories and warnings as to the availability and condition along these access highways can enable motorists to make informed route choice decisions.

VMS located near interchanges or construction areas can relay information to travelers about. weather, road, and traffic conditions Within the I-70 West Corridor study area, 32 full and 6 partial interchanges provide access to activity centers. To fully accommodate opportunities for route diversion and alternate mode choices, the ultimate number of VMS serving this purpose could reach 70 installations, based upon one sign per interchange per direction. The complexity of the roadway geometry may dictate additional VMS for comprehensive data disseminating coverage.

Placing a VMS at an average interval of every 2.5 miles, in each direction, raises concerns about aesthetics and cost. Signs attached to existing overpasses or to architecturally-designed sign structures may improve the appearance, but will increase capital costs. Lane closures for installation and maintenance of the signs will demand additional resources and disrupt traffic. The actual number of VMS installed within the I-70 West Corridor will depend on how complete a coverage will be demanded by all users. The ultimate number of VMS (approximately 110, assuming one every 2.5 miles and at each interchange, bidirectionally) will be used to size the communications system and the supervisory computer systems and message libraries.

The majority of motorists exposed to VMS along the corridor will be viewing the signs at relatively high rates of speed, from 55 to 75 miles per hour. This is unlike the systems currently in operation on highly congested roadway networks in New York City, Los Angeles, and Chicago. Visibility at a distance is an issue that will effect sign legibility requirements as well as sign placement.

Portable VMS can be used at corridor construction zones and at "chain check" stations to advise motorists of necessary actions and precautions. They are also useful for incident management applications throughout the corridor. These signs are mounted on small trailers so that maintenance and emergency crews can quickly perform set-up and break-down operations. They are easily programmed via internal controllers and/or computers.

Initial VMS should be located at high incident locations. In the I-70 West Corridor, these locations include those areas where weather-related incidents and traffic accidents are recurrent; where roadway geometrics change rapidly and dramatically (steep grades, sharp curves, proximate roadside obstructions); and in support of specific ITS projects recommended within the corridor (incident management strategies, real-time parking information systems, and commercial vehicle mainline bypass WIM/AVI) The VMS should be placed well enough in advance of the actual location to enable travelers to make route, speed, and lane change decisions in adequate time, avoiding sudden changes in direction and speed.

Potential initial locations along I-70 can include: the bottom of Floyd Hill (at the US 6/SH 119 interchange), the Twin Tunnel approaches, the Georgetown area, the Frisco area, Vail Pass, through Vail, and the Eagle area. High incident areas along other State Highways should also be considered. Known areas affected by weather, poor pavement surface/visibility conditions, heavy traffic, and/or geometric changes include: US 285 between C-470 and SH 9; US 6 and SH 119 leading to the Black Hawk/Central City area; US 40 approaching and along Berthoud Pass; US 6 approaching and along Loveland Pass; SH 9 south between Frisco and Breckenridge and north between Silverthorne and Kremmling; SH 40 approaching and along Rabbit Ears Pass; US 24 between Dowds Junction and Leadville; US 13 1 between Wolcott and Steamboat Springs; SH 82 between Glenwood Springs and Aspen (4 are currently planned along this route); SH 82 approaching and along Independence Pass; and SH 133 approaching and along McClure Pass.

Highway Advisory Radio. Highway Advisory Radio (HAR) can be used within the I-70 West Corridor to disseminate regional traveler information and to supplement information provided by VMS, such as incident locations, congestion, predicted travel times, road and weather conditions, and alternate route availability. HAR stations should be strategically located in areas of recurring incidents to advise and allow motorists to take alternate routes. Specific and unique messages can be broadcast from each station, controlled by a regional traffic operations center (TOC). Each station has a range of approximately three to five miles, which is reduced in the presence of mountains and canyons. HAR installations can potentially be subsidized, in part, through limited advertising and/or sponsorships by local area businesses.

Possible locations for additional HAR stations along I-70 include the Genesee area, Floyd Hill, Eisenhower Tunnel, Vail Pass, the Eagle area, and the Glenwood Springs area. Other stations should be considered along the US Routes and State Highways noted for potential VMS installation.

Certain qualifiers with respect to the use of HAR are notable. Messages must be updated continually and provide accurate information to ensure public acceptance that the information broadcast is indeed reliable and timely. Static signs advising that broadcasts are available in the HAR coverage area need to be posted along the roadside in conjunction with HAR installation. Public education programs are also necessary to inform travelers that HAR is available, useful, and beneficial.

Other Data Dissemination Methods. Other methods of information dissemination to travelers include television and radio broadcasts, computerized roadside kiosks, dial-up telephone hotlines, and computer "bulletin" services.

Commercial traffic reporting agencies are prevalent in major metropolitan areas across the United States. Metro Traffic Control provides commercial broadcast services within the Denver metropolitan area and an information exchange is currently being implemented between this organization and the Colorado interim Traffic Operations Center. At a minimum, road, weather, and traffic advisories for the I-70 West Corridor can be provided by Metro Traffic Control to travelers originating in the Denver metropolitan area. Metro Traffic Control has the ability and desire to sell information as a value-added service to other television and radio stations that broadcast traveler information. This organization should be encouraged to investigate the potential to share information with local area broadcast and print media serving the areas ***within the I-70*** West Corridor communities.

Traveler information kiosks, located at rest areas, municipal information centers, resorts, casinos, transit stops and multi-modal transfer centers, hotels and restaurants, and other likely information-disseminating centers can receive real-time traveler information from transportation operations centers. Data is typically downloaded to the kiosk computer at regular intervals and accessed by the user through an available program module. As kiosks are installed in conjunction with recommended and developing ITS projects throughout the I-70 West Corridor, strong consideration for developing and maintaining real-time weather, roadway, and traffic information modules should be exercised.

The Colorado interim TOC maintains a telephone dial-up state-wide weather/road/traffic information service. Currently, Public Information Officers (PIOs) collect and record data at regular intervals to maintain relatively accurate messages through this service. It is well-used and highly acclaimed by the public. The system for collecting and recording information uses traditional technology--telephone and fax dial-ups with the reporting and receiving organizations. As roadside infrastructure in deployed and as communications systems are upgraded, the service should be upgraded to enable more automatic collection and dissemination via further advanced technology applications to lessen the burden of manually-operated devices. As a simple example, construction activity reports, called or faxed into the interim TOC PIOs, should be automatically polled by the central computer to collect activity information from computerized databases. The central computer system could then automatically process that data and transmit it to the kiosk computer databases located throughout the corridor. No human intervention is required except to maintain the operations of the computer and communications systems. Reporting staff need only keep their respective databases current, freeing up their time for other responsibilities.

Computer information services, particularly the Internet's World Wide Web (WWW) Home Page configuration are gaining popularity by transportation agencies for reporting information to their customers. Many State DOT's have developed real-time traffic condition map/databases that are linked to their WWW Home Page and accessed by any Internet user. This presents an excellent opportunity to report I-70 West Corridor road/weather/traffic condition information when reliable real-time data collection systems are in place. Current PIO data collection and reporting capabilities can become the trial test for an I-70 West Corridor information system.

Several notes of caution: CDOT is developing a traffic reporting system for the Denver metropolitan area to be initiated on CDOT's Home Page. RTD has a transit schedule/public information Home Page on line. Other cities within the Denver metropolitan area are considering developing their own Home Page traffic reporting systems. Integrating these various Home Pages so that users can readily access all reported information (ie. quick and easy access to CDOT information from RTD information and vice versa) and continuity and accuracy between reported information (ie. no conflicting information between CDOT and City and County of Denver reports) is essential to maintaining public trust and continued use of the system.

Several of the municipalities served by the I-70 West Corridor operate and maintain cable television channels, dedicated as "public service stations." Real-time traveler information can be disseminated via the "bulletin boards" to their subscribers. CDOT has the ability to provide information, now, via their PIO program. This type of information sharing has good potential to improve and enhance public perceptions of the agency. The usual cautions apply: information must be accurate and reliable and updated frequently to maintain trust and use of the system.

The ENTERPRISE Croup is field testing the use of AM subcarriers to broadcast travel information in areas where HAR and FM broadcasts are impeded by terrain-related obstructions. Their initial field test resulting in dramatically promising results. Because CDOT is intimately involved in this research effort, the system, if concluded as viable, will become available in Colorado. The implementation of this system in the I-70 West Corridor should be considered as a replacement for or supplement to other recommended systems, such as HAR.

Road, weather, and traffic condition information for the I-70 West Corridor should be disseminated outside of the corridor area, via any of the viable data dissemination technology applications (VMS, HAR, kiosks, media broadcasts, AM subcarriers) to advise those planning trips into the region about potentially hazardous and/or congested conditions before they access the corridor. Outside regions that should be considered include the Denver, Colorado Springs, and other Front Range communities; Grand Junction and other Western Slope communities; other states, particularly Utah and the Salt Lake City area and Wyoming; and other adjacent municipalities and counties that have transportation access to I-70. Activity centers and facilities where such services may be important include major roadways, airports, transit and municipal information centers, rest areas, and via local computer and telephone dial-up bulletin boards and information services.

SENSORS / DETECTORS

Vehicle Detection. Sensors that detect vehicle presence, traffic volume and occupancy, weight, location, speed, and other traffic parameters provide data critical to a variety of ITS technologies in the corridor, including incident management, adaptive traffic control, traffic management strategies, and other ITS applications.

Incident detection/congestion management systems employ various sensor/detector technologies. Inductive loops are currently being used to detect vehicle presence within the corridor tunnels. The harsh weather conditions of the corridor has proven to be unfavorably taxing on the inductive loops embedded in the pavement. Other proven, non-embedded detection technology emerging into transportation applications, include video, microwave, infrared, and acoustics.

Vehicle detectors can be located at high accident/high hazard locations, on heavily traveled roadway segments, and on major arterials to provide input data for automatic incident detection algorithms (AIDA) and to provide information on congestion levels and prediction of travel times. Advanced warning of incidents and recurring congestion will allow travelers to alter their routes or delay their trips, thus reducing the effect of the incident and aiding in the reduction of congestion. Locations before and after interchanges are critical locations that would have the highest priority for implementation. In addition to the interchange locations on I-70, other areas of possible installation can include Floyd Hill, the Twin Tunnels and Idaho Springs areas, Vail Pass, Vail, the Eisenhower and Hanging Lake Tunnels, and Glenwood Springs. Other US Routes and State Highways accessing I-70 and relevant to needs with the corridor study area include those facilities traversing the mountain passes (Berthoud, Loveland, Rabbit Ears, Independence, McClure) and other congested routes (US 6/SH 119 to Black Hawk/Central City; SH 9 between Frisco and Breckenridge; and SH 82 between Glenwood Springs and Aspen are the most critical).

Automated credential processing/safe speed systems employ sensor/detector technologies. Vehicle detection systems can be used in the automation of commercial vehicle weigh/check stations. Vehicle detectors and weigh-in-motion (WIM) mats can be used in conjunction with advanced vehicle identification (AVI) and VMS technologies to allow commercial vehicles to bypass ports-of-entry and weigh/check stations at posted highway speeds. CDOT is currently planning such a mainline bypass system at the Dumont/Downieville weigh/check facility along the I-70 West Corridor. The system is expected to increase traveler safety in the area and allow for more productive commercial vehicle operations.

Other potential application areas for automated credential processing should include installation of systems at the Eisenhower and Hanging Lake tunnels since hazardous cargo-carrying vehicles are not allowed passage through the tunnel bores for safety (fire and spill) reasons. Upstream weigh/check stations can readily notify tunnel control centers automatically that trucks carrying HAZMAT shipments have been cleared and are approaching. Advance notice would enable tunnel operations crews to prepare for the arrival, establishing further efficiencies in monitoring and re-routing.

Vehicle detectors and WIM mats can also be used to measure vehicle speeds and weights, determining and reporting safe descent speeds for prevailing conditions. These applications are best utilized at the beginning of long and steep downgrades. Possible locations include eastbound travel from Genesee to C-470, westbound down Floyd Hill to the US 6/SH 119 interchange, eastbound from the Eisenhower Tunnel portal to north of Idaho Springs, and Vail Pass (westbound from the Vail Pass Rest Area into Vail and eastbound from the Vail Pass Rest Area to the SH 91 interchange). This technology is currently being evaluated along the westbound lanes of I-70, on the downgrade just west of the Eisenhower Tunnel. The technology is applicable to other US and State Highway routes in the study area along the mountain passes (Berthoud, Loveland, Rabbit Ears, Independence, McClure).

Vehicle detection systems can be applied to ***real-time parking information systems*** at parking lot entrances and exits, to relay parking lot capacity information. This information can be disseminated to travelers via HAR or VMS, directing potential parkers to the nearest available parking lot. This technology can reduce the congestion levels in corridor towns created by motorists searching for an available parking space. Installation is recommended at the three major parking facilities in Vail. Vehicle detection systems used for parking management should be integral with other ITS applications, utilizing existing VMS and HAR and integrating other ITS applications with the VMS and HAR designated specifically for vehicle detection systems. Locations for implementation include resort, casino, and other high-demand recreational areas where multiple parking areas can be accessed from more than one route (the most critical are Keystone, Vail, Black Hawk/Central City, and Glenwood Springs).

Over-size vehicle detection sensors alert system and vehicle operators that the vehicle is too high, ***too*** wide, or too heavy to safely continue along the current course. The detection system must be installed well in advance of the limiting obstruction to allow those in violation of requirements to , avoid the area without disrupting traffic flow. Detection can be accomplished using a variety of technologies: infrared, microwave (radar), acoustic, and video image processing.

An over height vehicle detection system has been in place at both approaches to the Eisenhower Tunnel controlling vehicle entrance into the minimal vertical clearance tunnel bores. The system uses microwave sensing technology, connected to automatically sound a siren and trip a conventional traffic signal to stop all traffic until the overheight vehicle is manually inspected and cleared. This system adequately serves this purpose. As the system components continue to deteriorate over time (the system was installed in the mid-l 970's), and maintenance becomes more costly than is justified by the purchase of a replacement system, a thorough investigation should be conducted of the latest sensor and detector systems. Consideration for efficiency, reliability, maintenance, and reduction of the manual portions of the operations should be considered as performance requirements.

Over-wide detection systems are not currently operating within the corridor. Although not an immediate need, occasional over-wide transport does occur along I-70. Over-wide vehicle do impede traffic flow, particularly through the tunnels, when faster vehicles are blocked from passing. Over-wide vehicle detection systems employ the same technologies as those for over-height detection systems.

Over-weight detection is currently best monitored with WIM/AVI technologies.

Bicycle, pedestrian, and animal safety systems use sensor/detector technologies. Some sensors used for vehicle detection can be applied as components of systems that detect bicycles, pedestrians, wildlife, and moving objects. By detecting the presences of non-motorized vehicles, animals, and other moving objects that may enter rights-of-way, approaching travelers can be alerted to proceed with caution. The detection systems would be linked with roadside data dissemination technologies (VMS, HAR) to provide the advanced warnings. Such systems should be deployed in areas where bicycle/pedestrian facilities cross or merge onto roadway facilities (Summit County has an extensive trail systems that interfaces with roadways; the Vail Pass recreation trail parallels I-70; an extensive trail system connects rest areas in Glenwood Canyon); on roadway systems serving pedestrian needs (sidewalks and crosswalks within municipal limits); and in areas where animal/vehicular conflicts are prevalent (I-70 between US 40 and Georgetown and between Glenwood Canyon and Eagle; all US Routes and State Highways within the corridor study area).

Automatic Vehicle Location (AVL). AVL technology is applicable for use on emergency response, patrol, transit, maintenance, and other vehicles that are operated on corridor facilities on a frequent and regular basis. Vehicle location information is most appropriately collected for fleet management systems and as data collection probes.

Fleet management systems integrate computer-aided dispatch technology with the AVL technologies that support dispatch functions. Vehicles serving as probes can provide real-time information on travel conditions and assist in identifying roadway incident locations and severity. The information could also be used to verify route selections for emergency service providers; to actuate dynamic traffic control systems; to predict travel times for dissemination to motorists; and to provide historical data for planning purposes. Most AVL technologies are suitable as components of recommended corridor-wide and project specific ITS deployments, the most important applications including Global Positioning Satellite (GPS), signpost-odometer, and dead reckoning technologies.

Project-specific applications include transit fleet management recommendations within and between Gilpin, Summit, Eagle, Garfield, Pitkin, and Routt counties and the Denver metropolitan area and corridor-wide fleet management systems for CDOT operations and maintenance vehicles. Probe vehicle applications would occur corridor-wide and in conjunction with systems in adjacent regions.

Emissions Testing. To control air pollution related to mobile emission sources within the I-70 West Corridor, environmental sensing/emission detecting systems are applicable at several locations along I-70 and other roadway facilities. These roadside units check pollutant emission levels for individual passing vehicles. The units can be linked to roadside VMS to notify travelers of a violation of Colorado standards. Pending changes to current legislation, offenders could be captured on remote video surveillance cameras and issued citations through the mail.

Weather and Road Surface Monitoring. Weather and road surface sensors are the backbone to collecting real-time data. The amount and accuracy road/weather/traffic information dissemination to the traveling public will depend on the coverage of these sensors and detectors within the I-70 West Corridor and on adjacent facilities.

Pavement sensors should be installed, initially, throughout the corridor at known locations where road surface icing occurs. In addition to advisories that a roadway segment may be hazardous, maintenance crews can remotely monitor pavement temperatures and weather conditions to prepare for and perform pre-hazard operations. Pavement sensors can measure current surface chemical composition and calculate necessary de-icing applications.

Weather stations measure ambient air temperatures, barometric readings, and wind velocities, enabling some relatively accurate weather condition predictions. Used in conjunction with pavement sensors, operators can collect and process a wide variety of data that can give a continuous "read" on real-time weather and roadway conditions.

Immediate installation locations for combined pavement sensor/weather station systems along I-70 include Floyd Hill, the Georgetown area, and from Frisco to Eagle (including Copper Mountain and Vail). Systems currently in place or planned for installation include the Genesee area, Dowds Junction, Glenwood Canyon, along SH 82 between Glenwood Springs and Aspen and through Independence Pass . Other routes within the corridor study area deserve consideration: the mountain passes (Berthoud, Loveland, Rabbit Ears, McClure) and along other known segments where weather extremes accelerate surface and visibility problems (SH 6/SH 119 to Black Hawk/Central City; SH 9 north and south of I-70; US 24 south; and SH 13 1 north). Pavement sensors should be installed at regular intervals along roadway facilities to provide adequate coverage of surface conditions. Weather stations are required less frequently, in prevalent and condition-specific (wind, dramatic temperature fluctuations, high precipitation) weather hazard areas.

The SCAN system, currently used at "in place" locations within the corridor, is a stand-alone system. Data processing and dissemination relies on proprietary algorithms that cannot be interconnected to or with other systems and applications. A cooperative arrangement with the manufacturer to integrate the SCAN system with other in place and future deployments will increase the amount and availability of information available to the system operator and the traveling public. This flexibility is necessary.

Currently, SCAN system data is only transmitted to the regional operator in control of specific installations. Data sharing is paramount, particularly in the I-70 West Corridor where multiple operators are responsible for transportation. One exception is the Independence Pass system where data is transmitted 24 hours a day to the control center at Hanging Lake Tunnel. Maintenance crews at the tunnel and on both sides of the pass share information to improve snow plow and sand truck operations. Interconnected supervisory systems, established at regional TOCs, will enable coordinated initiation of response plans and corridor-wide dissemination of weather/road information.

Visibility sensors provide data for traveler advisories, particularly where rapidly changing weather patterns create sight distance problems. These are typically incorporated in weather station monitors. Travel hazards, including blowing snow and dust, fog, and driving rains, impede traffic flow and create conditions ripe for traffic accidents. Visibility sensors should be placed in conjunction with the pavement sensor and weather station systems noted previously.

Avalanche and rock/mudslide warning systems are needed along I-70 and other state highways since there are numerous high-risk areas throughout the study area. A complementary, non-advanced technology application, that should be implemented with ITS solutions, is construction and extension of snow sheds at roadway locations crossing known avalanche paths. CDOT currently controls potential avalanche hazards by blasting snow accumulations, causing planned and controlled slides.

Several cautions are important in employing these techniques. Snow sheds are costly to construct and often criticized because they blemish the environment. Controlled blasting requires continual labor and rigorous calculations to estimate when an avalanche is imminent, based on slope angle, temperature, type of snow, and other factors.

Sensors and warning systems may be less expensive alternatives. Sensor technology is still in the development and testing stages. Warning systems (VMS, other roadside advisory signage) may be considered as more aesthetically-pleasing. They have potential to provide more accurate and timely monitoring capabilities than manual systems. As research and field test advancements are made in the development of avalanche and rock/mud slide detection sensors, reliance upon these systems will. increase. Locations along I-70 for avalanche and rock/mud slide detection/warning systems include Idaho Springs to the Dillon Valley, Vail Pass, Glenwood Canyon, and west of Glenwood Springs. Other routes traversing known avalanche and rock/mud slide paths include Loveland Pass (US 6), Berthoud and Rabbit Ears Passes (US 40), McClure Pass (SH 133), and Independence Pass (SH 82).

Fire Detection Systems. Fire detecting sensors are currently used as part of the Eisenhower and Hanging Lake tunnel control systems. These sensors act similarly to household fire alarms where heat and smoke are sensed and a signal sets off an alarm. The video surveillance systems are used in conjunction with the sensors to pinpoint and monitor fire-causing sources remotely. Vehicular tires are not prevalent along the corridor. Fire detection sensors may have applicability for use in the Twin Tunnels on I-70 and in other tunnels along state highway routes if the need is identified.

CELLULAR-BASED SYSTEMS

As comprehensive cellular coverage is established in the I-70 West Corridor, many beneficial, safety-related cellular-based ITS applications can be implemented. Cellular systems allow wireless communications via mobile telephones, roadside call boxes, and public and private non-mobile telephone units, without the high cost for supplemental infrastructure improvements.

Regular corridor users, operating personal cellular telephones in their vehicles, can become data probes, providing accurate travel time and incident reporting information Cellular-based tracking is being tested and evaluated for AVL, Mayday, and link-time monitoring applications. Supporting legislation and policies may need to be instituted to deploy these systems.

Cellular telephones can also be used by motorists to call dial-up information services. Newer telephone units enable connection with laptop computers, setting the stage for development of a variety of AVL/GPS route guidance and navigation systems. Condition reports can be collected from Internet Home Page applications. A corridor-wide cellular call-in program can be deployed immediately with minimal capital outlay. An agreement with the local service provider for toll-free service or reduced tariffs paid by the state is essential to the success of such a system.

CALL BOXES

Call boxes should be installed throughout the corridor, with initial installations focusing on critical locations such as high incident areas, runaway truck ramps, interchange entrance and exit ramps, rest areas/scenic overlooks, and other locations where public telephone access is limited and/or non-existent. Ultimate deployment would extend the entire length of the corridor, with call boxes spaced at one mile intervals along remote segments and at one-half mile intervals along high incident locations. It would require approximately 300 call boxes to comprehensively cover the I-70 West Corridor. Full installation will be costly and will require other investors.

The usual cautions with respect to call box capabilities include necessary two-way voice communications, unit tagging to pinpoint call location, solar powering, and best communications media for the area being serviced. Cellular-based system are currently the most reliable and cost-effective, however, coverage throughout the corridor is incomplete and unreliable. Initial sites for installation should include consideration for interchanges without current telephone access and high incident segments. High incident areas along I-70 include the segment from the US 40 interchange to Georgetown, Vail Pass, and west of Glenwood Springs through DeBeque Canyon. Call boxes should be installed along other state highway routes, particularly those traversing mountain passes. In addition to emergency assistance requests, call boxes can also be used to report incidents at no charge and for personal calls at the caller's expense.

COURTESY PATROLS

Courtesy patrols provide motorist assistance as units patrol roadway segments. On-board AVL equipment and reliable communication systems will be critical for an I-70 West Corridor Courtesy Patrol. Integration systems with incident detection programs and computer-aided dispatch should be deployed to support the patrol fleet. Ultimately, the Courtesy Patrols can be extended to cover I-70 throughout the entire corridor. Due to the financial constraints in provide comprehensive service, it may be more realistic to provide the Courtesy Patrols along select segments during high-risk travel periods--holiday, summer, and ski weekends, and during adverse weather periods. Locations for initial implementation on I-70 include the stretch from C-470 to Genesee, Floyd Hill to Idaho Springs, from the US 40 interchange to Georgetown, Eisenhower Tunnel to Silverthorne, Vail Pass, east Vail to Dowds Junction, and in Glenwood Canyon. The US 6/SH 119 route to Black Hawk/Central City, SH 40 over Berthoud Pass, and SH 82 between Glenwood Springs and Aspen are prime areas for Courtesy Patrol implementation on the off-interstate roadway system.

TRAFFIC OPERATIONS CENTERS

The systems architecture for corridor- and area-wide traffic management systems should include integration with the distributed network proposed for statewide deployment. Interconnect of regional TOC's to the network encourages local control and regional data sharing. Regional TOC's can maintain control over incident management and systems monitoring and operations. At the same time, inter-regional transportation management can be enhanced through shared databases, information exchange and dissemination, and multi-modal coordination. Redundant systems can be eliminated at TOC's by providing common hardware and software standards. By integrating multiple ITS functions and user services, the overall system cost is reduced and the operating effectiveness and efficiency is improved. This distributed approach to integration, coupled with an enhanced communications infrastructure, will enable the various agencies and organizations to effortlessly share information and coordinate common transportation activities at the local and regional levels.

The Hanging Lake Tunnel Control Center facility located in Region 3, the Eisenhower Tunnel Control Center facility located in Region 1, and the Colorado interim Traffic Operations Center in the Denver metropolitan area will provide the building blocks for the system design. The Colorado Transportation Management System (C-TMS) currently provides functional capability for the I-70 West Corridor from the interim TOC. The role of that center in I-70 West Corridor ITS expansion must be determined by the involved Engineering Regions. The area of responsibility for the Hanging Lake and Eisenhower tunnel control centers should be expanded to include additional ITS subsystems implemented in the I-70 West Corridor, with these facilities designated as Regional TOCs Issues involving additional labor and physical space requirements need to be addressed.

Data collected from the local/regional field devices/sensors, safety/warning systems, and other probes controlled by each regional TOCs will be transmitted via the distributed network for use by other operators. Depending on functional requirements, data will be processed at regional centers where local use is most important (ie. de-icing chemical application rates) and at the C-TMS were information is of statewide significance. Processed information will remain available on the IT1 network for use by other operators as needed.

TRAVELER INFORMATION

Many system needs, identified in Section II, revolve around the need for accurate and reliable real-time traveler information pertaining to weather, road, and traffic conditions, tunnel operations, incidents, construction activities, and recreational and resort area schedules. Such information will enable motorists to make informed pre-trip and en-route travel decisions to avoid undesirable situations. Other information supporting travel decision-making within the corridor, includes up-to-date information on transit service status and availability, parking location and availability, lane operations, and special events. Additional information important to commercial vehicle operators pertains to the status of weigh/check stations (open or closed), runaway truck ramps (available or occupied), hazardous material transport restrictions (required alternate routing), safety needs (chain laws and enforcement stations, speed restrictions), and road closures.

Out-of-state visitors and commuters planning a regional trip need information regarding transit and rideshare opportunities, schedules and fares; local tourist attractions and accommodations; public facilities; area businesses; and airports.

Information processing systems at the TOCs could supply a centralized directory of static and dynamic databases that can be accessed remotely by the traveling public via some type of communication path and end-user device, such as roadside VMS, HAR, kiosks, or telephones. Static information database systems would typically reside on the C-TMS computers and be updated by both regional and statewide personnel. Dynamic databases may be controlled locally or at the statewide level, depending on information needs.

Travelers will query downloaded databases via interactive devices, such as kiosks, according to their specific informational needs. Interactive features will allow travelers to obtain pre-trip planning information that is based on parameters that are unique to their trip, such as roadway travel time estimates based on real-time traffic, weather, and roadway conditions; best-mode calculations based on origin, destination, and estimated travel time; best-route calculations based on origin, destination, and mode; itinerary calculations; and multi-modal transportation reservations, confirmations, and financial transactions.

MASS TRANSPORTATION

Increasing ridership on transit systems can decrease congestion along I-70 (and ultimately accident rates) if at least 20 percent of the current vehicle demand is removed. Mass transport of people via buses, vans, shuttles, car/vanpools, trains, and airplanes can be promoted within the I-70 West Corridor using some traditional and innovative techniques.

Incentives. Use of transit and other alternate travel modes can be encouraged by the destination accommodator by offering discounts and specials bonuses to those travelers who arrive via modes other than by private automobile (or those who shared a ride). Special rates can be offered on hotels, lift tickets, games, meals, and special event activities with the proof alternate mode use.

Multi-Modal Transfer Facilities. State-of-the-art multi-modal transfer facilities can help improve the appeal of mass transportation. Real-time information dissemination regarding bus, van, shuttle, train and airplane arrivals and departures using AVL/GPS technologies enables users to plan their trips via transit more effectively. Traveler information provided for predicted travel times, weather conditions, transit schedules, and services available will improve the perceived reliability of public transportation. Convenience stores, dry-cleaning establishments, postal stations, and automated 'tellers on site can increase the utility of transfer centers. A multi-modal transfer center should be located near the entrance to the corridor.

Ridership on buses, vans, and shuttles providing, service to the I-70 West Corridor attractions can potentially be increased by attracting customers at the origination point of their trip. A best example is the introduction of a transfer facility and dynamic information center at Denver International @IA), Sardy Field (Aspen), Yampa Valley (Steamboat Springs) and Eagle airports. Passenger rail stations, such as Union Station in downtown Denver where the Winter "'Park" Train and Amtrak service originate, can be enhanced with transfer center/information centers where other surface transportation options are provided to and from the stations, activity centers, and hotels.

HIGH OCCUPANCY VEHICLE (HOV) INFRASTRUCTURE

Like transit alternatives, other high occupancy vehicle use of the corridor can contribute to reductions in traffic volumes throughout the corridor, thus reducing congestion and accident rates. To encourage HOV usage, travel times for HOV must be faster than for using private automobiles. This can be accomplished along I-70 and other state highway facilities by constructing separate, high-speed and bypass lanes to accommodate these vehicles. HOV lanes can parallel mixed-use traffic lanes for long distances (minimal ingress and egress) or they can be constructed in segments where facility usage is highly congested (similar to passing lane construction). Entirely separate HOV facilities could be constructed, regulated, and paid for by toll revenues.

Most HOV facilities deployed throughout the United States are intended to provide an alternate travel way without discriminating against certain classes of potential users. Many of these facilities are under-utilized because people still drive alone. Along the I-70, this will probably not be the situation because the average automobile occupancy rate exceed two persons per vehicle. However, consideration for separate tolled lanes, in addition to existing facilities, for any user who wants to pay the price, may extract additional vehicles from the already congested system and provide a funding mechanism to pay for costs of this type of facility, as well as for maintenance of existing facilities. Nationwide studies have noted that the more affluent are willing to pay for added luxuries and conveniences.

Technologies associated with HOV systems include automated barrier systems, toll facilities, AVI, smart cards and video surveillance. Each of these technologies are proven and can be obtained from a variety of manufacturers at competitive prices.

INCIDENT MANAGEMENT

Incident management should be provided as a regional, integrated service coordinated between operators within and between jurisdictions. Vehicle detection systems, deployed within the corridor, will provide input data for multiple transportation management subsystems, including incident management. Similarly, video surveillance cameras can be used for incident verification and assessment, in addition to general surveillance requirements of other ITS. VMS, both fixed and portable, and HAR system components should be integrated with incident management systems to disseminate incident-related information to the traveling public. An area-wide communications infrastructure, by definition, will support all of these functions.

Incident management within the I-70 West Corridor could be semi-automated. Because I-70 traverses a lot of uninhabited territory, the primary methods to provide incident detection should be automated. Data received from vehicle detection systems would be used as input to automatic incident detection software residing on regional TOC computer systems. CCTV cameras, located strategically along the corridor, would be automatically activated by the TOC computer system to display video of suspect sites where potential incidents have been detected. The incidents could be manually verified by the TOC operator and the appropriate response plan initiated.

The dissemination of incident-related traveler information could be semi-automated as well. Pre-canned messages automatically prompted to the TOC operator. The operator would be responsible for quality checks and initiating transmission of the messages to the signs. HAR recordings could be updated similarly. Sharing of incident-related information among regional TOCs, other operating agencies, and emergency service providers is paramount. System interconnects can also be automated via a wide area network (WAN) linking the various computer systems.

Mayday systems can enhance the utility of automated incident detection systems. Roadside call boxes, CSP communications systems, and traveler cellular telephone reports can be integrated with incident management systems for verification and response.

ROADWAY DELINEATION

Highly-reflective pavement markings used in conjunction with raised pavement markers can be used to improve roadway delineation. Roadway markings are often covered during the winter with snowpack and debris accumulating on travel way surfaces. Brighter, raised markings will allow for the markings to remain distinguishable under this conditions. Snowplow and other maintenance activities often destroy special reflective materials and raised markers. Flexible reflective, raised markers are being tested for endurance under these types of conditions by CDOT Region 3. If a good success rate is achieved, these types of marking systems should be deployed as lane delineations throughout the I-70 West Corridor (on state highways as well as the Interstate).

Another method of roadway delineation is lighted guidance tube technology. Uni- and bidirectional systems have been deployed as median or edge treatments, helping motorists distinguish horizontal curves and changes in roadway configurations, as well as to delimit construction zones. CDOT Region 3 deployed a lighted guidance system test section near Dowds Junction. They learned that tubes must be continually wiped free of debris to maintain reflectivity. The system is being improved to resolve this and other minor deficiencies. Lighted guidance tubes have applicability to many locations within the I-70 West Corridor. Applications at particularly troublesome areas, such as Genesee, Floyd Hill, the Georgetown area, Eisenhower Tunnel approaches, Vail Pass, and at temporary construction zones, can benefit travelers in making their way along the corridor.

Roadway delineation can also be improved by increasing the brightness of existing and installing roadway lighting throughout the corridor. Many remote locations do not have roadway lighting. Important to tunnel safety is lighting. The Eisenhower and Twin Tunnels have recently and are currently undergoing lighting upgrades. Lighting in all of the corridor tunnels needs to be maintained at a sufficient level. The capital and power costs to install roadside lighting along the entire corridor is not cost-effective.

LANE CONTROLS

Hi-Directional. In responding to corridor incidents it may be necessary to close lanes to the traveling public. For such cases appropriate lane control equipment must be stockpiled in strategic locations, where it is readily accessible.

Bi-Directional. Bi-Directional lane control includes moveable barrier systems. These automatic systems can be deployed instantaneously at high traffic locations to increase the capacity of the roadway in a single direction. Initial screenings recommend extension of reversible lane operations at the Eisenhower Tunnel through the Twin Tunnels east of Idaho Springs. The I-70 median would have to be graded and paved in this area for a barrier transfer system to move barriers to accommodate required lane configurations. This system should be implemented continuously as a discontinuous application will create bottlenecks on off-system segments that can potentially back-up into the mitigated section.

REMOTE VIDEO SURVEILLANCE

Previously identified trouble spots along the corridor serve as a baseline set for potential video surveillance sites on I-70. Users of runaway truck ramps, steep grades, tight curves, and preferential icing, avalanche, and rock slide areas would greatly benefit from general surveillance capabilities. High priority areas for installation include Genesee, Floyd Hill, Dowds Junction, Eisenhower Tunnel, Vail Pass, Twin Tunnels, and Hanging Lake Tunnel.

Full motion video surveillance can also be used to remotely verify proper operation of systems deployed within the corridor, such as VMS and HOV elements; to track hazardous material vehicles; to ensure safe tunnel operations; and to assess and prepare for maintenance calls. Continuous video coverage is critical to verify and assess incidents in support of automated incident management, requiring approximately 300 cameras. The operating load could be split between the regional TOCs and the C-TMS.

COMMUNICATIONS

The corridor-wide communications infrastructure must support various, equally-important ITS functions. The various functions can be categorized as follows. First, the infrastructure must provide two-way data and video transmissions between the fixed ATMS and Advanced Traveler Information System (ATIS) field components and the TOC computer systems. Secondly, the infrastructure must provide two-way voice and data transmissions between the TOCs and mobile units. Lastly, the infrastructure must provide two-way data communications between the regional TOCs, the C-TMS, and other information sources.

Data will be telemetered from elements of the field infrastructure, such as vehicle detectors, weather-related sensors, environmental sensors, and fire/smoke detectors, to the TOC central computer systems. Control signals will be transmitted from the TOC to the traffic control elements in the field, such as intersection controllers, ramp meters, and lane controls. Since the bandwidth requirements for these types of data transmissions are low, they can be provided over either leased copper telephone lines, fiber optics, or microwave. For diagnostic purposes, two-way communications are typically required to support electronic field devices.

Surveillance cameras located along the corridor, will transmit video to the TOC monitors for viewing. For full motion video, high bandwidth media, such as fiber optics or microwave, will be required. Data channels should also be provided over this link, to transmit pan-tilt-zoom control signals from the TOC supervisory computer systems to the cameras.

Depending on management philosophy, one- or two-way voice communications will be required between roadside call boxes and the TOC. Either leased telephone lines or cellular telephone could be used to support roadside call boxes.

Real-time traveler information systems are a final type of infrastructure-based function that will require communication links. Short bursts of data will be transmitted from the TOC supervisory systems to the roadside VMS, indicating what message to display. Comparable data transmissions will be sent to the HAR base station control systems. From a reliability and cost-effectiveness standpoint, cellular telephone would be a viable communication media for VMS and HAR. Finally, information kiosks located within the corridor can be connected to TOC databases via leased telephone lines or fiber optics.

Mobile communications are required to support two-way voice communications between the emergency response participants, CSP, Courtesy Patrols, CDOT maintenance personnel, and commercial vehicle operations for dispatching and fleet management purposes. Mobile Mayday personal emergency notification systems will transmit data signals to the CSP dispatch at the TOC. AVL equipment on-board fleet vehicles will transit data to the CAD systems at the TOC. All of these mobile communication requirements can be provided via radio.

The regional TOC computer systems will be interconnected through an ITI network, most probably using a wide area network (WAN) to facilitate the sharing of static and dynamic database systems. The WAN could also provide gateways to national and statewide information clearinghouses, public transportation authorities, weather services, and other information sources via dial-up telephones and modems.

There are many combinations of communications technology that could be implemented to support the various ITS user services within the corridor. As with all automated systems, the transmission media that interfaces two end-user devices should be transparent to the application. Furthermore, the ITS architecture envisioned for the I-70 West Corridor will.have an open design to permit a phased deployment and evolving technology, including, and especially, the communication infrastructure. Therefore, the weighting criteria for the choice of technology are both cost and management philosophy. Cost will be heavily influenced by the degree of user service integration that is realized during the corridor ITS implementation.

OTHER POTENTIAL ITS-RELATED APPLICATIONS

Adaptive Traffic Control. Advanced traffic and environmental sensors could be linked with traffic control and ramp meter systems throughout the corridor, to adapt traffic control strategies to current conditions. Intersection controllers on, or adjacent to, congested roadways could be linked with vehicle detection sensors to automatically adjust during peak periods or during incidents. Similarly, ramp meters can be dynamically controlled at high volume entry points that produce mainline bottlenecks. Intersection controllers and ramp meters could also be linked with automatic vehicle identification (AVI) systems on-board high-priority vehicles for signal preemption during incident response efforts and HOV operations. Adaptive traffic control would be most crucial for traffic mitigation in the event of partial or complete closure of I-70.

Speeding is a problem in the Glenwood Canyon area. Tunnel operators believe that more VMS for conveying recommended safe speeds and other safety-related roadway information to motorists would improve driving conditions. Dynamic speed limits can be implemented on segments of I-70 that are characterized by steep grades or curvatures, frequent accidents, adverse weather, or other attributes that affect safety. Candidate locations, in addition to the existing system at the Eisenhower/Johnson Memorial Tunnel, include areas of steep grade, such as Floyd Hill, or restricted geometric and horizontal curvature segments, such as through Idaho Springs.

Storm Water Run-off Pond Sensors. Sensors in roadway run-off ponds can detect when contaminant levels exceed acceptable limits and alert maintenance crews to remove said contaminants.

Congestion Pricing. Congestion pricing can be effective in reducing peak hour travel along the corridor. Boulder, Colorado is currently studying congestion pricing strategies. The I-l 5 Corridor Project in San Diego, California, is looking at the feasibility of SOV "'buying-in" to the excess road capacity on HOV lanes. If HOV lanes are constructed on I-70 this may be a realistic method of pricing. By the end of 1997, the studies should be completed, and depending on the outcome, congestion pricing may be an applicable solution for I-70 West Corridor congestion.

I-70 RURAL IVHS

NEEDS ASSESSMENT

SECTION IV
INSTITUTIONAL NEEDS

SECTION IV INSTITUTIONAL NEEDS

Successful ITS deployment demands many wholesale changes in the way participating agencies and organizations do business. Extensive data-sharing, multi-jurisdictional coordination and cooperation, and partnering between public and private organizations, as major requirements, compel new policies, roles, and responsibilities. Institutional change associated with ITS implementation spans all levels of operation: philosophical, legislative, policy, administrative, managerial, and work activities. The long-standing transportation institutions, at federal, state, regional, and local levels, have been examined to determine what barriers may prolong or prevent ITS implementation progress within the I-70 West Corridor.

ORGANIZATIONAL STRUCTURE

The organizational structure and the entire ITS program in Colorado must be examined to assess how ITS initiatives for the I-70 West Corridor can be successfully implemented. Many institutional barriers that will affect ITS implementation in the corridor are regulated at the organizational level. The structure of the organization and the interaction between organizations influences if and how ITS can be successfully implemented within a region. Transportation agencies are governed by policies, rules, regulations, and standards to promote consistency, to reduce liability, and to protect the health, safety, and welfare of publics that they serve.

Since the 1-70 Rural IVHS study was initiated by and focuses on CDOT, only that organizational structure has been evaluated. CDOT, as the agency responsible for the efficient movement of people and goods across Colorado, has established as its mission to "...work together to develop and maintain the best possible transportation system for Colorado." CDOT has undergone, over the past 5 years, several reorganizations to structure an ITS program with a statewide perspective. Administered under Headquarters domain, the ITS Program Office is ultimately responsible for coordinating all ITS initiatives statewide.

Inherent to the organization, the 6 Engineering Regions operate independently, charged with maintaining the roadway elements within their respective boundaries. In the past, ITS-related initiatives have been implemented and maintained under Regional control having little interface with the rest of the organization.

Needs with respect to the organization are diverse. The ITS Program Office needs to maintain some level of statewide control over the development and implementation of ITS programs and projects so that all subsystems are integrated to fulfill statewide continuity and connectivity. The Regions want to maintain some level of autonomy to operate and maintain subsystems within their respective domains. The divisions within the organization must coordinate and cooperate, each making trade-offs, to ensure that data is shared and system integrity is maintained.

CDOT has made commendable in-roads to create an environment that responds to ITS organizational needs. The establishment of the Statewide ITS Implementation Team has brought Headquarters and Region staff into a forum where cooperative plans and programs are being set under the Smart Path name.

Staffing the organization to respond effectively to the ITS program has been successful at Headquarters. The establishment of the ITS Program Office has enabled training of existing staff and new hires with specialized expertise to manage and perform ITS activities.

At the Regions, existing staff members have been assigned ITS responsibilities in addition to their existing activities. These individuals are already over-extended with work responsibilities, some unable to respond to ITS activities at the level desired.

The ITS program in Colorado has evolved into a viable operation. To accelerate the evolutionary process, several organizational changes can be administered:

- Establish co-directors for the Statewide ITS Implementation Team--one that represents the interests of the Regions and one that represents statewide interests. The co-directors would need to allocate adequate time to organize, manage, and administer Team goals, objectives, and programs;

- Hire an ITS Engineer in each Region that has sole responsibility to ITS. This individual needs to be a strong ITS champion and be technically trained. This individual needs appropriate authority to make ITS-related decisions for the Region; and

- Share ideas, information, accomplishments, and lessons learned between Regions and Headquarters. A decentralized organizational structure tends to discourage communication. Organizational interconnectivity must be promoted from the top down. Regional Transportation Directors should inspire information exchanges.

Once the internal organization is prepared to promote and coordinate ITS initiatives, organizational initiatives can be developed to meet the institutional needs within the I-70 West Corridor. The most prominent organizational need expressed by all stakeholders is a need to be included in the process, whether it is planning, policy setting, or decision-making. To accomplish this with respect to ITS, the following structures can be initiated:

- a corridor-wide ITS association can be created that includes members from various stakeholder groups throughout the corridor. This association should strive to promote ITS in the region as well as identify and design specific ITS projects.

- the corridor-wide association should be represented on the Statewide ITS Implementation Team to represent the interests of the region and promote projects for the I-70 West Corridor;

- an inter-organization task force should be established to lead development of a corridor-wide incident management plan. Such a plan would detail specific actions to be taken by the various service providers operating within the I-70 West Corridor in the event of an emergency. The corridor-wide incident management plan would need to be continually updated as resources and policies evolve.

IMPLEMENTATION BARRIERS

Most institutional barriers are statewide issues, not just specific to the I-70 West Corridor. These need to be resolved at the federal and state levels so that certain ITS projects and programs for the I-70 West Corridor can proceed. The following is a sampling of the issues that currently inhibit rapid deployment of ITS in Colorado.

Policy/Regulations. Some policies and regulations are inherently opposing to ITS. The best way to illustrate how legislation affects ITS initiatives is through example.

Federal law and Colorado statute disallowed private use of public rights-of-way, for the simple reason that uncontrolled activity by others within the roadway proper could impede traffic operations and compromise the health, safety, and welfare of the traveling public. ITS is data intensive, requiring communications media that can transmit large amounts of data quickly. Fiber optics is, currently, the best media. It is expensive to procure and install. Telecommunications companies use fiber for most methods of communication and are establishing a comprehensive and continuous network to meet their data needs. They have to buy easements (like right-of-way) to lay fiber in the ground. It is expensive. These companies can cut costs and accelerate schedules if continuous statewide and interstate corridors are available to them--like transportation corridors (roadway, rail).

Recognizing both transportation and telecommunications needs, the Colorado legislature enacted a law allowing telecommunications companies to lay fiber in public roadway rights-of-way. The implications of this law are both good and bad. CDOT has lost bargaining power to trade rights-of-way for communications service since the legislation gives all telecommunications companies the right to enter the rights-of-way. This same provision allows multiple and separate easements that has potential to cause major traffic disruptions when installation and maintenance is programmed.

Other legislation that affects ITS implementation includes:

- private organizations cannot promote their business on public property--one way to finance an ITS project is to allow sponsors to advertise on a system in exchange for financial support;

- FCC prohibits advertising on publicly-operated air waves--broadcast sponsorships in exchange for financial support are again disallowed;

Cost and revenue-sharing is another form of financing ITS projects. ITS projects are often cost-intensive and require the partnership of public and private entities to accomplish successful implementations. Private industries may be willing to help with the cost of developing and implementing ITS technologies, but will also want to share in the revenues collected from them. Public-private ventures can be arranged such that each entity is responsible for some combination of the following responsibilities: project initiation and planning, design, financing, construction, ownership, operation, and revenue collection.

Risk/Liability. ITS projects by nature involve high technologies and in some cases can involve emerging, unproven technologies. Also, legislative and organizational changes are not guaranteed. With these factors, ITS projects possess an inherent risk factor. The traveling public may be willing to pay for operating costs, but it is unlikely that they will assume any risks. The risk must be shared between the public and/or private entities. In allocating risk between public and private entities, the "pooling argument" states that public agencies should assume the risk, thus spreading the risk over more people. Conversely, if the private entity, which is assumed to have more expertise in cost analysis, is unwilling to assume the risk, then the project should not be undertaken. Although, it is generally accepted that if the project should greatly benefit the public, then the public sector should assume the risk. ITS risks involving legislation, regulation and government activity can be minimized through public sector involvement.

Information Exchange/Ownership. Critical to a successful ITS system is widespread information dissemination. Sharing of information is complicated when a private entity enters into the arena. When a public agency shares information with the private sector, confidential information needs to be screened out as issues in privacy arise. When a private entity owns the data collection device, e.g. a video surveillance camera, issues in data ownership should be resolved before implementation. In some cases, the public agency will grant the private agency access to the right-of-way to install equipment in exchange for either shared use of the facilities, or access the data being collected.

I-70 RURAL IVHS

NEEDS ASSESSMENT

SECTION V

SUPPLEMENTAL INFORMATION

SECTION V SUPPLEMENTAL INFORMATION

TERMINOLOGY

Founded in 1988, Mobility 2000 was an informal assembly of industry, university, and government representatives created to promote the use of advanced technologies to improve highway safety and efficiency. The initiative was formalized in 1991, when the Intermodal Surface Transportation Efficiency Act (ISTEA) was enacted, and the national Intelligent Vehicle Highway System (IVHS) program was established. A growing sense soon developed in the IVHS community, especially in the public transit arena, that "intelligent vehicle highway systems" did not embrace all the transportation modes addressed in the national IVHS program. In 1994, the national IVHS program was renamed the Intelligent Transportation System (ITS), to clarify the multi-modal intent.

The ***I-70 Rural IVHS Corridor Planning and Feasibility Analysis*** was initiated and funded when the national program was known as IVHS. Due to the familiarity with the term IVHS among the stakeholders involved, and the time and expense that would be required to change the study's name in the contract documents, the original title was retained. References within the Information Search, and other documents, will use IVHS and ITS interchangeably. Most references will be to ITS unless a specific project or document carries the IVHS designation in its formal title.

Acronyms are often used to identify ITS technologies and applications. Those commonly used ITS-related acronyms, and other abbreviations, referred to in this document are defined below.

AASHTO	American Association of State Highway and Transportation Officials
AAWS	Animal Alert Warning System
ADA	Americans With Disabilities Act
ADAS	Atlanta Driver Advisory System
AFMS	Advanced Freeway Management Systems
AHAR	Automatic Highway Advisory Radio
AHS	Automated Highway System
AM	Amplitude Modulation
AM	Automated Mapping
APTS	Advanced Public Transportation Systems
ARTS	Advanced Rural Transportation Systems
ASCE	American Society of Civil Engineers
ASTM	American Society of Testing and Materials
ATAF	American Trucking Association Foundation
ATIS	Advanced Traveler Information Systems
ATMS	Advanced Traffic Management Systems
AVC	Automatic Vehicle Classification

AVCS	Advanced Vehicle Control Systems
AVI	Automatic Vehicle Identification
AVL	Automatic Vehicle Location system
BLM	Bureau of Land Management
BPS	Bits Per Second (data transmission rate)
CAAA	Clean Air Act Amendments
CAD	Computer Aided Dispatch
CASTA	Colorado Association of Transit Agencies
CATI	Colorado Advanced Technology Institute
CCTV	Closed-Circuit Television
CDOT	Colorado Department of Transportation
CIMC	Colorado Incident Management Coalition
CMCA	Colorado Motor Carriers Association
CML	Colorado Municipal League
CMS	Changeable Message Signs
CMS	Congestion Management System
CPU	Central Processing Unit
CS	Communications Systems Functional Area/Action Team Review Group
CSP	Colorado State Patrol
CTC	Colorado Transportation Commission
CTI	Colorado Transportation Institute
C-TMC	Colorado Transportation Management Center
CVO	Commercial Vehicle Operations
DATIS	Dulles Area Traveler Information System
DCA	Data Collection/Aggregation Functional Area/Action Team Review Group
DIA	Denver International Airport
DRCOG	Denver Regional Council of Governments
DTD	Division of Transportation Development
EAP	Early Action Project
EEI	Environmental/Economic Impact Functional Area/Action Team Review Group
ER	Emergency Response Functional Area/Action Team Review Group
ET	Education/Training Functional Area/Action Team Review Group
ETC	Electronic Traffic Control
ETTM	Electronic Toll and Traffic Management
FM	Federal Aviation Administration
FCC	Federal Communications Commission
FHWA	Federal Highway Administration

FIR	Field Inspection Review
FLA	Federal Lands Highway Program
FM	Frequency Modulation
FMS	Freeway Management Systems
FMS	Fixed Message Sign
FOR	Final Office Review
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
FTMS	Freeway Traffic Management Systems
GIS	Geographic Information Systems
GOCO	Great Outdoors Colorado
GPS	Global Positioning Systems
HAR	Highway Advisory Radio
HELP	Heavy Equipment License Plate
HOV	High Occupancy Vehicle
IDEA	Innovations Deserving Exploratory Analysis
IEEE	Institute of Electrical and Electronic Engineers
II	Institutional Issues Functional Area/Action Team Review Group
IMC	Incident Management Coalition
IMIS	Integrated Motorist Information System
IRD	International Road Dynamics
ISO	Intermountain Standards Organization
ISTEA	Intermodal Surface Transportation Efficiency Act
ITE	Institute of Transportation Engineers
ITI	Intelligent Transportation Infrastructure
ITS	Intelligent Transportation Systems (formerly IVHS)
ITOC	Interim Traffic Operations Center
IVHS	Intelligent Vehicle Highway Systems (presently ITS)
LCD	Liquid Crystal Display
LED	Light-Emitting Diode
LEO	Low-Earth Orbit (Satellite)
MnDOT	Minnesota Department of Transportation
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
MPO	Metropolitan Planning Organization
NCHRP	National Cooperative Highway Research Program

NEMA	National Electrical Manufacturers Association
NII	National Information Infrastructure
NHS	National Highway System
NHTSA	National Highway Traffic Safety Association
NOAA	National Oceanic and Atmosphere Administration
NPP	National Program Plan
NTSC	National Television Standards Committee
NWRCOG	Northwest Regional Council of Governments
NWS	National Weather Service
OSI	Open Systems Interconnect
OVMD	Optical Vehicle-Motion Detector
PIO	Public Information Officer
PCN	Personal Communications Network
POE	Port Of Entry
PPP	Public/Private Partnerships Functional Area/Action Team Review Group
PSCo	Public Service Company of Colorado
PTAM	Public Transportation/Alternative Mode Functional Area/Action Team Review Group
RAFTA	Roaring Fork Transit Agency
RDSO	Radio Data System Operations
RF	Radio Frequency
RICC	Regional Incident Control Center
RTD	Regional Transportation District (Denver area public transportation authority)
RTP	Regional Transportation Plan
SAE	Society of Automotive Engineers
SCADA	Supervisory Control and Data Acquisition Systems
SOV	Single Occupancy Vehicle
SSTC	Summit Stage Transfer Center
STIP	Statewide Transportation Improvement Plan
SW	Safety and Warning Functional Area/Action Team Review Group
TCC	Transportation Commission of Colorado
TDM	Transportation Demand Management
TIP	Transportation Improvement Plan
TIS	Traveler Information Systems Functional Area/Action Team Review Group
TMC	Transportation Management Center
TMO	Traffic Management/Operations Functional Area/Action Team Review Group
TOC	Traffic Operations Center
TRB	Transportation Research Board

TSM	Transportation Systems Management
TSCS	Traffic Surveillance and Control Systems
TWP	Twisted Pair (communications medium cable, usually copper)
UHF	Ultra High Frequency (television subcarrier broadcast)
USFS	United States Forest Service
VGTC	Vail/Gypsum Transit Center
VHF	Very High Frequency (television subcarrier broadcast)
VIDS	Video Image Detection System
VMS	Variable Message Signs
VMT	Vehicle Miles Traveled
WHI	Western Highway Institute
WIM	Weigh-in-Motion
WIVIS	Weather Identifier and Visibility System

I-70 RURAL IVHS

NEEDS

ASSESSMENT

APPENDIX A

TRANSPORTATION NEEDS SURVEY

I-70 RURAL IVHS

TRANSPORTATION NEEDS SURVEY

GENERAL

1. What is your current level of knowledge regarding IVHS?

- ______ This is the first I have heard of it.
- ______ I have heard of it, but I am skeptical.
- ______ I am aware of the general technologies and applications.
- ______ I am very familiar with IVHS technologies and applications.

2. Do you think advanced technology applications can help manage, operate, and/or maintain transportation systems? [Circle one] *Yes No Maybe*

3. Are you familiar with local policies and State legislation on how public agencies can conduct business? *[Circle one]* *Yes No*

4. Are you familiar with private sector ground rules for doing business (profit, economic viability, risk)? *[Circle one]* *Yes No*

AGENCY/BUSINESS ORGANIZATION

1. What type of group do you represent? [Check one]

______ Federal Agency	______ State Agency
______ County Agency	______ Municipal Agency
______ Planning Agency	______ Legislative Representation
______ Business Service	______ Business Product
______ Tourism Service	______ Recreational Service
______ Law Enforcement	______ Emergency Response Service
______ **Public** Transportation	______ Commercial Vehicle Operation
______ Other ____________________	______ Other ____________________

2. Please list and prioritize the services or products that you provide? *[Rank order your list of services/products in the* ***left*** *most column beginning* with *"I" as the most important]*

______ ____
______ ____
______ ____
______ ____
______ ____
______ ____
______ ____
______ ____

3. What are your responsibilities within your organization? [Check all that apply]

______ Advisory	______ Review	______ Decision-Making
______ Policy-Making	______ Development	______ Setting Goal
______ Management	______ Planning	______ Production
______ **Operations**	______ Maintenance	______ Marketing
______ **Other** ____________________	______ Other ____________	______ Other ______________

4. What can your organization provide to improve the movement of people and goods? [Check *all that apply]*

______ Legislative Action	______ Monetary Support
______ Management Support	______ Products/Equipment
______ Traveler Information	______ Information Dissemination
______ Communication Links	______ Maintenance
______ Cooperative Agreement	______ Manpower
______ Other ____________________	______ Other ____________________

TRANSPORTATION NEEDS SURVEY

5. What do you think your role can be in the planning process for the I-70 Corridor (Denver to Glenwood Springs)? *[Rank order (1 =most important) all that apply]*

______ Advisory
______ Policy
______ Informational
______ Other______________
______ Review
______ Direction
______ Resource
______ Other______________
______ Decision-Making
______ Goal Setting
______ Participation

6. What specific expertise, activities, and/or actions can you contribute to the I-70 Rural M-IS study?

1. ______________________________
____
3. ______________________________
4. ______________________________

TRANSPORTATION ISSUES

1. From your perspective, identify major concerns and issues regarding rural transportation?

1. ______________________________
____
3. ______________________________
4. ______________________________
____
6. ______________________________
7. ______________________________
8. ______________________________

2. What major obstacles are you currently encountering related to the function of rural transportation systems? [Check *all that apply)*

______ Funding
______ General Maintenance
______ Emergency Respons
______ General Public Attitude/Perception
______ Jurisdictional Barriers
______ Communication
______ Inter-Organizatioual Cooperation
______ Information Dissemination
______ Other______________
______ Other______________

What major transportation goals should be addressed for the I-70 Corridor from Denver to Glenwood Springs (including state highways, county roads, and other facilities that connect to I-70 and *service your area)? [Rank order (1 =most important) those that apply]*

______ Improve Safety
______ Increase Mobility
______ Reduce Congestion
______ Encourage Alternate Modes
______ Overcome Iustitutioual Barriers
______ Other ______________________________
______ Other ______________________________
______ Enhance Economic Productivity
______ Improve Environmental Quality
.______ Reduce Disruptions from Weather-Related Conditions
______ Improve Public Perception

What current and potential pitfalls do you think may be encountered in developing an adequate transportation system? *[Check all that apply]*

______ Institutional Barriers
______ Public Acceptance
______ Local Government Participation
______ Funding
______ Other ______________________________
______ Other ______________________________

TRANSPORTATION NEEDS SURVEY

I-70 RURAL NHS

TRANSPORTATION NEEDS

1. Rank order (l-most important; g-least important) the following systems for their ability to mitigate regional transportation issues:

_____ Roadway Capacity Improvements
_____ Congestion Management
_____ Incident Management
_____ Public Transportation
_____ Private Transit
_____ Rail Passenger
_____ Air Passenger Transport
_____ Bicycle/Pedestrian Facilities
_____ Intermodal Facilities
_____ Commercial Vehicle Operations

2. Rate (l=imperative; 2=important; 3=minor 4=insignificant) each of the following objectives to improving the movement of people and goods within the I-70 Corridor

_____ Improve Roadway Capacity
_____ Increase Traveler Safety
_____ Preserve Environment
_____ Develop Better Access
_____ Develop Trail System
_____ Manage Commercial Vehicle Travel
_____ Relieve Roadway Congestion
_____ Enhance Traveler Mobility
_____ Decrease Single Occupancy Vehicle Use
_____ Provide Traveler Information Systems
_____ Improve Emergency Response
_____ Monitor Hazardous Materials Transport

3. Rate (on a scale from 0 to 100; 100 being most beneficial) the following approaches to solve transportation problems within the I-70 Corridor.

ROADWAY

_____ Capacity Improvements (additional lanes,, horizontal/vertical geometry)
_____ Safety Improvements (shoulders, signing, striping)
_____ Access Improvements (accel/decel lanes, channelization, control devices)
_____ Pullouts
_____ Speed Limits
_____ Bridge Replacements
_____ Resurfacing
_____ General Maintenance (crack/rut repair, sand removal)
_____ IVHS/Advanced Technology Applications
_____ Other _____
_____ Other _____

TRANSIT

_____ Intercity Bus Service
_____ Regional Shuttle Bus Service
_____ Regional Paratransit Services
_____ Privately-Operated Shuttle Bus Services
_____ Regional and/or Local Light Rail Transit
_____ IVHS/Advanced Technology Applications
_____ Other _____
_____ Other _____

RAIL

_____ Commuter/Passenger Rail
_____ Freight Transport Via Rail
_____ High Speed Rail (Maglev, Bullet Train)
_____ Other _____
_____ Other _____

TRANSPORTATION NEEDS SURVEY

AVIATION

______ Tourist Air Travel Service
______ Local Commuter Air Service
______ Advanced Technology Applications
______Other ______
______Other ______

BICYCLES/PEDESTRIANS

______ Regional Bike Path System
______ Rural Roadside Bike Routes (shoulder treatment)
______ Regional Walker/Hiker Trail System
______ Advanced Technology Applications
______Other ______
______Other ______

INTERMODAL CONNECTIONS

______ Multi-Modal Transfer Centers
______ Shuttles Between Different Mode Facilities
______Other ______
______Other ______

TRAVELER INFORMATION

______ Border Welcome Centers
______ Regional Information Centers
______ Rest Areas
______ IVHS/Advanced Technology Applications to Provide Real-Time Information
______ Other ______
______ Roadside Call Boxes
______ Roadside Information Kiosks
Signage Roadside Signage
______ Other ______

REGIONAL TRANSPORTATION MANAGEMENT

______Emergency Response System Improvements
______Incident Management System Improvements
______Commercial Vehicle Operations Automation Systems
______ Hazardous Materials Transport Monitori
______Other ______
______ Other ______

POTENTIAL TRANSPORTATION SOLUTIONS

1. What IVHS programs cau provide the most benefit? *[rank or&r (1 =most important) those that apply]*

______ Develop Traffic Operations Center Hubs
______ Provide Real-Time Information to Travelers
______Enhance Attractiveness of Altemative Modes
______Improve Incident Detection and Response
______Improve Emergency Medical Response
______Create a Regionwide IVHS Communications System
______ Provide Communications Links to Other Regions
______Develop Public/Private Partnerships
______Develop Natural Disaster Predictive Systems (avalanche, rock slides)
______ Implement a Program Management System
______Other ______
______ Other ______

I-70 RURAL IVHS

TRANSPORTATION NEEDS SURVEY

2. Rate, on a scale from 0 to 100 (100 = most important), the following technologies/applications: [As you *rate each item, indicate if the technologylapplication is E = Early Action: L = Long-Term; or B = Both]*

RATING		E/L/B
______	Additional Variable Message Signs (VMS)	______
______	Cellular Telephone Reporting	______
______	Upgrade Computer Equipment	______
______	Public Roadside` Telephones	______
______	Sensor-Activated Environment	______
______	Courtesy Patrols	______
______	Automatic Avalanche Detection	______
______	Hanging Lake/Eisenhower Tunnel TOC Hubs	______
______	Real-Time Traveller Information Links	______
______	Intelligent Rest Areas	______
______	Transit/Ride&are Services	______
______	Intermodal Facilities	______
______	-High-Occupancy (HOV) Lanes/Ramps	______
______	Incident Management (Detection/Response Systems)	______
______	Road/Weather/Traffic Information Dissemination	______
______	Travel Path Delineation (Lighting/Reflective Markings)	______
______	Bi-Directional Lane Controls	______
______	Remote Video Surveillance	______
______	Automatic Median Barriers	______
______	Subcarrier Traffic Message Channels	______
______	Communication Links to TOCs	______
______	Communication Links to the Colorado State Patrol	______
______	Communication Links to Local Jurisdictions	______
______	Personal MAYDAY Systems	______
______	Electronic Transit Monitoring	______
______	Adaptive Traffic Control Devices	______
______	Hazardous Materials Transport Monitoring	______
______	Dynamic Truck Warning Systems	______
______	Automatic Speed Controls	______
______	Obstacle Detection Systems	______
______	Overheight/Overweight Vehicle Detection	______
______	Traffic Flow Monitoring	______
______	Truck Safety Systems	______
______	Integrated Motor Carrier Databases	______
______	In-Vehicle Navigation/Route Guidance	______
______	Peak Shaving/Road Pricing	______
______	Other	______
______	Other	______
______	Other	______

3. What specific IVHS functional *areas* should *be* addressed for the I-70 Corridor? *[Rank order (1 =most important} all that apply)*

______ Surveillance	______ Communications	______ Traveller Interface
______ Traffic Controls	______ Navigation/Guidance	______ Data Processing
______ In-Vehicle Systems	______ Incident Management	______ Intermodal Facilities
______ Dispatch	______ IVHS Program Management	______ System Architecture Development

______ Other ______________________________

______ Other ______________________________

I-70 RURAL IVHS

TRANSPORTATION NEEDS SURVEY

4. Please list specific projects for the I-70 Corridor that you think can/should be implemented. *[Check the appropriate box if the project is suitable for early action, or long-range, or both.]*

LOCATION	APPICATION	EARLY ACTION	LONG RANGE	BOTH

5. Several User Groups will benefit from the implementation of M-IS. Rate, on a scale from 0 to 100 (100 = most important), the following end users that IVHS applications in the I-70 corridor should focus on:

______ Through Traveller (*i.e.* a Kansas City to Salt Lake City trip via I-70)
______ Specific Site Visitor (i.e. shier from Denver to Vail)
______ Local Inhabitant (residents, local commuters)
______ Businesses/EstablishmentsArea
______ Operating/Maintenance Agencies (CDOT, local jurisdictions)
______ Emergency/Incident Response Teams (CSP, paramedics, fire districts)
______ Other ______
______ Other ______

IMPLEMENTATION BARRIERS

1. What prerequisites do you consider important to implement IVHS applications in the I-70 Corridor? *[Rank or&r (I1=most important) all that apply]*

______ Federal Dollars
______ Colorado Transportation Commission Support
______ Legislative Changes
______ Political Support
______ Outreach Efforts
______ Institutional Changes
______ Other ______
______ Other ______

2. Where do you think dollars should come from to implement Early Action and Long-Term projects? *[Indicate a percentage for each that apply.]*

______ Federal Funds
______ State Funds
______ Local Funds
______ Private Sector Participation
______ Other ______
______ Other ______
100%

3. What governmental funding pools do you think the dollars for M-IS implementation can come from?

______ Federal IVHS Funds
______ Defense Conversion Fuuds
______ Grant Programs such as M-IS IDEA
______ State Resurfacing Funds
______ State Replacement Funds
______ State Capacity Improvement Funds
______ Local Road/Bridge Funds
______ State/Local Tax Dollars
______ Other ______
______ Other ______

OUTREACH PROGRAM

1. Does the "open house" format provide enough information for you to form an opinion regarding the viability of IVHS? *(Circle one)* *Yes* *No*

TRANSPORTATION NEEDS SURVEY

2. Are there other forums that can provide a better understanding of IVHS? *[Rate on a scale from 0 to 100 (O=least beneficial; 100=most beneficial) all that apply]*

______ Telephone Contacts
______ Presentations
______ Team Building Sessions
______ Formal Workshops
______ Other ____________________
______ Other ____________________

3. What presentation/information materials are most effective in helping you understand the benefits of IVHS? *[Rate on a scale from 0 to 100 (O=least beneficial; lOO=most benficial) all that apply]*

______ Slide/Tape and Video Overviews of IVHS
______ Newsletters
______ Information Briefs
______ Technical Papers
______ News Articles
______ Project-Specific Displays
______ Strategic Plans (National and State)
______ Other ____________________
______ Other ____________________

4. To what extent have your perceptions and/or opinions in *support* of IVHS changed as a result of the information you ob-*tained* at *the* I-70 Corridor Open House? *[Circle the appropriate number within the indicated range]*

Very Little .... Great Deal

1 2 3 4 5 6 7 8 9 10

COMMENTS

Please record any additional comments that you may have regarding IVHS in general, the I-70 Corridor and any other transportation-related issues:

____

Name: ____________________ Title: ____________________
Agency: ____________________ Address: ____________________
City, State, Zip: ____________________
Telephone No. ____________________ Fax No. ____________________

Fold and Mail

If you have questions, call l-800-358-5301

I-70 RURAL IVHS

place
stamp
here

De Leuw, Cather & Company
1700 Broadway, Suite 1016
Denver, CO 80290

Attn: Barbara McClure Schroeder
CC-041 494

I-70 RURAL IVHS

NEEDS

ASSESSMENT

APPENDIX B

DYNAMIC MODELING REPORT

DYNAMIC MODELLING OF WINTER WEEKEND TRAFFIC FROM SKI RESORTS IN COLORADO

by

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A special thanks to my advisor, Bruce N. Janson, for his support and assistance. Bruce's contribution to this report has been immeasurable.

ABSTRACT

The development of Advanced Traffic Management Systems (ATMS) as a major component of Intelligent Vehicle Highway Systems (IVHS) is targeted to address the complex problem of traffic congestion. This strategy includes real-time diversion of traffic during congestion-causing events by making efficient use of available capacities in the highway network.

This report presents the results of applying a Dynamic Traffic Assignment Model (DYMOD) to the I-70 corridor west of Denver to Glenwood Springs including ski resorts. Average daily traffic (ADT) volumes throughout the network were used to estimate a regional origin-destination (O-D) trip matrix. Then, hourly traffic counts at the only three permanent counter locations in this region, together with ski resort attendance figures from Colorado Ski Country USA, were used to estimate the additional traffic demands that occur on a typical winter Sunday afternoon. These trips were added in proportion to the ADT estimated trip matrix, where we assumed 10% of the ADT trip matrix to represent average background traffic on a usual day. Finally, hourly traffic near one ski resort was used to approximate skiers' departure times over the analysis period from 2 to 7 PM.

A geographic information system (GIS) network database representing all major federal and state roads in this corridor was developed from digital line graph files. For each link of network was coded its length, number of lanes, speed limit, free-flow travel time, and estimated capacity. DYMOD was applied to predict traffic volumes and delays throughout the network, particularly for eastbound traffic toward Denver from Eisenhower Tunnel to Idaho Springs on a typical winter Sunday afternoon. Further analyses not presented here showed that average current delays could be reduced by 4% if overall traffic in the corridor were spread by 10%. Use of model for other delay mitigation strategies is discussed.

CHAPTER 1

Introduction

Background

The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) and the U.S. DOT Appropriations Act allocated significant resources to Intelligent Vehicle-Highway Systems (IVHS) projects, now called Intelligent Transportation Systems (ITS). ISTEA also authorized the U.S. Secretary of Transportation to designate participants in a newly created IVHS Corridors Program.

IVHS technologies aim to enhance the efficiency of private and public transportation systems by providing accurate information on the location and status of the vehicles and traffic conditions to both drivers and users of these transport modes. IVHS technologies are often grouped into the following four broad categories:

- **Advanced Traffic Management Systems (ATMS),** which aim to optimize safety and capacity within existing roadway constraints. ATMS approaches include integrated signal and traffic control to influence use of major arterials.
- **Advanced Traveler Information Svstems (ATIS),** used to provide travelers with information on congestion, traffic, weather and road conditions, location or routing advice. ATIS technologies can provide these data at home, at work, at public activity centers, or via in-vehicle systems.
- **Fleet Management and Control Systems (FMCS),** comprising Commercial Vehicle Operations (CVO) and Advanced Public Transportation Systems (APTS). These use computer databases, monitoring systems, and displays to improve the efficiency and safety on transit systems, and to reduce operating costs and increase revenues for transit systems.
- **Advanced Vehicle Control Systems (AVCS),** covering a group of technologies which can support drivers in performing vehicle control functions. Vehicle control systems include lateral control and guidance systems and controls for autonomous driving.

The Colorado DOT has identified I-70 corridor west of Denver as an opportunity to implement IVHS strategies as a leading example of improving safety and mobility for the travelers on rural roads with heavy emphasis on ATMS and ATIS. Project Pathfinder in

California and Project Prometheus in Europe are examples of two extensively planned, monitored, and documented projects using Advanced Traffic Management Systems (ATMS) to provide safer and more efficient travel. Pathfinder is a 3-year project in Santa Monica Smart Corridor to which General Motors is providing 25 cars with Etak Navigators (computer screens displaying digital maps and route guidance information). ATIS are being implemented in order to enhance the efficiency of travelers' choices with respect to alternative routes, modes, destinations, and departure times. Dynamic route guidance systems (DRGS) are systems that focus on assisting route choice by communicating travel times and altemative route information to drivers. Each of these travel guidance systems under development and testing relies on a traffic simulation model that helps planners to estimate the impacts of potential measures, and assists them in selecting the best way to mitigate traffic disruptions due to incidents.

Objectives

The purpose of this report is to describe the process and present results of modelling of traffic conditions in the I-70 corridor west of Denver serving over twelve ski resorts and many communities in the Rocky Mountains of Colorado. A GIS database of roads throughout the corridor was first developed to in order to implement the Dynamic Traffic Assignment Model (DYMOD). DYMOD was used to estimate vehicle volumes, speeds, and delays throughout the corridor, especially for traffic returning to Denver along I-70 on a typical winter Sunday afternoon (2 to 7 PM). This report demonstrates the use of DYMOD as a transportation planning and analysis tool in rural areas where activities induce very significant time-of-day variations in travel demand that frequently exceed capacities at peak times, long average trip lengths, many varied trip purposes, and difficult terrain and weather conditions that often reduce road capacities even further.

Scope

The scope of this report consists of four parts:

(1) Review of available literature related to:

(a) Intelligent Vehicle Highway Systems (written by Darjadi & Janson (1994) as part of a comprehensive study by De Leuw Cather, Inc., Kaman Sciences, and the University of Colorado at Denver on potential IVHS applications to the I-70 corridor).

(b) Dynamic traffic assignment (DTA) ‘models.

(2) Develop highway network for the I-70 corridor using a transportation geographic information system (GIS) software package. This network including access roads to ski areas along I-70 west corridor (Denver to Glenwood Springs).

(3) Estimate a peak-hour Origin-Destination (O-D) trip matrix representing trips in the corridor from 2 to 7 PM on a typical winter Sunday.

(a) Obtain two months of an hourly traffic counts (February and March, which are the peak ski months), at three locations of the network for each Sunday. Only three permanent traffic detectors are located in this corridor.

(b) Use a synthetic O-D estimation algorithm SYNOD based on the work of Van Zuylen and Willumsen (1980) to generate an origin-destination trip matrix

(4) Implement and test the Dynamic Traffic Assignment Mode1 (DYMOD) to predict travel times, volumes, and speeds throughout the corridor, particularly on I-70 and on roads near ski resorts.

Principal Results and Conclusions

Figure 1.1. shows observed vs predicted volumes for two highway links. The ability of the model to produce predicted flows is indicated by the closeness of the predicted volumes to the observed ones. The difference between observed and predicted flows on I-70 links at Eisenhower Tunnel remains below 12% for the entire analysis period (2:00 to 7:00 PM). The highest discrepancy between observed and predicted flows is seen between 6:00 to 7:00 PM. However, there is a big diierence between abserved and predicted flows on State Highway 40 around Winter Park which is about 20%. The highest discrepancy between observed and predicted flows is seen during the peak hour (4:00 to 5:00 PM).

Partial results of predicted speeds on I-70 links from Dillon to Idaho Springs are shown in Figure 1.2. The changes of predicted speeds on these links caused by queuing are very significant. Traffic going from Dillon to ‘before’ Eisenhower Tunnel has almost constant speeds between 60 and 65 mph. However, speeds reduce to 35 mph when those traffics entering Eisenhower Tunnel and becomes worse on links around Georgetown, Empire, and

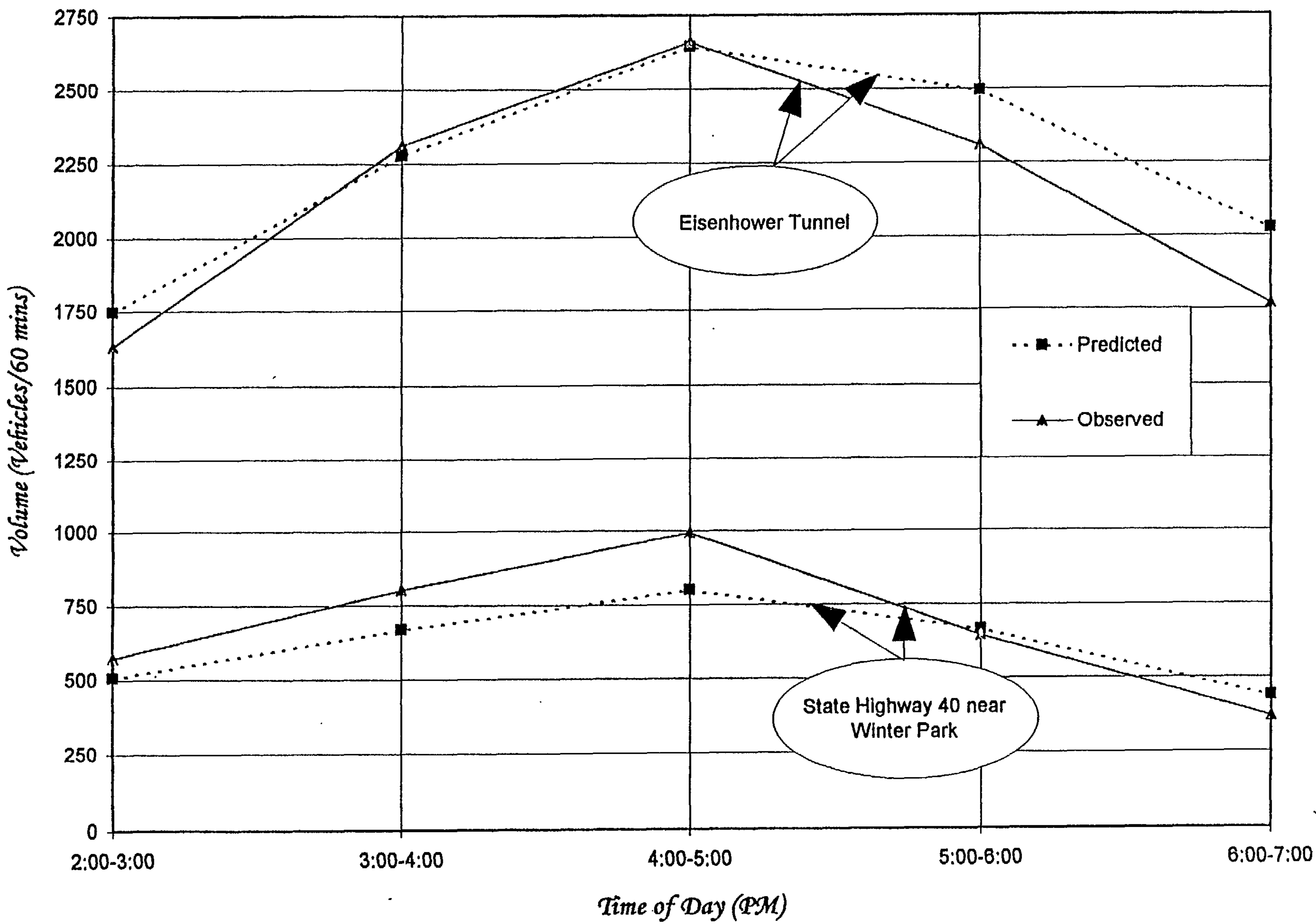

Fig. 1.1: Observed vs Predicted Volumes

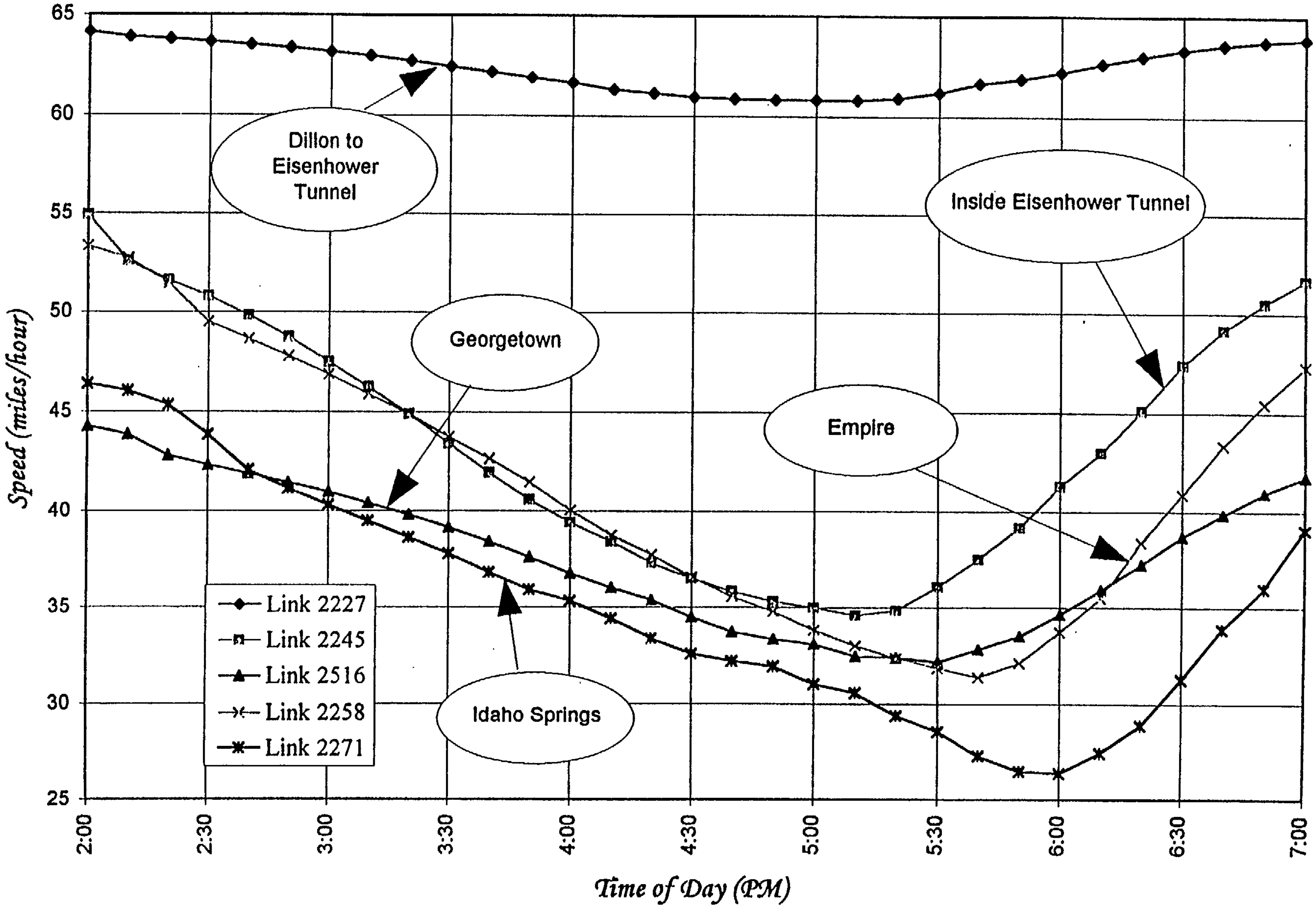

Fig. 1.2: Predicted Speeds on I-70 Links

8/96

Idaho Springs, which dip below 30 mph.

The results, in general, demonstrate that DYMOD is able to (1) predict volumes and speeds, and (2) estimate delays during congestion. The accuracy of these estimates during the congested period requires further validation.

Outline

A review of ruraI intelligent vehicle highway system (IVHS) and traffic assignment techniques is given in Chapter 2 Chapter 3 describes the development of thenetwork used for this study. Chapter 4 focuses on how the O-D matrices were estimated and Chapter 5 described about DYMOD. The discussion of the results is given in Chapter 6, and finally, Chapter 7 presents conclusions and some suggestions of this study.

CHAPTER-2

Review of Rural M-IS and Traffic Assignment Techniques

Rural IVHS

A pilot project performed by Utah State University focused on the application of IVHS technologies that could potentially improve travel safety and reduce travel delays on rural roads. This pilot project was organized into the following two phases, which address several travel needs identified for rural areas (O' Neill, 1993).

Phase 1 of the project focused on the distinction of rural roads from urban roads in their:

(1) traveler requirements and user needs,

(2) types of accidents and casual factors, and

(3) applicable and existing IVHS technologies.

The study concluded that the following characteristics separate the ruraI from urban roads:

(1) Substantial travel distances (Le., longer trip lengths).

(2) Safety, but not necessarily congestion, is a major problem.

(3) Wide range of traffic volumes and trip purposes.

(4) Less familiarity of drivers with travel paths.

(5) Higher average speeds due to less congestion and greater distances between points of traffic control.

(6) Nighttime driving poses greater risks (fewer street Iights, longer driving times induce sleep, etc.).

A second major issue addressed by their research was to develop a better understanding of accidents on Utah's rural roads. An extensive literature review was conducted to answer two questions:

1. What approaches have others taken to investigate safety benefits associated with IVHS technologies?

2. What techniques and models have been used to analyze accidents, particularly in rural areas?

Safety improvements have not been the principle focus of much IVHS research. Most efforts have been directed at reducing congestion through traffic monitoring, incident detection, vehicle navigation systems, and signal control systems. To evaluate the safety benefits of IVHS technology requires reliabIe modeIs to predict and quantify their benefits, or to build prototype systems and observe their impacts. The later approach is expensive and time-intensive, and thus only works well for a limited number of applications over a long period of time. Hence, a combination of predictive modelling and well-executed (monitored and documented) demonstrations is probably the most effective R&D strategy.

The question concerning what techniques have been used to analyze accidents is easier to answer. Statistical methods have been used to analyze many accident cases. -Regression techniques have been used to relate a range of variables associated with accidents to the number or rate of accidents. In addition, time series analyses have been utilized to predict future accidents. AnaIysis of historical accident data is required to identify the types of accidents occurring on rural roads.

The final step in the first phase was to inventory and describe the tvpes of technology used in IVHS applications in rural areas.

Phase 2 of the project was to refine the focus of their efforts specifically to (1) develop and test a model for identifying accident types on ruraI roads, and (2) perform a cost-benefit analysis for a prototype Advanced Traveler Information Systems (ATIS).

ATIS incorporates several technologies to collect data on current traffic conditions, interpret the information, and communicate it to travelers. Most commonly used technologies are as follows:

- Radio Data Systems (RDS).
- Electronic Maps and Yellow Pages.
- Global Position Satellite (GPS) Systems.
- Dead Reckoning Navigation Systems.
- Route Guidance Systems (RGS).
- Highway Advisory Radio (HAR).
- Advanced Weather Warning Systems.

Potential users of these systems in rura1 areas include:

- Tourists taking day trips from urban areas to resorts.
- Private shuttle services from the airport to resorts.

- Rural school bus operators.
- Many others using the rural road network for work, recreational, or commercial transport and related reasons.

For identifying accident types on rural roads, a fuzzy set model, which is a hybrid of hierarchical and optimization clustering models, was modified and tested. Cluster analysis techniques have also been applied by others conducting IVHS research on travelers' decisions to identify common characteristics of people who may use pre-trip information.

The final cost-benefit analysis required (1) estimating accident costs that would be avoided if a guidance system were in place and used to varying degrees of effectiveness or compliance, and (2) estimating costs to install, operate, and maintain a system, since full costs over the life-cycle of the technology is important to its planning, design, and implementation.

Traffic Assignment Techniques

Many traffic assignment techniques are based on an underlying assumption of user equilibrium (UE), which postulates that travelers try to minimize their own individual traveI time or costs when choosing routes (Wardrop, 1952). Traffic assignment techniques widely used are: (1) stochastic equilibrium assignment (multinomial logit and multinomial probit); (2) all-or-nothing assignment; (3) deterministic equilibrium assignment (capacity restraint and mathematical optimization). The most popular traffic assignment algorithms generally consist of variations of the traditional iterative capacity restraint approach (Bureau of Public Roads, 1964; Easa, 1991). These algorithms consist of a series of ah-or-nothing assignments combined with computations to improve estimates of link travel times and volumes. The link travel times are adjusted using link performance functions after each iteration, and link volumes of successive iterations are combined using some type of linear combination method. This technique is most applicable for peak-hour assignments (Ortuzar and Wiiumsen, 1990).

Static traffic assignment methods are considered inappropriate for time-varying situations, since they do not possess the capability of capturing the dynamic nature of traffic flow through the network For this reason, a dynamic assignment model called DYMOD was developed to address the time-varying dynamics of traffic flow (Janson, 1993).

Dynamic Trafffic Assignment

An important shortcoming of static traffic assignment models is that they do not have a time dimension (i.e., all vehicles are assigned to the network as if in steady flowing streams). Unlike static traffic assignment, a dynamic traffic assignment model incorporates time so it can predict the time-dependent behavior of traffic flow much more realistically. There are two basic approaches for solving dynamic traffic assignment probIems: mathematical optimization and computer simulation. Optima1 control theory formulations belong to the former.

Dynamic traffic assignment problems, like their static counterparts, are distinquished in two basic ways (among others) depending on the behavioral assumption of individual routing decisions. These are:

(1) Users attempt to minimize individual trave1 costs called dynamic user-optimal traffic assignment.

(2) Users cooperate in minimizing total transportation cost called dynamic system-optimal traffic assignment.

Merchant and Nemhauser (1978) formulated as a discrete time, nonlinear, and nonconvex mathematical programming approach. Later, Carey (1987) introduced the extended formulation of the previous model which is convex and nonlinear. A decade year later, Friesz et at (1988), Wie (1989), and Ran et aL (1991) used optimal control theory to propose dynamic generalizations of the static user-optimal route choice model as a continuous time generalizations of the discrete time formulation by Merchant and Nemhauser.

Among the other approaches, Mahmassani and Herman (1991) have describe the simulation approach that they and others working with them have developed to model dynamic traffic flows. Two other simulation approaches developed and implemented in EngIand are CONTRAM (Leonard et al., 1978) and SATURN (Van VLiet, 1982). These later two models are more applicable to modelling intersection movements, queuing delays, and time-varying flows on detailed urban/suburban networks of limited size. The Autoguide system in London uses these simulation models to forecast traveI times. However, the implementation of these models is prohibitive for large network.

CHAPTER 3

Network Development

Study Area

Responding to concerns of Colorado Department of Transportation (CDOT) over growing congestion problems along the western corridor of I-70, especially near Eisenhower Tunnel and the ski resorts on weekends, it was deemed necessary to apply our research work to these areas. Only primary roads and interstate highways were included in the network structure.

The network for this study shown in Figures 3.1 'and 3.2 contains twelve ski resorts, and most of those locations have a high attendance of skiers or visitors the entire season. Those ski resorts are listed in Table 3.1. All of these ski resorts are located within ten counties of Colorado, for which boundary coordinates and general census data were obtained from 1990 TIGER/Line files (shown in Figure 33) and then converted into a GIS database. These counties are (1) CIear Creek, (2) Gilpin, (3) Grand, (4) Lake, (5) Eagle, (6) Pitkin, (7) Garfield, (8) Summit, (9) Jefferson, and (10) Routt.

Network Representation

TransCAD, a Geographic Information System software package for transportation systems analyses was used to create the network starting from digital line graph files of centerline cordinates obtained from CDOT's Transportation Development Division. The network consists of highway links connected by nodes. Nodes are classified as intermediate nodes and zone centroids. Zone are nodes that represent ski resorts or urban areas where significant numbers of trips are generated (productions or attractions), and which are connected to other nodes by zone centroid connectors.

There are 2406 nodes in the network (including 22 zones) and 2566 links (including 64 zone connectors). All links are unidirectiona1 only and their geographic representation is such that (1) no two links connect the same two nodes, and (2) each two-way street is represented by two separate links connecting two different node pairs. At an intersection, four nodes and six links are needed to indicate the twelve possible turn movements (see Figure 3.4).

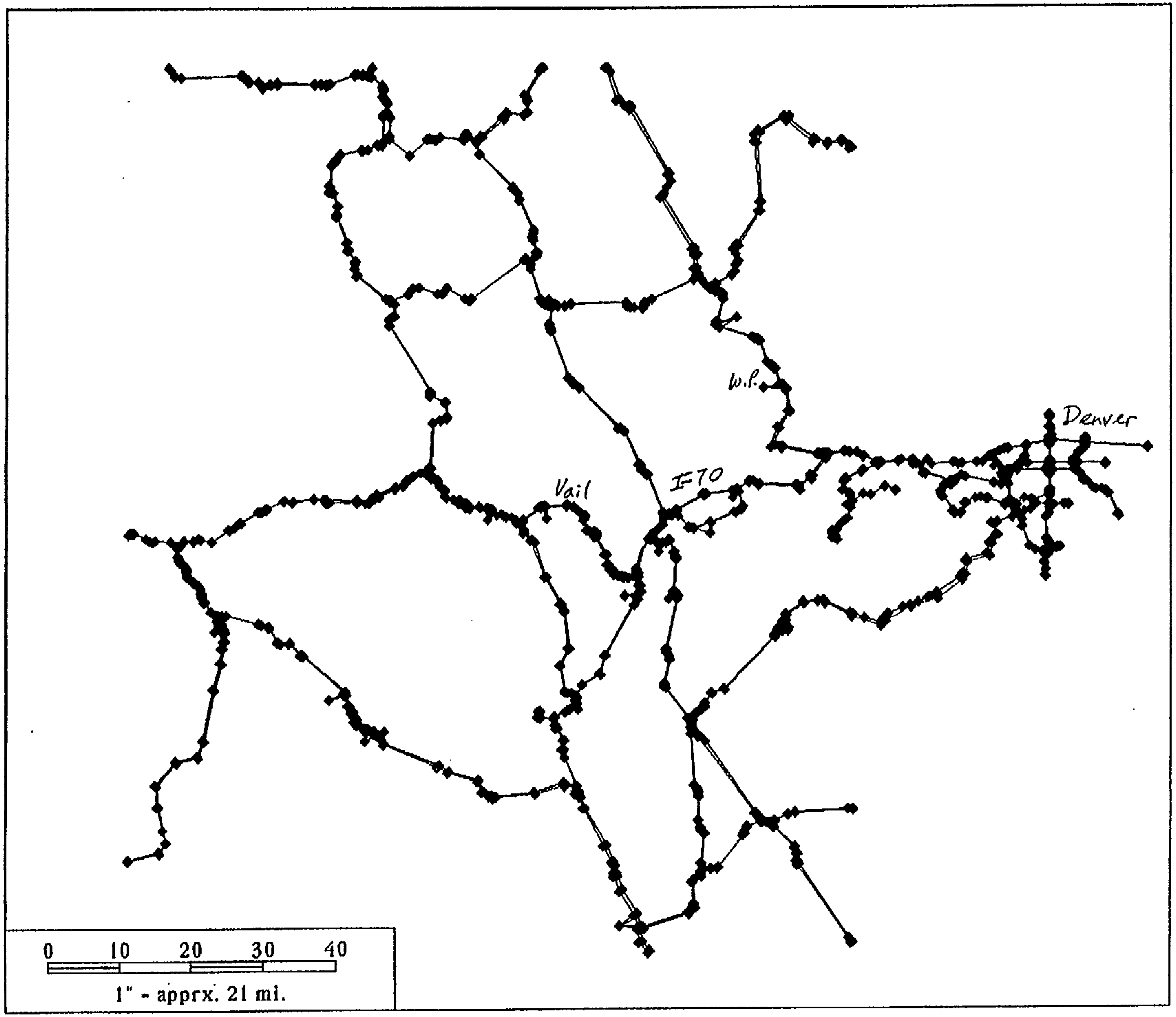

Fig. 3.1. I–70 West Colorado Network

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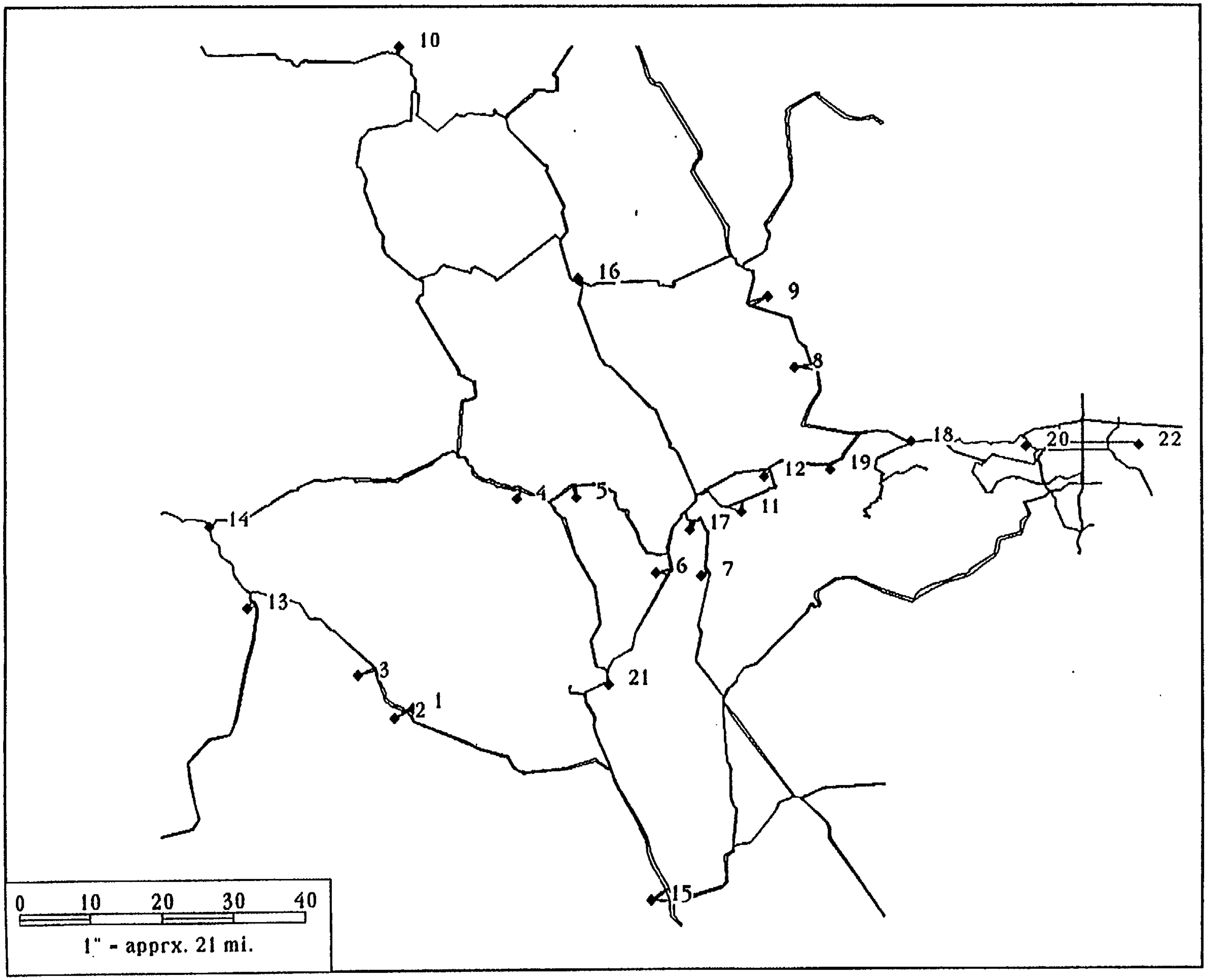

Fig. 3.2. Colorado Ski Resorts and Other Destinations

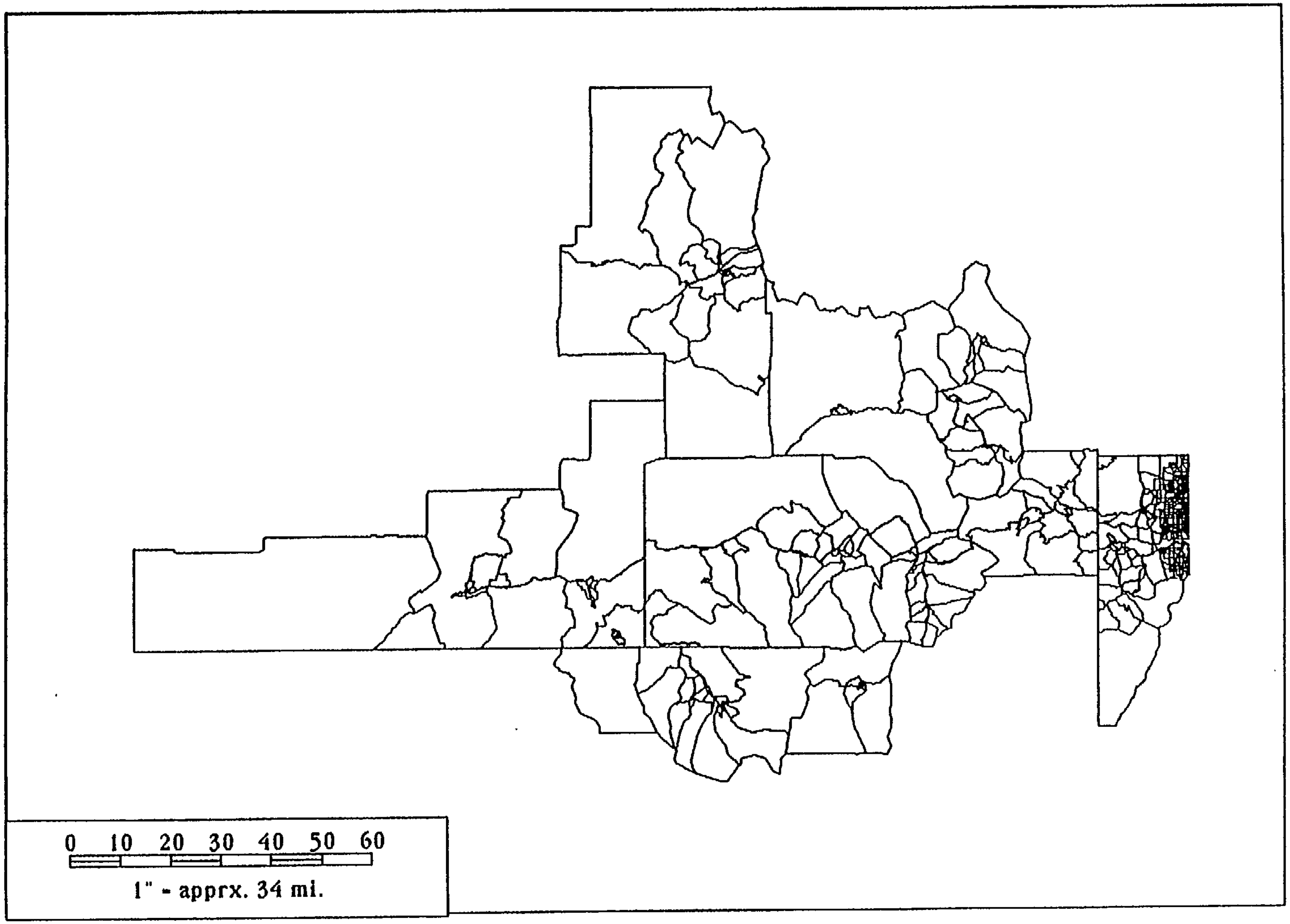

Fig. 3.3. Ten Counties in Central West Colorado

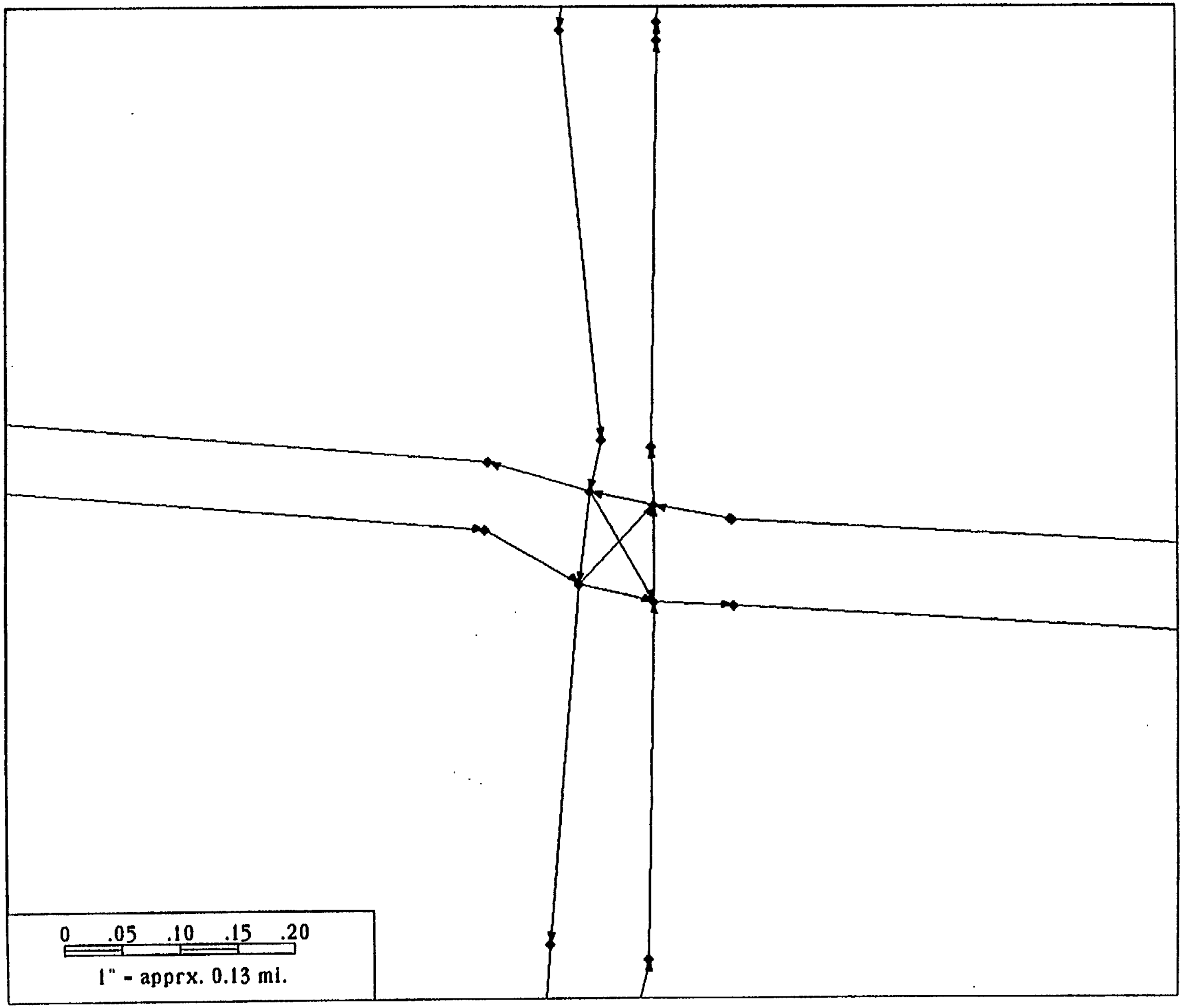

Fig. 3.4. Intersection Turn Movements

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Table 3.1. Annual Skier Visits to Ski Resorts

Zone #	Destination Resorts	1992/93	1993/94	County
1	Aspen Mountain	460585	359846	Pitkin
2	Aspen Highlands	145364	106197	Pitkin
3	Snowmass	921169	814852	Pitkin
4	Beaver Creek	488603	504516	Eagle
5	Vail	1570350	1527698	Eagle
6	Copper Mountain	878000	842210	Summit
7	Breckenridge	1164000	1215013	Summit
8	Winter Park	1019181	1008040	Grand
9	Silver Creek	79316	93516	Grand
10	Steamboat Springs	1053002	1021149	Routt
11	Keystone	1041781	1095857	Summit
12	Loveland Basin	232723	295000	Summit

Source: Colorado Ski Industry Statistics

Characteristics of the Network

The Data Editor in TransCAD displays data in a spreadsheet format (columns and rows) and functions like a spreadsheet with special editing features. The data attached to every link in this study network include:

1. ID
2. From-Node
3. To-Node
4. Directionality Code
5. Length
6. Road Name
7. Number of Lanes

8. ADT
9. Percent of Truck
10. Speed Limit
11. Capacity and
12. Free Flow Travel Time.

Some of these data values (ID, from node and to node, coordinates points, speed limit, number of lanes, ADT, percent of trucks) were obtained from an existing CDOT database. Link capacities were estimated according to the Highway Capacity Manual (1985) based on the functional class and road characteristics of each link. Each free-flow travel time was calculated as the link' s length divided by its speed limit.

The other database layer represents the nodes, where their attributes are limited to ID, x coordinate, y coordinate, and any description (such as city name or the population). All coordinates obtained are in Universal Transverse Mercator (UTM) projection which is widely used by the United States GeoIogical Survey (USGS) for their quadrangle maps.

CHAPTER 4

Origin-Destination (O-D) Trip Table Generation

Trip Matrix DeveIopment

Traffic flows and origin-destination (O-D) information are the two type of data used to estimate travel demand throughout the corridor. O-D information indicates the pattern of flows based on drivers specific destinations. An extensive survey of travelers is needed to prepare an O-D trip matrix from survey information. These surveys include home interviews, roadside surveys, and so on. These survey techniques are highly expensive, time consuming, and labor intensive. Because of these difficulties, obtaining trip tables through less expensive methods is the motivating factor to the development of synthetic technique that uses available information in the form of Iink traffic counts.

Methods to estimate O-D trip matrix from available data on traffic counts have been investigated and developed by many researchers (see Cascetta and Nguyen, 1978). Such approaches include maximum entropy, Bayesian inference estimation, and generalized least squares techniques. The maximum entropy approach of Van Zuylen and Willumsen (1980) produces a most likely trip table from traffic counts. In this study, the motivation was to develop a mode1 that would estimate traveler destinations quickly, and to exploit computational efficiencies in the application. In this research, a model called SYNOD (see Appendix A) developed by Prof. Janson based on the approach of Van Zuylen and Willumsen was applied to estimate a trip matrix that is hopefully a good approximation of the true O-D trip matrix Unfortunately, no O-D matrix for this region has ever been developed. This program performs iterative modifications of an initial trip matrix so that estimated link volumes agree with observed counts on a subset of selected network links.

Use of Trafic Counts from Permanent Counters

Only three permanent traffic counters (westbound and easbound) are monitored by CDOT in the I-70 mountain corridor west of Denver. These counters are located on I-70 at the Genesee Interchange, I-70 at Eisenhower Tunnel, and State Highway 40 near Winter Park.

These counters are induction loop detectors imbedded in the pavement in each lane of each travel direction. Volume data for each hour of the period January 1993 through June 1994 were obtained from CDOT for each of these locations.

Traffic counts from State Highway 40 for two months (February and March, 1994) were used to approximate the time-of-day distribution of skier departure times in each hour from 2:00 to 7:00 PM of a typical Sunday afternoon. For lack of similar data for any of the other resorts, these Winter Park departure percentages with some sensible shifts were applied to each of the other eleven ski resorts.

Table 4.1. Opening-Closing Dates of Ski Resorts

Ski Resorts	Opening/Closing Date	# of Sundays
Aspen Highlands	Nov. 25 - April 10	20
Aspen Mountain	Nov. 25 - April 10	20
Snowmass	Nov. 25 - April 10	20
Beaver Creek	Nov. 20 - April 17	22
Vail	Nov. 20 - April 17	22
Cooper Mountain	Mid Nov. - Late April	24
Keystone	Late October - April 17	25
Breckemidge	Nov. 13 - April 17	23
Winter Park	Nov. 17 - April 17	22
Silver Creek	Dec.7-AprilI3	17
Steamboat Springs	Nov. 25 - April 10	20
Loveland Basin	Mid October - Mid May	30

Source: Colorado Ski Industry Statistics

Available Traffic Counts and Volume Proportions

To augment these counts with data on skiers traveling to and from ski resorts, the data listed in Table 4.1 from Colorado Ski Country USA provides the statistical summary of skier visits and presents the 'opening and closing' dates of each ski resort. The assumption of each value = [one-hour avg. veh. count (averaged over 8 Sundays in Feb + March '94) / avg. Sunday skiers = 25% '93-'94 total season skiers/22 Sundays] * 100

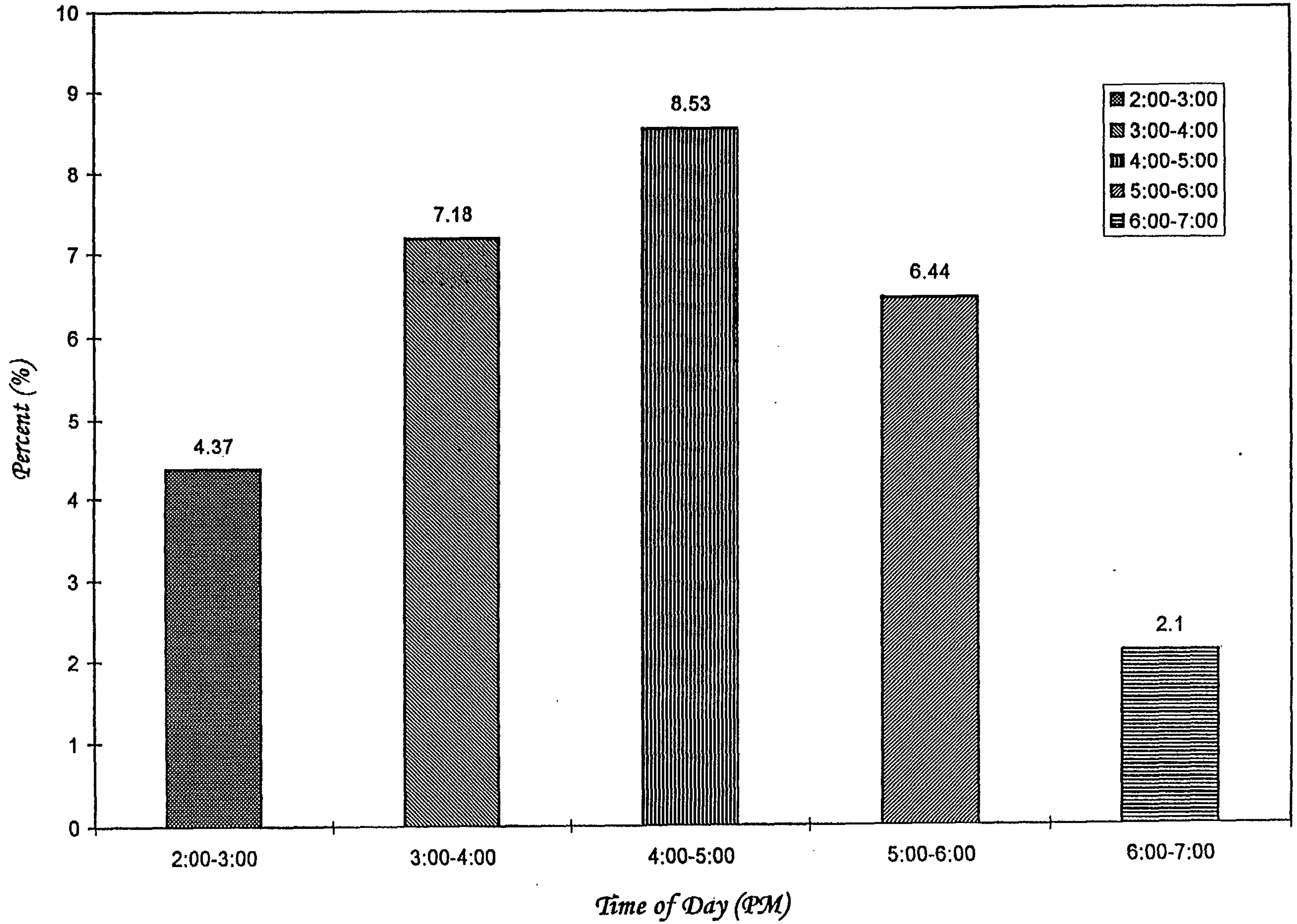

Fig. 4.1: Vehicle/Skier Proportions at Winter Park

5-hr. Analysis

Table 4.2. I-70 Colorado Ski Country Network ~~Average 1 hour~~ Trip Matrix; No Intrazonal Trips.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Total
1	Aspen Mountain	0	43	116	25	120	16	11	4	6	4	18	4	114	186	92	26	38	49	46	110	21	282	1331
2	Aspen Highland	13	0	34	8	36	5	3	1	2	1	5	1	34	55	27	7	11	15	14	32	6	85	395
3	Snowmass	319	316	0	205	77	34	9	6	4	26	32	9	77	239	247	85	32	25	79	125	47	1039	3032
4	Beaver Creek	55	55	15	0	56	23	20	6	8	16	23	7	21	62	261	86	69	53	56	131	20	664	1707
5	Vail	37	35	304	136	0	100	89	23	39	28	99	18	302	523	432	198	299	358	243	710	78	1061	5114
6	Cooper Mountain	23	23	141	71	135	0	47	12	21	13	53	10	140	245	185	88	150	192	129	381	43	479	2581
7	Breckenridge	148	146	22	66	116	49	0	19	23	26	69	16	26	78	420	231	129	146	176	392	75	1578	3951
8	Winter Park	4	4	12	74	75	50	56	0	32	38	62	14	22	68	489	224	190	203	155	430	40	1170	3412
9	Silver Creek	0	0	1	6	11	6	6	2	0	4	5	2	2	6	74	25	20	15	14	34	4	176	413
10	Steamboat Springs	75	75	15	46	113	49	46	19	20	0	52	18	14	56	603	207	157	120	127	307	50	1632	3801
11	Keystone	43	44	49	241	83	35	40	18	19	39	0	16	58	223	419	166	131	111	133	271	58	1078	3275
12	Loveland Basin	9	9	20	32	39	10	9	3	5	8	12	0	22	51	79	45	30	30	31	69	12	216	741
13	Carbondale	36	35	10	28	26	10	7	2	3	7	9	3	0	35	111	35	23	14	20	41	9	296	760
14	Glendwood Spring	58	58	13	42	27	11	7	2	2	8	10	3	16	0	110	36	21	13	23	44	11	330	845
15	Buena Vista	12	12	25	36	73	27	26	7	10	17	25	7	28	60	0	109	87	62	57	147	19	748	1594
16	Kremmling	1	1	2	8	13	5	6	2	2	4	5	2	3	8	63	0	18	14	13	32	4	145	351
17	Frisco	42	42	6	21	43	17	16	6	8	11	22	6	8	25	209	79	0	45	53	118	22	598	1397
18	Idaho Springs	2	2	4	20	42	20	20	5	6	13	15	6	6	19	316	81	66	0	30	76	10	680	1439
19	Georgetown	5	5	6	29	39	13	14	4	5	12	13	4	9	29	198	65	46	28	0	70	10	452	1056
20	Golden	44	43	17	100	121	70	84	27	38	40	95	20	29	105	675	174	282	332	250	0	74	1357	3977
21	Leadville	14	14	12	8	19	7	6	2	3	3	8	2	12	24	55	20	19	21	21	50	0	167	487
22	Denver	28	28	52	175	171	96	101	33	52	51	131	23	63	169	378	439	320	443	346	965	100	0	4164
Total		968	990	876	1379	1435	653	623	203	308	369	763	191	1006	2266	5443	2426	2138	2289	2016	4535	713	14233	

21 ~~33~~

volumes was based on judgement as follows: (1) 25 percent of skiers visiting on Saturdays, (2) 25 percent of skiers visiting on Sundays, and (3) 50 percent of skiers visiting on weekdays- Figure 4.1 shows the profiles of vehicle-to-skier ratio for Sunday winter afternoon hour. Based on proportions shown in Figure 4.1, we then estimated the volume of vehicles departing from each of the other ski resorts in each hour of the analysis period.

O-D Proprtions Matrix

By applying the synthetic O-D estimation algorithm SYNOD (see Appendix A), and using 10% of Average Daily Traffic (ADT) on each link in each direction (equal to 20% of bidirectional total ADT) an analysis period trip matrix was developed to represent average background (or non-skier related) traffic on a typical winter Sunday for the entire S-hour analysis period. Ten percent is generally found to be the amount of daily traffic in the peak hour for rural areas. By applying the percentages that agree with Figure 4.1, the trip departure percentages in the DYMOD program control file are then applied to this entire 5-hour analysis period matrix. These trips were added in proportion to the ADT estimated trip matrix The result is the 22 x 22 zone-to-zone trip matrix shown in Table 4.2 indicating the number of trips traveling between each zone pair. Origin zones are identified for the rows, with columns in the identical order. Row sums represent total trip productions, and column sums represents total trip attractions. Vail produces the most trips among. the ski resorts (zones 1 - 12), while Denver attracts the most trips among the urban areas (zones 13 - 22).

CHAPTER 5

Dynamic User-Eqxilibrium Model

Background

Dynamic user-equilibrium (DUE) is a temporal generalization of the static equilibrium assignment problem with additional constraints to ensure temporally continuous trip paths and first-in first-out (FIFO) trip ordering between all origin-destination pairs. In DUE, the full assignment period of several hours is discretized into shorter time interval (such as l-10 minutes each), for which trip departure times-must be estimated.

In this study, a mathematical programming approach called the Dynamic Traffic Assignment Mode1 (DYMOD) as presented in Appendix B is applied. The dynamic traffic assignment problem is defined as follows: (1) given a network with link travel times, and (2) given a set of zone-to-zone trip tables containing the number of vehicle trips departing from each zone and headed towards each zone in successive time intervals, then determine the volume of vehicles on each link of the network in each time interval

The algorithm is decomposed into two subproblems which both of them have the function of minimizing the travel time on all the links. The first subproblem is solved with a fixed set of node time intervals using the Frank-Wolfe (F-W) algorithm or another method of linear combinations. The second subproblem is then solved to obtain a new set of node time intervals that perform temporally continuous shortest paths given the link travel times obtained from solving first subproblem. When the convergence criterion is satisfied, such as when changes in assigned flows or node time intervals are acceptably low, the iterative process of solving first subproblem and then the second subproblem terminates.

Model Implementation

There are three input fries needed to run this model:

(1) Link ID, from-node, to-node, free-flow travel time, and capacity.

(2) Origindestination trip matrix of analysis period trips.

(3) Program control file (number of links, maximum node number, convergence parameters, and percent trips departing each zone in each time interval).

Appendix C shows those input files mentioned above for our network

CHAPTER 6

Results and Discussion

Twelve links were chosen to predict volumes and speeds on I-70 links particularly from Eisenhower Tunnel to Idaho Springs for eastbound returning traffic on Sunday afternoon. Two locations were chosen to compare observed versus predicted volumes: eastbound Interstate 70 at the Eisenhower Tunnel and southbound State Highway 40 near Winter Park In addition, eleven links were chosen to examine estimated volumes and speeds near ski resorts.

Predicted Volumes and Speeds on I-70 Links

Predicted volumes on I-70 links are shown in Figures 6.1 to 6.3. For most of the links shown in these figures, the predicted volumes have values in the range from 570 to 450 vehicles per lo-minute intervals. Almost all of the links have the highest volumes between 4:00 PM and 5:00 PM except traffic entering Idaho Springs between 5:30 PM and 6:00 PM for the highest flows.

Figures 6.4 to 6.6 show the predicted speeds on I-70 links. There is a big change in speeds between 'before' Eisenhower Tunnel and entering Eisenhower Tunnel to Idaho Springs. For these links, the steep decrease in speeds occur from 3:00 to 530 PM. Traffic from Dillon to before' Eisenhower Tunnel have constant speeds between 60 and 65 mph. However, when the traffic enters Eisenhower Tunnel, speeds reduce to 35 mph and become worse until Idaho Springs, which dip below 30 mph.

Comparison of Predicted Versus Observed Volumes

The link at Eisenhower Tunnel and the link at State Highway 40 near Winter Park were chosen to compare observed versus predicted volumes (see Figure 6.14). For the link at Eisenhower Tunnel, the predicted volumes are slightly higher from 2:00 to 3:00 PM and 5:00 to 7:00 PM than the observed ones. This discrepancy is due to difficulties in estimating the true travel demands, but differences remain below 12% for those period and below 5% during peak hour (4:00 to 5:00 PM).

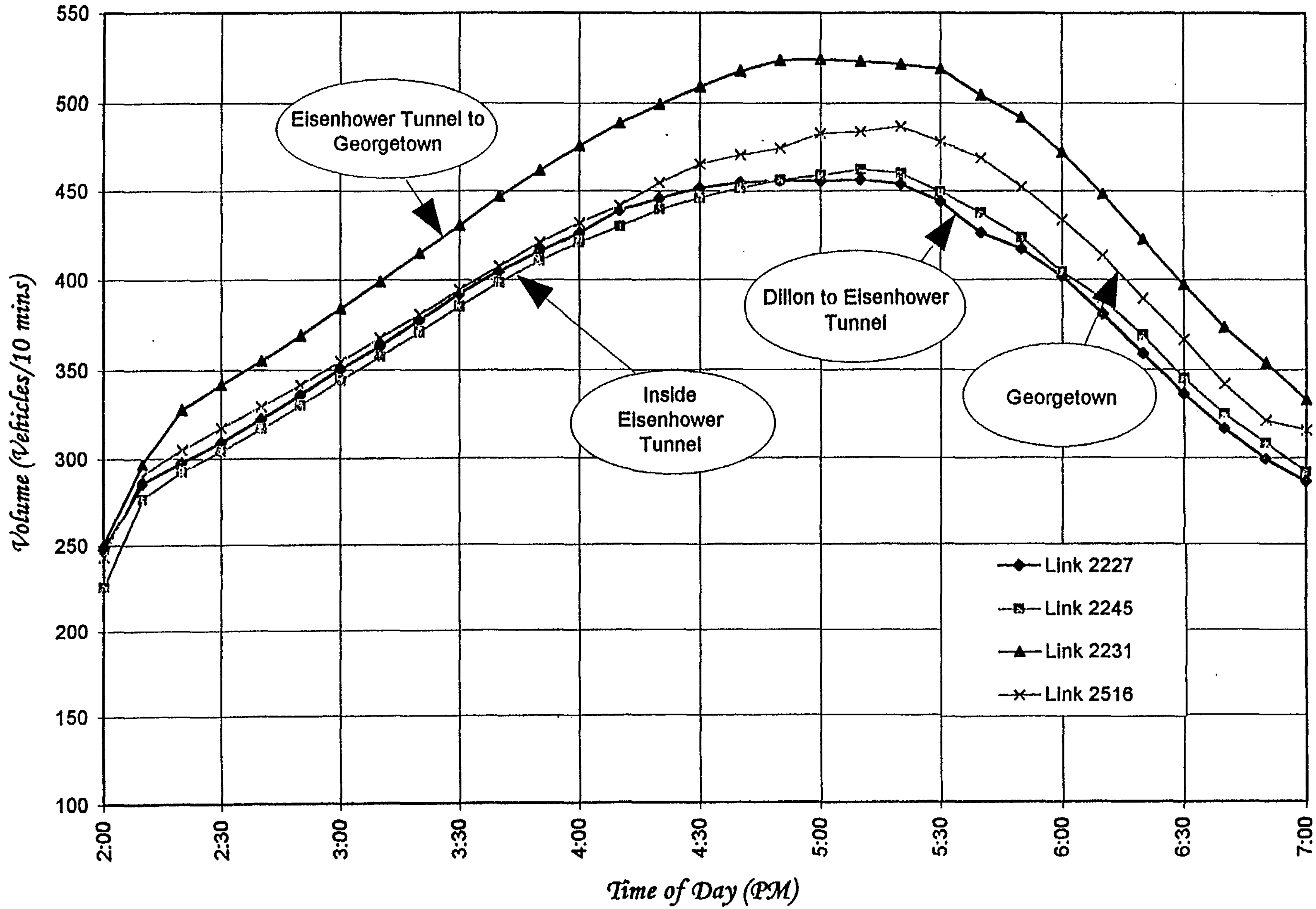

Fig. 6.1: Predicted Volumes on I-70 Links

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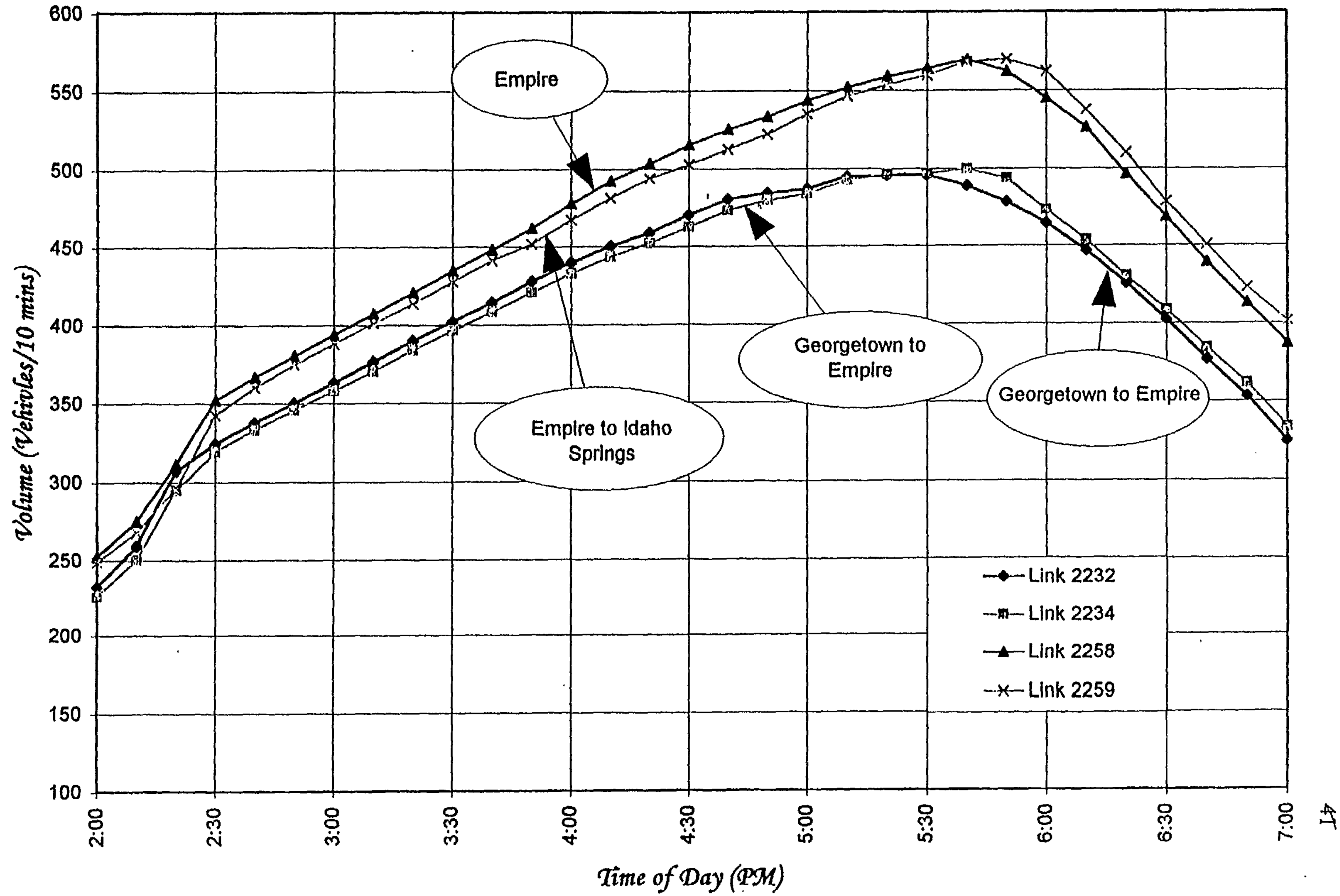

Fig. 6.2: Predicted Volumes on I-70 Links

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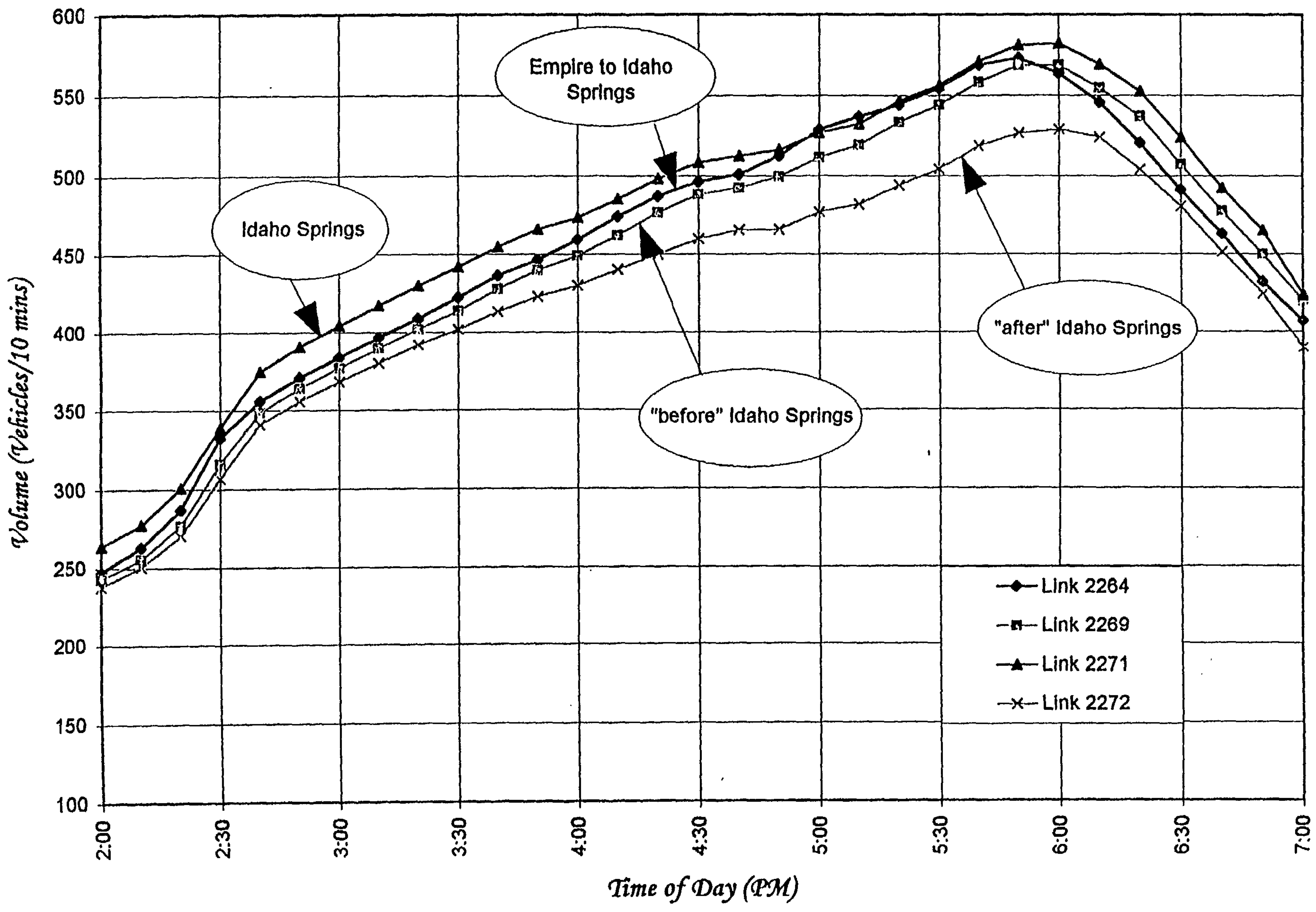

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Fig. 6.3: Predicted Volumes on I-70 Links

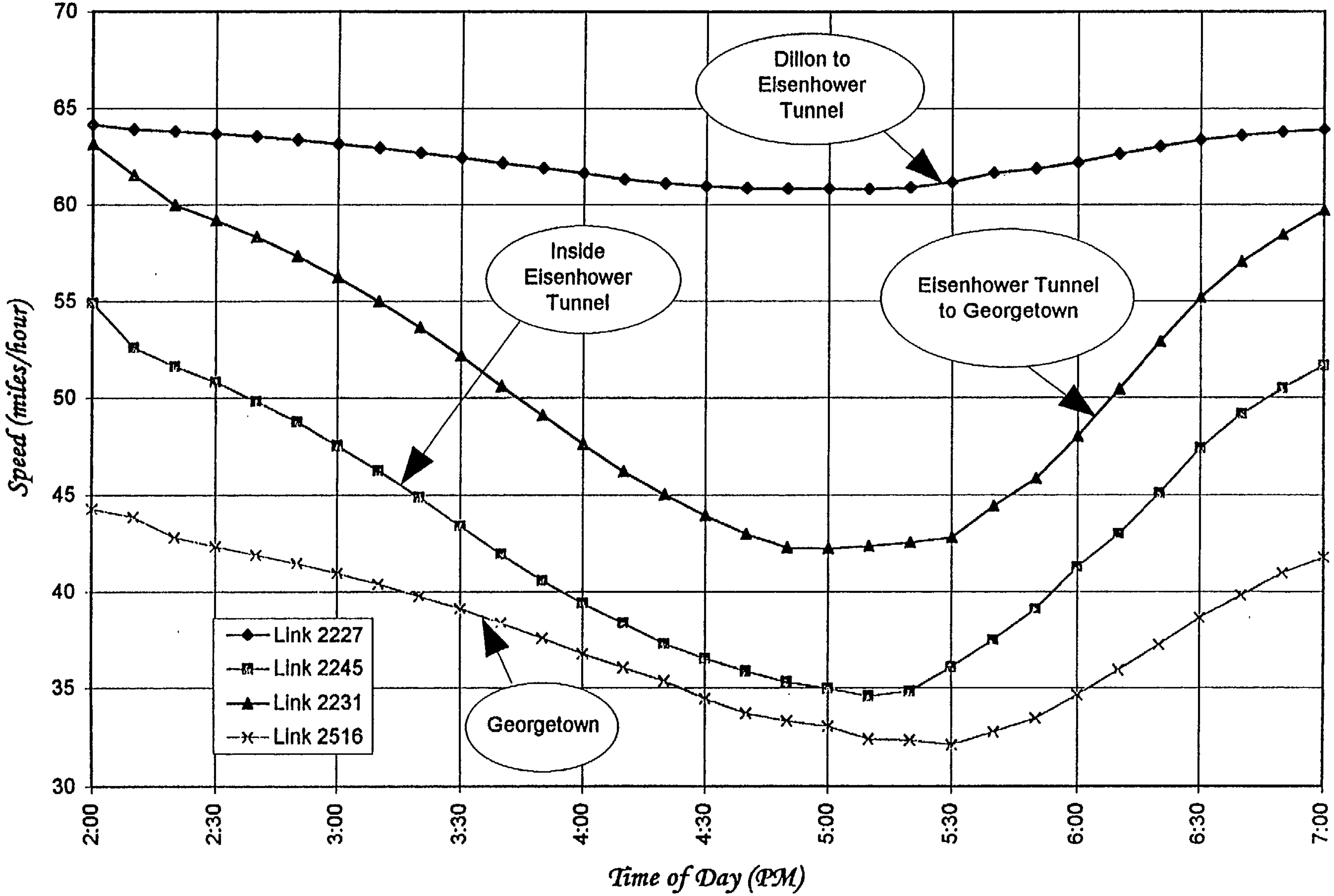

Fig. 6.4: Predicted Speeds on I-70 Links

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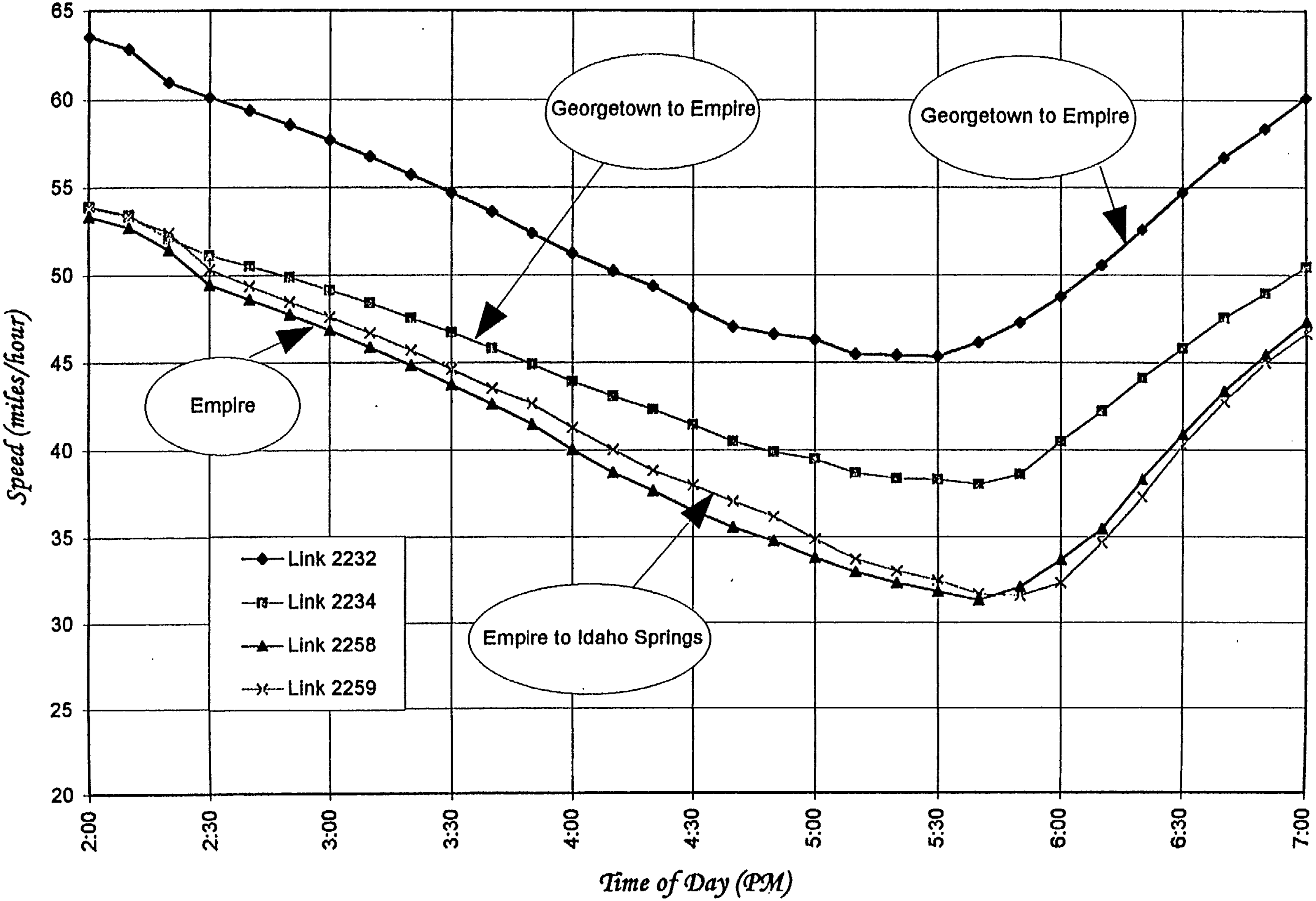

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Fig. 6.5: Predicted Speeds on I-70 Links

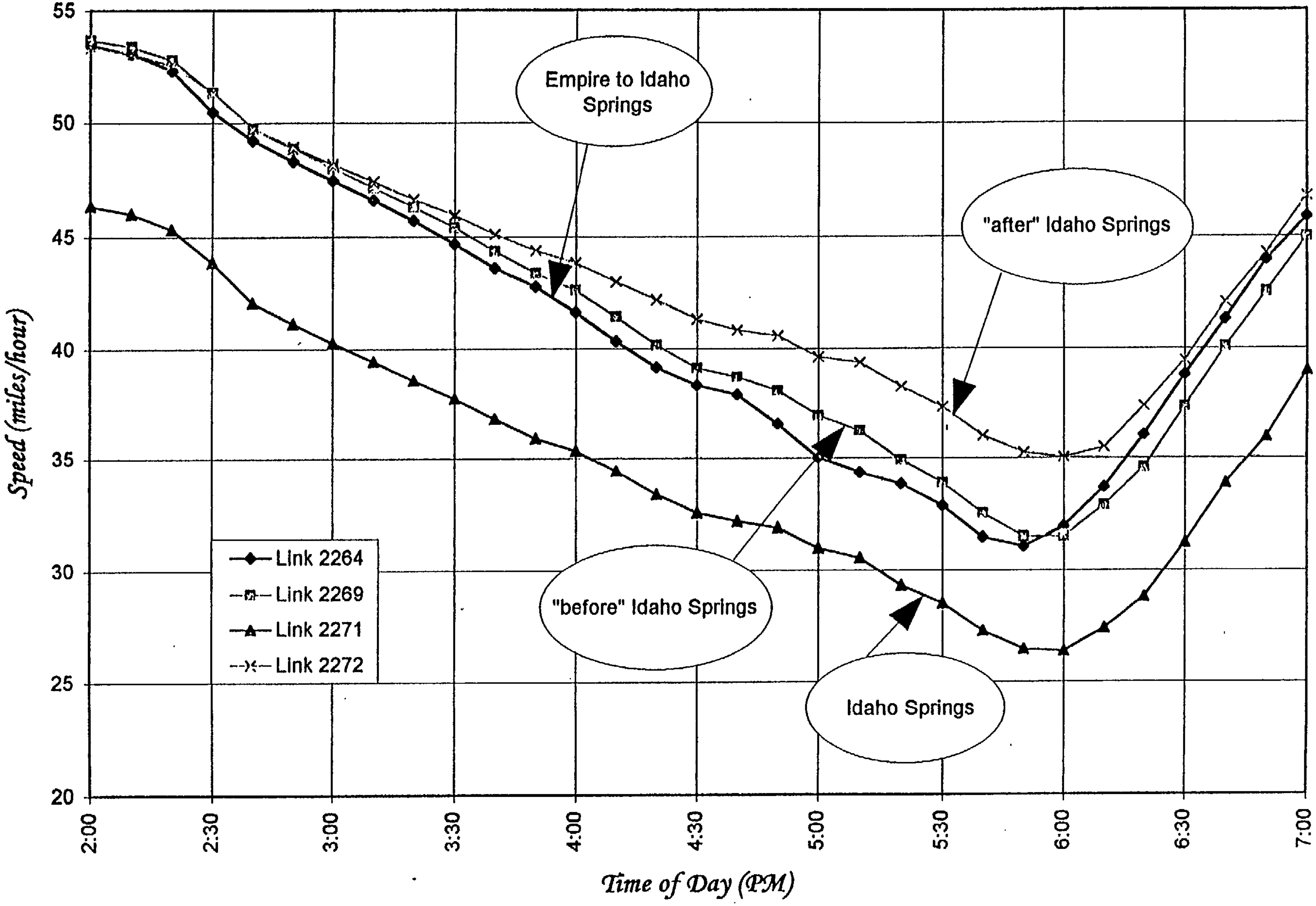

Fig. 6.6: Predicted Speeds on I-70 Links

In comparison, for the link at State Highway 40 near Winter Park, the predicted volumes are lower (below 20%) from 2:00 to 5:00 PM, but higher between 5:00 and 7:00 PM than the observed ones. It may indicates a lower coded capacity than true capacity for that Iink

Predicted Volumes and Speeds on Ski Resorts

Figures 6.7 to 6.13 show predicted volumes and speeds on links near the twelve ski resorts. Among all the ski resorts studied, only five ski resorts have flows above 100 vehicles per l0-minute interval, and the rest are between 40 to 90 vehicles per lo-minute interval, except Silver Creek which has the lowest flows below 25 vehicles per lo-minute interval. The model predicts that most of the ski resorts reach their peak flows between 3:30 and 4:30 PM and some resorts have the peak flows between 5:00 and 5:30 PM (Silver Creek and Beaver Creek). In Figure 6.10, the predicted speeds have the value in the range of 30 to 45 mph during peak hour. However, Figure 6.11 to 6.13 show an interesting result which is that high flows do not greatly affect speeds during the peak hour near Steamboat Springs, Beaver Creek, Keystone, and Loveland Basin.

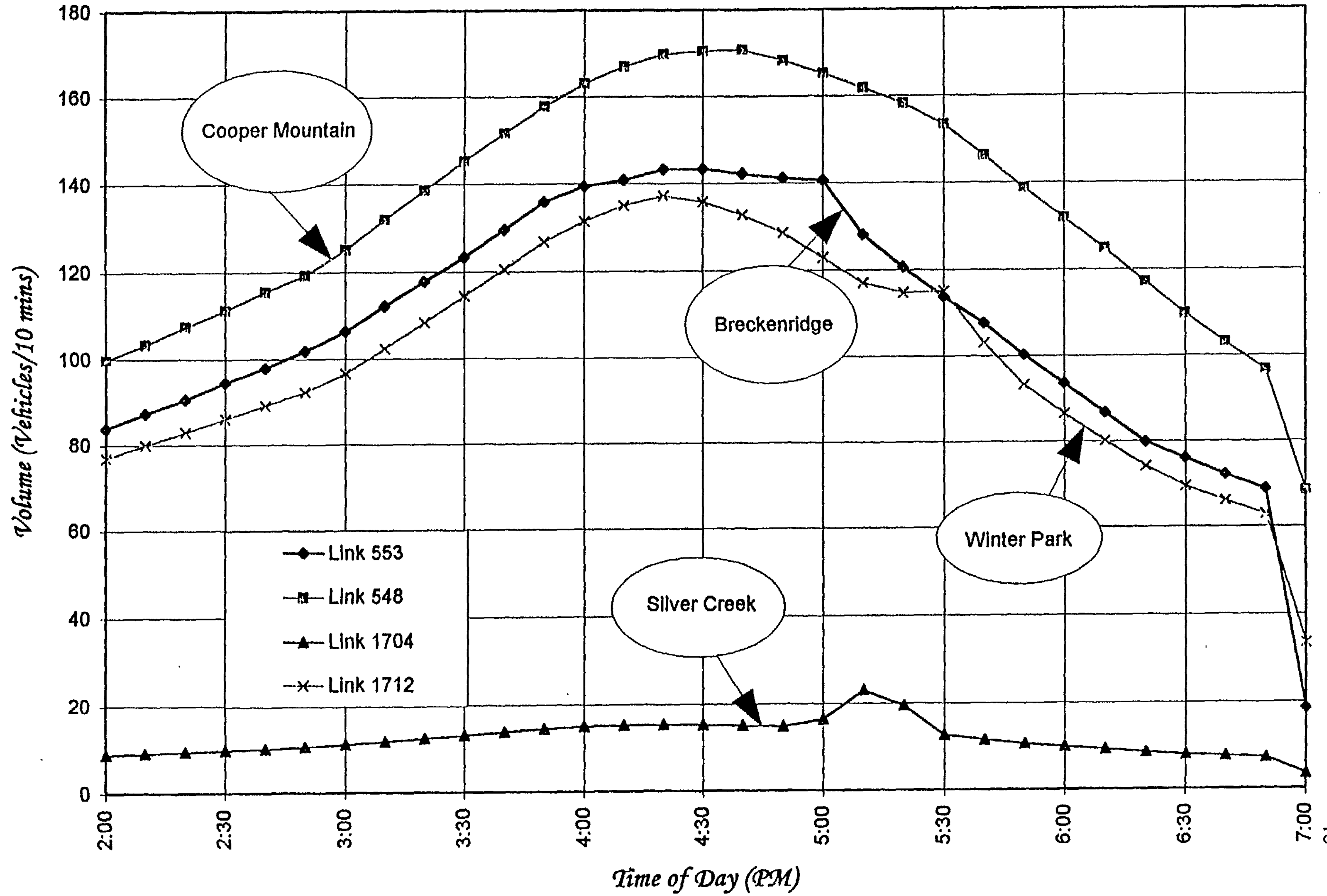

Fig. 6.7: Predicted Volumes on Ski Resorts

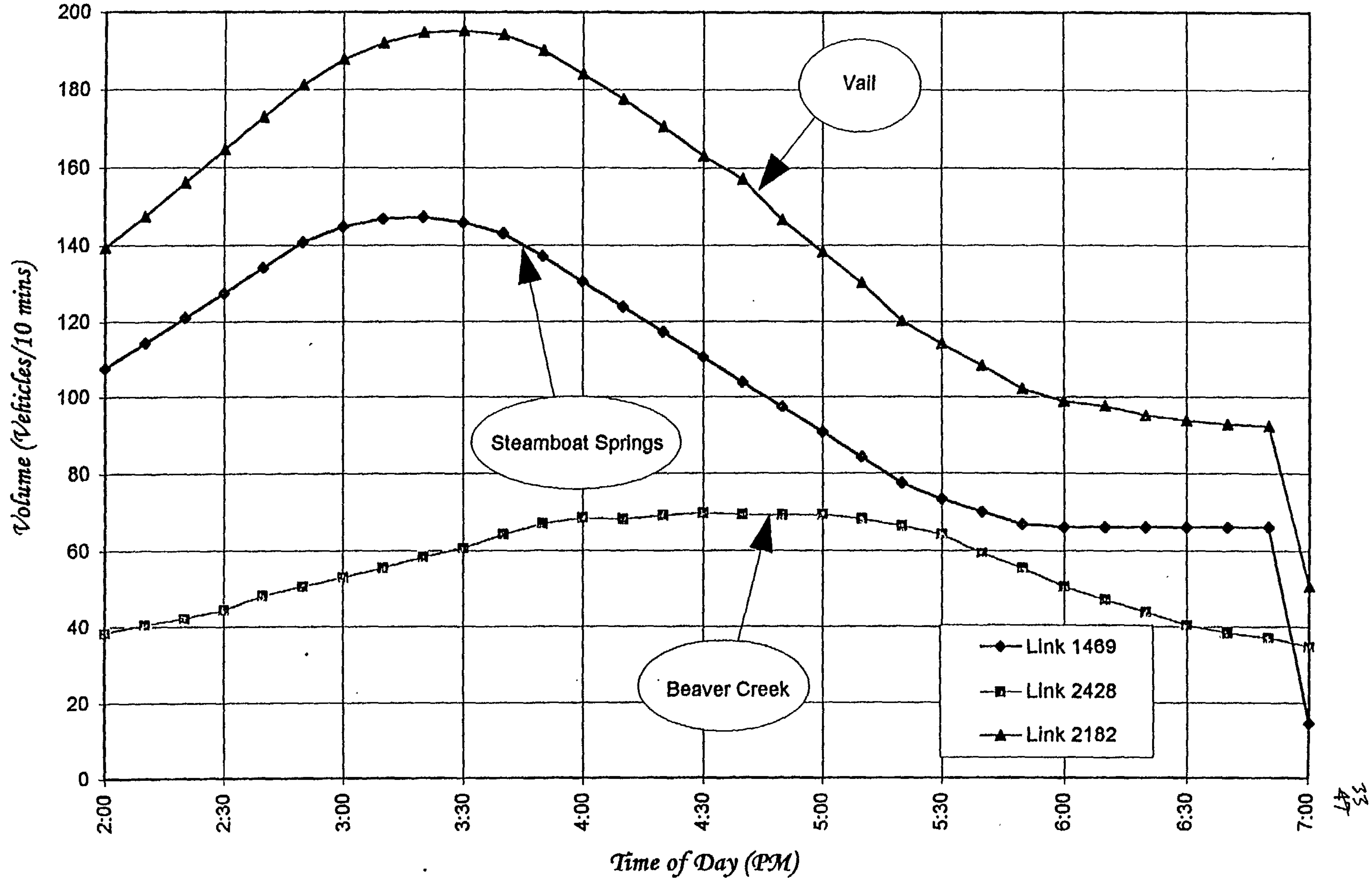

Fig. 6.8: Predicted Volumes on Ski Resorts

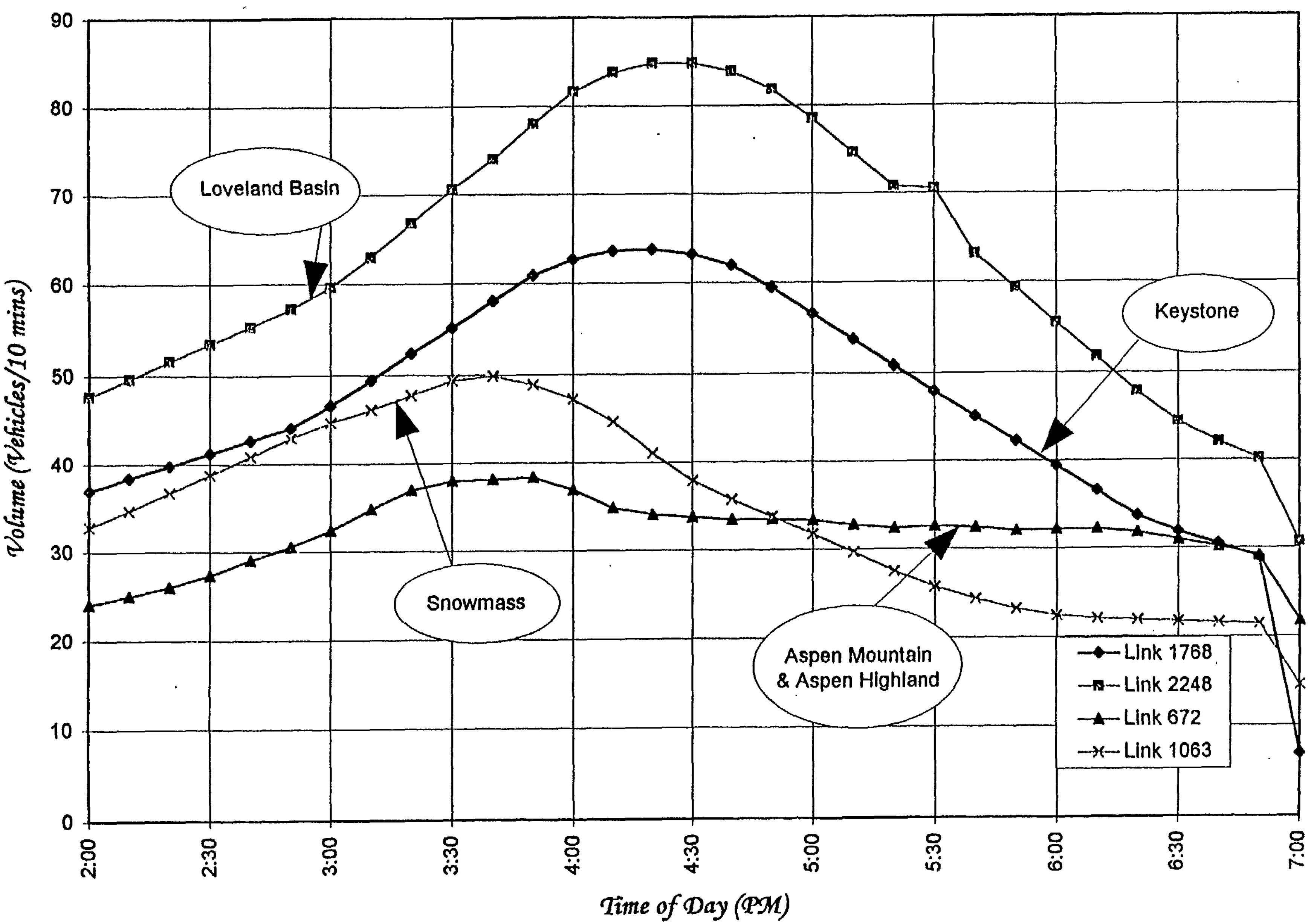

Fig. 6.9: Predicted Volumes on Ski Resorts

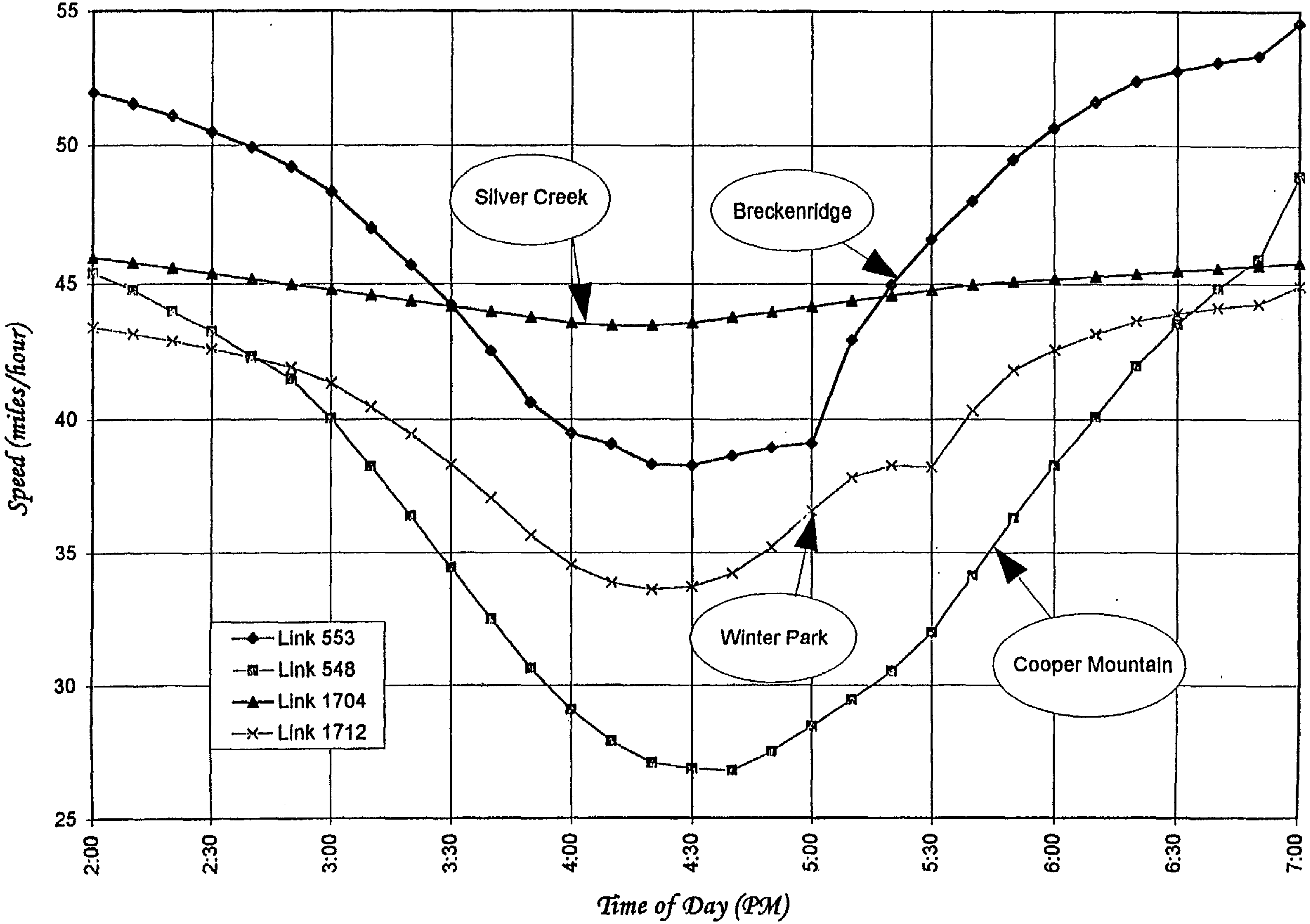

Fig. 6.10: Predicted Speeds on Ski Resorts

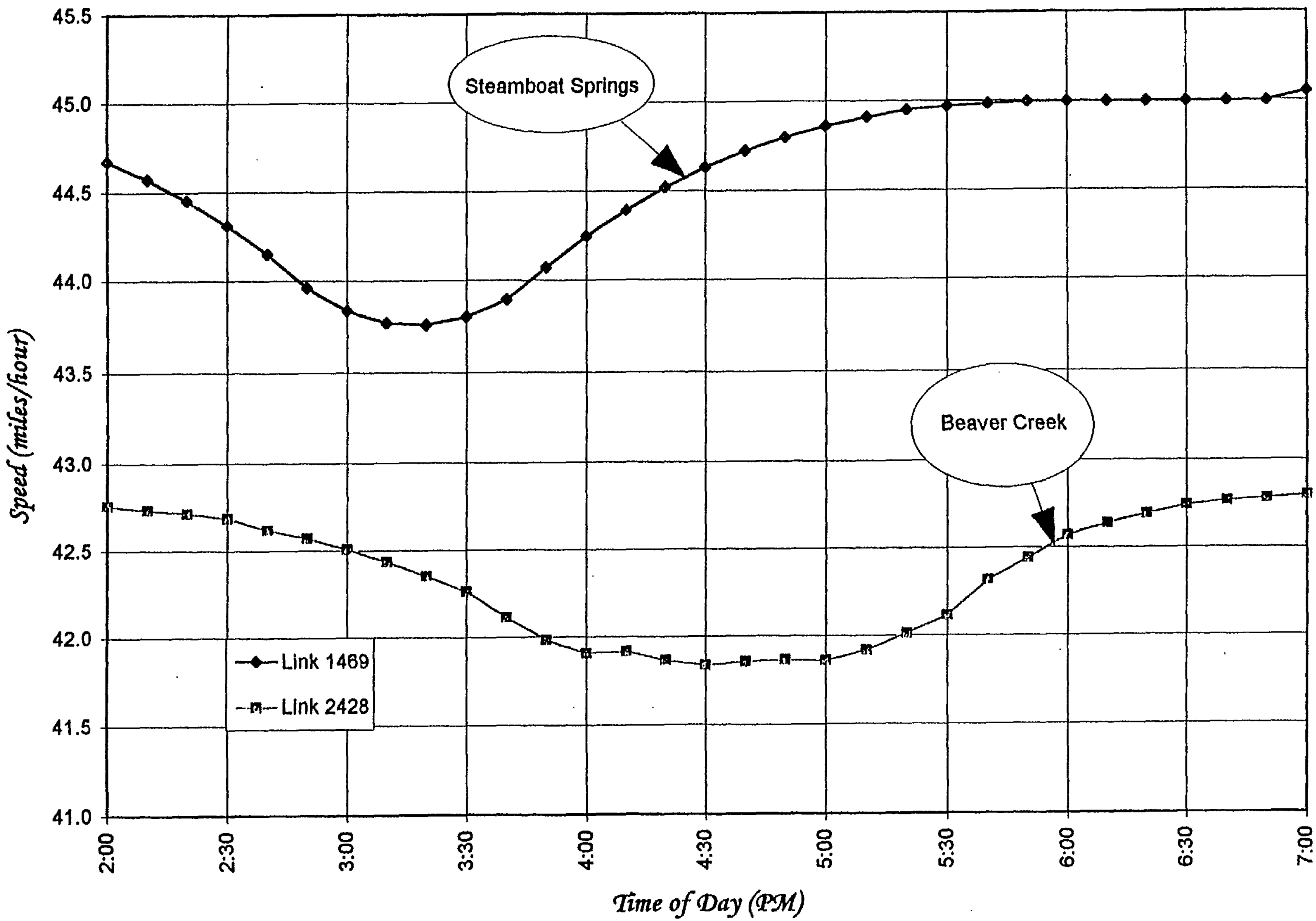

Fig. 6.11: Predicted Speeds on Ski Resorts

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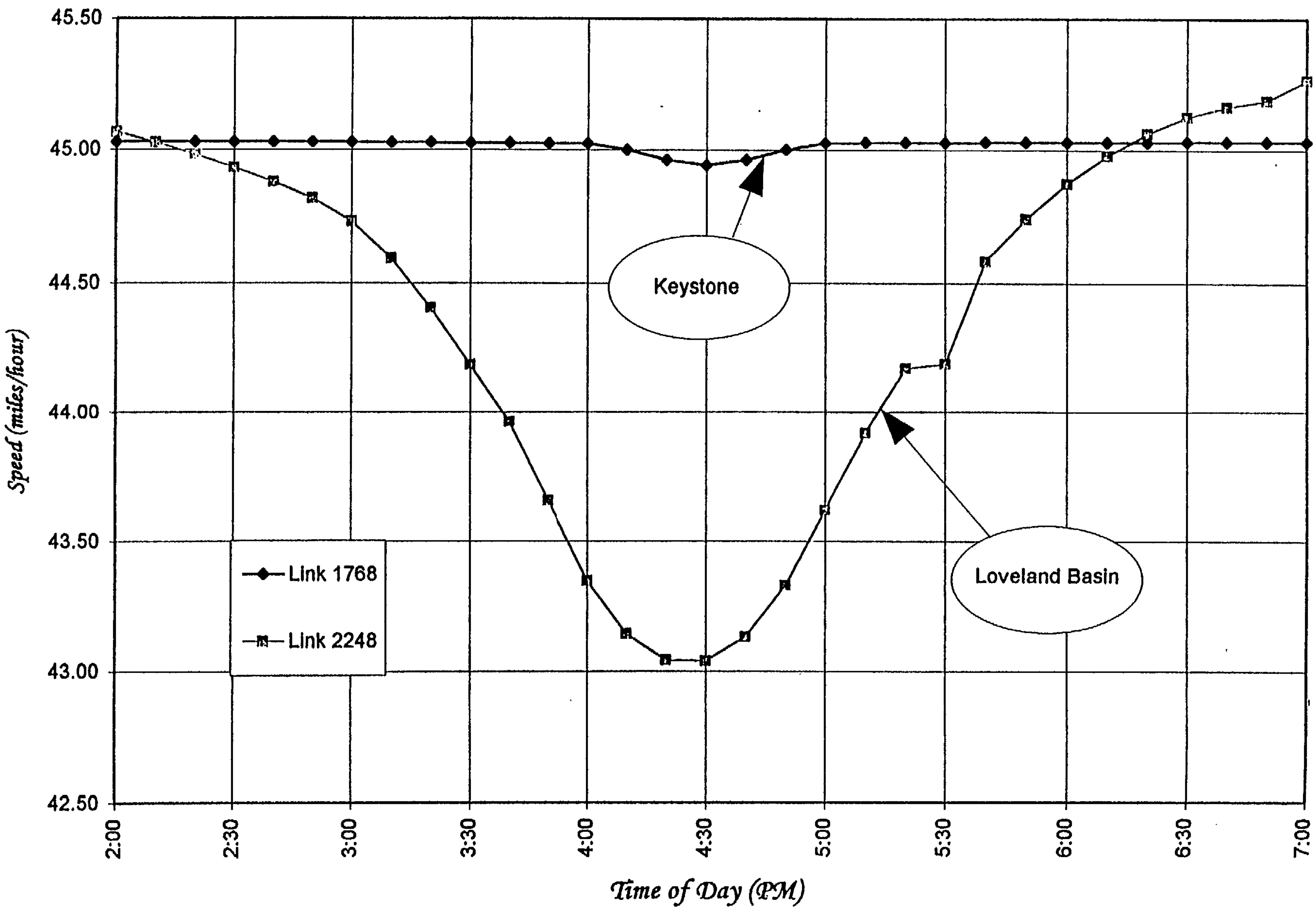

Fig. 6.12: Predicted Speeds on Ski Resorts

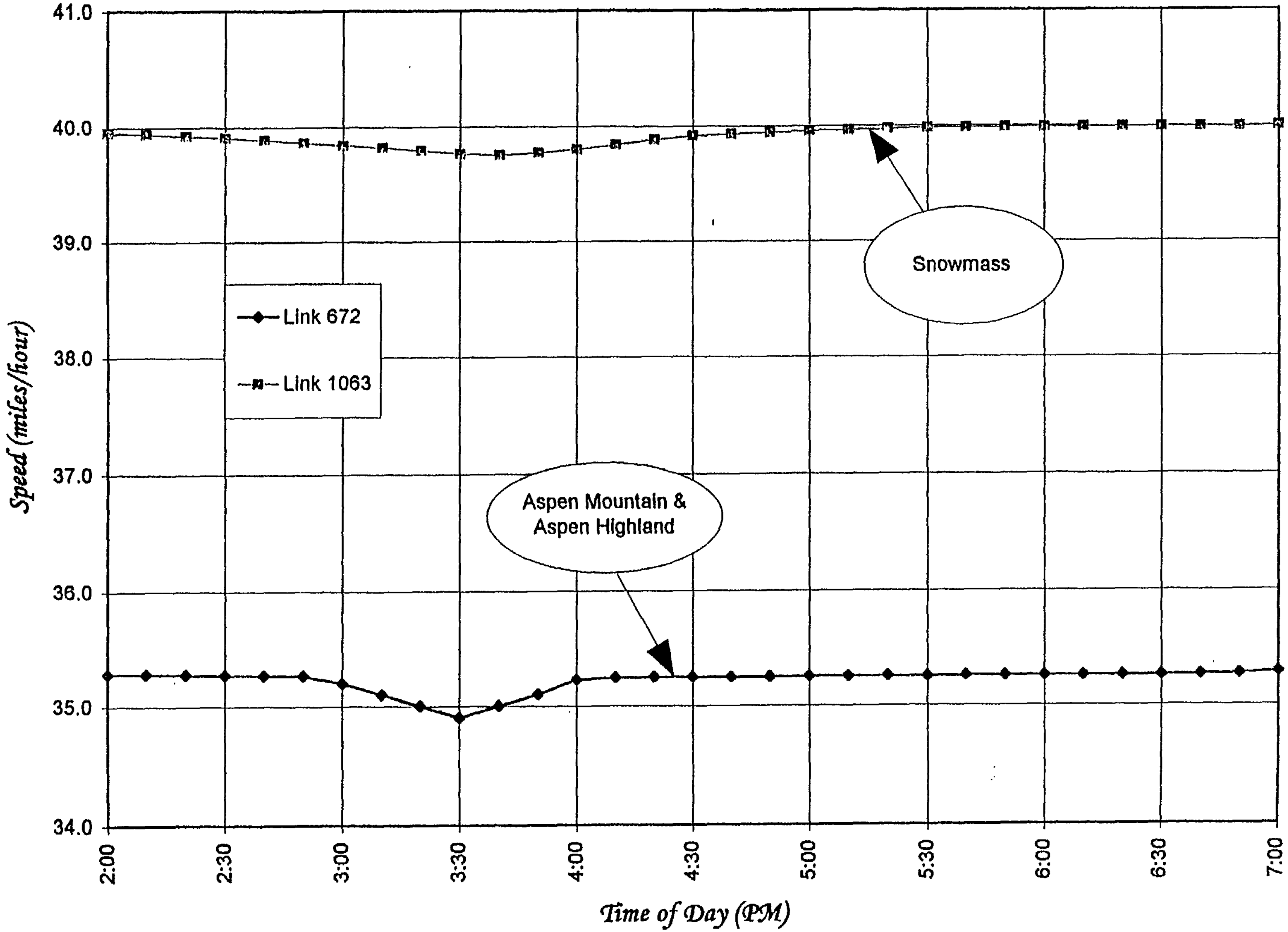

Fig. 6.13: Predicted Speeds on Ski Resorts

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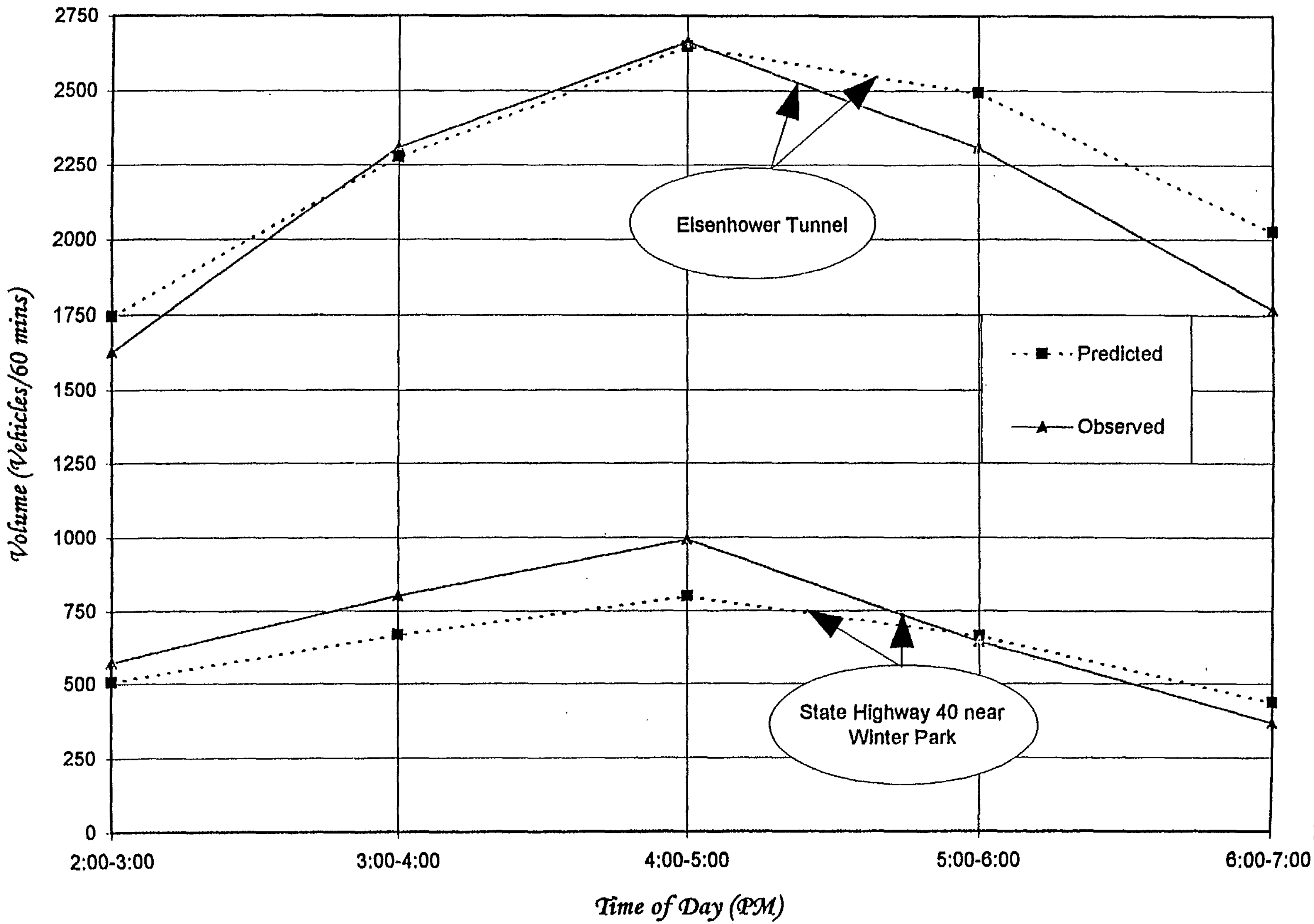

Fig. 6.14: Observed vs Predicted Volumes

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CHAPTER 7

Conclusions and Suggestion

This report presents the results of applying the Dynamic Traffic Assignment Model (DYMOD) as a planning aid. The primary object of this effort was to determine whether the model is able to estimate traffic volumes and delays throughout the network.

A network representing the corridor of roads surrounding I-70 west of Denver was developed. One hourvolume counts at selected locations of the network were used to estimate an O-D trip matrix and trip departure in each lo-minute interval of the analysis period. With these input data, DYMOD was applied to predict volumes and speeds. The comparison of predict versus observed volumes showed that the difference remain below 12% for the flows on I-70 link at Eisenhower Tunnel and predicted speeds caused by queuing reduced from 65 to below 30 mph near Idaho Springs. Also, the analysis shows that current delays could be reduced by 4% if overall traffic in the corridor were spread by 10%. The author suggests that prohibiting heavy truck traffic from I-70 between 3 and 6 PM particularly on links from Eisenhower Tunnel to Idaho Springs may effectively reduce delays to passenger travel.

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APPENDIX A

SYNOD Formulation and Algorithm

The SYNOD algorithm requires setting up a list of links with counts and identifying the O-D pairs whose trips use a particular link p_{rs}^{k}. SYNOD estimates a most likely trip O/D's to best fit base trip O/D proportions and satisfy observed traffic counts. Base trips can be uniform non-zero values if prior trips unknown. Link use probabilities by O/D pair must be input to SYNOD2 developed by Bruce N. Janson. The procedures of SYNOD algorithm are as follows:

1) Initialize b_{nk}= 1 for all arcs' k. Set iteration counter n to 0.

2) Increment iteration counter $n = n + 1.$

3) Take every link in the list not yet processed and calculate the estimated flows v_k^n

$$v_k^n = \sum_r \sum_s \left\{ \prod_a b_a^n p_{rs}^a \right\} p_{rs}^k T_{rs}$$

Where T_{rs} is a priority trip matrix.

4) Use observed link Volumes to calculate updating factor U_k for arc ***k*'s** balancing factor.

$$\hat{v}_k = \sum_r \sum_s \left\{ \prod_a b_a^n p_{rs}^a \right\} p_{rs}^k U_k T_{rs} \qquad \text{and} \qquad b_k^{n+1} = b_k^n U_k$$

If all arcs are processed in iteration ***n*, *go*** to step 5. Else, go to step 3.

5) If the convergence criteria are met for all modelled flows, stop. Then

$$q_{rs} = \left\{ \prod_k b_a^n p_{rs}^a \right\} T_{rs}$$

Else, go to step 2.

APPENDIX B

Dynamic User Equilibrium with Scheduled Departures

(UP) Minimize $$\sum_{ij\in K}\sum_{t\in T}\int_0^{x_{ij}^t} f_{ij}^t(w)dw$$

subject to:

$$x_{ij}^t = \sum_{r\in Z}\sum_{d\le t} v_{rij}^{dt} \qquad \text{for all ij} \in \text{K, t} \in \text{T}$$

$$q_{rn}^d = \sum_{t\ge d}\left[\sum_{in\in K} v_{rin}^{dt}\alpha_{ri}^{dt} - \sum_{nj\in K} v_{rnj}^{dt}\alpha_{rn}^{dt}\right] \qquad \text{for all n} \in \text{N, r} \in \text{Z, d} \in \text{T}$$

$$v_{rij}^{dt} \ge 0 \qquad \text{for all r} \in \text{Z, ij} \in \text{K, d} \in \text{T, t} \in \text{T}$$

Where all $\{\alpha_{ri}^{dt}\}$ are optimal for:

(LP) Maximize $$\sum_{s\in Z}\sum_{i\in N}\sum_{d\in T} b_{ri}^d$$

subject to:

$$\alpha_{ri}^{dt} = (0,1) \qquad \text{for all r} \in \text{Z, i} \in \text{N, d} \in \text{T, t} \in \text{T}$$

$$\sum \alpha_{ri}^{dt} = 1 \qquad \text{for all r} \in \text{Z, i} \in \text{N, d} \in \text{T}$$

$$b_{ri}^d = \max\left[e_{ri}^d, b_{ri}^{d-1} - (1-h)\Delta t\right] \qquad \text{for all r} \in \text{Z, i} \in \text{N, d} \in \text{T}$$

$$\left\{e_{rj}^{d} - \max\left[b_{ri}^{d}, (t-d)\Delta t + \Delta f_{ij}^{tp}\right]\right\} \alpha_{ij}^{dt} \leq f_{ij}^{t}(x_{ij}^{t})\alpha_{ri}^{dt}$$

for all r $\in$ Z, ij $\in$ K, d$\in$ T, t $\in$ T, p = t-1, $\Delta f_{ij}^{tp} = f\left(x_{ij}^{p}\right) - f_{ij}^{t}\left(x_{ij}^{t}\right)$

$\left[b_{ri}^{d} - (t-d+1)\Delta t\right]\alpha_{ri}^{dt} \leq 0$ for all r $\in$ Z, i $\in$ N, d$\in$ T, t $\in$ T

$\left[b_{ri}^{d} - (t-d)\Delta t\right] \alpha_{ri}^{dt} \geq 0$ for all r $\in$ Z, i $\in$ N, d$\in$ T, t $\in$ T

$b_{rr}^{d} = 0$ for all r $\in$ Z, d$\in$ T

where,

N = set of all nodes.

Z = set of all zones (i.e., trip-end nodes).

K = set of all links (directed arcs).

Δt = duration of each time interval (same for all t).

T = set of all time intervals in the full analysis period (e.g. 12 ten-minute intervals for a 2-hour peak-period assignment).

x_{ij}^{t} = number of vehicle trips from zone r in time interval t (variable).

v_{rij}^{dt} = number of vehicle trips from zone r in time interval d assigned to link ij in time interval t (variable).

$f_{ij}^{t}\left(x_{ij}^{t}\right)$ = average travel impedance on link ij in time interval t (variable).

q_{rn}^{d} = number of vehicle trips from zone r to node n departing in time interval d via any path; zero for any node n $\notin$ Z (variable).

e_{ri}^{d} = shortest path travel time less FIFO delay time at node I from origin zone r to node i for trips departing in time interval d (variable).

b_{ri}^{d} = shortest path travel time from origin zone r to node i for trips departing in time interval d (variable).

α_{ri}^{dt} = zero-one variable indicating whether trips departing from zone r in time interval d cross node i in interval t (henceforth called a "node time interval") (0 = no; 1 = yes) (variable).

h = minimum fraction of time interval that trips departing from zone r in time interval d+1 must follow trips departing in time interval d.

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~~64~~

APPENDIX C

SYNOD and DYMOD Input Files

SYNOD and DYMOD Link File (170DYMOD.LNK).

SYNOD Control File (SYNOD.CTL).

DYMOD O/D Trip Matrix (I70DYMOD.TRP).

DYMOD Control File (I70DYMOD.CTL).