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Report No. UT-10.13

DEVELOPMENT OF A DECISION SUPPORT TOOL FOR ASSESSING VULNERABILITY OF TRANSPORTATION NETWORKS

Prepared For:

Utah Department of Transportation
Research Division

Submitted By:

Utah State University
Department of Civil and Environmental Engineering

Authored By:

Sarawut Jansuwan
Thitima Wonginta
Anthony Chen

August 2010

INSIDE COVER

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16. Abstract

This research develops a decision support tool for assessing vulnerability of transportation networks. This report consists of 1) describing the trends of freight movements in Utah, 2) identifying the current and potential freight chokepoints/bottlenecks in Utah, 3) estimating a simplified truck Origin-Destination (O-D) trip table using the commodity flow data from the U.S. Department of Transportation Freight Analysis Framework (FAF), 4) developing a visualization tool combined with geographical information systems (GIS) features for transportation network vulnerability analysis as a decision support tool, 5) conducting a case study based on the disruption scenarios of highway bridges using the highway system in the state of Utah to evaluate the decision support tool, and 6) providing suggestions for future research.

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- Walt Steinvorth, UDOT Planning,
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- Shawn Peppers, Utah Department of Public Safety.

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EXECUTIVE SUMMARY

The transportation network is an indispensable component of everyday life in modern society. Disruption to the network can make peoples' daily lives extremely difficult as well as seriously cripple economic productivity. Current efforts in transportation research to characterize highway network vulnerability tend to be qualitative due to the absence of well defined quantitative measures. The development of a decision support system provides a quantitative approach for comparison of various network disruptions and the trade-off among potential response measures. The Utah Transportation Center (UTC) at Utah State University (USU), in partnership with the Utah Department of Transportation (UDOT) has accomplished the following:

- Development of a decision support tool for assessing transportation network vulnerability, and
- Conducting a case study based on the disruption scenarios of highway bridges using the Utah highway network.

The vulnerability assessment focuses on evaluating truck-freight bottlenecks/choke points, which are high value according to their potential economic impacts on U.S. commerce. As part of the project, the state-specific commodity flows within, out of, into and through Utah were extracted from the U.S. Department of Transportation Freight Analysis Framework (FAF) version 2.2 database and then converted into truck trips to generate a truck Origin-Destination (O-D) trip table. Using the truck O-D trip table, the vulnerability of freight chokepoints were assessed using two quantitative measures: 1) O-D connectivity (or detour route) in terms of distance and 2) freight flow pattern change in terms of vehicle miles traveled (VMT).

This project was tasked specifically with developing a Freight Chokepoint Analysis Tool (FCAT) for assessing the vulnerability along the Utah highway network. FCAT is a Geographic Information System (GIS) decision support tool developed in MapWindow, an open source GIS software, and Microsoft Visual Basic.NET that supports the visualization of geospatial data in

GIS formats with plug-in tools. A copy of the FCAT research software may be obtained through the UDOT Research Division or the authors of this report. With FCAT, user can do the following:

- View, manage and edit freight chokepoints in a GIS map,
- Create what-if scenarios (e.g., disruption of chokepoints, road closures) for the vulnerability assessment,
- Assess the vulnerability of freight chokepoints and visualize outputs in a GIS map,
- Interactively display and query shortest paths between any O-D pair,
- Compare assessment results before and after network disruptions, and
- Create thematic maps of freight flow pattern of before and after network disruptions.

The case study adopts a "what-if" analysis approach by generating the disruption scenarios of the structurally deficient bridges in Utah due to earthquakes. To generate the scenarios, two information sources were used: 1) structurally deficient Utah bridges from the National Bridge Inventory (NBI) database and 2) Utah seismic hazard map developed by the structural group at Utah State University (Halling et al., 2002). Disruption scenarios from an earthquake, based on assumed impassable status of bridges after a strong earthquake, were selected for five structurally deficient bridges in or near high seismic hazard areas: three rural interstate bridges (Eagle Canyon on I-70, Silver Creek on I-80, and Beaver County on I-15) and two urban interstate bridges (Roy 5600 South on I-15, and N. Salt Lake Beck Street on I-15). Eight disruption scenarios were conducted for the case study: one for each of the five selected rural and urban interstate bridges, one for the three rural bridges combined, one for the two urban bridges combined, and one for all five bridges combined. In each scenario, the following results were reported:

- Profile of each bridge (location, functional class, span length, and pre-earthquake NBI condition rating)
- Increased travel distance table and the top three O-D pairs impacted by the scenario
- Increased VMT table and the top three O-D pairs impacted by the scenario

- Increased travel distance and VMT by zone
- Summarized key findings of the scenario.

In general, disruptions to the rural bridges could significantly increase the travel distance (taking a long detour) due to the limited alternative routes in the rural area, while disruptions to urban bridges would alter the freight flow pattern as indicated by the increase in VMT in the urban area. In addition, disruptions to multiple bridges could have a much higher impact in terms of travel distance and VMT compared to the single bridge failure scenarios.

The report also provides recommendations for future research: 1) enhancing the user-friendliness of the decision support tool, 2) improving the accuracy of truck O-D trip table by collecting additional information, and 3) incorporating the Utah Statewide Travel Model (USTM) into the decision support system as an integrated system for assessing potential vulnerability in the future. In addition, the latest version of FAF 3.0, which is expected for release in summer 2010, should be used to update the network and the O-D commodity flow database. In terms of potential applications, FCAT can be used to prioritize Utah bridges for maintenance and retrofitting, detour route planning for effective freight movements, integrating vulnerability analysis into the statewide planning model, etc.

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1. INTRODUCTION

1.1 Background

The transportation network is an indispensable component of everyday life in the modern society. Platt (1995) refers to such physical or virtual networks (i.e., road networks, power lines, water distribution networks, communication networks, and the Internet) that are vital to people's health, safety, comfort, and economic activities as *lifelines*. Disruption to these lifelines can seriously damage the economic productivity of the society as well as making peoples' daily lives extremely difficult (Miller, 2003). Transportation networks are one of the lifelines which demand meticulous security consideration especially in the aftermath of recent disastrous events around the world. Given that transportation networks are so critical to the functioning of modern society and yet are so fragile, it is important to understand their vulnerability and the consequences to disruption in order to manage risks associated with critical events. Berdica (2002) defined vulnerability as "a susceptibility to incidents that can result in considerable reductions in road network serviceability." "Incidents" are events that can directly or indirectly result in considerable reductions or interruptions in the serviceability of a link/route/road network.

Despite the significance of the subject, the current knowledge based on the subject is limited due to the lack of empirical insights, models, data, and decision support tools. Current efforts in transportation research to characterize network vulnerability tend to be qualitative due to the absence of well-defined quantitative measures. While the qualitative indices are useful in communicating the risk of threats to the public, they do not possess the necessary basis for comparison of various threats and the trade-off among potential response measures. The development of a decision support system with quantitative measures is particularly important because of the complexity of the problem.

Thus, the primary objective of this research effort is to develop a decision support tool for assessing vulnerability of transportation networks and improving the productivity in decision-making of the state DOT. The vulnerability assessment focuses on evaluating truck-freight bottlenecks/choke points, which are high value according to their potential economic impact on U.S. commerce. A geographic information system (GIS)-based visualization tool that combines freight transportation network and statewide truck flows data will enhance the ability in assessing the transportation vulnerability as well as managing the consequences due to disruptions. The tool capability has been demonstrated using the case studies of the disruptions of bridges in rural and urban areas. Two key measures including 1) O-D connectivity and 2) freight flow pattern are assessed and used to estimate the vulnerability of different disruptions in the transportation system. The outcomes of this research are expected to assist the policymakers and planners in understanding the adverse consequences of chokepoints in transportation networks and in planning for the statewide transportation security.

1.2 Objectives

The aim of this project is to develop a decision support tool for analysis of transportation network vulnerability to address the critical issue of freight bottlenecks/choke points in Utah. Specifically, the objectives of the research are to:

- Describe the trends of freight movements and survey the current and potential freight bottlenecks/choke points in Utah,
- Review the current and potential freight bottlenecks/chokepoints on the highway transportation system in Utah.
- Develop methods for assessing the potential vulnerability of a transportation network,
- Develop a visualization tool combined with geographical information systems (GIS) features for transportation network vulnerability analysis as a decision support tool,

- Conduct a case study based on the state highway system in Utah to evaluate the decision support tool, and
- Provide recommendations for future research.

1.3 Organization of the report

The organization of this report is summarized as follows:

- Chapter 2 describes the trends of freight movements in the State of Utah. Using available data from public domain, the project team describes the current and future demands of freight shipments in the state.
- Chapter 3 reviews and surveys the freight bottlenecks and chokepoints in the State of Utah. The definitions of bottleneck and chokepoint from the previous studies are reviewed. The GeoFreight Visual Display Tool is used to identify freight bottlenecks and chokepoints in Utah.
- Chapter 4 describes a simplified procedure for estimating truck origin-destination (O-D) trip table using the commodity flow data from the Freight Analysis Framework (FAF) Database. The truck O-D trip table is used as inputs for vulnerability assessment of freight transportation networks.
- Chapter 5 describes the development of FCAT: a decision support tool for assessing the vulnerability of freight chokepoints.
- Chapter 6 illustrates the application of FCAT using the disruption scenarios of the structurally deficient bridges in the Utah strategy highway network. Results of the vulnerability assessment expressed in terms of O-D connectivity and freight flow pattern change are summarized in this chapter.
- Chapter 7 summarizes findings, conclusions and recommendations for future research.

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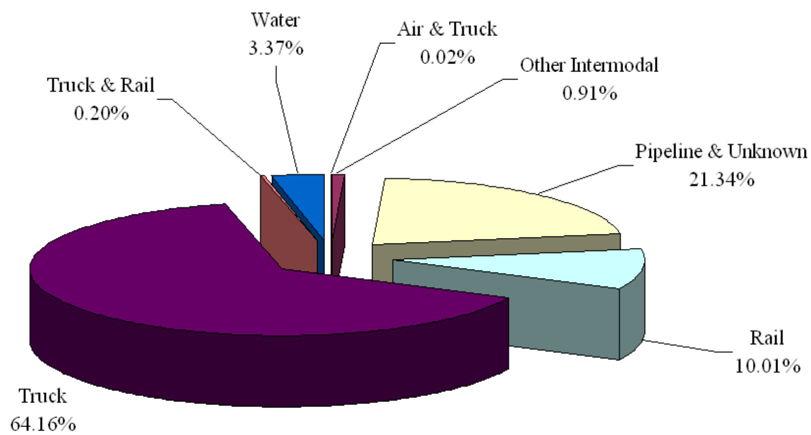
2. TRENDS OF FREIGHT MOVEMENTS

The freight transportation system is an essential backbone for supporting the industrial activities and economic competitiveness of the nation. Growth of freight transportation in volume and value has been rising steadily over the past decade. This trend is expected to continue in the future decades. According to the latest figures from FHWA (2006), the annual freight volume and value is growing approximately 2% and 3.5% annually, respectively. This growth has significantly contributed to the congestion at freight facilities and transportation highways, especially at the location where the capacity is restrained. These bottlenecks restrict the performance and productivity of freight movements and have an adverse impact on the nation's economy as they delay large number of truck freight shipments.

In Utah, demand for freight transportation, especially truck, has been rising steadily and the forecast shows the continuous growth at least over the next two decades. According to the USDOT (2006), freight transportation volume measured in tonnage carried by truck accounts for 65% of the modal share. The freight value is about $125 billion in 2002 and is expected to increase to $500 billion by 2035. Using the FAF Commodity Origin-Destination Database (2002), this chapter provides a brief summary of the trends of freight movements in the United States and the State of Utah. This chapter is organized as follows: Section 2.1 presents the national freight transportation trends by mode, volume, and value; Section 2.2 focuses on the freight transportation trends in Utah; and Section 2.3 provides additional details of the top ten commodities in Utah.

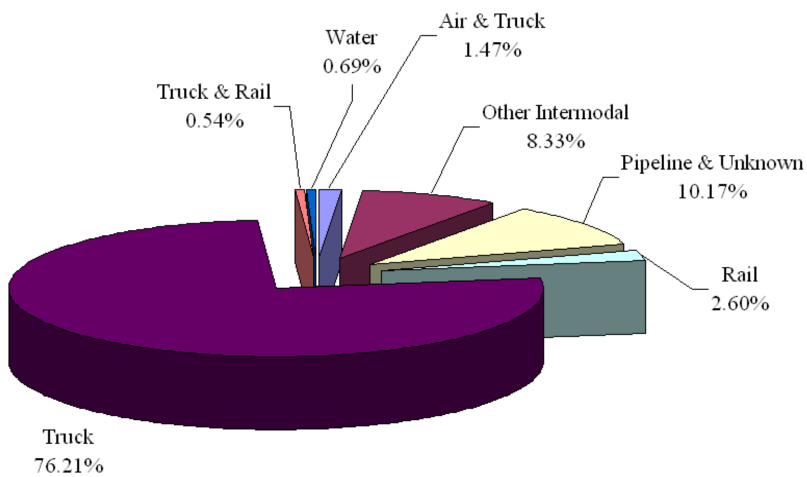
2.1 National Freight Transportation Trends

The charts in this section provide information about the freight transportation trends from 2002 to 2035 in the United States. Figures 2.1 and 2.2 show the modal share of freight shipment by volume and by value for the base year 2002. As can be seen, majority of the freight shipment measured in volume (in tonnage) and value (U.S. dollar) is carried out by trucks. Trucks alone account for 64.16% in volume and 76.21% in value for the domestic freight transportation. Figures 2.3 and 2.4 depict the domestic freight transportation trends by percentages of mode share in volume (million of tons) and value (billion of dollars) from 2002 to 2035. As can be seen, the projection of freight growth is increasing steadily. From 2002 to 2035, freight volume and value increase nearly 100% and 150%, respectively.



Source: U.S. Department of Transportation, 2002 Freight Analysis Framework

Figure 2.1 Modal Share of Freight Shipment by Volume in 2002 (National)



Source: U.S. Department of Transportation, 2002 Freight Analysis Framework

Figure 2.2 Modal Share of Freight Shipment by Value in 2002 (National)

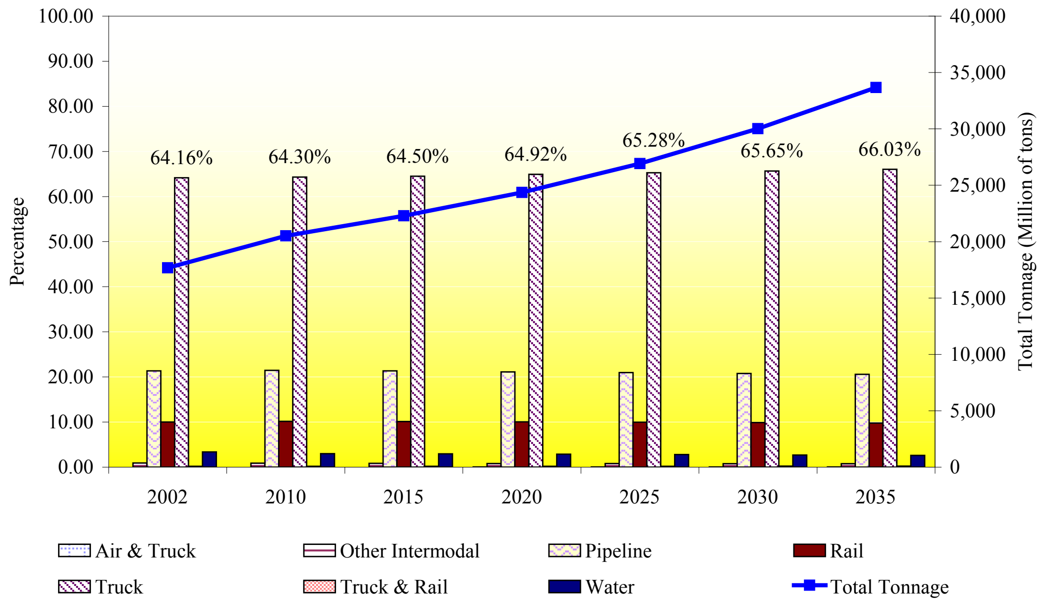


Figure 2.3 Projection of Freight Growth and Mode Share by Volume from 2002 to 2035 (National)

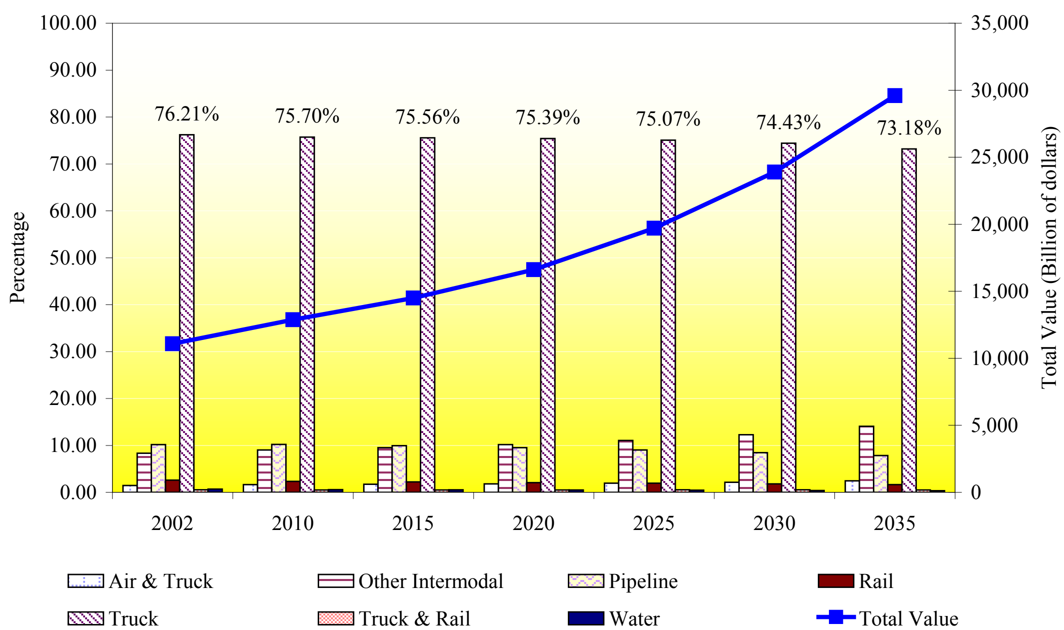


Figure 2.4 Projection of Freight Growth and Mode Share by Value from 2002 to 2035 (National)

2.2 Freight Transportation Trends in Utah

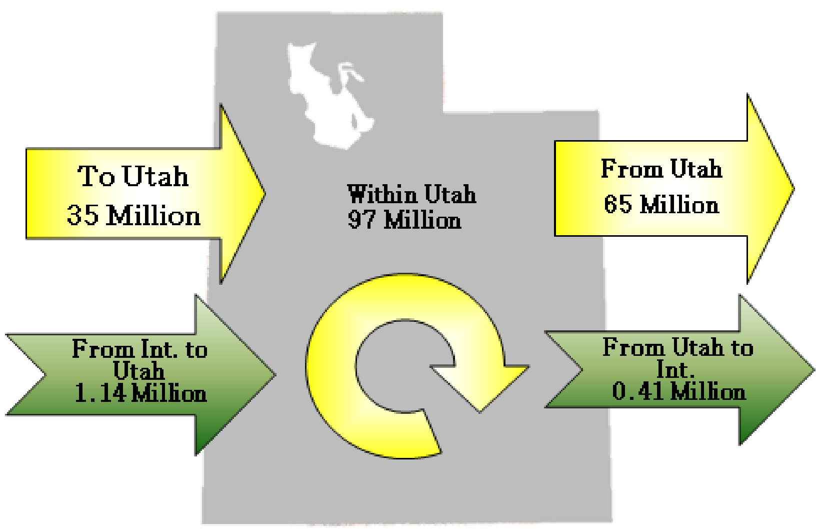
The tables and charts in this section provide information about the freight transportation trends from 2002 to 2035 in the State of Utah. Tables 2.1 and 2.2 summarize the modal share of freight shipment in Utah by volume and value for the base year 2002. Nearly 200 million tons of freight was moved from, to, and within Utah in 2002. Specifically, 97 million tons were moved within Utah, 65 million tons were moved out of Utah, 35 million tons were moved into Utah and 1.5 million tons were international freight. The value of these freight shipments was approximately 125 billion dollars. Figure 2.5 and 2.6 depict the freight movements in Utah by volume and value for base year 2002. Figure 2.7 and 2.8 show the modal share of freight shipment by volume and by value for the base year 2002. In Utah, the majority of the freight shipment measured in volume (in tonnage) and value (U.S. dollar) is carried out by trucks. Similar to the national trends, truck is the dominant mode of freight transportation in Utah. Figures 2.9 and 2.10 depict the freight transportation trends in Utah by percentages of mode share in volume (million of tons) and value (billion of dollars) from 2002 to 2035. The projection of freight growth in Utah appears to increase at a faster rate than the national average. By 2035, freight volume will be more than double while freight value will be more than triple.

Table 2.1 Modal Share of Freight Shipment in Utah by Volume in 2002 (Million of Tons)

Mode	Within State		From State		To State		From State to International		To State From International	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Air & Truck	0.00	0.00	0.11	0.18	0.01	0.02	0.00	0.05	0.00	0.05
Other Intermodal	0.13	0.14	0.34	0.53	0.17	0.49	0.00	0.84	0.00	0.20
Pipeline & Unknown	19.97	20.52	18.99	29.17	12.98	36.58	0.00	0.00	0.23	19.82
Rail	2.22	2.28	18.75	28.80	7.14	20.11	0.14	33.46	0.46	40.15
Truck	74.94	77.01	26.51	40.72	14.73	41.52	0.27	65.55	0.45	39.68
Truck & Rail	0.05	0.05	0.39	0.60	0.45	1.28	0.00	0.08	0.00	0.05
Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.05
Total	97.31	100.00	65.11	100.00	35.48	100.00	0.41	100.00	1.14	100.00

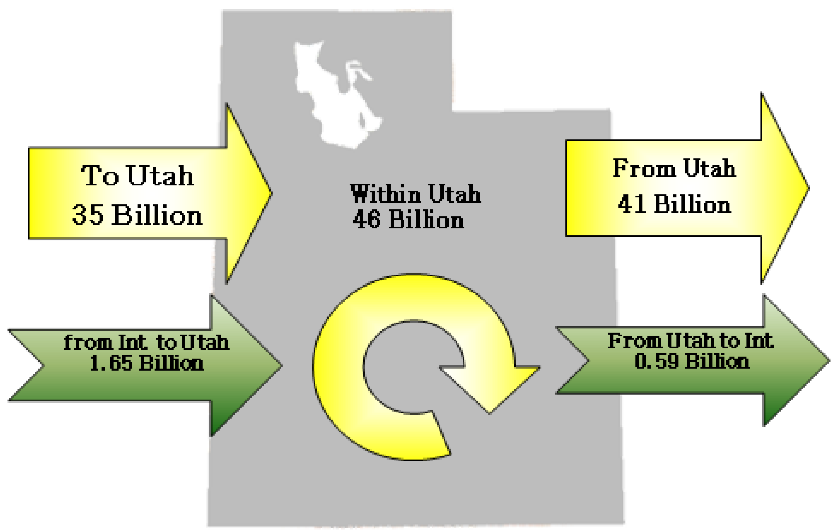
Table 2.2 Modal Share of Freight Shipment in Utah by Value in 2002 (Billion of Dollars)

Mode	Within State		From State		To State		From State to International		To State From International	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Air & Truck	0.02	0.03	1.02	2.52	0.01	0.02	0.00	0.04	0.48	29.21
Other Intermodal	1.12	2.42	6.76	16.63	0.17	0.49	0.01	1.12	0.00	0.25
Pipeline & Unknown	3.69	7.98	5.86	14.42	12.98	36.58	0.00	0.00	0.04	2.12
Rail	1.52	3.29	1.78	4.38	7.14	20.11	0.02	3.62	0.12	7.35
Truck	39.88	86.14	25.12	61.78	14.73	41.52	0.56	95.17	1.01	60.97
Truck & Rail	0.06	0.13	0.11	0.26	0.45	1.28	0.00	0.03	0.00	0.06
Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.03
Total	46.29	100.00	40.66	100.00	35.48	100.00	0.59	100.00	1.65	100.00



Note Int.: International, Unit: Tons

Figure 2.5 Freight Movement in Utah by Volume (2002)



Note Int.: International, Unit: US. Dollars

Figure 2.6 Freight Movement in Utah by Value (2002)

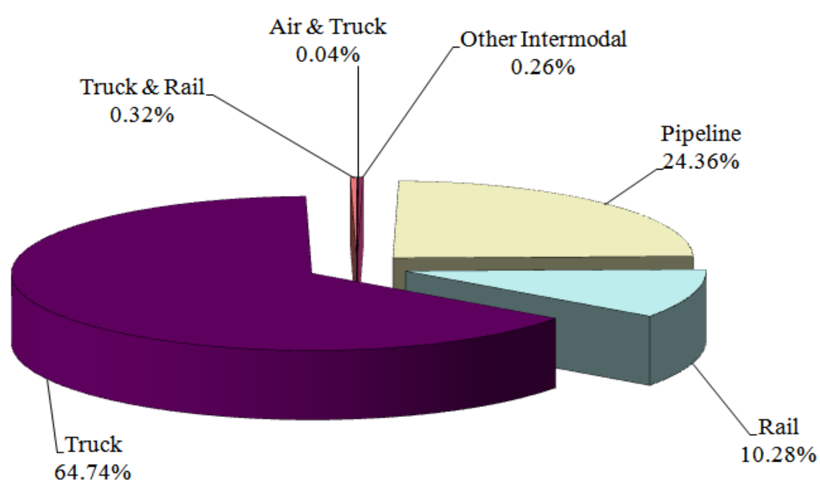


Figure 2.7 Modal Share of Freight Shipment by Volume in 2002 (Utah)

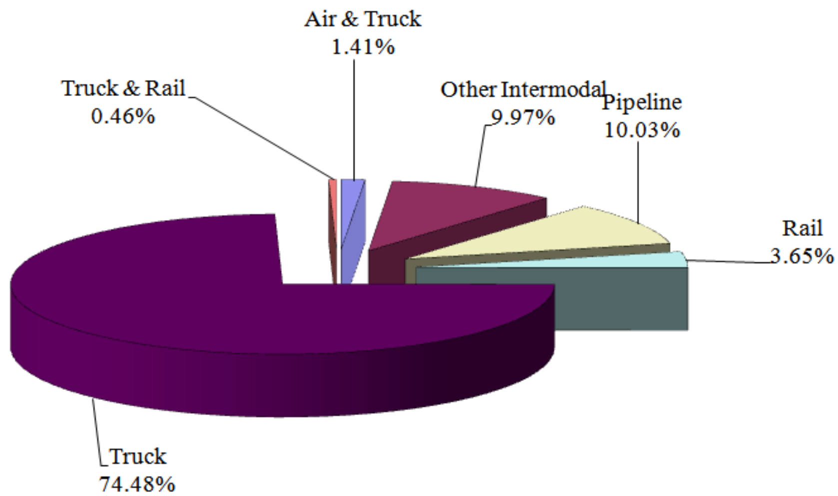


Figure 2.8 Modal Share of Freight Shipment by Value in 2002 (Utah)

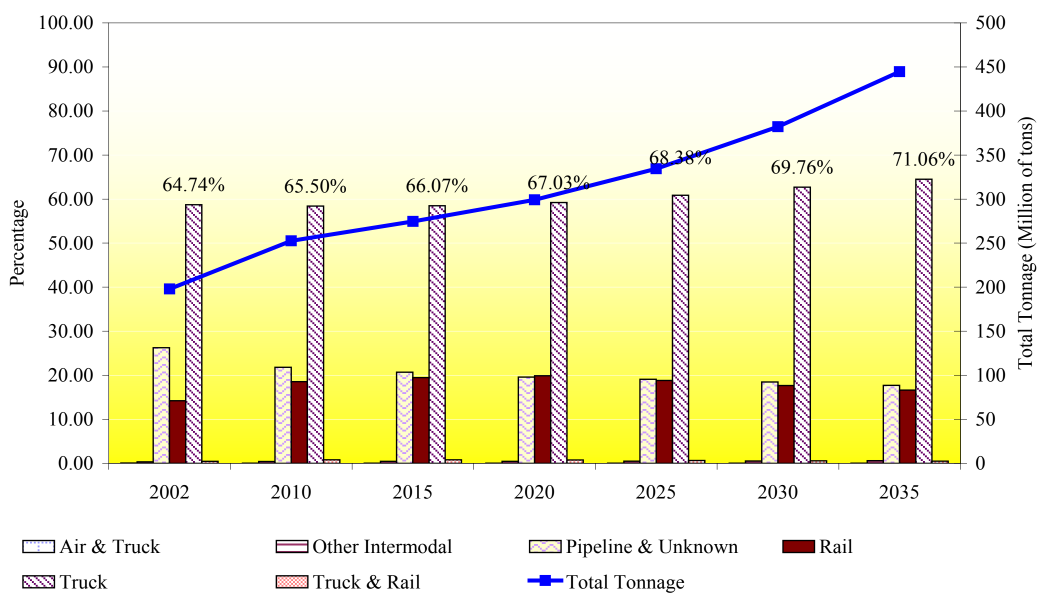


Figure 2.9 Projection of Freight Growth and Mode Share by Volume in Utah from 2002 to 2035 (Utah)

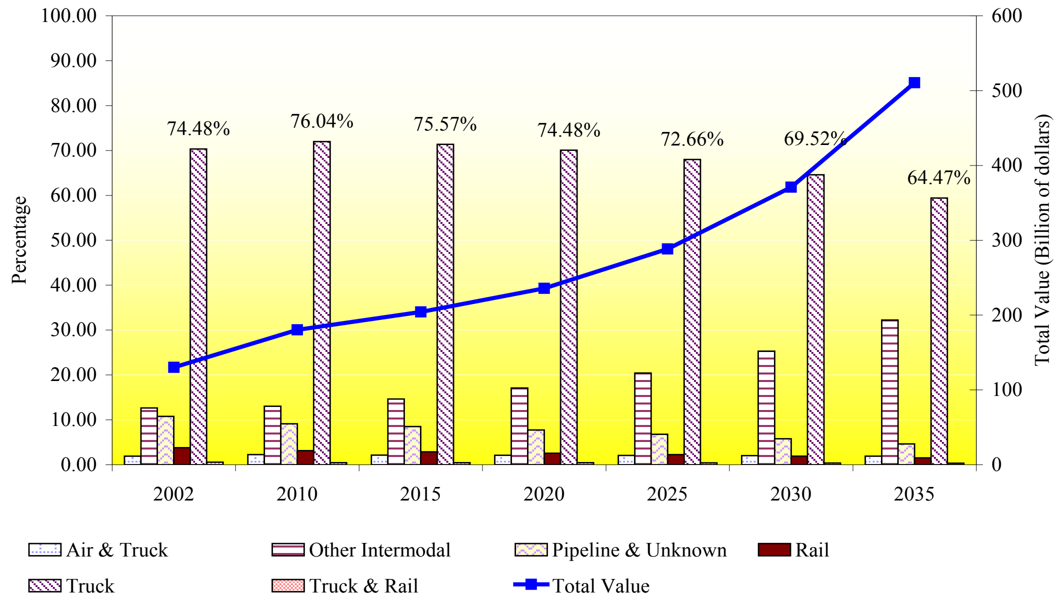


Figure 2.10 Projection of Freight Growth and Mode Share by Value in Utah from 2002 to 2035 (Utah)

2.3 Top Ten Commodity Flows in Utah

In order to provide a better understanding of freight transportation demand in Utah, the top ten commodity flows are described in this section. Tables 2.3 and 2.4 provide a summary of the top ten commodities by volume and value in Utah for 2002 and 2035. Figures 2.11 to 2.16 further disaggregate these top ten commodities by volume and value according to truck flow movements: from Utah to other states in Figures 2.11 and 2.12, from other states to Utah in Figures 2.13 and 2.14, and within Utah in Figures 2.15 and 2.16. These tables and figures suggest that coal and fuel oils are the top commodities by volume from 2002 to 2035. Precision instruments will become the top commodity by value in 2035. These figures illustrate that the top value commodity from Utah to other state is motorized vehicles while machinery and precision instruments are the top value commodity from other states to Utah for 2002 and 2035 respectively. For the shipment within Utah, the top value commodities are machinery and motorized vehicles for 2002 and 2035. In addition, the top volume commodity shipped from, to and within Utah remains to be fuel oils for 2002 and 2035.

Table 2.3 Top Ten Commodities by Volume in Utah for 2002 and 2035

Commodity	2002 (Million of tons)	Commodity	2035 (Million of tons)
Coal-n.e.c.	35.35	Coal	62.63
Coal	33.49	Coal-n.e.c.	55.39
Fuel oils	22.86	Fuel oils	37.29
Gasoline	11.35	Precision instruments	33.75
Nonmetal mineral products	8.79	Nonmetal mineral products	28.00
Basic chemicals	7.38	Waste/scrap	21.42
Cereal grains	7.24	Gasoline	21.08
Waste/scrap	6.25	Basic chemicals	20.10
Nonmetallic minerals	5.68	Cereal grains	16.80
Crude petroleum	5.50	Other foodstuffs	13.22

Note Commodities are sorted by volume
n.e.c. = not elsewhere classified.

Table 2.4 Top Ten Commodities by Value in Utah for 2002 and 2035

Commodity	2002 (Billion of dollars)	Commodity	2035 (Billion of dollars)
Motorized vehicles	11.12	Precision instruments	183.71
Mixed freight	10.57	Mixed freight	41.62
Coal-n.e.c.	10.39	Motorized vehicles	37.17
Machinery	9.63	Machinery	31.93
Precision instruments	8.84	Misc. manufacturing products.	26.19
Misc. mfg. prods.	6.87	Pharmaceuticals	21.09
Other foodstuffs	6.49	Electronics	20.53
Electronics	6.23	Other foodstuffs	17.04
Textiles/leather	5.93	Coal-n.e.c.	16.33
Pharmaceuticals	5.40	Transport equip.	12.29

Note Commodities are sorted by value
n.e.c. = not elsewhere classified.

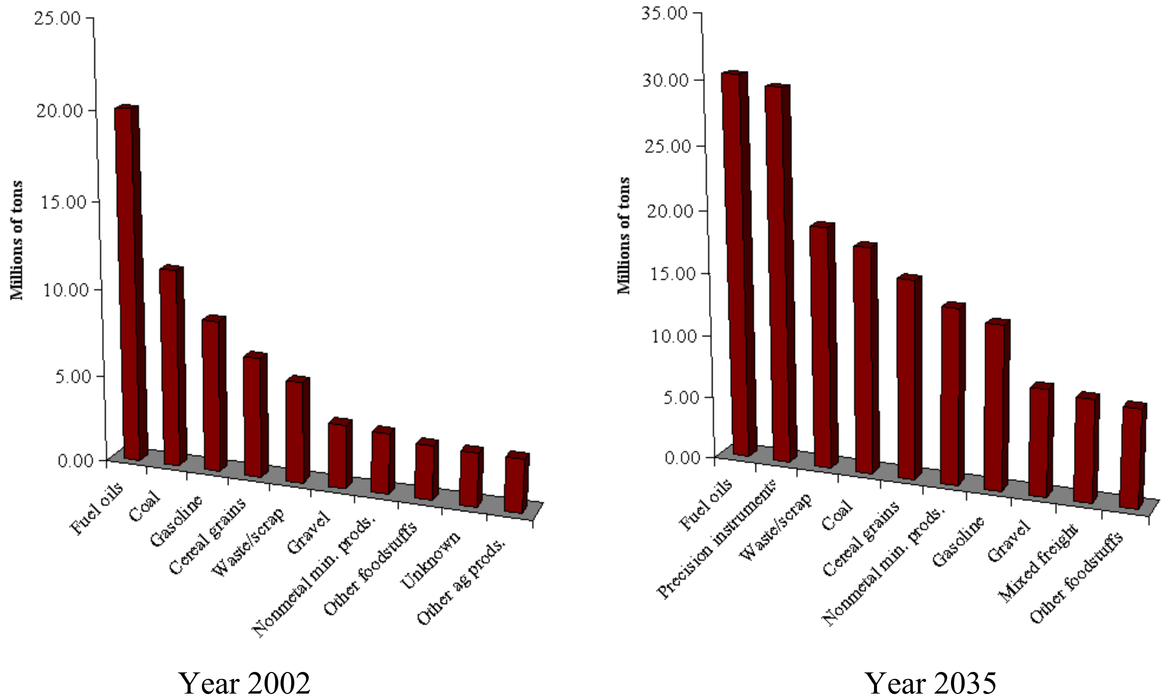


Figure 2.11 Top Ten Commodities by Volume Shipped from Utah to Other States by Truck

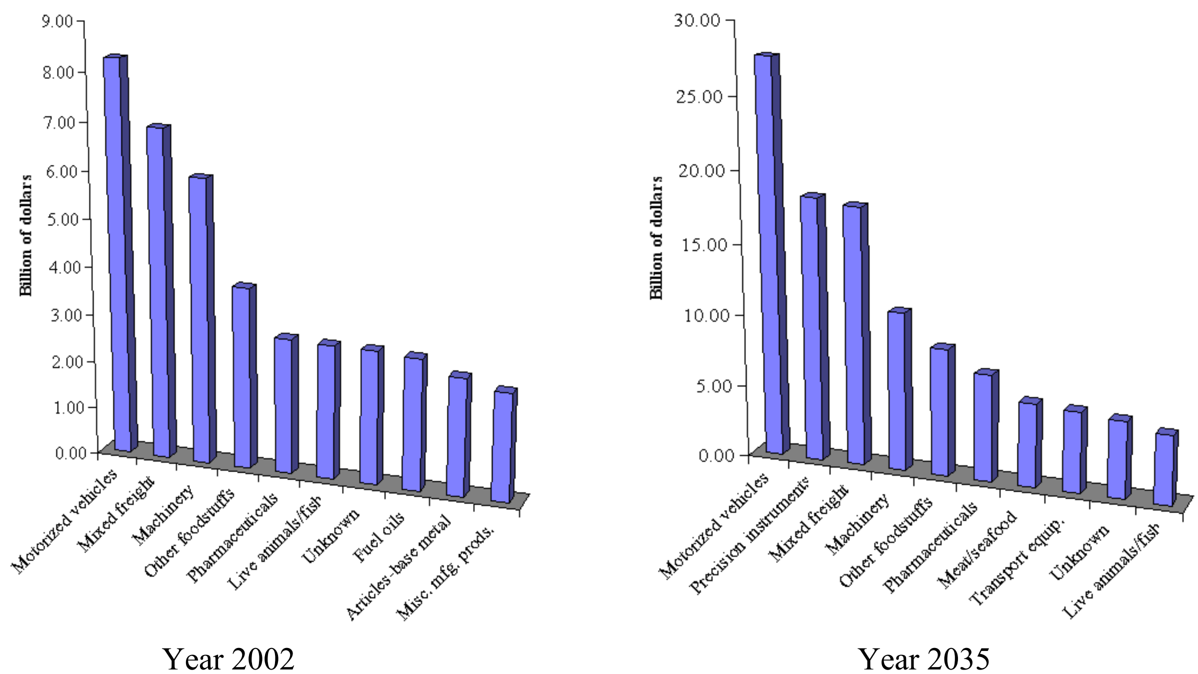


Figure 2.12 Top Ten Commodities by Value Shipped from Utah to Other States by Truck

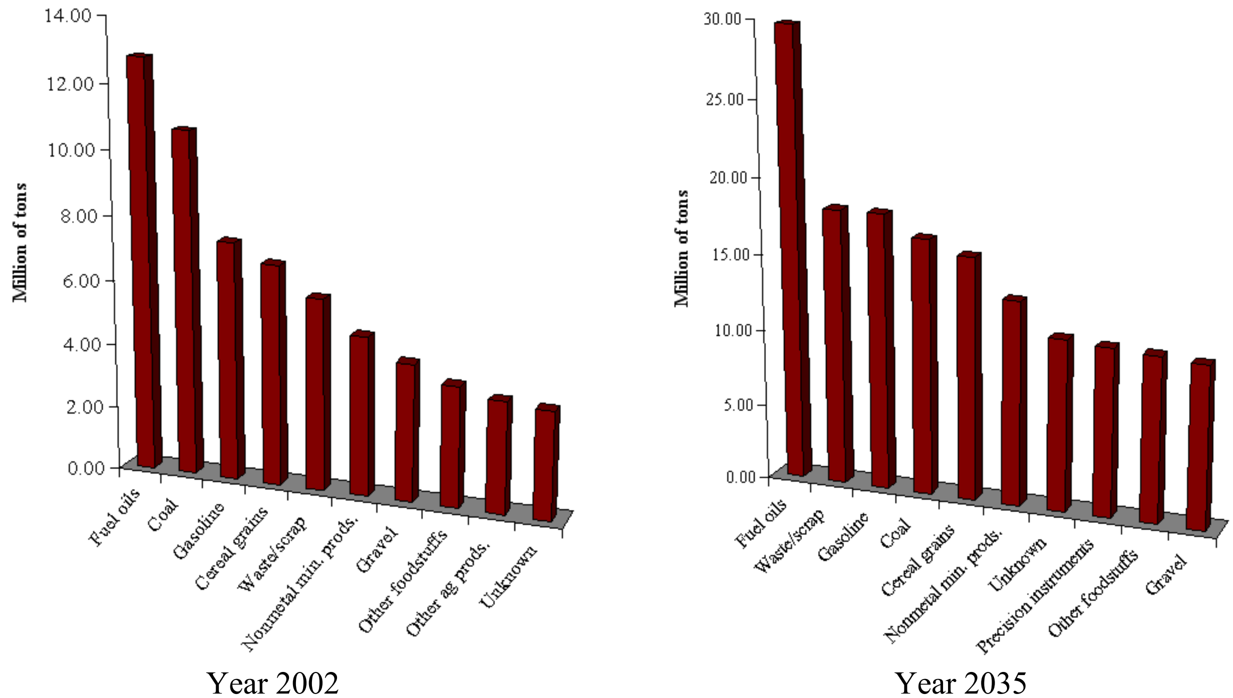


Figure 2.13 Top Ten Commodities by Volume Shipped from Other States to Utah by Truck

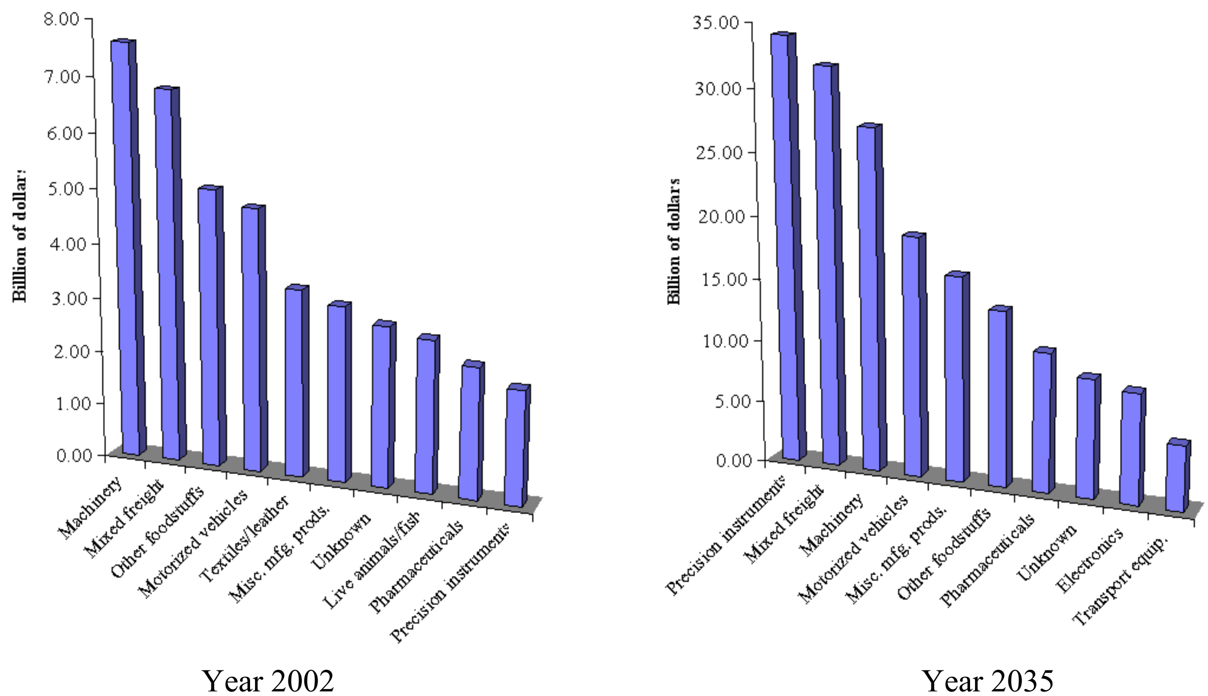


Figure 2.14 Top Ten Commodities by Value Shipped from Other States to Utah by Truck

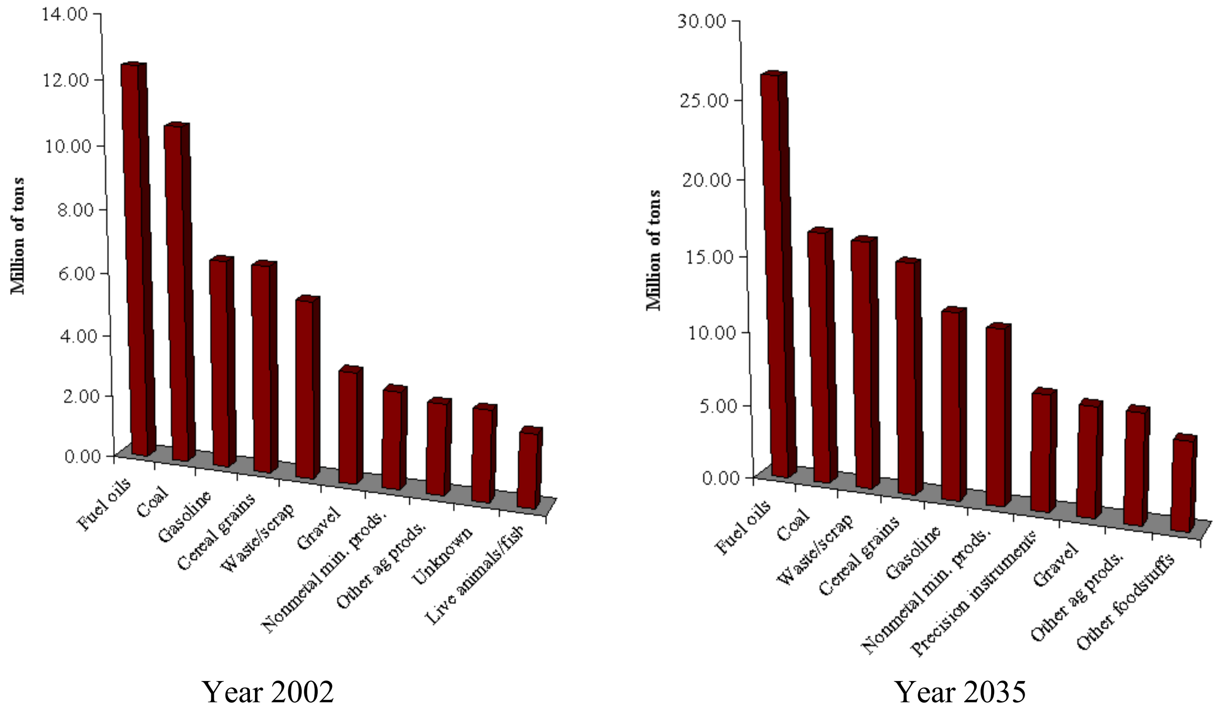


Figure 2.15 Top Ten Commodities by Volume Shipped Within Utah by Truck

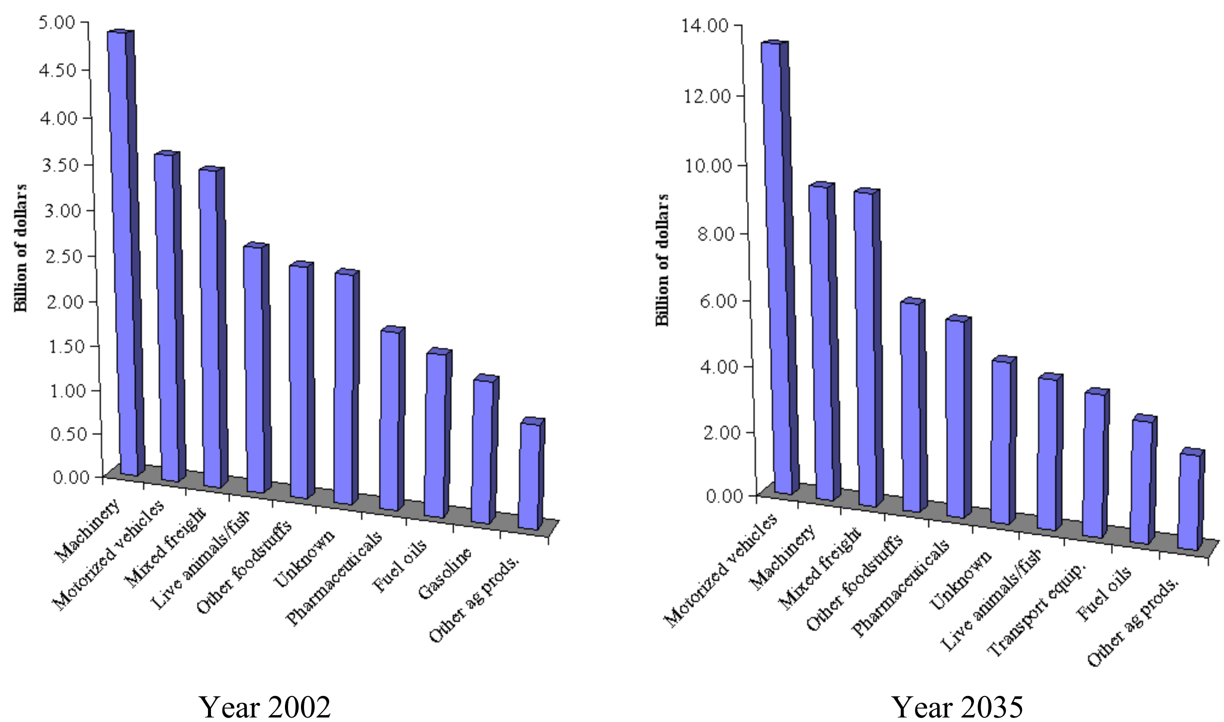


Figure 2.16 Top Ten Commodities by Value Shipped Within Utah by Truck

3. REVIEW OF FREIGHT BOTTLENECKS AND CHOKEPOINTS IN UTAH

In this chapter, the freight bottlenecks and chokepoints in the State of Utah are reviewed and described. The GeoFreight Visual Display Tool, developed by the Oak Ridge National Laboratory (ORNL) for the U.S. Department of Transportation (USDOT), is used to identify freight bottlenecks and chokepoints in Utah. This chapter is organized as follows: Section 3.1 presents the definitions of bottlenecks and chokepoints; Section 3.2 provides a brief description of the GeoFreight Visual Display Tool; and Section 3.3 presents the bottlenecks/chokepoints identified by GeoFreight in Utah.

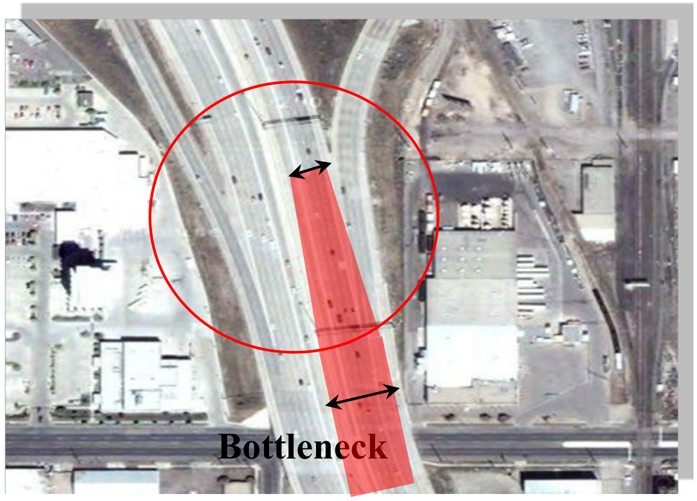
3.1 Definitions of Bottlenecks and Chokepoints

Currently, there are no formal or universal definitions for bottlenecks and chokepoints. The Washington State Department of Transportation (WSDOT, 2005) provides the following definitions:

Bottlenecks: Places where roadways physically narrow, causing congestion (examples: lane drops; narrowing shoulders). See Figure 3.1

Chokepoints: Places where delay occurs because of traffic interference and/or the roadway configuration (examples: freeway interchanges; lack of left-turn lanes at intersections; seasonal road closures. See Figure 3.2.

The Wasatch Front Regional Council (WFRC) in Utah, on the other hand, defines chokepoints as "*the critical narrow locations that have difficulty to pass through*". There are generally few alternatives for moving around these locations and they may be susceptible to incidents.



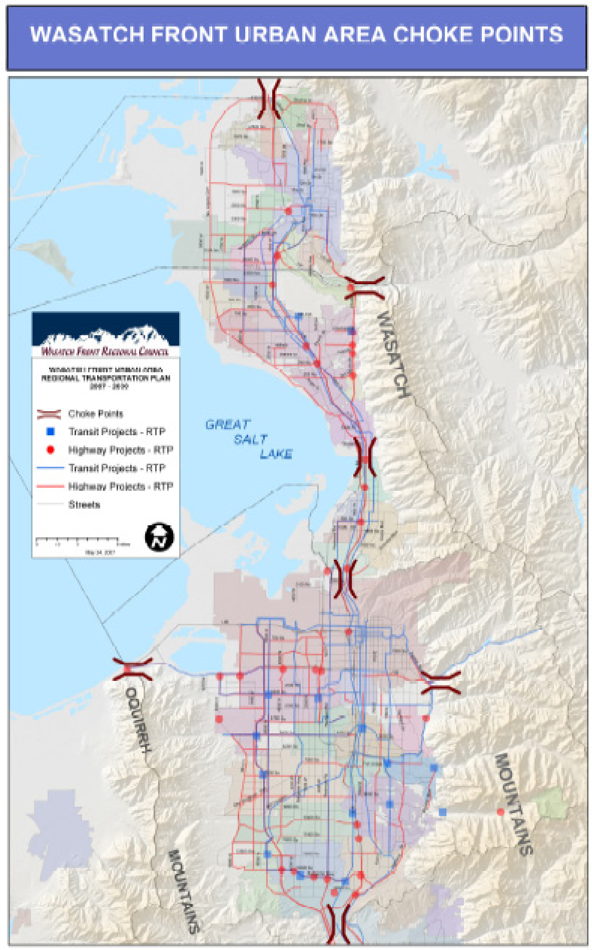
Source: maps.google.com

Figure 3.1 Bottleneck

Source: www.wfrc.org

Figure 3.2 Chokepoint

However, the WFRC definition does not make a distinction between a “bottleneck” and a “chokepoint”. These terms are used interchangeably. In the 2007-2030 Regional Transportation Plan, seven bottlenecks/chokepoints were identified in the Wasatch Front urban area shown in Figure 3.3.



Source: WFRC Regional Transportation Plan: 2007-2030

Figure 3.3 Bottlenecks/Chokepoints in the WFRC Area

3.2 GeoFreight Visual Display Tool

GeoFreight Visual Display Tool or GeoFreight for short is a geographic information system (GIS) – based decision support tool that enables transportation decision makers and planners to analyze national freight patterns for highway, rail, and water concurrently (BTS, 2004). GeoFreight was developed by the Oak Ridge National Laboratory (ORNL) with funding provided by the Bureau of Transportation Statistics (BTS), USDOT, under a partnership with the Office of Intermodalism in the Office of the Secretary of Transportation and the Office of Freight Management and Operations in the Federal Highway Administration (FHWA).

GeoFreight uses a routing model to assign data on freight flows to various components of the transportation network. The tool allows freight policymakers and planners to:

- Identify potential bottlenecks,
- Measure facilities' intensity of use,
- Compare facilities,
- Describe national importance of these facilities,
- Examine domestic and international flows, and
- Evaluate potential vulnerability of transportation systems.

GeoFreight combines GIS and several freight databases to analyze freight movements on the highway, rail, air, and maritime transportation networks. It combines freight volumes with measures of available infrastructure, intensity of infrastructure use, observed traffic delays, and significance of facilities to domestic and international trade to show the potential for bottlenecks. The tool allows users to display and visualize the geographic relationships between freight movements and transportation network infrastructure. Examples of the display and visualization tool include:

- Thematic maps display the major freight facilities at airports, locks, and major seaports and the freight handled by these major facilities.
- Analytical maps can simultaneously display freight flows by multiple modes (i.e., highway, rail, and water).
- Summary tables can be used to view results of origin-destination (O-D) freight flows for a selected region or a network segment.

Figure 3.4 shows a congestion map using statistics from the Highway Performance Measurement System (HPMS) database. Highway congestion in the HPMS database measures both recurrent delay and non-recurrent (or incident) delay. Recurrent congestion is the consequence of typical daily traffic volume and travel pattern where the capacity is not adequate, and happening in roughly the same time and place on the same day of the week (USDOT, 2007). Non-recurrent congestion typically occurs due to unpredicted events (i.e., accidents, road closures, work zones, bad weather, etc.). In GeoFreight, it provides the following three delay measures:

- ***Total delay per mile*** is the total delay divided by the length of the roadway segment. This performance measure is used to compare the congestion of unequal length of roadway segments and corridors.
- ***Total delay per lane-mile*** is the total delay divided by the length and number of lanes of the roadway segment. This performance measure is used to compare the congestion of unequal length and number of lane roadway segments and corridors.
- ***Total delay per 1000 vehicle mile traveled*** (VMT) is the delay per 1000 vehicles divided by the length of the road segment. This performance measure is used to compare transportation impacts such as fuel consumption, transportation economic impacts and so on.

These delay measures from the HPMS database can be used as criterion to identify and display the current and potential bottlenecks/chokepoints in the highway network.

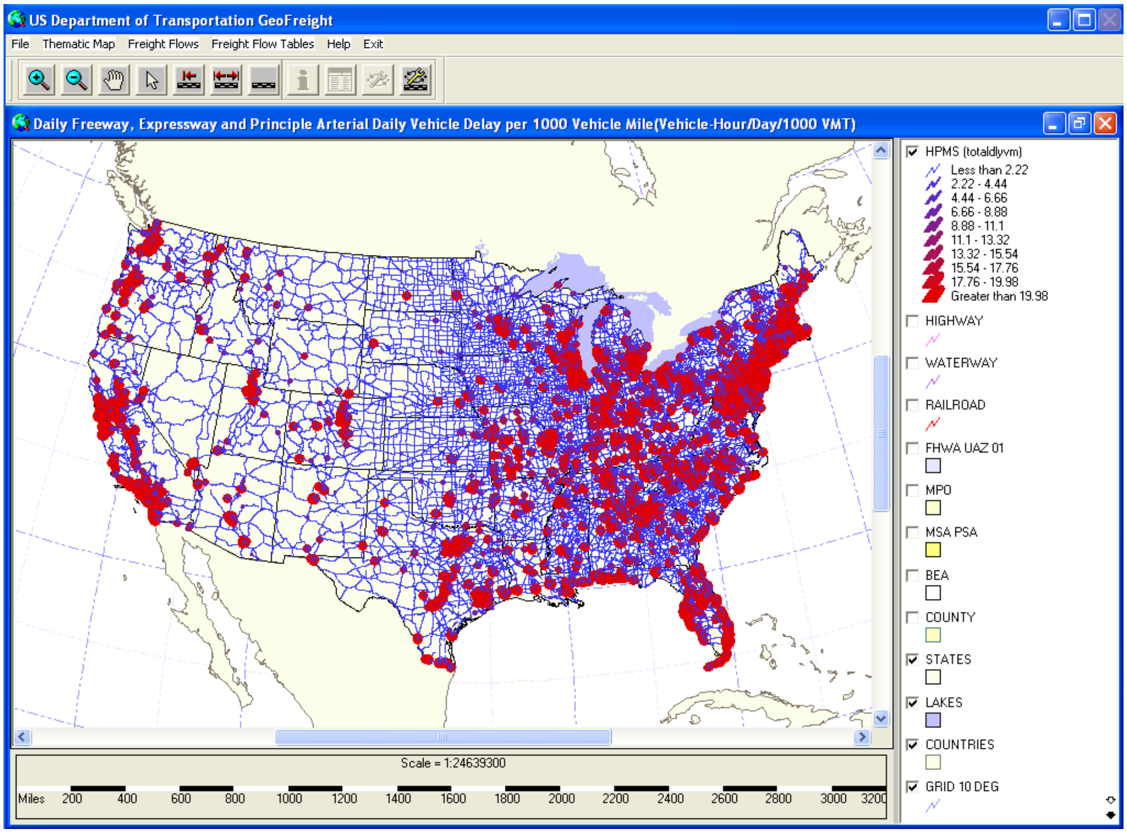


Figure 3.4 Congestion map in GeoFreight

Another unique feature of GeoFreight is the Origin-Destination Flow function. This feature allows users to display the origins and destinations, and associated statistics, of freight traveling through a user-specified segment on the route. Figure 3.5 provides an illustration of the O-D freight flow at the specified segments.

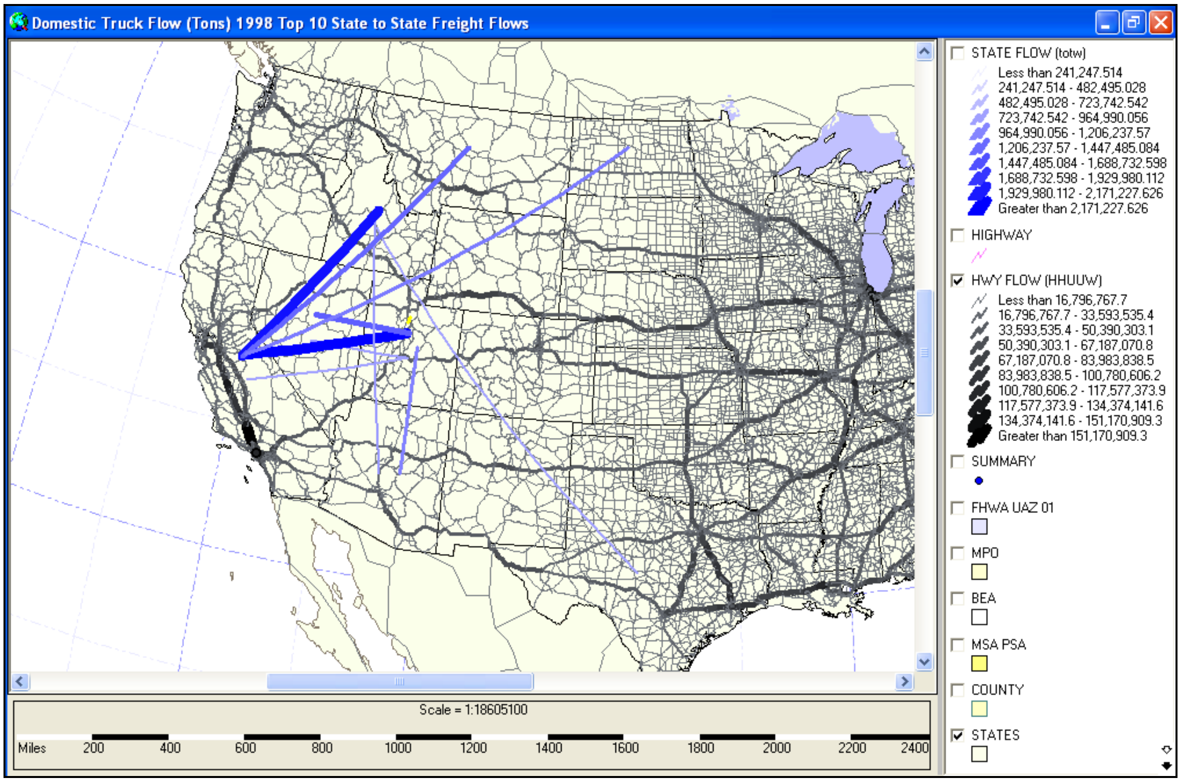


Figure 3.5 Origin-Destination Flows Map

3.3 Bottlenecks/Chokepoints in Utah Identified by GeoFreight

In this section, the bottlenecks/chokepoints in Utah are provided as identified by GeoFreight. Figure 3.6 displays the congestion map in Utah using three delay measures (delay per mile, delay per lane-mile, and delay per 1000 VMT). The bottlenecks/chokepoints are located by scanning the congestions maps for the high congested segments, as indicated by these delay measures.

As can be seen, majority of the delay occurs in the Wasatch Front area (especially in Salt Lake City and Ogden). Figures 3.7 to 3.9 show the detailed locations of the bottlenecks/chokepoints in the four Metropolitan Planning Organizations (MPO) in Utah: Wasatch Front Regional Council (WFRC), Mountainland Association of Governments (MAG), Cache MPO (CMPO), and Dixie MPO (DMPO). Tables 3.1 to 3.3 further report the bottleneck/chokepoint locations classified by total delay per mile, total delay per lane-mile, and total delay per 1000 VMT for the four MPOs in Utah.

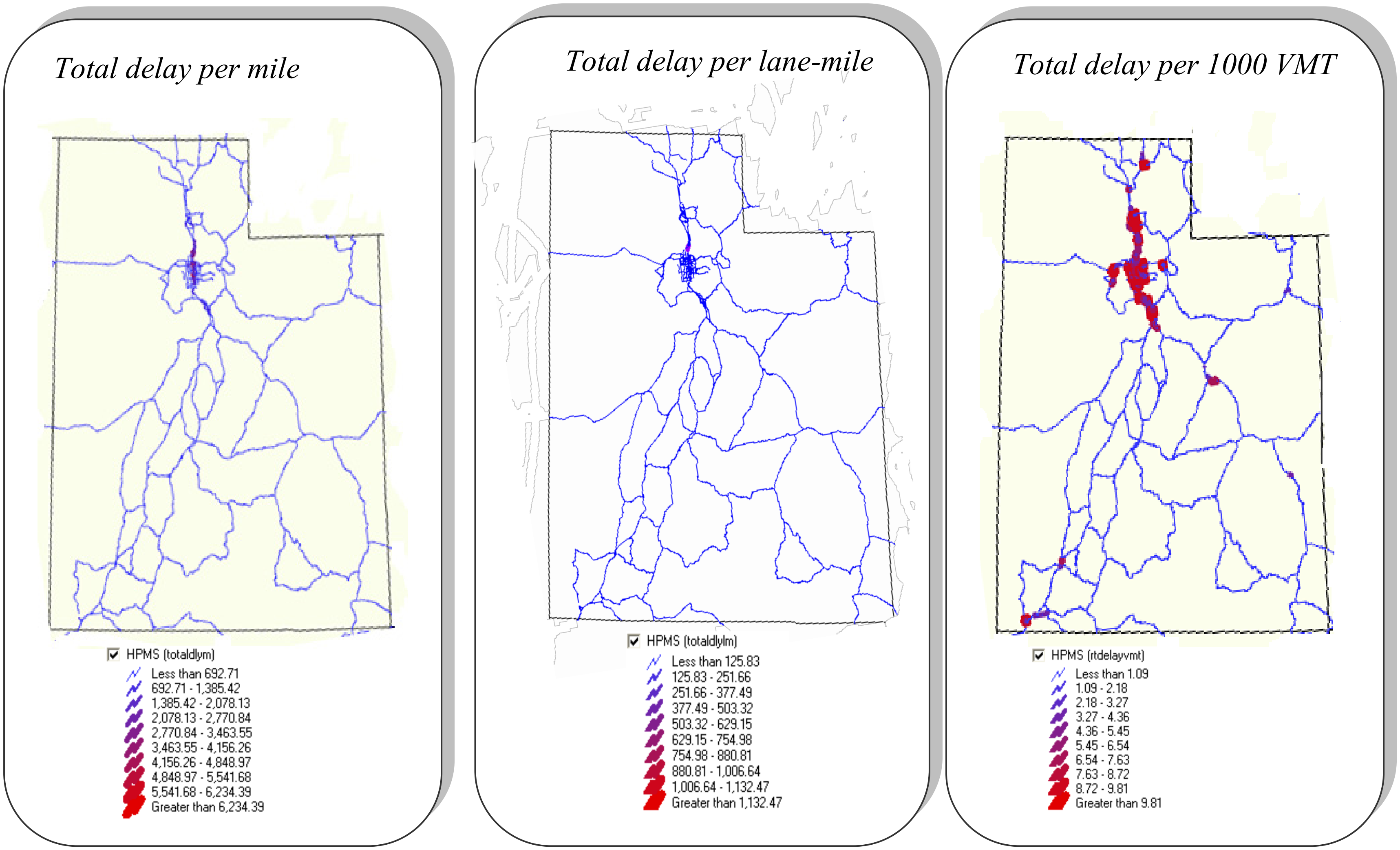


Figure 3.6 Congestion Map in Utah using Three Delay Measures

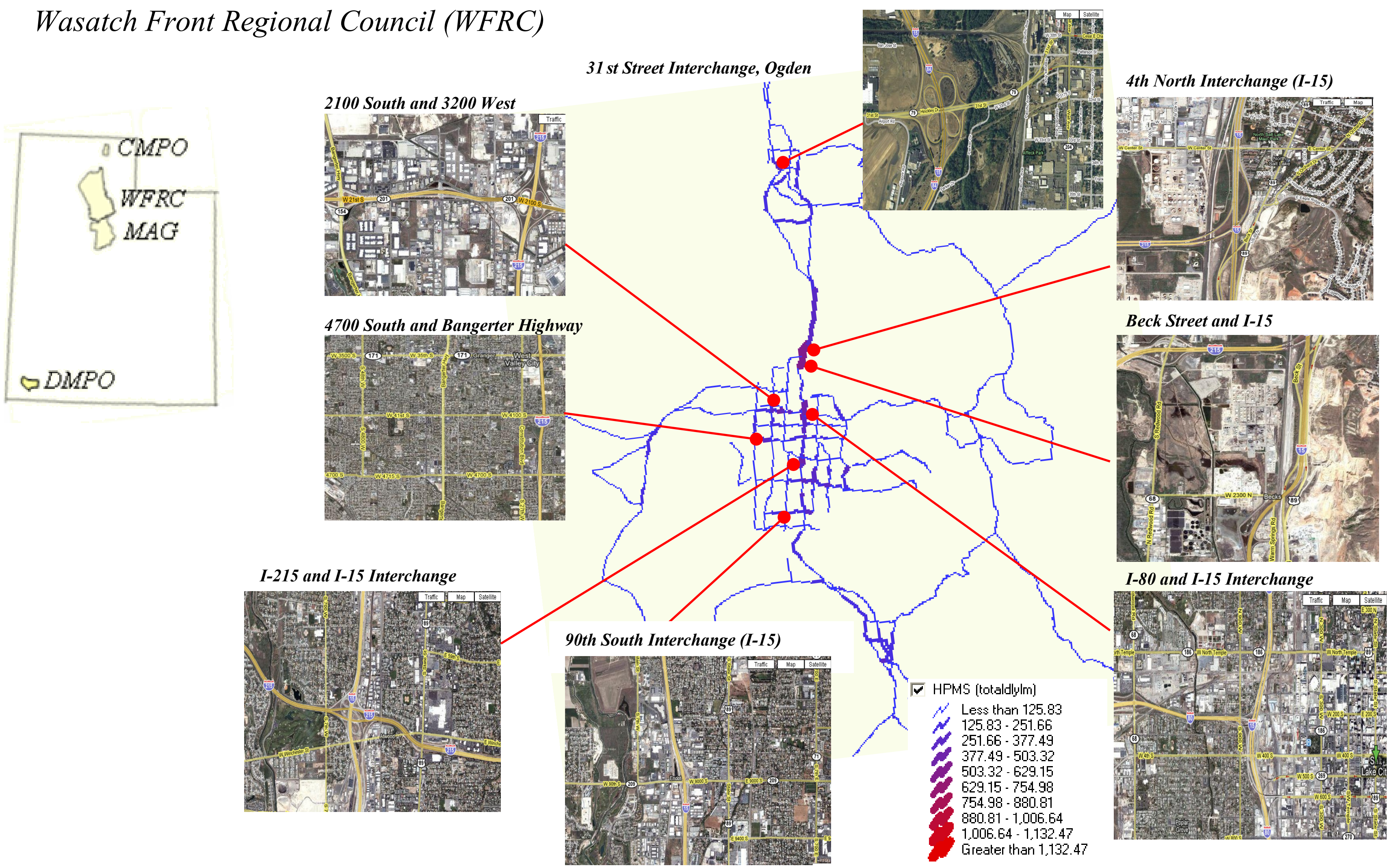


Figure 3.7 Locations of Bottlenecks/Chokepoints in Wasatch Front Regional Council (WFRC)

Mountainland Association of Governments (MAG)

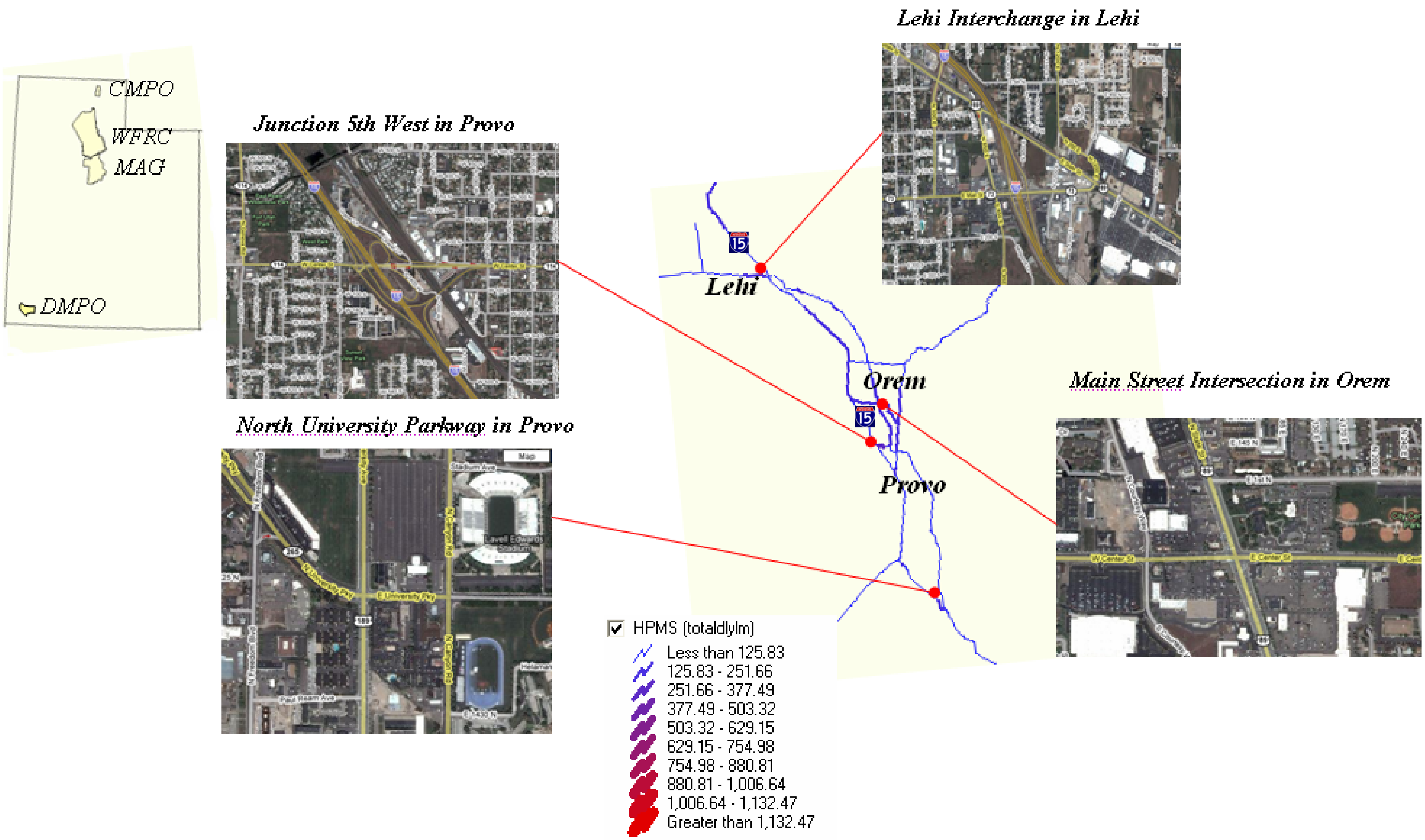


Figure 3.8 Locations of Bottlenecks/Chokepoints in Mountainland Association of Governments (MAG)

Cache MPO (CMPO) and Dixie MPO (DMPO)

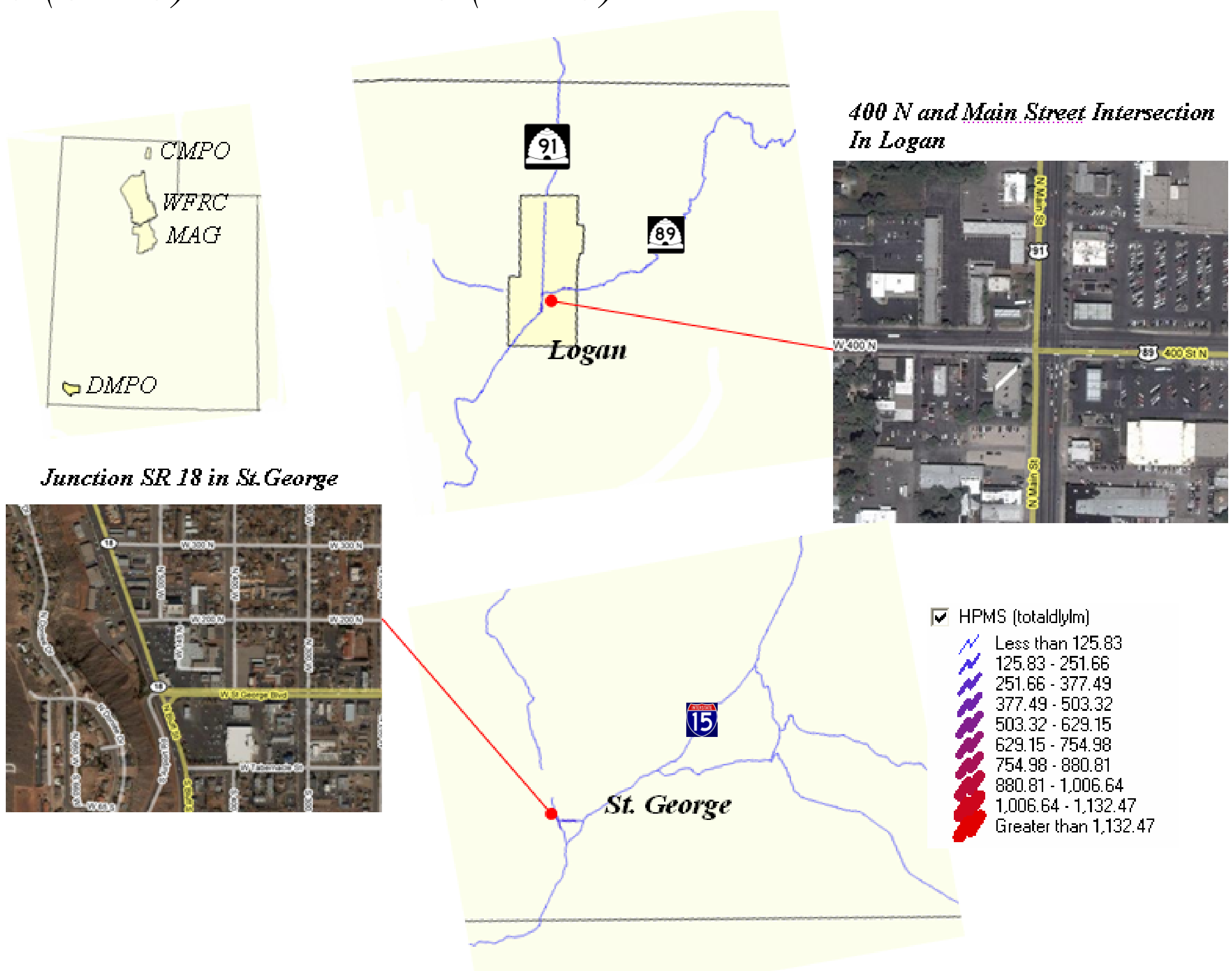


Figure 3.9 Locations of Bottlenecks/Chokepoints in Cache MPO (CMPO) and Dixie MPO (DMPO)

Table 3.1 Bottleneck/chokepoint locations classified by total delay per mile

List	City	MPO	AADT/lane	Recurrent delay per mile	Incident delay per mile	Total delay per mile
I-215 and I-15 Interchange	Salt Lake City	WFRC	25,107	1,464.50	2,196.90	3,661.40
I-80 and I-15 Interchange	Salt Lake City	WFRC	25,025	1,459.80	2,189.80	3,649.60
4th North Interchange	Salt Lake City	WFRC	28,467	1,245.40	1,868.10	3,113.60
90th South Interchange	Salt Lake City	WFRC	21,466	1,022.20	1,533.10	2,555.30
Beck St. and I-15	Salt Lake City	WFRC	28,937	844.10	1,265.90	2,110.00
2100 South and 3200 West	Salt Lake City	WFRC	20,774	791.50	870.80	1,661.50
31st Street Interchange	Ogden	WFRC	22,138	527.10	790.60	1,317.70
4700 South and Bangerter Hwy	Salt Lake City	WFRC	15,298	291.40	320.50	611.90
Main Street (N-S, E-W)	Provo	MAG	9,383	419.60	461.50	881.10
Junction 5th West in PR	Provo	MAG	16,510	314.50	346.00	660.50
North University Pky-North Uni	Provo	MAG	9,621	286.90	315.60	602.30
Lehi Interchange	Lehi	MAG	7,537	31.70	34.70	66.40
400 North-Main Street	Logan	CMPO	9,484	283.10	310.80	593.80
Junction SR 18	St. George	DMPO	10,638	405.30	445.80	851.00

Table 3.2 Bottleneck/chokepoint locations classified by total delay per lane-mile

List	City	MPO	AADT/lane	Recurrent delay per lane-mile	Incident Delay per lane-mile	Total Delay per lane-mile
Beck St. and I-15	Salt Lake City	WFRC	28,937	211.10	316.40	527.50
4th North Interchange	Salt Lake City	WFRC	28,467	207.60	311.40	518.90
2100 South and 3200 West	Salt Lake City	WFRC	20,774	197.90	217.70	415.40
I-215 and I-15 Interchange	Salt Lake City	WFRC	25,107	183.10	274.60	457.70
I-80 and I-15 Interchange	Salt Lake City	WFRC	25,025	182.50	273.70	456.20
4700 South and Bangerter Hwy	Salt Lake City	WFRC	15,298	145.70	160.30	306.00
31st Street Interchange	Ogden	WFRC	22,138	131.80	197.70	329.40
90th South Interchange	Salt Lake City	WFRC	21,466	127.80	191.60	319.40
Junction 5th West in PR	Provo	MAG	16,510	157.30	173.00	330.30
Main Street (N-S, E-W)	Provo	MAG	9,383	69.90	76.90	176.90
Lehi Interchange	Lehi	MAG	7,537	95.00	104.20	199.20
North University Pky-North Uni	Provo	MAG	9,621	71.70	78.90	150.60
400 North-Main Street	Logan	CMPO	9,484	70.80	77.70	148.50
Junction SR 18	St. George	DMPO	10,638	101.30	111.40	212.80

Table 3.3 Bottleneck/chokepoint locations classified by total delay per 1000 VMT

List	City	MPO	AADT/lane	Recurrent delay per 1000 VMT	Incident Delay per 1000 VMT	Total Delay per 1000 VMT
2100 South and 3200 West	Salt Lake City	WFRC	20,774	9.50	10.50	20.00
4700 South and Bangerter Hwy	Salt Lake City	WFRC	15,298	9.50	10.50	20.00
Beck St. and I-15	Salt Lake City	WFRC	28,937	7.30	10.90	18.20
4th North Interchange	Salt Lake City	WFRC	28,467	7.30	10.90	18.20
I-215 and I-15 Interchange	Salt Lake City	WFRC	25,107	7.30	10.90	18.20
I-80 and I-15 Interchange	Salt Lake City	WFRC	25,025	7.30	10.90	18.20
31st Street Interchange	Ogden	WFRC	22,138	6.00	8.90	14.90
90th South Interchange	Salt Lake City	WFRC	21,466	6.00	8.90	14.90
Junction 5th West in PR	Provo	MAG	16,510	9.50	10.50	20.00
Main Street (N-S, E-W)	Provo	MAG	9,383	7.50	8.20	15.70
North University Pky-North Uni	Provo	MAG	9,621	7.50	8.20	15.70
Lehi Interchange	Lehi	MAG	7,537	4.20	4.60	8.80
400 North-Main Street	Logan	CMPO	9,484	7.50	8.20	15.70
Junction SR 18	St. George	DMPO	10,638	9.50	10.50	20.00

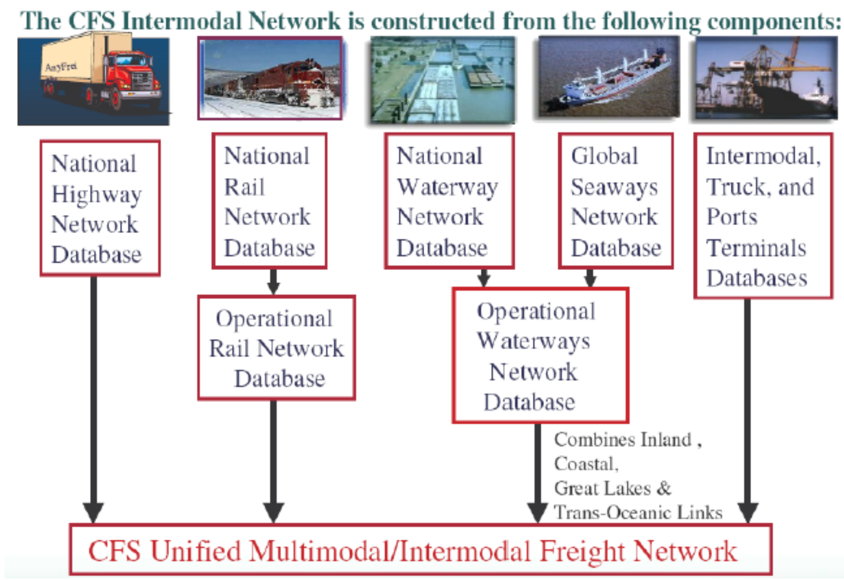
4. ESTIMATION OF TRUCK ORIGIN-DESTINATION TRIP TABLE FROM COMMODITY FLOWS

This chapter describes a simplified procedure for estimating truck origin-destination (O-D) trip table using the commodity flow data from the Freight Analysis Framework (FAF) Database. The truck O-D trip table will be used as inputs in vulnerability assessment of freight chokepoints in transportation networks. This chapter consists of the following sections:

- Overview of Freight Analysis Framework Database,
- Truck O-D trip table estimation procedure,
- Truck O-D trip tables for the State of Utah,
- Traffic Assignment and Model Validation,
- Conversion Factors Adjustment, and
- Results and Truck Flows Map

4.1 Overview of Freight Analysis Framework Database

The Freight Analysis Framework (FAF) Database was developed by the Bureau of Transportation Statistics (BTS) for the Federal Highway Administration (FHWA). The current version of the FAF Commodity Origin-Destination Database provides estimates of commodity flows for the base year 2002 and the forecast years from 2010 to 2035 with a five-year interval. The key data source of the FAF Database is based on the Commodity Flow Survey (CFS) data, which were built entirely from public data sources of several organizations including the Census Bureau, U.S. Department of Commerce, BTS, U.S. Department of Transportation, Foreign Waterborne Cargo, the U.S. Army Corps of Engineers; and other sources as illustrated in Figure 4.1.



Source: Southworth and Peterson, 2000

Figure 4.1 Data sources of Commodity Flow Survey (CFS)

In the following, several key features of the FAF commodity flow database are highlighted:

- Database format
- Zoning system
- Mode of freight transportation
- Standard Classification Transported Goods (SCTG) code
- Freight flow network

- Database Format

The FAF Commodity Origin-Destination Database, which is publicly accessible from the Freight Management and Operations Database from the FHWA website[1], provides data in two formats: Comma Delimited (.csv) or Microsoft Access file (.mdb). The measurement units of the commodity flow database are in thousand of tons (represented by KT) and million of dollars (represented by MDOL). The FAF commodity flow database consists of the following three databases:

- DOM database is the commodity flows between domestic origins and domestic destinations.

[1] Available at: http://ops.fhwa.dot.gov/freight/freight_analysis/faf/index.htm

- BRD database is the commodity flows by land from Canada and Mexico to domestic destinations via ports of entry on the U.S. border and from the domestic origins via existing ports on the U.S. border to Canada and Mexico.
- SEA database is the commodity flows by water from overseas origins via ports of entry to domestic destinations and from domestic origins via ports of exit to overseas destinations.

- Zoning System

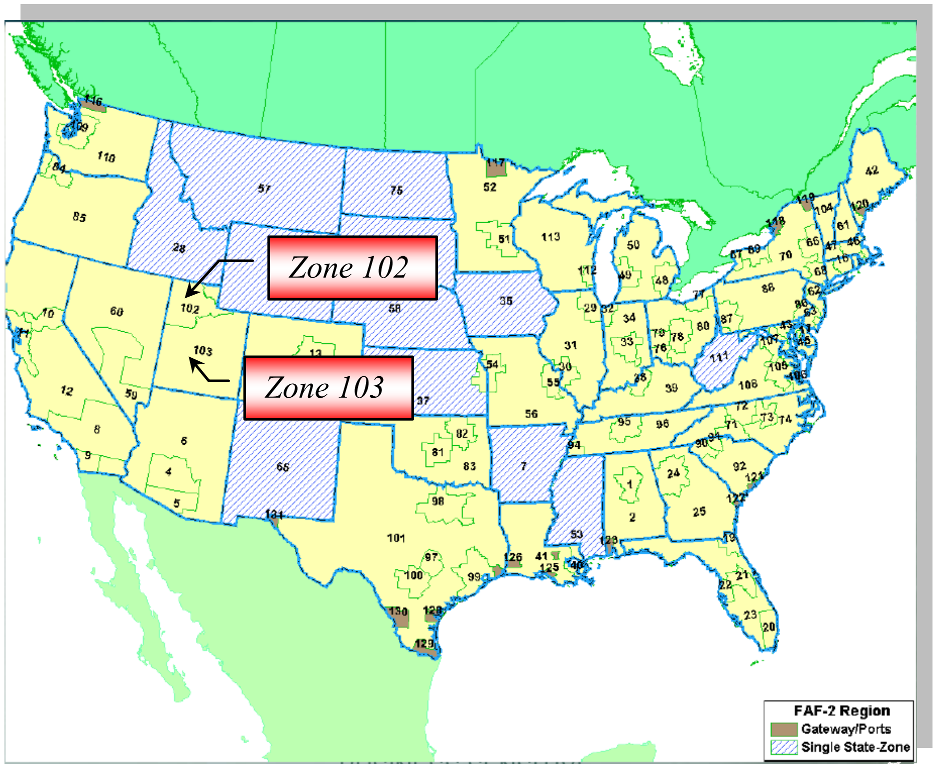
The FAF commodity flow database is comprised of 114 domestic zones and 7 international trading zones. In addition, there are 17 international gateways including major ports and international crossings. The FAF zoning system is illustrated in Figure 4.2. The domestic zones in the United States are classified into three areas:

- Metropolitan Statistical Areas (MSA)
- Consolidated Statistical Areas (CSA)
- States or Balances of States

There are two domestic zones in Utah:

Zone 102: UT part of the Salt Lake City-Ogden-Clearfield, UT-CSA region

Zone 103: Remainder of UT



Source: Battele, 2002

Figure 4.2 FAF Zoning System

- Mode of Freight Transportation

The FAF commodity flow database classifies freight transportation into seven modes:

- Truck
- Rail
- Water
- Air (including Truck-Air)
- Truck-Rail
- Other Intermodal
- Pipeline/Unknown

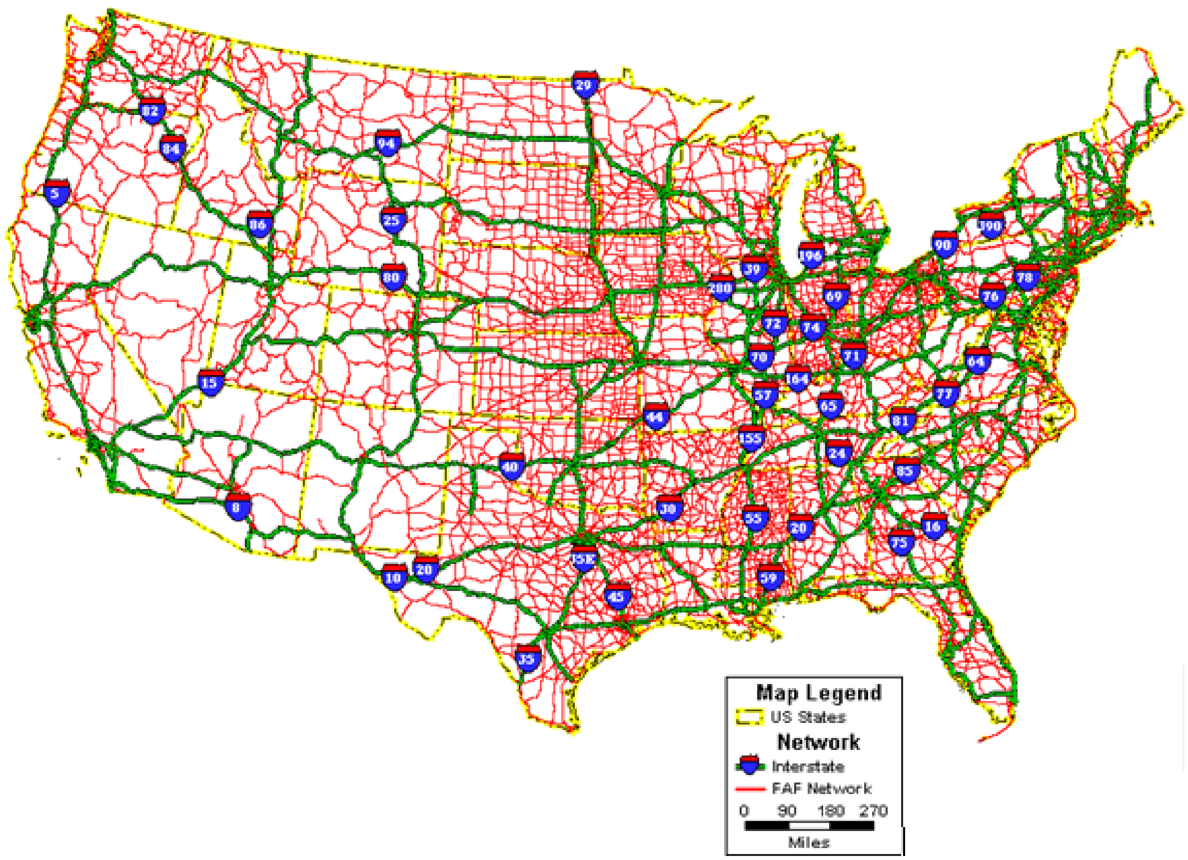
For the purpose of this study (which is vulnerability assessment of truck-freight bottlenecks/chokepoints), the major focus is freight shipment by truck.

- Standard Classification Transported Goods (SCTG) Code

The FAF commodity flow database employs the SCTG code to classify the commodity using a five-digit numbering system. The total transported goods code in this study is 43 categories and they are defined as a two-digit number according to the SCTG code. The details of the SCTG codes are provided in Appendix A.

- Freight Flow Network

The FAF commodity flow database provides the freight flow network in two formats: Shapefile or TransCAD file. These files can be displayed and edited using a GIS software such as ArcGIS, TransCAD, MapWindow, etc. Figure 4.3 provides an illustration of the FAF truck freight network using the TransCAD file.



Source: Battele, 2002

Figure 4.3 FAF Truck Freight Network

4.2 Truck O-D Trip Table Estimation Procedure

Using the FAF commodity flow database as the main source of data, a simplified procedure was developed for this study to estimate truck O-D trip table from commodity flows. This method accounts for all types of truck flows including intrastate trips (within state) and interstate trips (trips originating from the state and trips destined to the state), and through trips. The estimation procedure consists of six steps as illustrated in Figure 4.4.

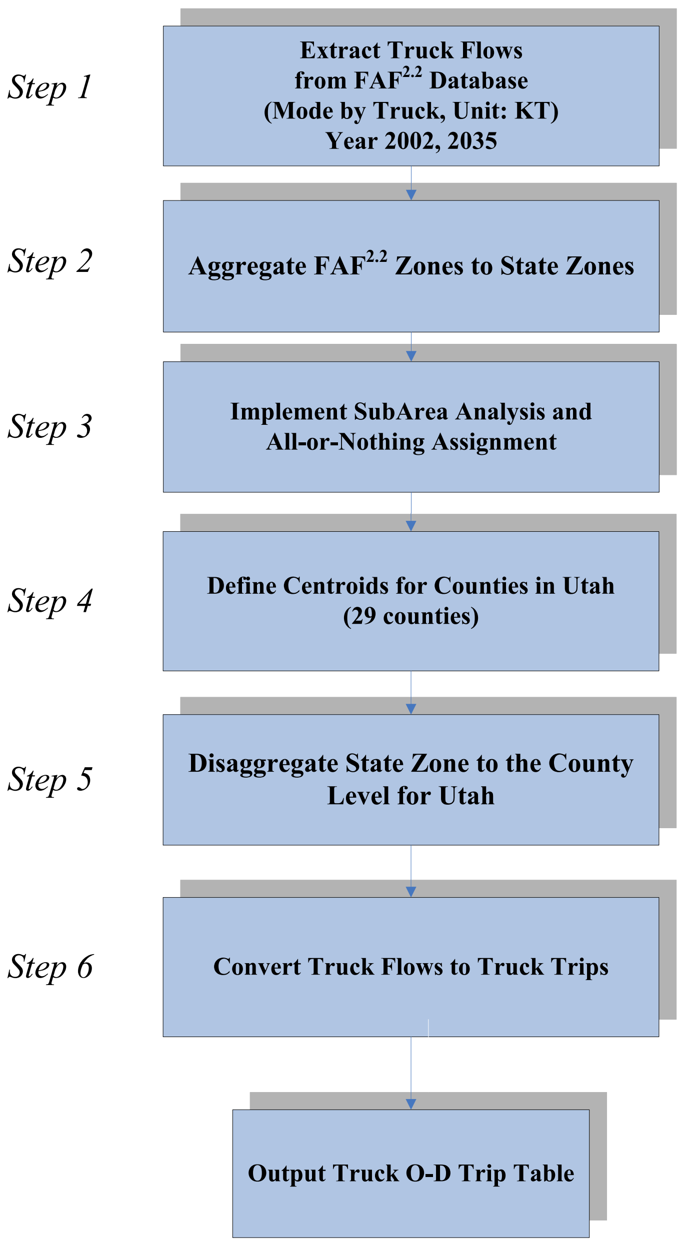


Figure 4.4 Truck O-D Trip Table Estimation Procedure

Step 1: Extract Truck Flows from the FAF Database

The first step is to extract truck flows from the FAF commodity flow database using the DOM database. In this step, the database inquiry technique is employed in Microsoft Access to select the required data. Figure 4.5 displays the concept of data inquiry and management. The outputs of this step are truck flows for a given state by weight for the current and forecast years.

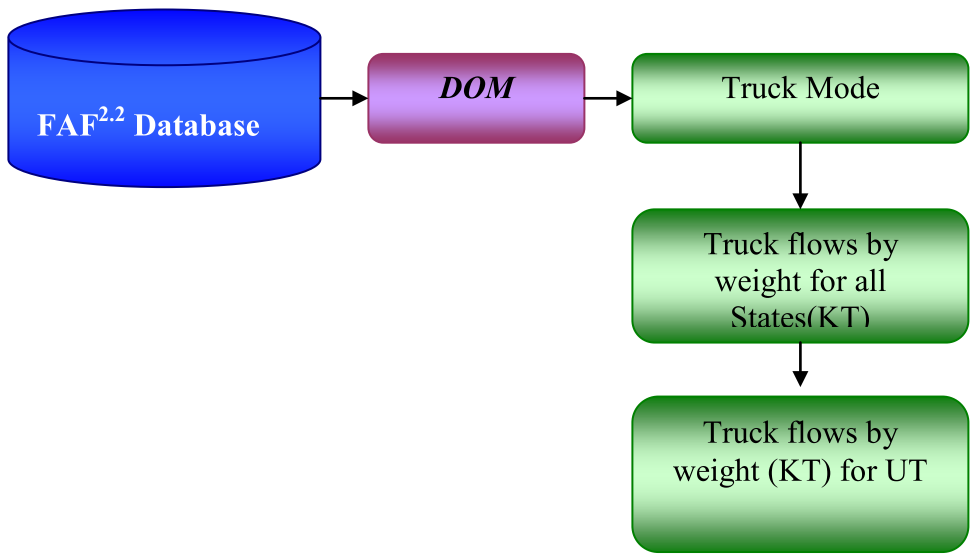


Figure 4.5 Concept of FAF Database Inquiry

Step 2: Aggregate FAF Zones to State Zones

This step aggregates the 114 FAF zones to 49 state zones. It requires quantifying four types of truck flows including:

1.) Truck flows within Utah (Internal-Internal, I-I)

2.) Truck flows from Utah to other states (Internal-External, I-E)

3.) Truck flows from other states to Utah (External-Internal, E-I)

4.) Through truck flows (E-E)

Figure 4.6 provides an illustration of the four types of truck flows in Utah. Figure 4.7 depicts the procedure to aggregate the FAF zones to state zones. The results of I-I, I-E, and E-I truck flows are provided in Appendix B. It should be noted that the FAF database does not provide enough information to estimate the through truck flows (E-E). In order to estimate the through truck flows, Step 3 to Step 5 are carried out.

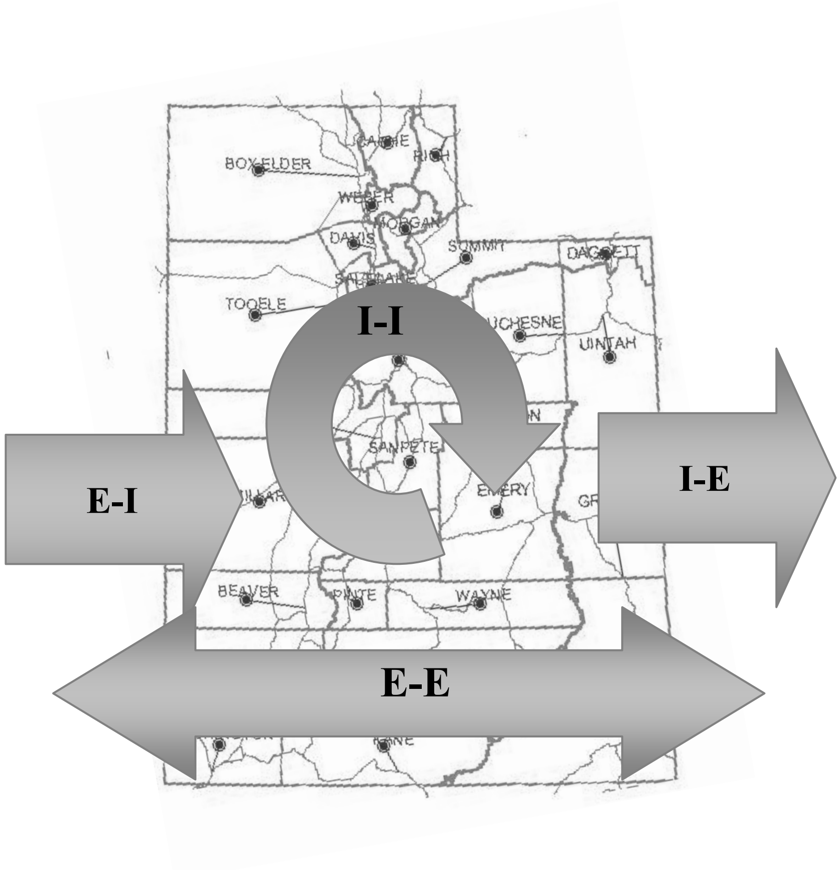


Figure 4.6 Types of Truck Flows

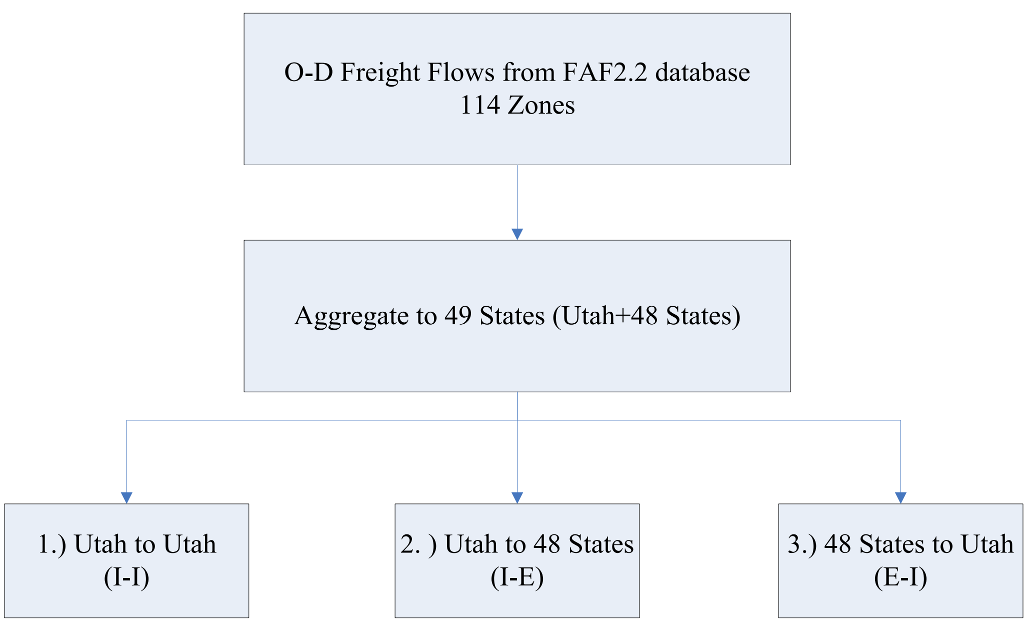


Figure 4.7 Procedure to Aggregate Truck Flows

Step 3: Implement Subarea Analysis and All-or-Nothing Assignment

The overall process of Step 3 is depicted in Figure 4.8. The first task is to identify the state centroids for all states in the United States, excluding Alaska and Hawaii. There are 49 centroids (including District of Columbia). The state centroids are located either at the state capital or at the major city in the state, and they are depicted in Figure 4.9.

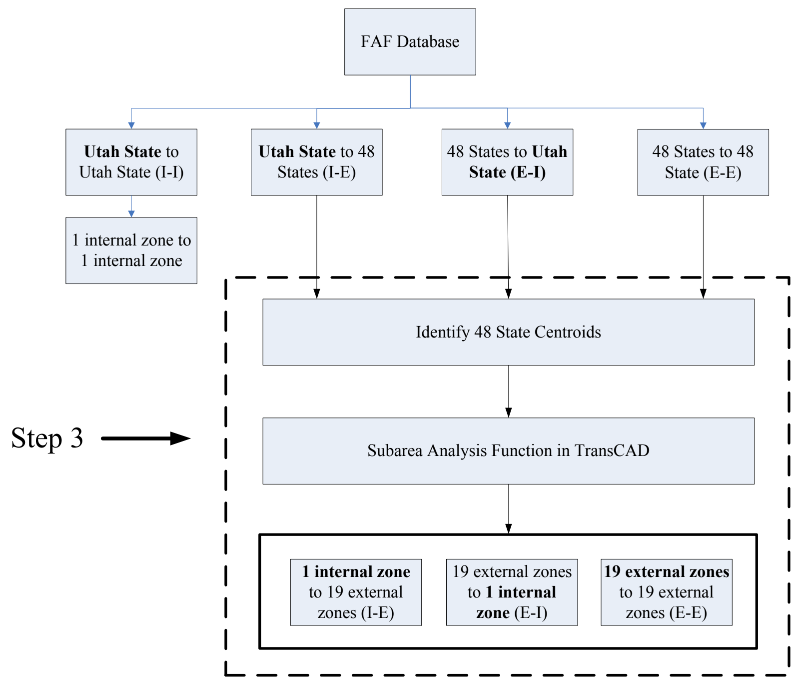


Figure 4.8 Overall Process of Step 3

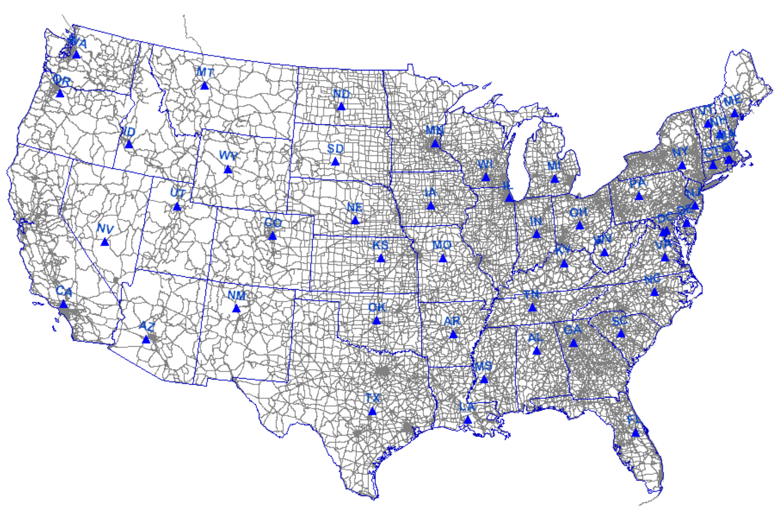


Figure 4.9 State Centroids in the United States

The next task is to determine the truck flows passing through Utah. In this task, the Subarea Analysis and All-or-Nothing Assignment functions are applied in TransCAD (see TransCAD manual for details of these two functions). Note that TransCAD also automatically identifies the external stations that enter and exit to/from Utah. There are 19 external stations identified by the Subarea Analysis as shown in Figure 4.10.

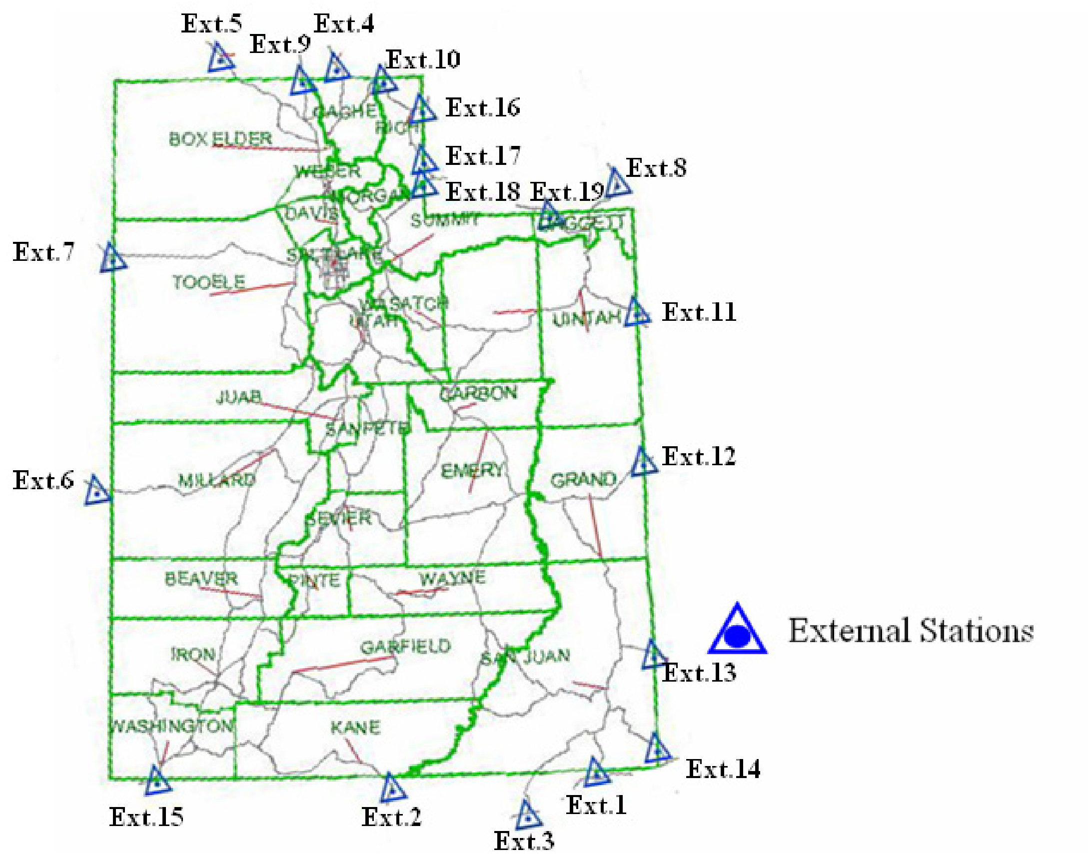


Figure 4.10 External Stations

<u>Step 4: Define Centroids for Counties in Utah</u>

This step identifies the centroids for the counties in Utah that will be used to estimate the truck flows within Utah (i.e., intrastate trips). These centroids and centroid connectors are predefined in the FAF network. Figure 4.11 shows the centroids and centroid connectors for the 29 counties in Utah.

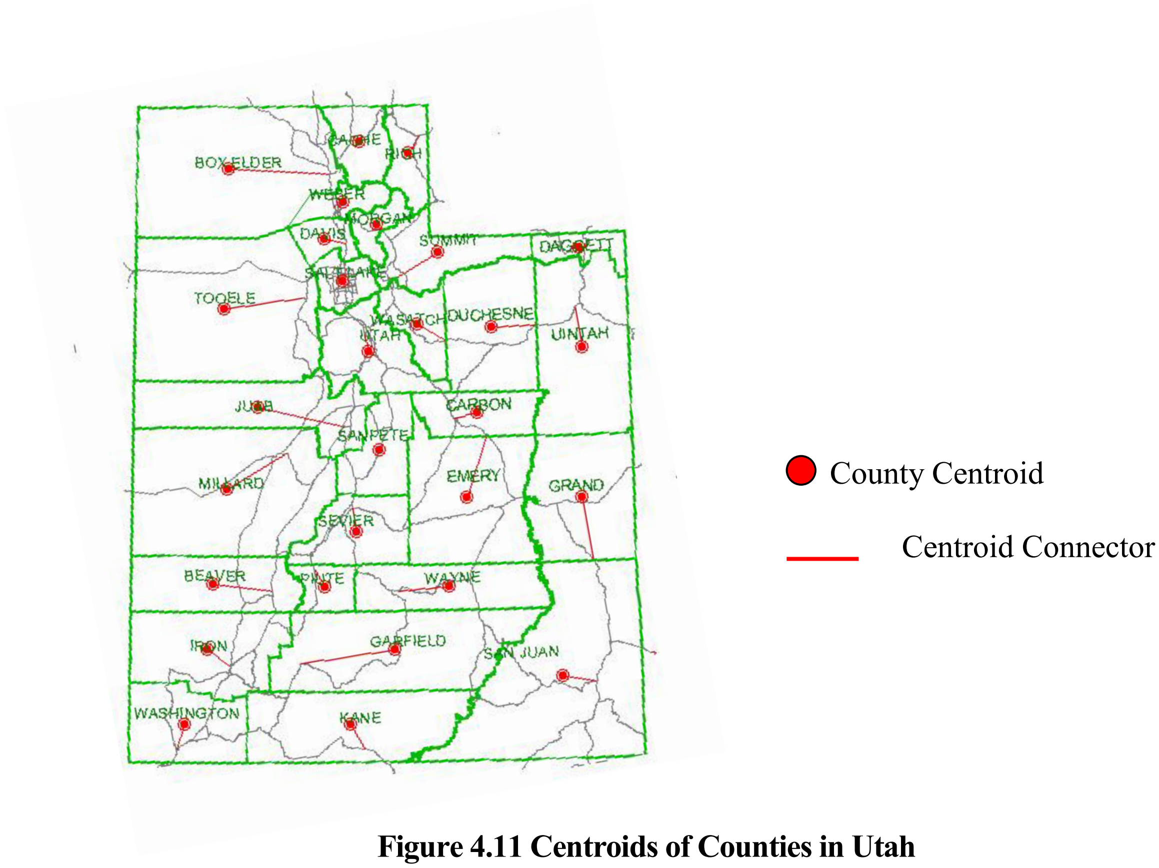


Figure 4.11 Centroids of Counties in Utah

Step 5: Disaggregate Truck Flows to the County Level

The overall process of Step 5 is depicted in Figure 4.12. This step is to disaggregate the truck flows from the state level to the county level using population and employment rate as the disaggregation factors. It should be noted that population and employment factors for the forecast year 2035 is extrapolated from the population[2] and employment[3] projections. These factors are calculated according to Equations (4.1) and (4.2).

$$F_{POP}(i) = \frac{population\_county_i}{\sum_{i=1}^{N=29} population\_county_i} \tag{4.1}$$

$$F_{EMP}(i) = \frac{employment\_county_i}{\sum_{i=1}^{N=29} employment\_county_i} \tag{4.2}$$

2 Counties of Utah-Population Projections provided by Utah Governor's Office of Planning and Budget (GOPB)

3 State of Utah Employment Projections By County and Multi-County District provided by U.S. Bureau of Economic Analysis; Utah Department of Work Force Services

Using the truck flows from Step 3 and the above factors, the Disaggregate Function in TransCAD is used to disaggregate the truck flows to the county level. The results of this step are provided in Appendix C.

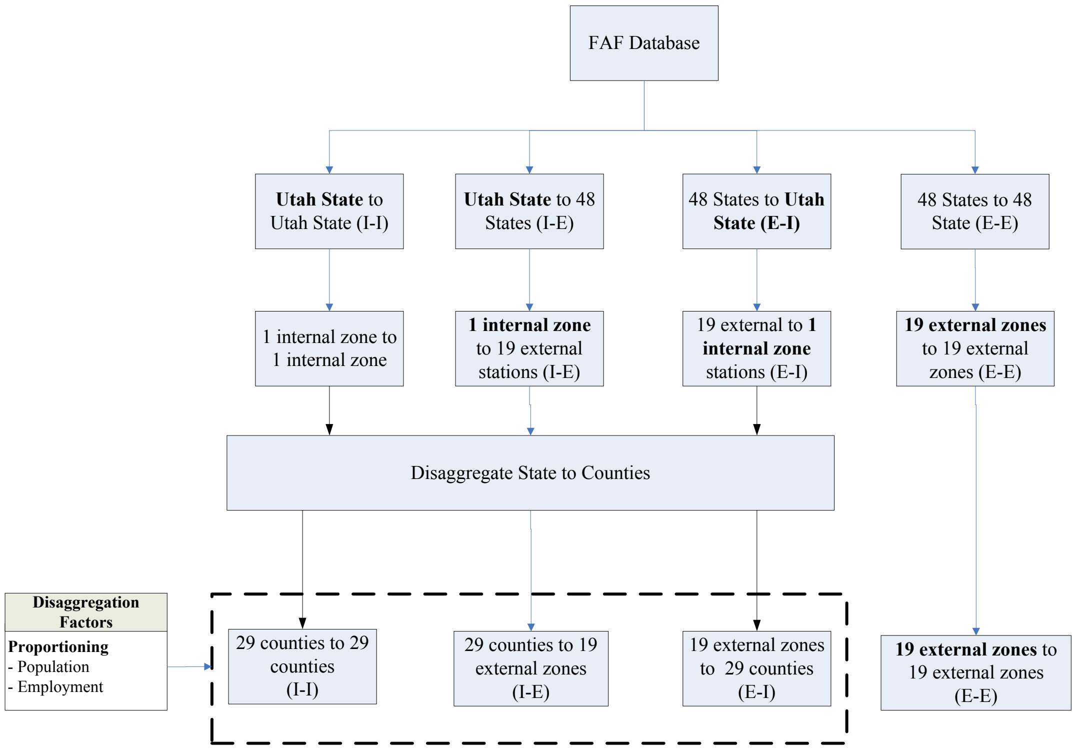
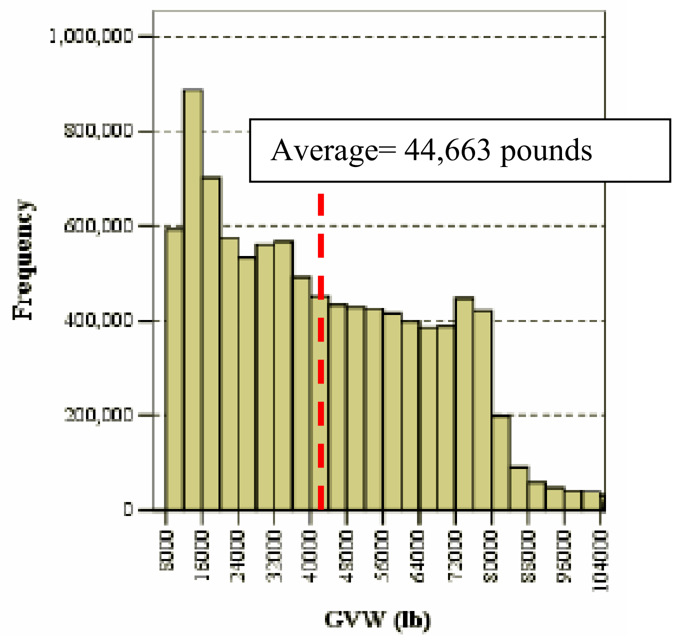


Figure 4.12 Overall Process of Step 5

Step 6: Convert Truck Flows to Truck Trips

This step converts the truck flows from Step 5 to truck trips. In this step, the average payload of commercial vehicle from the Weight-In-Motion (WIM) stations in Utah is used. Based on the study by Schultz and Seegmiller (2006), the average payload of commercial vehicle in Utah is about 44,663 lbs./veh. or 22.33 tons/veh. as shown in the Gross Vehicle Weight (GVW) histogram in Figure 4.13.



Source: Schultz, G.G and Seegmiller, L.W. (2006)

Figure 4.13 GVW Histogram from WIM stations

4.3 Truck O-D Trip Tables for the State of Utah

As a case study, the truck O-D trip table estimation procedure described in Section 4.2 is applied for the State of Utah for the base year (2002) and forecast year (2035). The size of the trip table is 48x48 (29 internal zones or counties within Utah and 19 external stations). The details of these two trip tables are available in MS Excel format. Here a summary of the estimation results is provided. Figures 4.14 and 4.15 show the proportions of truck trips for the base year and forecast year, respectively. Tables 4.1 and 4.2 provide the amounts of truck trips generated from and attracted to each of the 29 counties in Utah. It should be noted that these truck O-D trip tables are estimated based on the FAF commodity flow database, the average payload of commercial vehicle derived from the WIM data in Utah, and the assumptions used in the aggregation (Step 2) and disaggregation procedure (Steps 3 to 5).

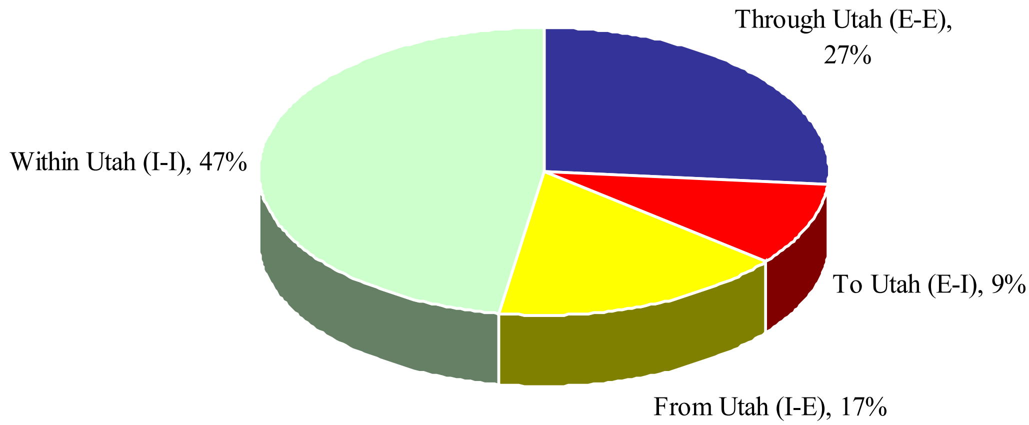


Figure 4.14 Utah truck trip proportions (Year 2002)

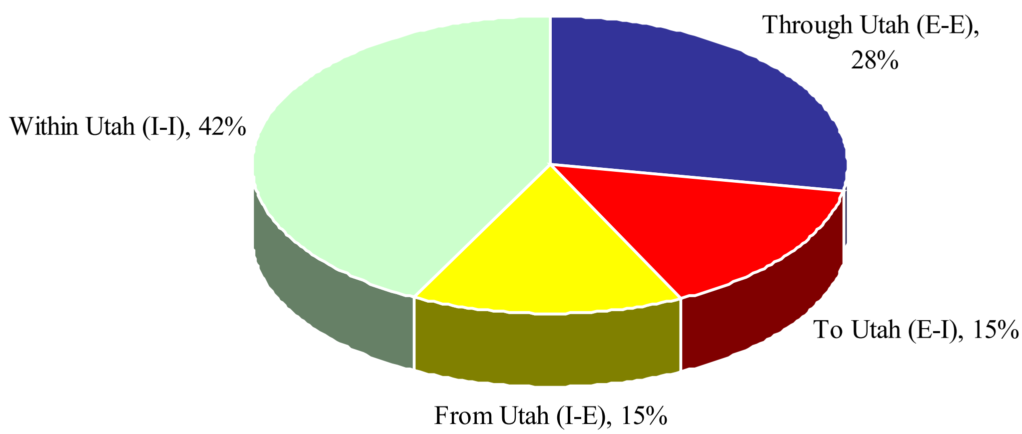


Figure 4.15 Utah truck trip proportions (Year 2035)

Table 4.1 Truck trips from and to each county in Utah (Year 2002)

No	County	Truck Trips	
		To	From
1	Beaver County	10,531	12,001
2	Box Elder County	77,095	80,995
3	Cache County	165,678	204,877
4	Carbon County	34,231	35,731
5	Daggett County	1,550	1,970
6	Davis County	430,215	482,713
7	Duchesne County	25,635	26,622
8	Emery County	18,476	18,116
9	Garfield County	7,952	9,566
10	Grand County	14,916	18,067
11	Iron County	61,015	68,378
12	Juab County	14,907	13,907
13	Kane County	10,417	11,492
14	Millard County	21,376	23,942
15	Morgan County	12,810	13,674
16	Piute County	2,382	2,856
17	Rich County	3,368	4,907
18	Salt Lake County	1,592,457	1,895,939
19	San Juan County	23,883	17,778
20	Sanpete County	40,319	38,803
21	Sevier County	32,986	34,010
22	Summit County	55,025	73,971
23	Tooele County	79,422	85,099
24	Uintah County	45,279	48,267
25	Utah County	676,790	713,335
26	Wasatch County	29,208	31,378
27	Washington County	171,962	172,483
28	Wayne County	4,383	5,479
29	Weber County	351,137	396,598

Table 4.2 Truck trips from and to each county in Utah (Year 2035)

No	County	Truck Trips	
		To	From
1	Beaver County	29,424	21,669
2	Box Elder County	159,424	173,491
3	Cache County	421,573	405,487
4	Carbon County	60,497	71,178
5	Daggett County	2,570	4,066
6	Davis County	927,027	828,437
7	Duchesne County	49,966	47,053
8	Emery County	29,266	26,830
9	Garfield County	15,134	21,836
10	Grand County	26,969	33,677
11	Iron County	206,656	147,976
12	Juab County	41,607	30,336
13	Kane County	23,691	42,511
14	Millard County	44,524	35,668
15	Morgan County	56,821	17,260
16	Piute County	3,642	2,576
17	Rich County	6,491	6,109
18	Salt Lake County	3,362,481	4,641,755
19	San Juan County	36,092	35,928
20	Sanpete County	82,485	70,440
21	Sevier County	57,035	66,290
22	Summit County	194,396	213,537
23	Tooele County	284,642	122,169
24	Uintah County	95,546	74,816
25	Utah County	2,148,780	1,632,963
26	Wasatch County	115,431	71,220
27	Washington County	981,951	525,437
28	Wayne County	7,437	14,306
29	Weber County	733,611	827,840

4.4 Traffic Assignment and Model Validation

In this step, previously analyzed truck trips are assigned to the Utah highway network. In this task, the All-or-Nothing (AON) traffic assignment functions in TransCAD are used to assign flow between O-D based on the shortest distance. The results of this process are the estimated daily truck flows of each highway segment. After obtaining the truck flows, the model validation was implemented to test the consistency between the estimated and observed truck flows. The observed truck flows were computed from the percentage of single and combo truck using the 2002 Annual Average Daily Traffic (AADT) data provided by UDOT.

The locations for the comparison were selected from the interstate highways which are on interstate highway 15, 70 and 80 respectively. These interstate highways are recognized as the major truck routes for Utah. In total, there are 62 locations used for this model validation process. The statistical measure used here is the percent root mean square error (RMSE). The percent RMSE provides the relative closeness of estimated and observed truck flows for each individual data. They can be computed using the following formula:

$$\%RMSE = \frac{\sqrt{\frac{\sum_{i=1}^{N}(O_i - E_i)^2}{N}}}{\frac{\sum_{i=1}^{N}O_i}{N}} * 100 \qquad (4.3)$$

Where O is the observed truck flows,

E is the estimated truck flows

N is the number of data

The comparison results between observed and estimated truck flows are depicted in Figure 4.16. The percent RMSE is approximately 73%. As can be seen in Figure 4.16, the results are scattered under the 45 degree line which implies that the model is underestimated. This means that truck flows that were generated from the model are lower than the actual observed data. More specifically, about 75% of the estimated data are underestimated. It should be noted that truck O-D trip table in this study was analyzed from the commodity flow database, and using only the commodity flows can underestimate the local freight activities especially the local freight activity at the metropolitan areas. Therefore, the next process is to adjust the truck O-D trip table while considering two factors:

1) The conversion factors for truck tonnage to truck trips and
2) The number of workdays per year.

More details of adjustment process are described in the next section.

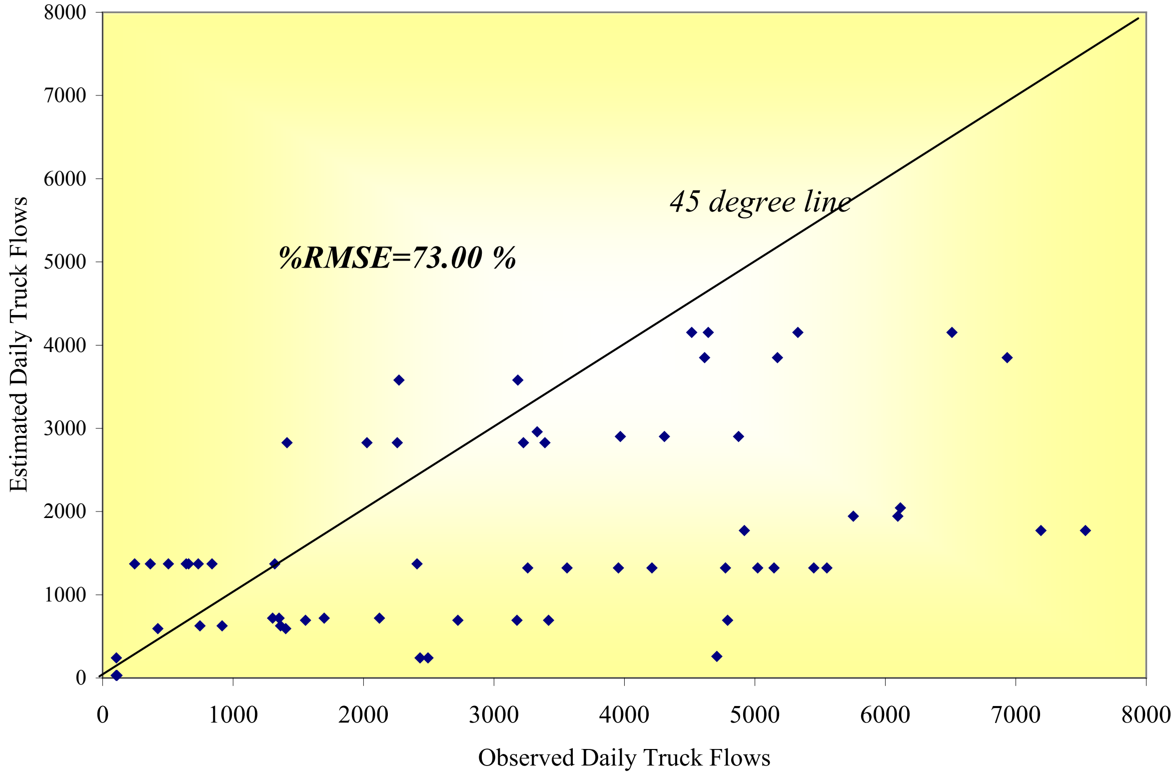


Figure 4.16 Comparison of observed and estimated daily truck volumes

4.5 Conversion Factors Adjustment

From section 4.2, the average truck payload is 44,663 lbs./vehicle or 22.33 tons/vehicle. This conversion factor is slightly higher than the studies in other states. For instance, the average payload of the top ten counties in Ohio is approximately 16.07 tons/vehicle, the tonnage to truck trips rate for New Jersey is 20.0 tons/vehicle and the maximum payload factors for Texas are about 17.89 tons/vehicle for local haul and 25.77 tons/vehicle for long haul (see Appendix D for more detail).

In this study, the truck payload equivalent factor (TPEF) is employed as derived from the Federal Vehicle Inventory and User Survey (VIUS) data. For Utah, the average payload classified by vehicle class using VIUS information can be summarized in Table 4.3. Truck class 5 is used as the proxy class due to the highest frequency collected at Weigh in Motion (WIM) stations. The result indicates that the average payload for this class is 41,196 lbs/vehicle or 20.6 tons/vehicle. This number is in the reasonable range compared to the above researches.

To convert the annual to average daily truck flows, Krishnan and Hancock (1998) suggested that the annual number of trucks be divided by 260 days. In the current study, however, the working days per year for trucks are adopted from Highway Capacity Manual (HCM). According to HCM (2000), the average truck workdays is 5 days per week plus 44% capacity on weekends, yielding 306 workdays per year, minus 6 federal holidays. As a result, the total truck workdays yield 300 days per year. Therefore, two factors are adjusted including:

1) Factor for converting tonnage to truck trips............. Divide tonnage by 20.6 tons/truck.

2) Factor for converting annual to workdays… ……... Divide by 300 workdays.

Table 4.3 Average Payload (lbs) by FHWA Vehicle Class VIUS (Utah)

Class	Description	Average Payload (lbs.)
Class 1	Single Unit: 2-axle	5,917
Class 2	Single Unit: 3-axle	16,510
Class 3	Single Unit: 4-axle or more	32,118
Class 4	Truck/Tractor Trailers: 4-axle or less	15,307
Class 5	Truck/Tractor Trailers: 5-axle	41,196
Class 6	Truck/Tractor Trailers: 6-axle or more	53,222
Class 7	Combination Trucks: 5-axle or less	27,606
Class 8	Combination Trucks: 6-axle	32,503
Class 9	Combination Trucks: 7-axle or more	77,802

4.6 Results and Truck Flows Map

After the adjustment, the truck O-D trip table is updated and assigned to the highway network using All-or-Nothing (AON) traffic assignment. Figure 4.17 shows the daily truck flows on the Utah highway. And, the observed and estimated truck flows are compared and depicted in Figure 4.18. As can be seen, after adjusting the factors, the percent RMSE decreases to 56.7% and the underestimated data decreases to 52.0%. To illustrate the results, the GIS map as shown in Figure 4.19 is used to compare assigned and observed truck flows.

The results of estimated data show the better agreement with the observed truck flows especially on the rural interstates. However, there might be inconsistency at the interstate highways near Salt Lake City and the metropolitan areas. This may be caused from the high truck flows that generated from the local freight facilities, e.g. retail store, intermodal freight center, freight company. The updated information of these data sources will improve the quality of truck O-D trip table, specifically in the metropolitan areas like Salt Lake City.

The accuracy of these results depends significantly on the quality of data and the methodology used to estimate the trip tables. These truck O-D trip tables should be updated as soon as better quality data sources are obtained. To improve truck O-D trip table, the following data should be collected.

- Truck vehicle mile travel (TVMT) for each county in Utah used for the disaggregation of county-level commodity flows,
- Truck surveys at state borders and county-to-county level,
- Truck surveys at freight companies and distribution centers for each county and
- The commercial TRANSEARCH database from Global Insight on commodity flows for Utah.

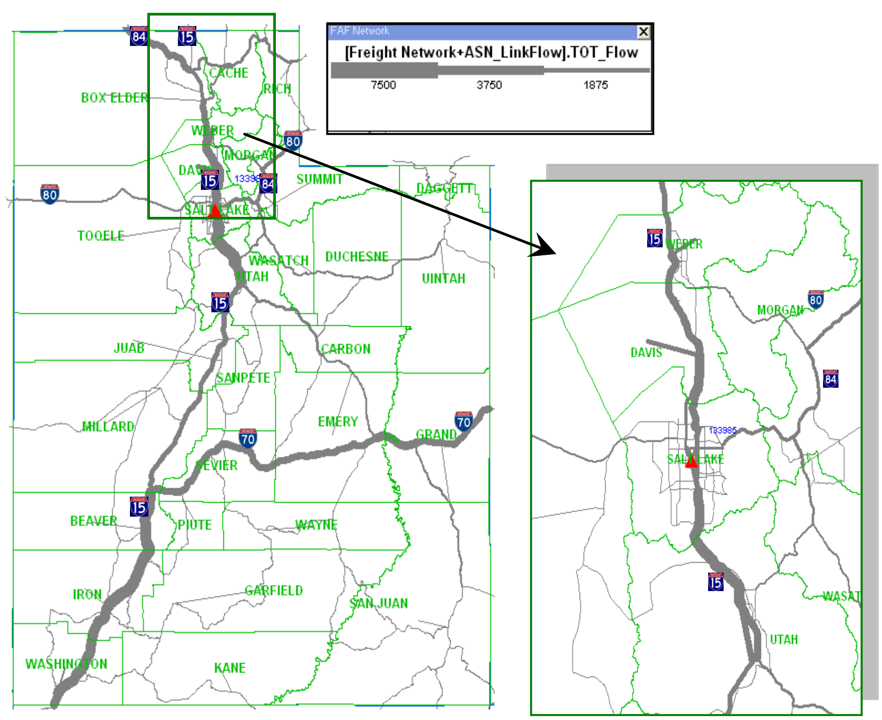


Figure 4.17 Daily truck flow map of Utah

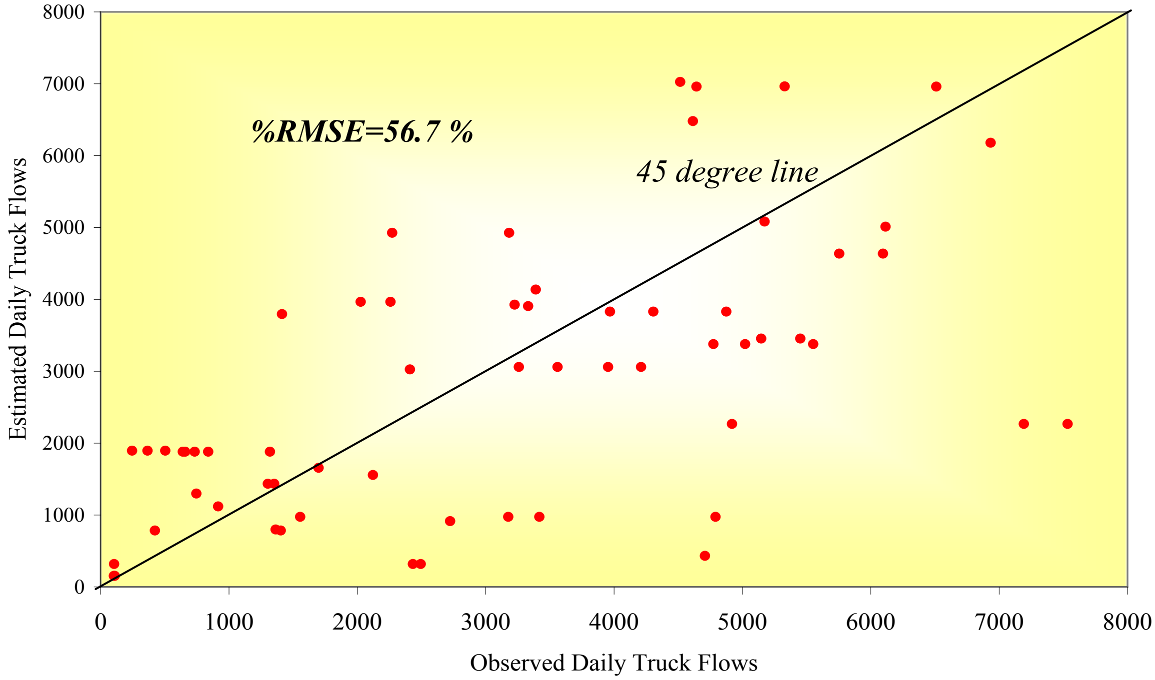


Figure 4.18 Comparison of observed and estimated daily truck flows (after adjustment)

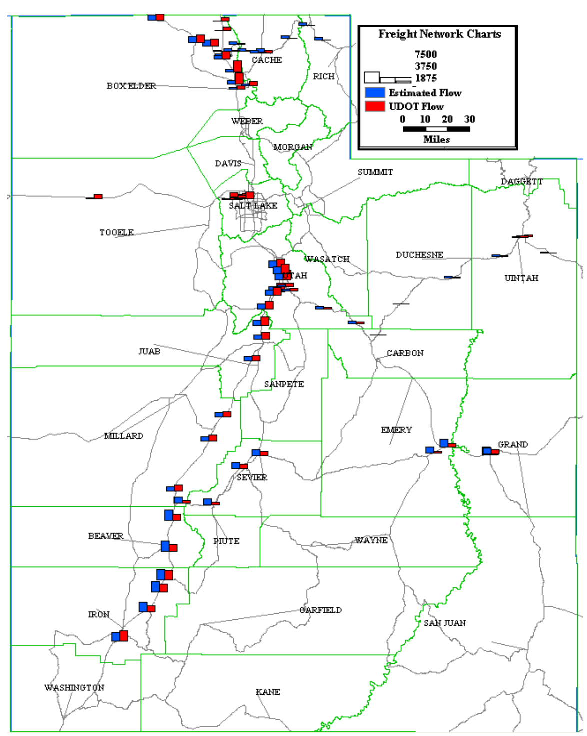


Figure 4.19 Comparison of observed and estimated daily truck flows at selected locations

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5. FREIGHT CHOKEPOINT ANALYSIS TOOL

This chapter describes the development of a decision support tool for assessing the vulnerability of freight chokepoints called FCAT (Freight Chokepoint Analysis Tool). FCAT is developed using the MapWindow GIS platform to support the visualization of geospatial data (e.g., freight transportation network, zone boundary, zone centroid, chokepoint, etc.) in GIS formats with plug-in tools for assessing the vulnerability of freight chokepoints. The organization of this technical memorandum includes the following sections:

- What is FCAT?
- FCAT framework
- FCAT input data
- Vulnerability assessment methods in FCAT
- FCAT key features
- FCAT user manual

5.1 What is FCAT?

FCAT is a GIS-based decision support tool that allows the user to assess the vulnerability of freight chokepoints in transportation networks. The assessment results can be visualized, stored, edited and managed in GIS formats. With FCAT, the user can:

- Run FCAT with GUI (graphical user interface)
- Display freight chokepoints in a GIS map
- View/Manage/Edit a GIS map
- Create what-if scenarios (e.g., disruption of chokepoints) for vulnerability assessment
- Assess the vulnerability of freight chokepoints (i.e., O-D connectivity (or detour route) and freight flow pattern change)
- Interactively display and query path between any O-D pair
- Change network link attributes for another scenario run
- Create thematic maps of before and after network disruptions
- Compare assessment results before and after network disruptions

The GUI is depicted in Figure 5.1. It includes the main menu, menu item, toolbar button, preview map, legend, map area, and assessment panel.

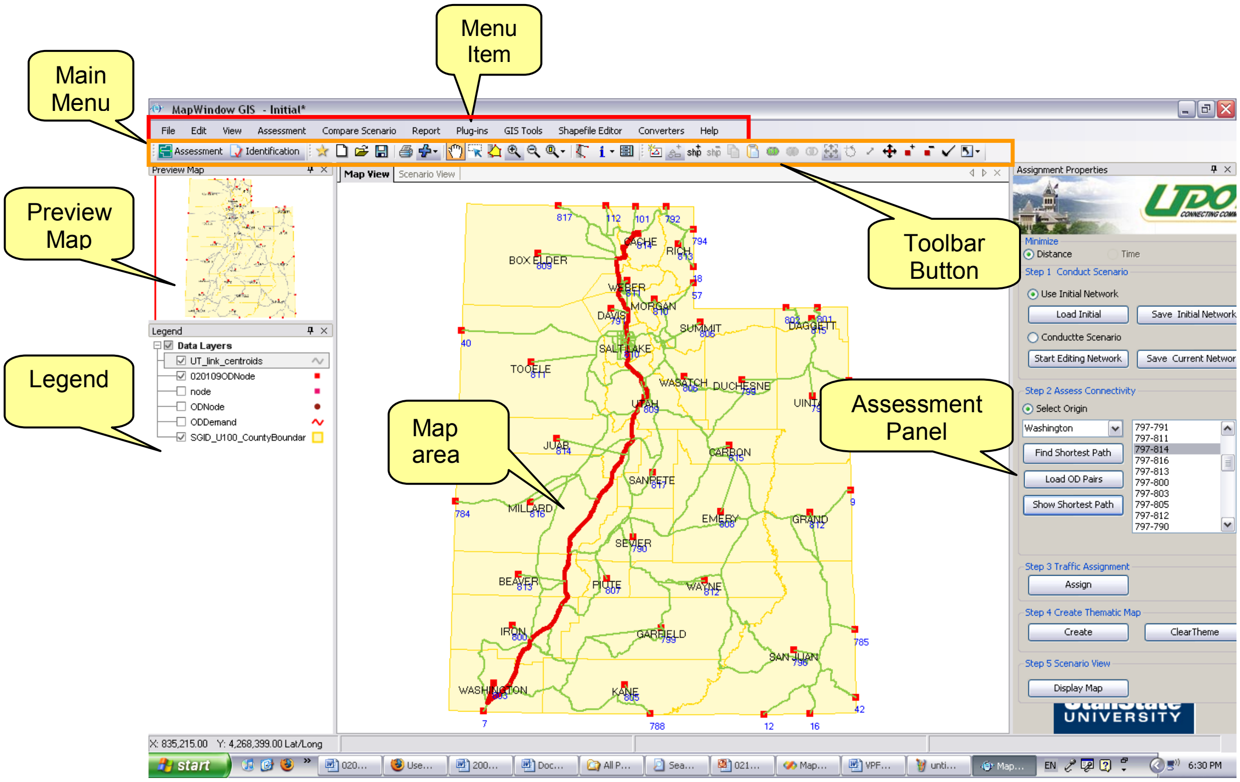


Figure 5.1 FCAT Graphical User Interface (GUI)

5.2 FCAT Framework

FCAT is a GIS decision support system developed in MapWindow, an open source code and programmable GIS software, using Microsoft Visual Basic.NET. MapWindow, originally developed at Utah State University (USU) by the Environmental Management Research Group (EMRG, 2005), supports manipulation, analysis, and viewing of geospatial data and associated attribute data in several standard GIS data formats. MapWindow is a mapping tool, a GIS modeling system, and a GIS application programming interface (API) all in one convenient redistributable open source form. FCAT was developed as a plug-in in the MapWindow API, which allows the developer to customize the function in an open source environment. Note that MapWindow is free to use and redistribute to your clients and other end users. A copy of the FCAT research software may be obtained through the UDOT Research Division or the authors of this report. The overall framework of FCAT is depicted in Figure 5.2.

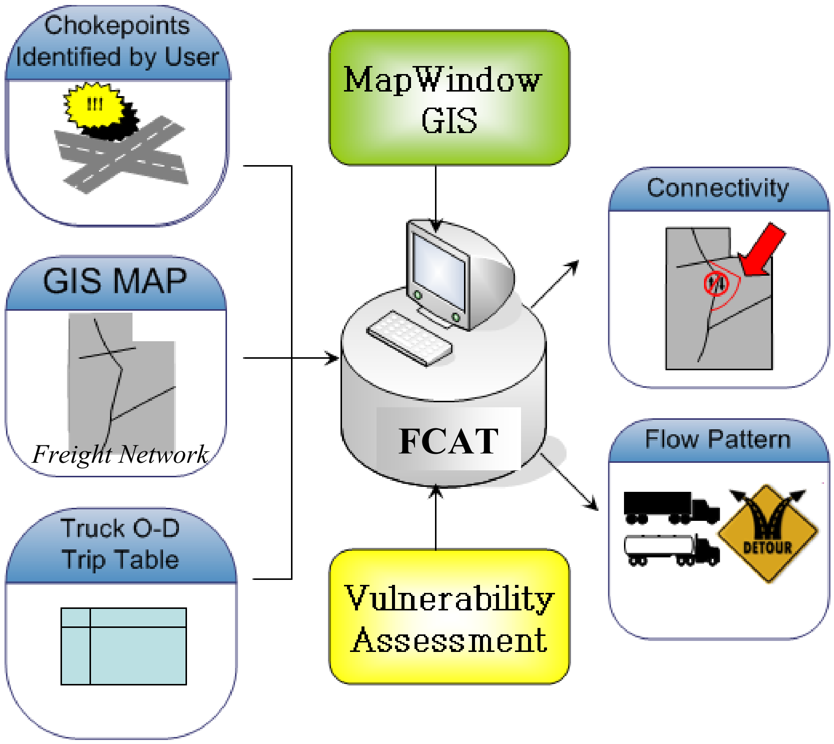


Figure 5.2 FCAT framework

5.3 FCAT Input Data

To use FCAT for vulnerability assessment, the following inputs are required:

- Freight network in a GIS shapefile format
- Truck O-D trip table
- Chokepoint locations

Freight Transportation Network

To use FCAT for vulnerability assessment, one of the key inputs is the freight transportation network. The Utah truck freight transportation network is extracted from the FAF[4] network provided by the Office of Operations from the FHWA. Figure 5.3 shows the national freight network for the whole United States, and the Utah freight network extracted from the FAF

[4] Map Available at: http://ops.fhwa.dot.gov/freight/freight_analysis/faf/

network. The Utah freight network consists of 817 nodes, 908 links, 48 zones (29 internal zones and 19 external stations), and 2,304 O-D pairs.

Network Attributes

FCAT requires the following network attributes in the GIS shapefile for assessing network vulnerability.

- From node and to node (for connectivity analysis)
- Link length (for connectivity analysis)
- Enable/disable (for identifying potential freight chokepoints used in the scenario analysis)
- Total and directional demand (for freight flow pattern analysis)

FCAT will read these attributes in a GIS shapefile format and generate outputs as text (or ASCII) files for further analysis.

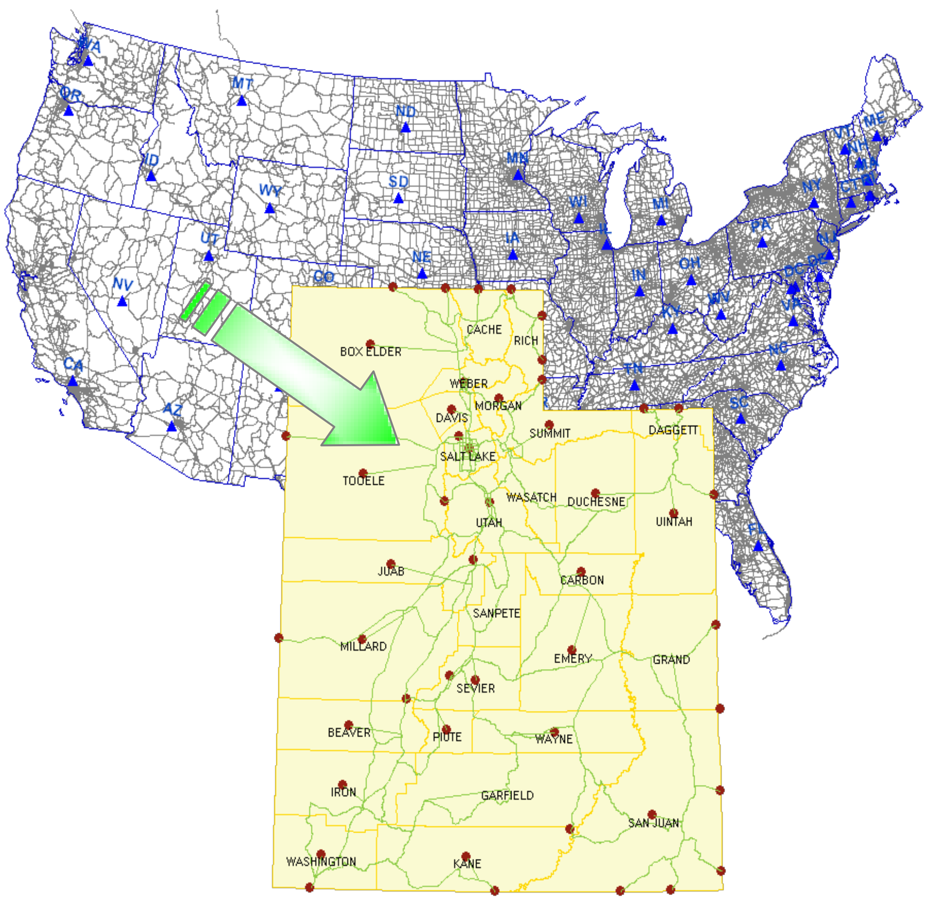


Figure 5.3 Utah freight transportation network

Truck Origin-Destination (O-D) Trip Table

The daily truck O-D trip table obtained from Chapter 4 is also stored in a GIS shapefile format. When user opens the FCAT program, this shapefile is automatically loaded. To update or edit the O-D trip table, user can use the Table Editor tool.

Freight Chokepoint Locations

Freight chokepoint locations are identified by the user as part of the "what-if" analysis. To disable a link, user can use the Attribute Table Editor to disable a link (see Section 5.5).

5.4 The Vulnerability Assessment Method in FCAT

This section describes the vulnerability assessment methods used in FCAT. For vulnerability assessment, the following two measures are used:

- O-D connectivity (or detour route)
- Freight flow pattern change

O-D Connectivity

To assess the O-D connectivity, the shortest path algorithm by Dijkstra (1959) is used. Since the usual best route may not be available when the chokepoint is disrupted, the shortest paths of all O-D pairs are recalculated and traced to show the detour routes. The increased travel distances after the disruption are computed. Here, the steps of the Dijkstra algorithm are provided.

- Dijkstra's Algorithm

This algorithm is an iterative application of the one-to-one (or the one-to-many) shortest path problem. All links (i,j) in the network are assumed to have non-negative distances l(i,j). The algorithm begins at a specified source node *r* and successively finds the closest, second closest, and so on, node to the source node, until a specified terminal node is reached (or until the shortest paths to all network nodes are found). As such, the algorithm is *label setting*. In the evolution of the algorithm, each node can be labeled as in one of two states:

1. Open State: when the node still has a *temporary label*.
2. Closed State: when the node is assigned a *permanent label*.

The following vectors are used to store path lengths and predecessor nodes:

1. d(j)= length of current shortest path from node *r* to node *j*
2. p(j) = immediate *predecessor node* to *j* in the current shortest path

The algorithm can be summarized as follows:

Step 0: *Initialization*. Set d(r)=0, p(r)=*, node *r* is *closed* (permanently labeled).

Set d(j)=∞, p(j)=0, all nodes *j* are *open*. Set last node closed label *k*=*r*.

Step 1: *Update labels*. Examine all links (k,j) outbound from last closed node. If node *j* is closed, go to next link; if node *j* is open, set length label to:

d(j) = Min [d(j), d(k)+l(k,j)]

Step 2: *Choose next node to close*. Compare d(j) for all open nodes; choose the node with the minimum d(j) as the next node to close (add to shortest path tree), call node *i*.

Step 3: *Find Predecessor Node*. Consider the links (j,i) leading from *closed* nodes to *i* until one is found that satisfies:

d(i) - l(j,i) = d(j)

Call this predecessor node *q* and set p(i)=*q*. Node *i* is closed.

Step 4: *Stopping Rule*.

(a) For one-to-all nodes shortest paths, if all nodes are closed, then *stop*.

(b) For a one-to-one node shortest path, if destination node is closed, then *Stop*.

Otherwise, set k=i, and return to Step 2.

- *Increased travel distance*

Let $d_{rs}(G(N,L))$ be the distance on the shortest path between origin *r* and destination *s* under network G(N,L) (i.e., network is intact without disruptions), *g* be one or more chokepoints being disrupted, and $d_{rs}(G(N,L-g))$ be the distance on the shortest path between origin *r* and destination *s* under network G(N,L-g), where L-g is the resulting network after *g* (i.e., one or more chokepoints) is removed from the network, then

$$\Delta d_{rs}(g) = d_{rs}(G(N, L-g)) - d_{rs}(G(N, L)),$$

which is the difference between the shortest path after g is removed from the network and the shortest path with the network intact (i.e., $\Delta d_{rs}(g)$) is essentially the additional cost in terms of distance on the detour route since the usual best route may not be available after g (one more chokepoint) is removed from the network.

<u>Freight Flow Pattern Change</u>

To assess the freight flow pattern, the traffic assignment technique is used to allocate freight flows onto the Utah freight network. The AON traffic assignment is used which assigns flows onto the shortest path. AON assumes that flows are assigned based on the fixed travel cost (distance) and does not vary with congestion. To measure the freight flow pattern change, the VMT is used as the impact measure defined as follows:

$$VMT_{rs}(G(N, L)) = d_{rs}(G(N, L)) \times f_{rs}$$

where $d_{rs}(G(N, L))$ is the distance on the shortest path between origin r and destination s under network G(N,L) in units of mile, and f_{rs} is the daily truck flow (veh/day) between origin r and destination s. The freight flow pattern change is computed based on the increased VMT when chokepoint g (one or more chokepoints) is removed from the network, that is:

$$\Delta VMT(g) = VMT_{rs}(G(N, L-g)) - VMT_{rs}(G(N, L))$$

$$= f_{rs}[d_{rs}(G(N, L-g)) - d_{rs}(G(N, L))] = f_{rs}[\Delta d_{rs}(g)]$$

5.5 FCAT Key Features

In this section, the key features of FCAT and utility tools are presented for assessing the vulnerability of freight chokepoints. With FCAT, the user can:

- Display and edit freight chokepoints

The user can edit freight chokepoints by using the "Attribute Table Editor" tool to enable or disable the link segment (see Figure 5.4). After changing the "enable/disable" status, user can save the chokepoint in the shapefile database. To display the freight chokepoint, user simply chooses the saved shapefile to open.

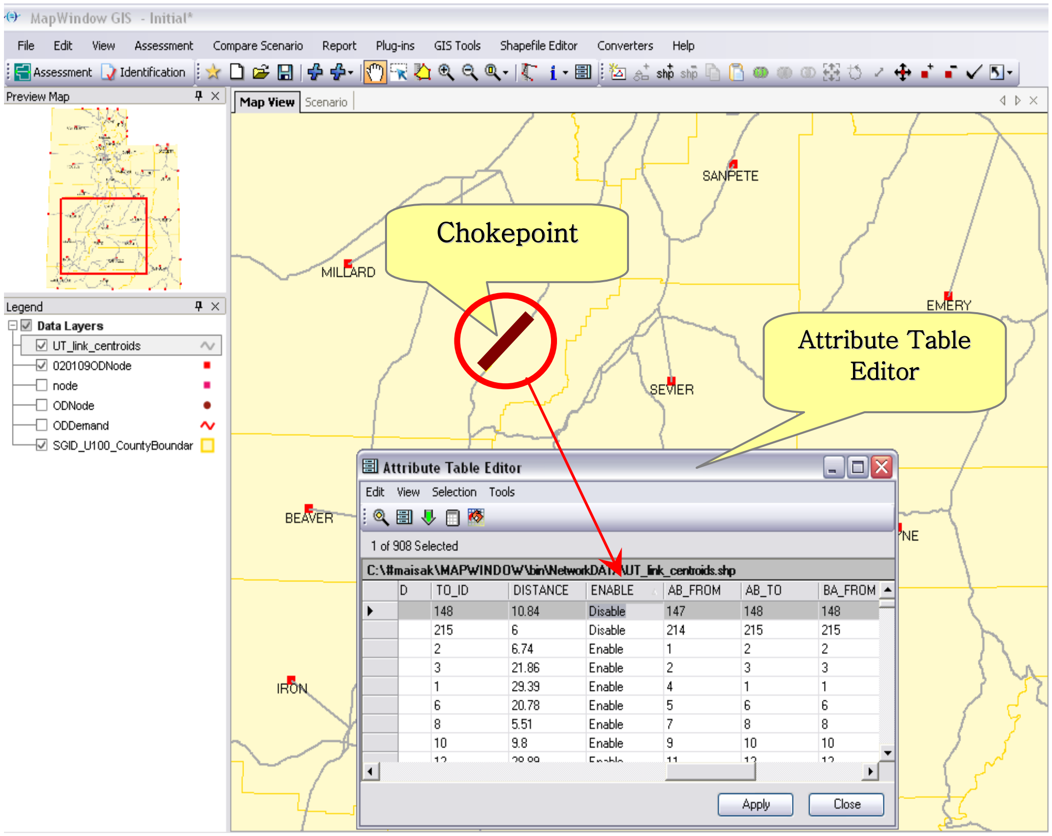


Figure 5.4 Attribute Table Editor in FCAT

- Assess O-D connectivity

User can assess the O-D connectivity using step 2 of the assessment tool shown in Figure 5.5. The results are displayed in Figure 5.6 to show the best routes before and after network disruptions. Increased travel distances for all origins to all destinations are also provided in a MS Excel spreadsheet when user clicks All to All Matrix.

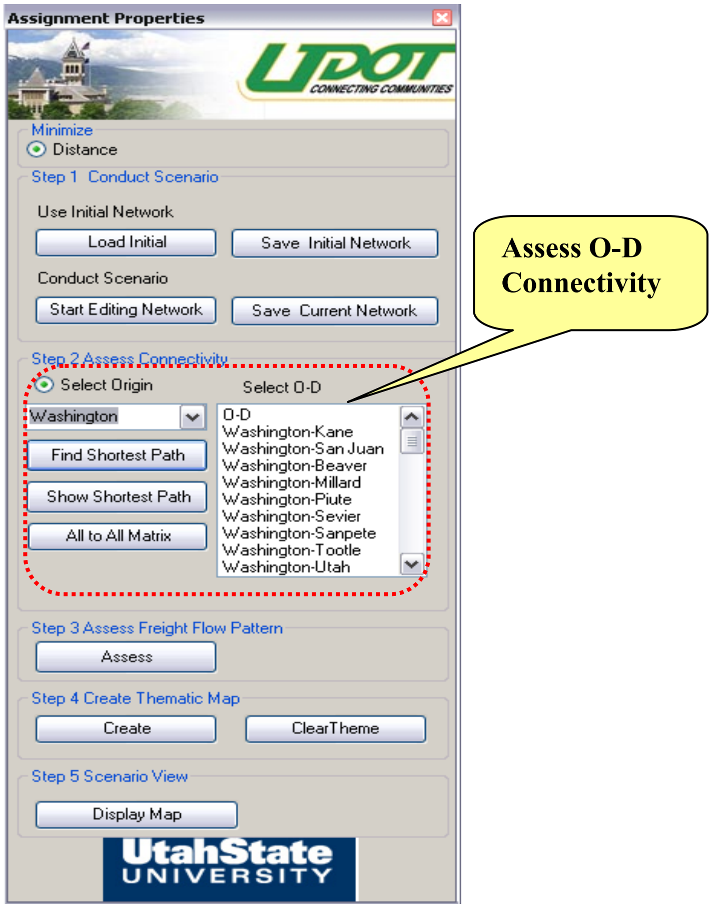


Figure 5.5 FCAT O-D connectivity assessment step

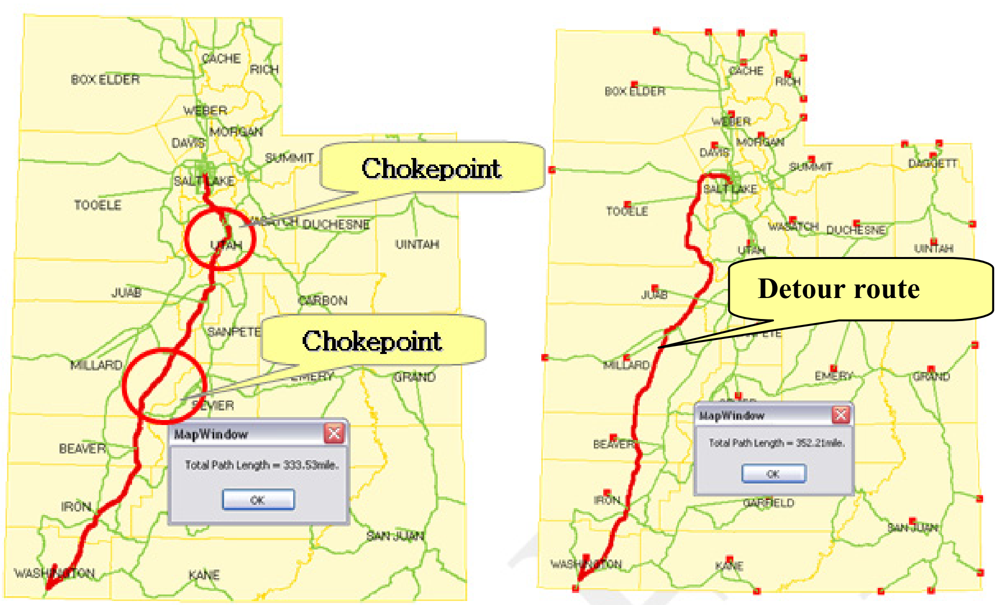


Figure 5.6 Results of O-D connectivity assessment

- Assess freight flow pattern change

User can also assess the freight flow pattern using step 3 of the assessment tool shown in Figure 5.7. This function will assign truck flows from all origins to all destinations based on the AON assignment method. User can display the assigned flows (directional and total flows) of each link using the identifier tool (see Figure 5.8).

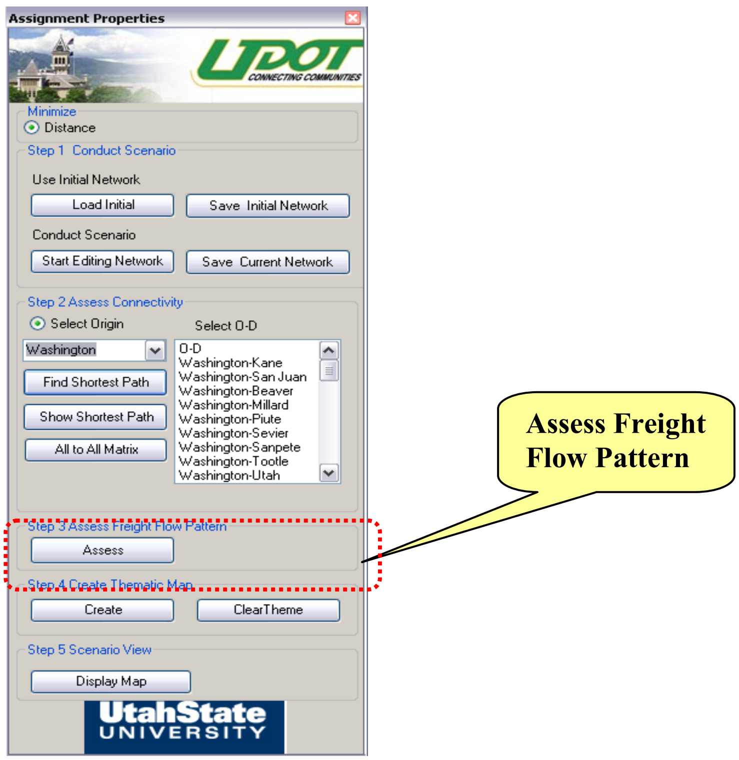


Figure 5.7 FCAT freight flow pattern assessment step

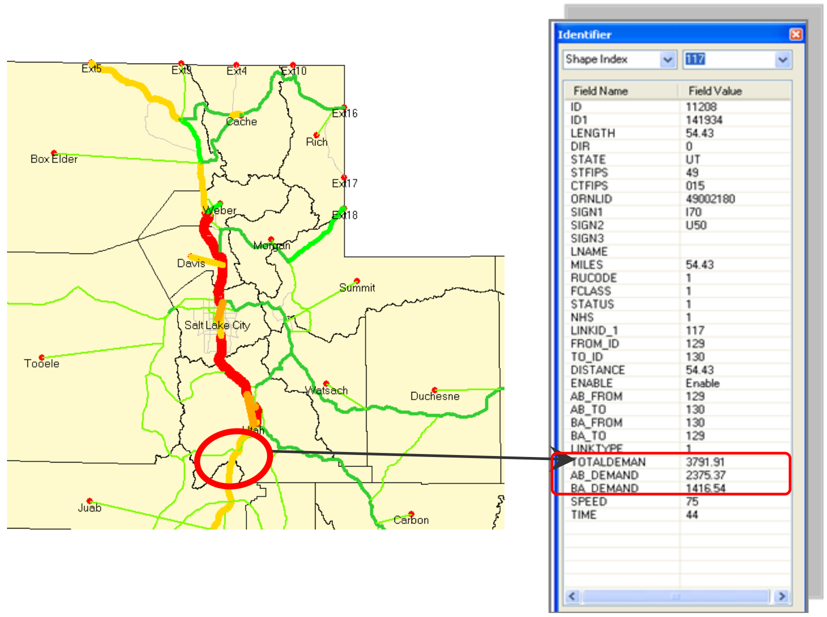


Figure 5.8 Assigned freight flows and identifier tool

- Create thematic map of freight flow pattern

User can create a thematic map of assigned freight flows using the "Create Thematic Map" function in step 4 of the assessment panel or using the "Coloring Scheme Editor" (see Figure 5.9 and 5.10).

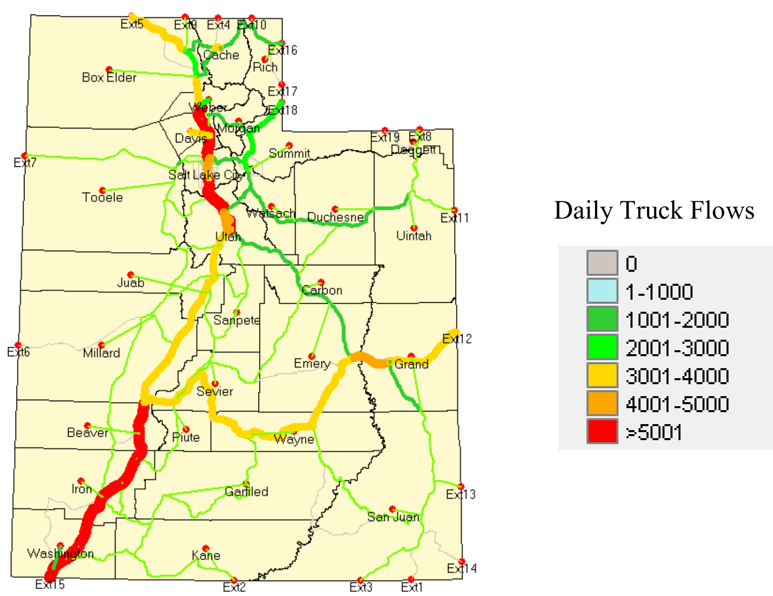


Figure 5.9 Assigned freight flow map

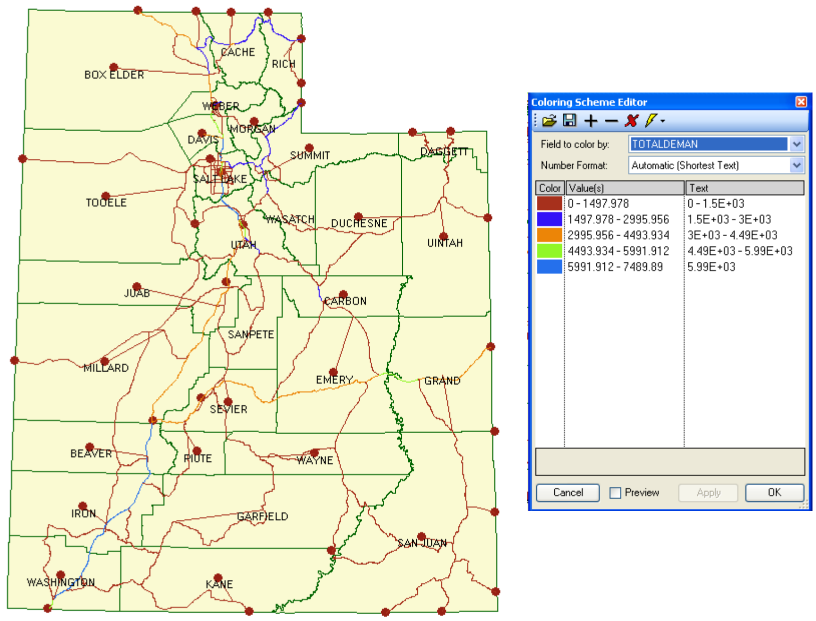


Figure 5.10 Coloring scheme editor

- Compare scenarios

User can compare scenarios using the “Scenario View” in step 5. The multiple scenario interface, built on snap function in MapWindow, is displayed in Figure 5.11. FCAT also allows user to dock the Scenarios Views in different locations of the main window.

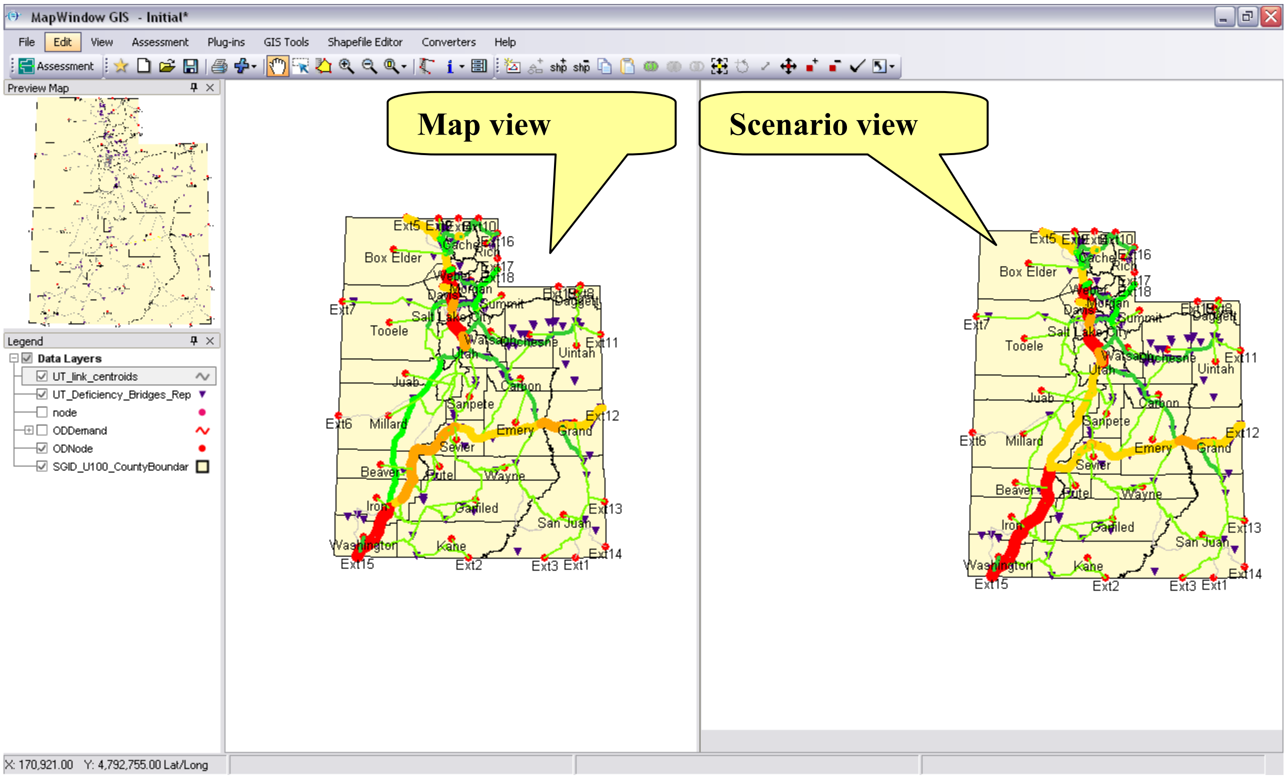


Figure 5.11 Scenario View in FCAT

- View/Edit GIS map by using GIS tools

FCAT is a customizable, extensible mapping tool with powerful capabilities to view, manipulate, and analyze geospatial data. FCAT provides the fundamental GIS tools including the raster, vector, and image tools. The GIS tools include:

- Export Selected Shapes to New Shapefile
- Merge Shapefile
- Calculate Polygon Area
- Reproject a Shapefile
- Buffer Shapes
- Convert CSV to Shapefile

5.6 FCAT User Manual

5.6.1 How to Use the Manual

The user manual is designed to explain various functions of the software, including step-by-step instructions for using software. After installing the program, users are advised to go through the Graphical User Interfaces section for knowledge of program functions. Note that the description of MapWindow tools are adopted from "A Practical Look at MapWindow GIS (1st Edition)" by Watry and Ames (2008).

5.6.2 Installing FCAT

To install FCAT, the computer needs to have the Microsoft .NET framework. Many of the Microsoft Windows programs are developed using the .NET framework. Therefore, for a computer running Microsoft Windows XP or 2000, it is likely that the .NET framework is already installed. If the user is unsure whether the computer has the .NET framework or not, an installation program **dotnetfx.exe** is included in the FCAT installation CD. Running the program will install the .NET framework on the target computer. After installing the .NET framework, user can proceed to run the **FCAT_Setup.exe** program and follow the setup instructions to complete the installation of FCAT.

5.6.3 Main Window

The Main Window of FCAT uses the parent form of MapWindow. Figure 5.12 shows the program's main window and other panels including the Toolbar Buttons, Preview Map, Legend, and Assessment Tool.

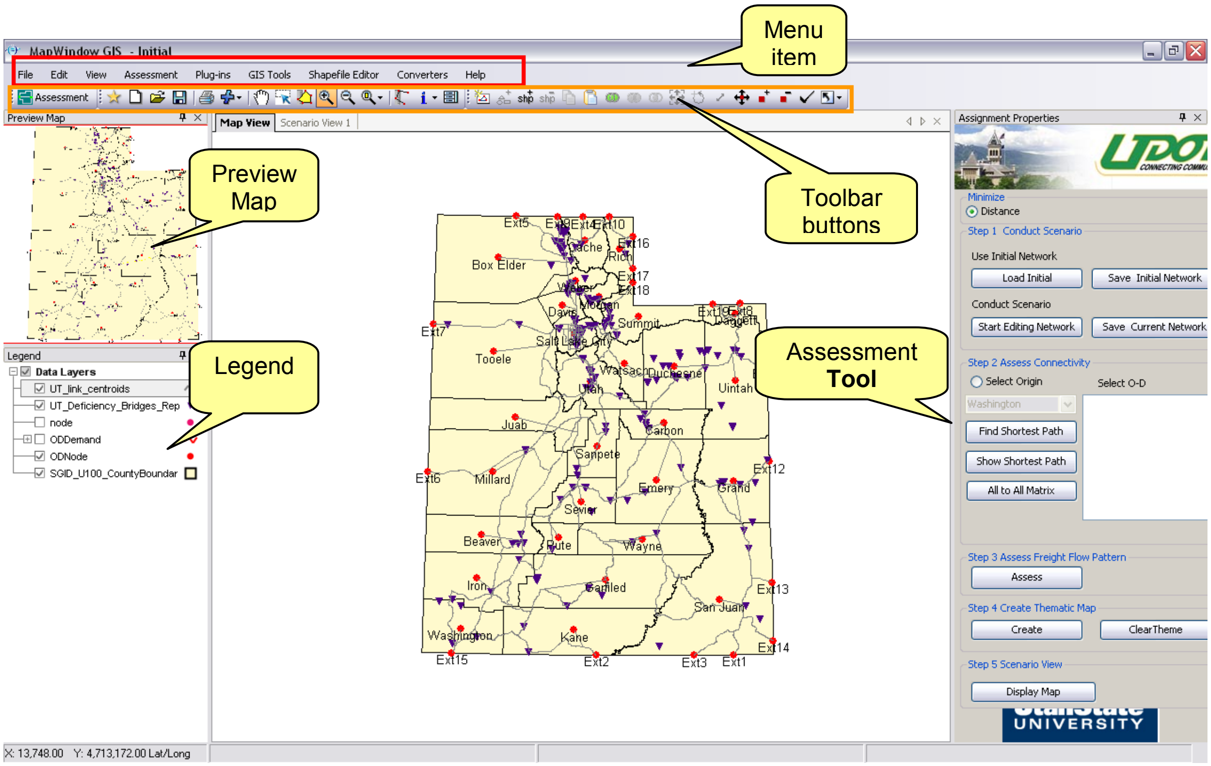


Figure 5.12 Main window

5.6.4 FCAT Menu Items

There are seven menu items in the main menu of FCAT. Each menu item contains sub-items which can be described as follows:

- File: Control functions related to creating, opening, and saving of individual project and GIS files.
  - Archive/ Restore Project
  - New Scenario: Create a new project
  - Open:
    - Open Project (*.mwprj)
    - Open Database (*.dbf)
  - Open Project Into Group
  - Save: Save under an existing project name
  - Save As: Save as a new project

- Print: Print a hard copy of the map
- Project Setting: Control general preferences of the application
- Recent Project: Contain a list of recently opened projects
- Check Update: Check for new software of MapWindow updates
- Close: Close the project but not the program
- Exit: Close the program
- GeoDatabase
  - Load Features
  - Export Database to Shapefile
  - Import Shapefile to Database

- Edit
  - Copy: Place any of the following elements on the system clipboard
    - Copy Map
    - Copy Legend
    - Copy Scale Bar
    - Copy North Arrow
  - Export: Export any of the following elements to a graphic file.
    - Save Map Image
    - Save Geo Ref Map Image
    - Save Scale Bar
    - Save North Arrow
    - Copy Scale Bar
    - Copy North Arrow
  - Preview
    - Update Preview Full
    - Update Preview
    - Clear Preview
- View
  - Add Layer: Add a geospatial layer to the map
  - Remove Layer: Remove the selected geospatial layer
  - Clear Layer: Clear all layers from the map
  - Set Scale

    - Show Scale Bar
    - Zoom In: Change the current cursor behavior to zoom in mode
    - Zoom Out: Change the current cursor behavior to zoom out mode
    - Zoom to Full Extents: Zoom the map to the full extents of all currently loaded data
    - Zoom to Preview Extents
    - Previous Zoom: Return the map to the previous zoom
    - Next Zoom: This is used with Previous Zoom to move back and forth within the saved zoom extents.
    - Bookmark View: Annotate and Save Bookmarked View
    - Bookmark Delete: Delete Bookmark
    - Bookmarked View: Open Bookmarked View
    - Panel
        - Show Legend: Hide or show Legend
        - Show Preview Map: Hide or display Preview Map
- Assessment
    - Assess Connectivity
    - Assess Freight Flow Pattern
    - Compare Scenario
- GIS Tools
    - Raster
        - Assign Project to Grids
        - Reproject Grids
        - Change Grid Formats
        - Resample Grids
        - Merge Grids
        - Clip Grid With Polygon
        - Georeference an Image or Grid
        - Generate a Contour Shapefile
        - Change No Data Value
    - Vector
        - Assign Project to Shapefile

- Reproject a Shapefile
- Buffer Shapes
- Calculate Polygon Areas
- Clip Polygon Areas
- Clip Shapefile with Polygon
- Erase Shapefile with Polygon
- Export Shapes to New Shapefile by Mask
- Merge Shape
- Merge Shapefiles

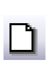
- Converters
  - CSV (Comma Separated Value) to Shapefile
- Help
  - MapWindow Documentation (Online)
  - MapWindow Documentation (Offline)
  - Keyboard Shortcuts
  - Welcome Screen
  - About

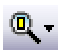
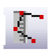
5.6.5 FCAT Toolbars

Main Toolbar

MapWindow provides the main toolbar as shown in
Figure 5.13. The name of a toolbar button is shown when the mouse is placed over the button.

Figure 5.13 Main toolbar buttons

-  -New Project
-  -Open Project
-  -Save Project

-  -Print
-  -Add/Remove/Clear Layer
-  -Pan
-  -Select
- - Measure Area
-  -Zoom In
-  -Zoom Out
-  -Zoom
-  -Measure Distance
-  -Identifier Tool
-  -Table Editor

Assessment Toolbar

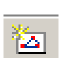
The assessment toolbar is shown in Figure 5.14. This toolbar button is used for assessing transportation network vulnerability.

Figure 5.14 Assessment toolbar

Shapefile Editor Toolbar

The shapefile editor toolbar is shown in Figure 5.15. These buttons are used for editing a GIS shapefile.

Figure 5.15 Shapefile Editor toolbar buttons

-  -Create new shapefile
-  -Add a new generic predefined shape to current shapefile
-  -Add new shape to current shapefile
-  -Remove shape from current shapefile
-  - Copy selected shapes to clipboard

- - Paste a shape from the clipboard
- - Merge two shapes
- - Erase current layer at selected shapes
- - Erase current layer beneath selected shape
- - Move existing shapes in selected layer
- - Rotate a shape about its centroid or a specified point
- - Resize (expand or shrink) a shape
- - Move an existing vertex in a shape
- - Add a vertex to an existing shape
- - Remove a vertex from an existing shape
- - Check and clean up the shapefile
- -Undo Options
  - o Undo Last Change
  - o Enable Undo Capability
  - o Disable Undo Capability

5.6.6 FCAT GIS Tools

User can use the following tools to view and edit the GIS map.

Zoom In / Zoom Out / Zoom to Full Extent

When working with a GIS map, it may be necessary to Zoom In to view an area in more detail, or Zoom Out to see a larger area. User can select Zoom In / Zoom Out using toolbar buttons / or menu item View -> Zoom In or View -> Zoom Out. Figure 5.16 demonstrates how to use Zoom In and Figure 5.17 is a Zoom In area.

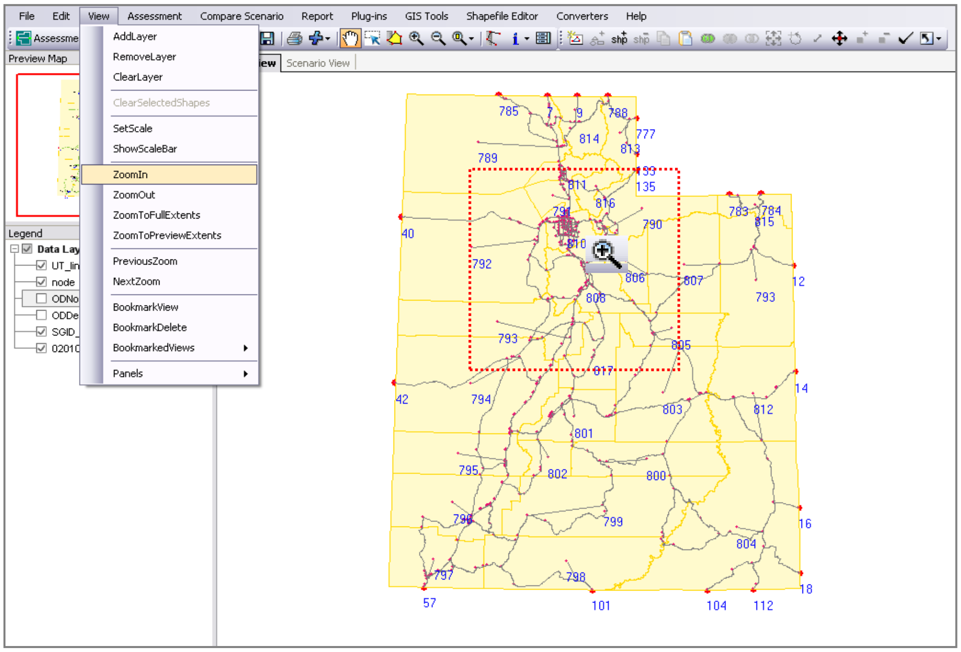


Figure 5.16 Using Zoom in to view area in detail

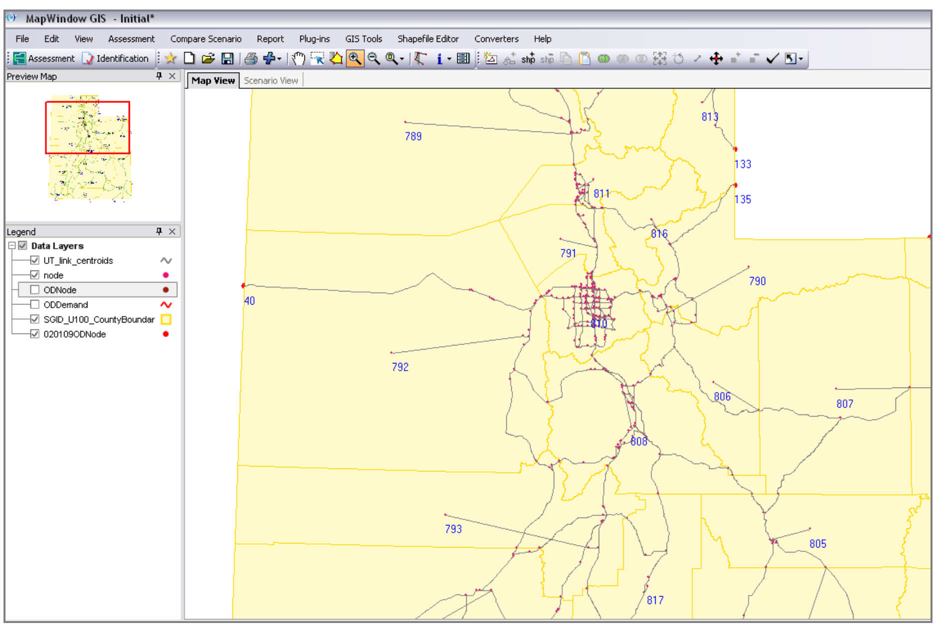


Figure 5.17 Zoom In area

Zooming to full extent resets the map view so that every feature of every layer is contained within the visible extent. To use Zoom to Full Extent, use Zoom toolbar button and drop down, select  or View -> Zoom to Full Extent. Figure 5.18 shows a map after clicking Zoom to Full Extent.

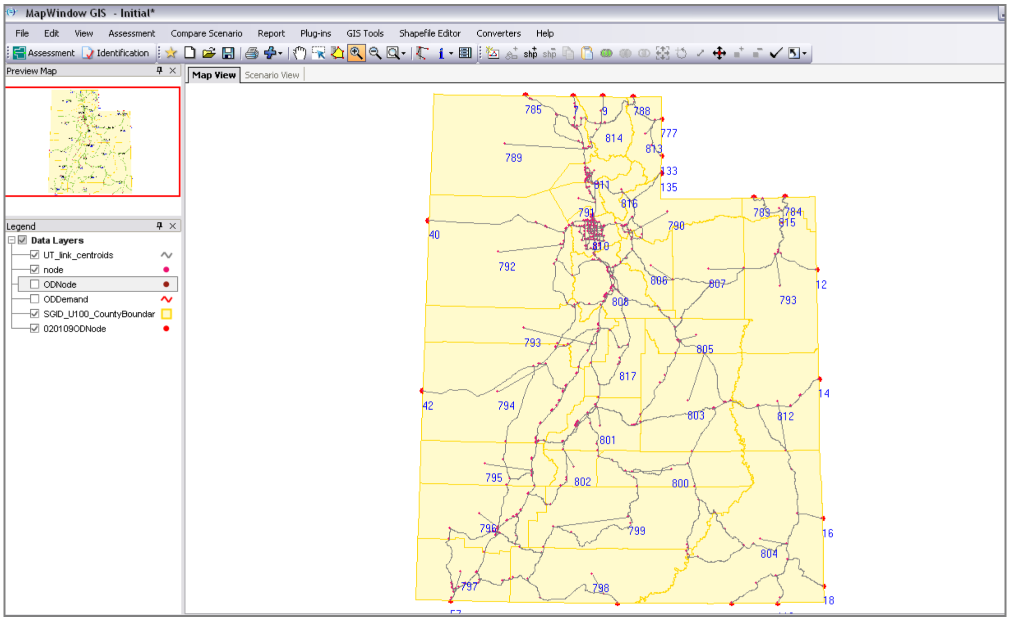


Figure 5.18 Zoom to Full Extent

Pan / Panel / Dock and Undock

Panning allows the user to move the map display around to show areas outside of the current viewing area without changing the scale of the map. To use Pan, Click . To display Preview Map and Legend, user can click View -> Panel. In MapWindow, user can click and drag the window and panels to dock at a desired location. Figure 5.19 shows how to undock the window in this program.

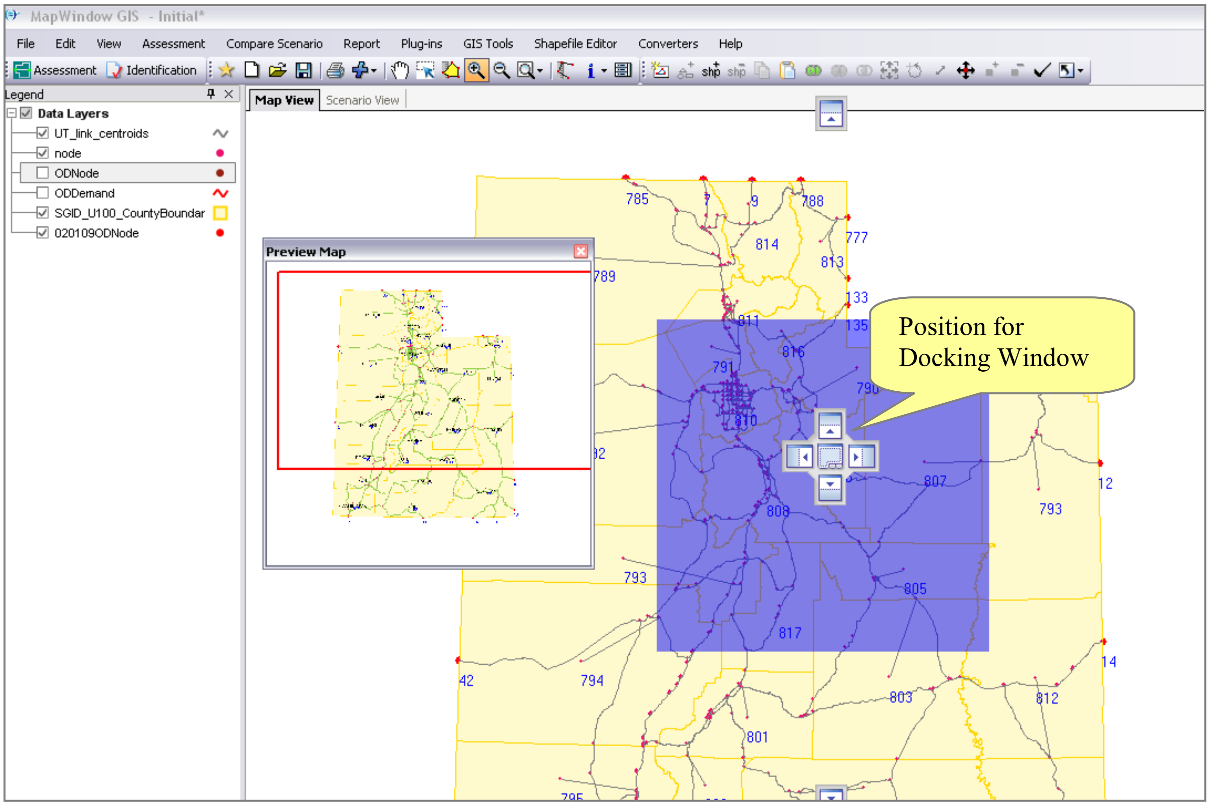
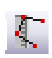


Figure 5.19 Undocked window

Measuring Distance/Measuring Area

The distance measurement tools are used to calculate distances between two or more user-defined points on the map. User can click  to measure distance. On the bottom left of the main application window, the cumulative distance is displayed.

The area measurement tool is used to calculate the area between three or more user-defined points on the map. User can click  to measure polygon's area. Click on the first point, click on the next point and as many points as needed to complete the border around the area needed to be measured. Right Click to end and see the results of the area measured.

Adding Layer

MapWindow supports three different types of Shapefiles:

1. Point Layer
2. Polygon
3. Polyline

Adding layer data by clicking  or by clicking on View -> Add Layer. When the “Add Map Layer” window opens, navigate to the desired data directory, then click on the GIS data to add it as a new layer in the user’s project. To add multiple layers, hold down the control key and select each additional layer by clicking on it. Figure 5.20 shows the data layers used in FCAT.

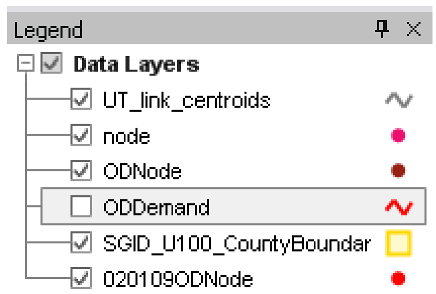


Figure 5.20 Layers used in FCAT

Legend Editor

The Legend Editor is a graphical representation of all the map layers in the current project (See Figure 5.21). The Legend Editor offers layer manipulation functionality for changing a layer’s symbology or the order of display for the layers.

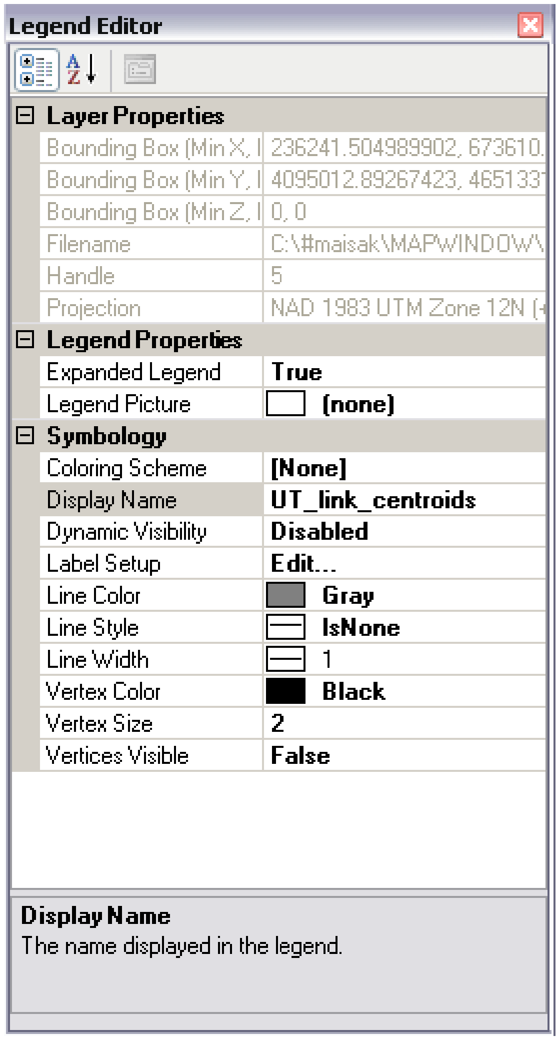


Figure 5.21 Legend Editor

Coloring Scheme Editor

User can change the color of each category by using the Coloring Scheme Editor shown in Figure 5.22. There are three options to do this: Continuous Ramp, Equal Breaks, and Unique Values.

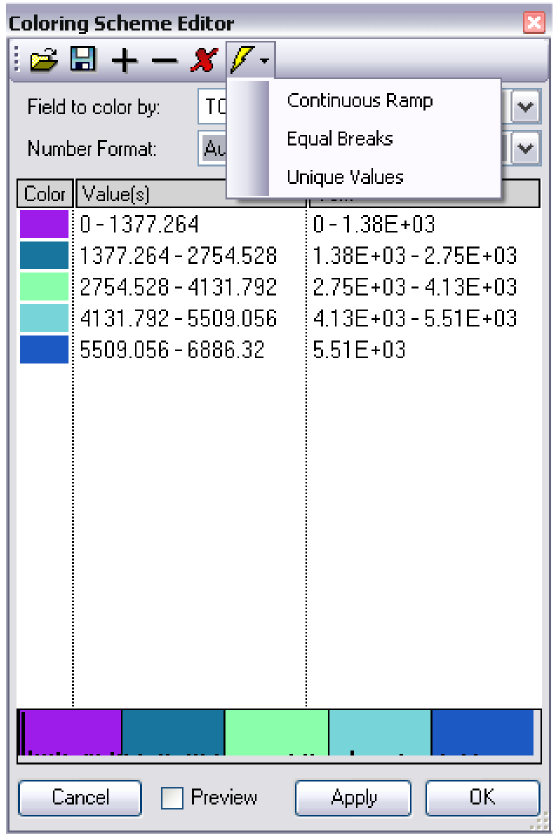


Figure 5.22 Coloring Scheme Editor

Attribute Table Editor

With the Attribute Table Editor tool shown in Figure 5.23, user can

- Edit
  - Add a Field: Add an attribute column to the attribute table.
  - Remove a Field: Delete an attribute column from the attribute table.
  - Rename a Field: Change the name of an attribute column.
- View
  - Show Only Selected Shapes: Display only those features selected.
  - Show All Shapes: This option appears when Show Only Selected Shapes is already selected.
  - Zoom to Selected Shape: Zoom to only those features selected.
- Selection
  - Query: Queries or searches of the attribute table can be defined.
  - Select All: All features are selected.
  - Select None: Any selected features are unselected.

- Switch Selection: Any selected features are unselected, and any unselected features are now selected.
- Export Selected Features: Selected features are exported out as a new shapefile.

- Tools
  - Find: Search and locate text in any column in the attribute table
  - Replace: Search and locate text in attribute table and replace it with other text.
  - Import Field Definitions From DBF: Import the attribute column definitions from a different shapefile (or DBASE IV file)
  - Field Calculator Tool: Allow the user to fill attribute columns with calculated values (calculated from other attribute value)
  - Generate or Update MHSHAPEID File: Update or creates a unique identifier attribute column.

Figure 5.23 Attribute Table Editor

<u>5.6.7 FCAT Transportation Vulnerability Assessment Tool</u>

To begin the assessment process, click 

button in the menu bar to open the assessment panel. Figure 5.24 shows the assessment panel and the assessment steps including Conduct Scenario, Assess Connectivity, Assess Freight Flow Pattern, Create Thematic Map and Scenario View.

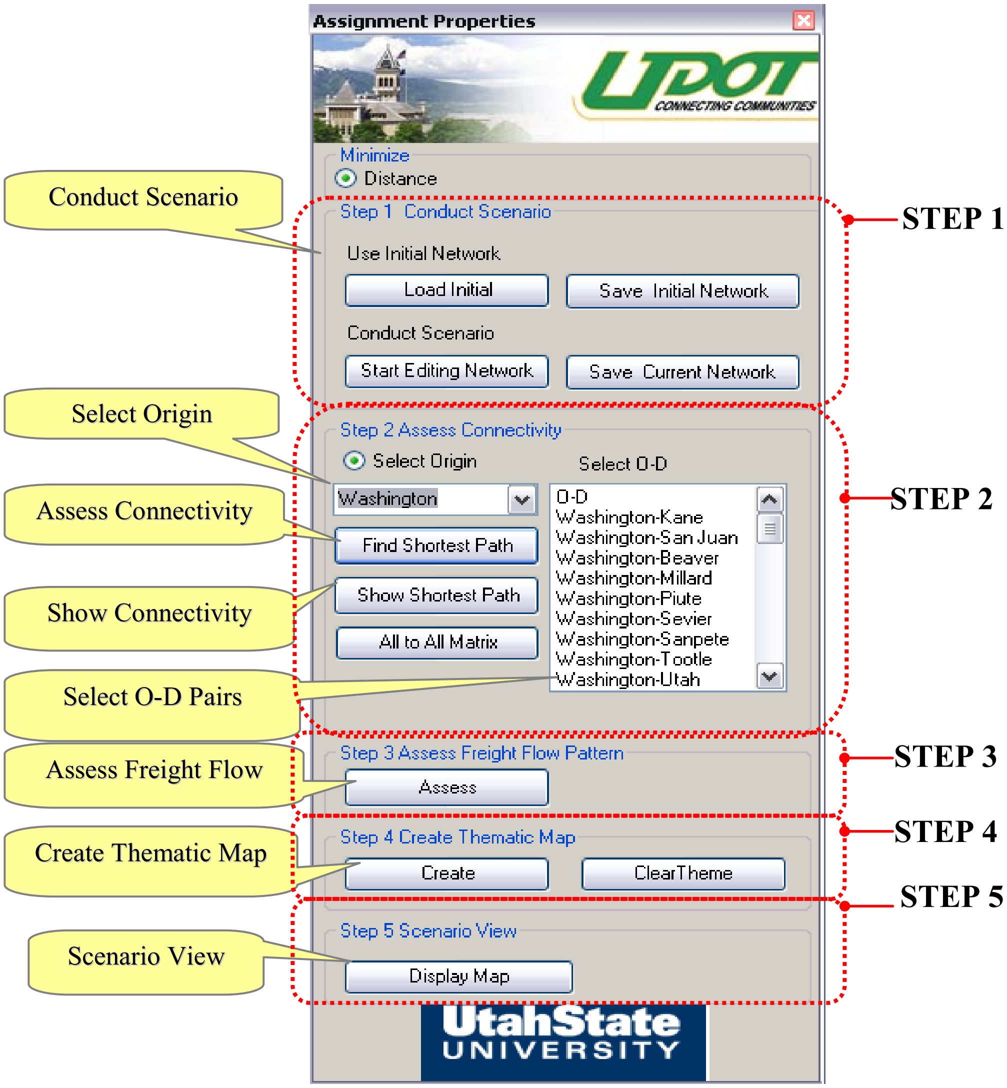


Figure 5.24 FCAT assessment panel

To assess the vulnerability in FCAT, follow the step-by-step instructions below:

Step 1: Conduct Scenario

To edit chokepoints using the "Attribute Table Editor" tool:

1. Select **UT_link_centroids** shapefile in the Data Layer shown in the left hand side, this shapefile will be highlighted.
2. At Step 1, click **Start Editing Networ**k, the message **"Use Select Tool to Select Shapefile, Change Enable-> Disable using Table Editor"** will appear.

3. Click at **Select Tool**  in Menu bar. Use **Select Tool** to click at the shapefile. The selected shapefile will be highlighted. Note that you can select multiple shapefiles by holding **Ctrl key**.
4. After finished, click Table Editor in the Menu Bar or Right-Click on **UT_link_centroids** shapefile in Data Layers and select **View Attribute Table.**
5. The **Attribute Data Editor** will be opened and the selected shapefiles will be highlighted. Scroll to the right hand side at the "Enable" column, then click at the **Enable** cell and change from **Enable** to **Disable** and click Apply.
6. After editing all chokepoints, click **Save Current Network** in the assessment panel. The chokepoints will be highlighted in blue color.
7. To enable all chokepoints (base scenario), click **Load Initial** and **Save Initial**. All "Disable" cells will change to **Enable**.

Figure 5.25 shows step 1 in FCAT.

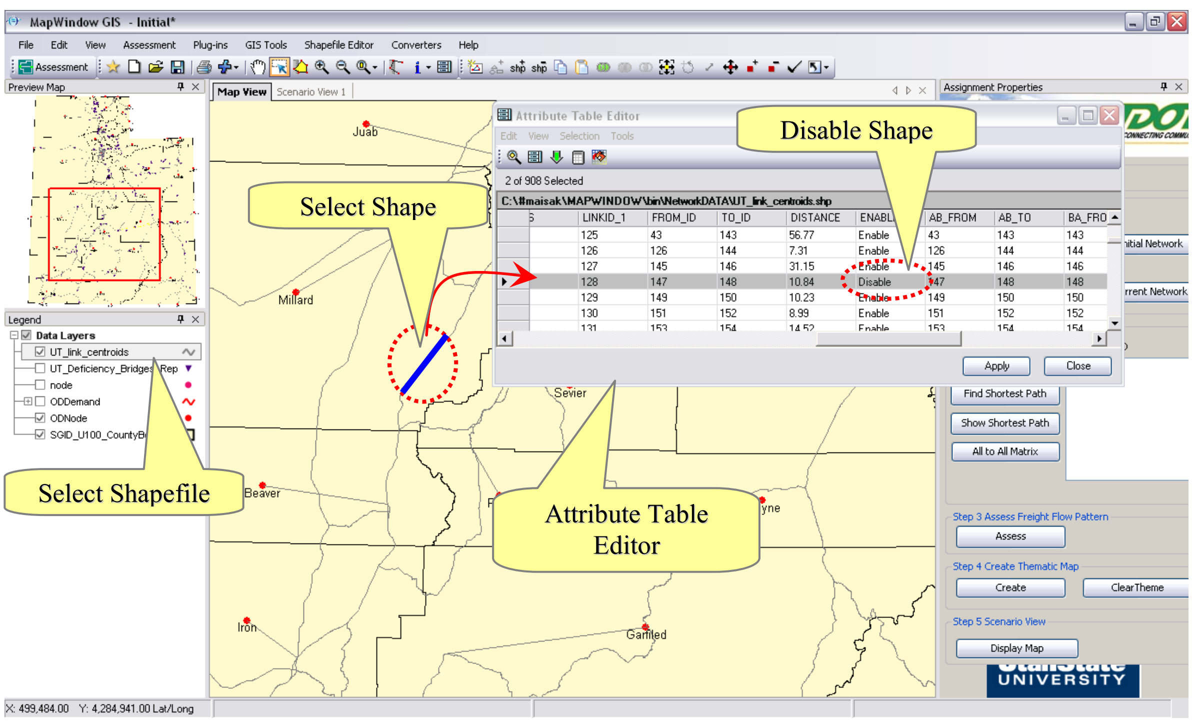


Figure 5.25 Step 1: Conduct Scenario

Step 2: Assess Connectivity

To assess O-D connectivity:

1. Click **Select Origin**, you can select county or external station from the drop down menu. (see Figure 4.26)
2. Click **Find Shortest Path**, program will ask “Use Current Network Condition for Finding Shortest Path?”. Click Yes, program will compute the shortest path from the selected county or external station to all zones. If program runs successfully, program will return message “0: Success”
3. One to All O-D will be listed in the Select O-D box (see Figure 4.26). To show the shortest path between particular O-D pair, click on that O-D pair and click **Show Shortest Path.**
4. The shortest path between O-D pair will be traced and it shows the shortest distance (unit of mile) in the message box (See Figure 4.27).
5. To generate All to All O-D pairs shortest distance matrix, click **All to All Matrix**. The output matrix is generated in the CSV format. User can find the all2all.csv file using the following directory path …\FCAT\Bin\all2all\all2all.csv.
6. The MS Excel file namely **Workspace00.xls** is provided in folder **Workspace**. (directory path …\FCAT\Bin\Workspace\ Workspace00.xls). User can copy result from no.5 to **Scenario Matrix** sheet in this file. (See Figure 5.28) All results including **Increased Travel Distance (TD)**, **Increased Vehicle Miles of Travel (VMT)** will be updated with color codes. For more details of color code, please see section 6.2 in Chapter 6.

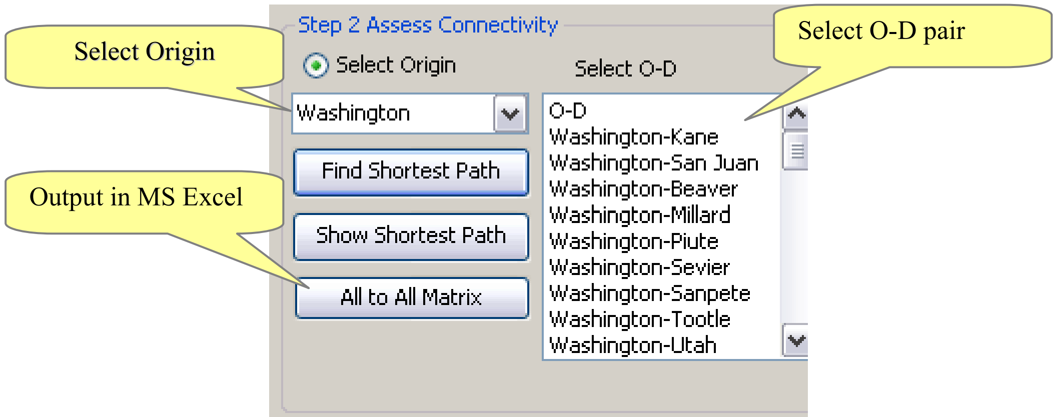


Figure 5.26 Step 2: Assess Connectivity

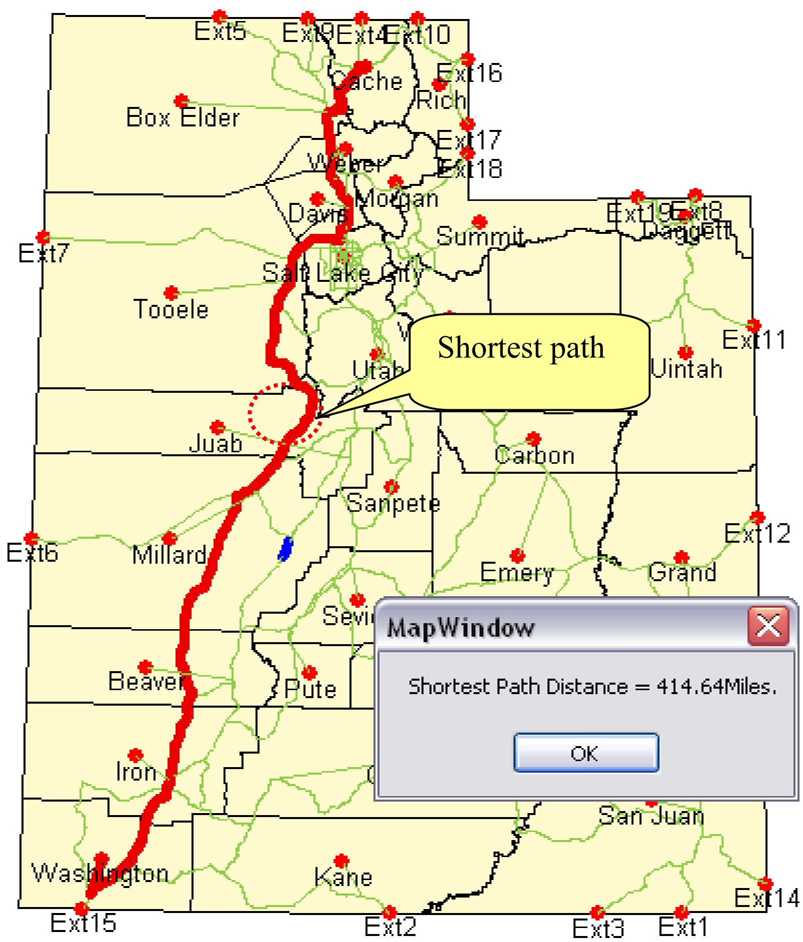


Figure 5.27 Shortest path and its distance

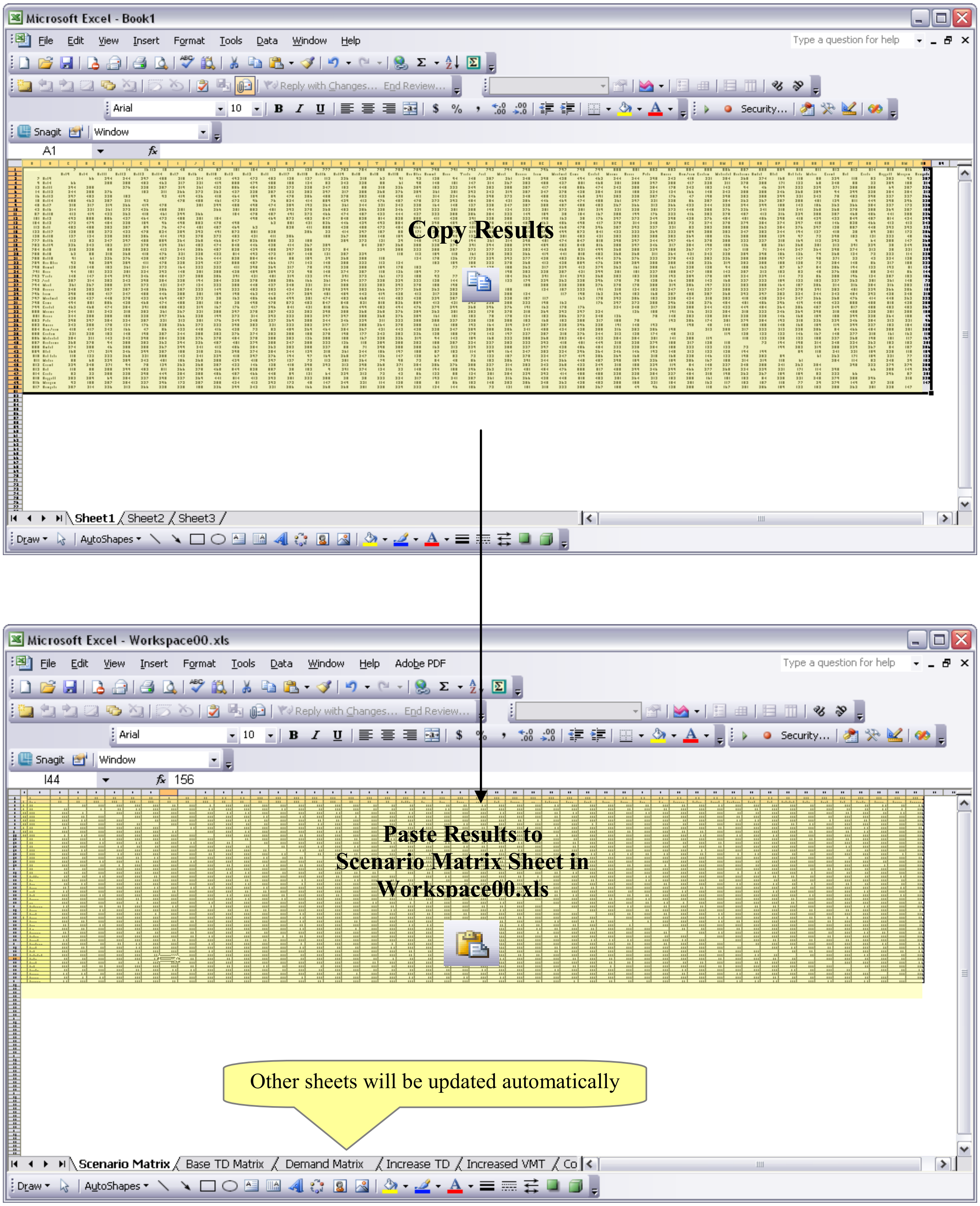


Figure 5.28 Results in MS Excel and workspace file

Step 3: Assess Freight Flow Pattern

To assess the freight flow pattern, click **Assess** in Step 3 (see Figure 5.29). Program will ask "Use the Current Network Condition". Click "Yes" to start assess freight flow pattern, then the traffic assignment process box with the progress bar will be opened (see Figure 5.30). Please wait for the process to finish (it may take 3-5 minutes).

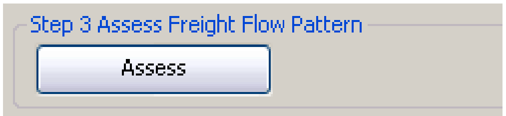


Figure 5.29 Step 3: Assess freight flow pattern

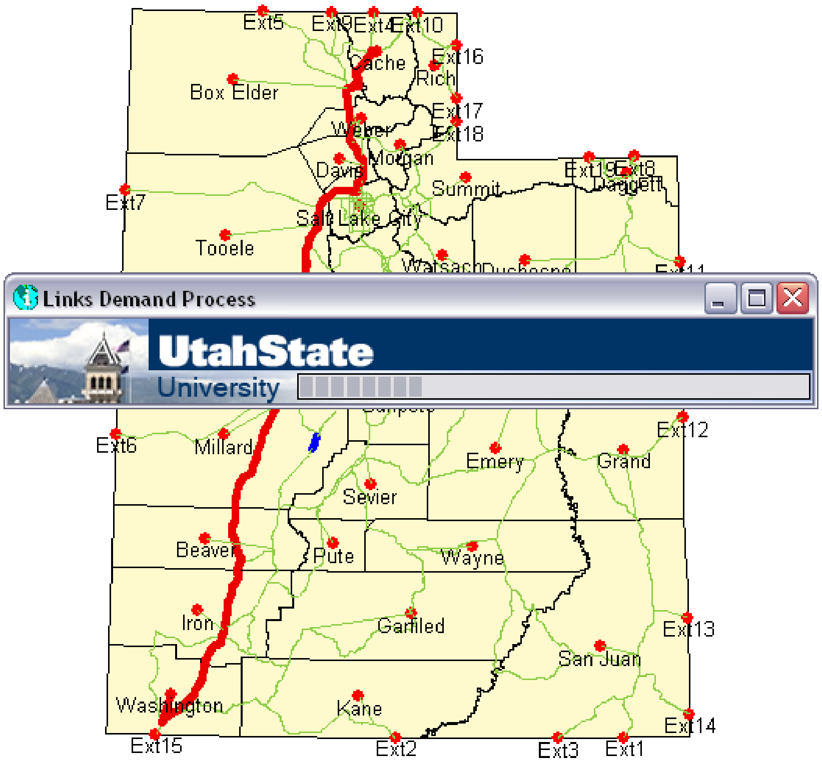


Figure 5.30 Traffic assignment process and progress bar

Step 4: Create Thematic Map

After step 3 is done, the GIS thematic map of the assigned flow can be created. Click **Create** in step 4, program will generate thematic map using color and line thickness to represent assigned freight flow (see Figure 5.31). To clear thematic map, click **Clear Theme**.

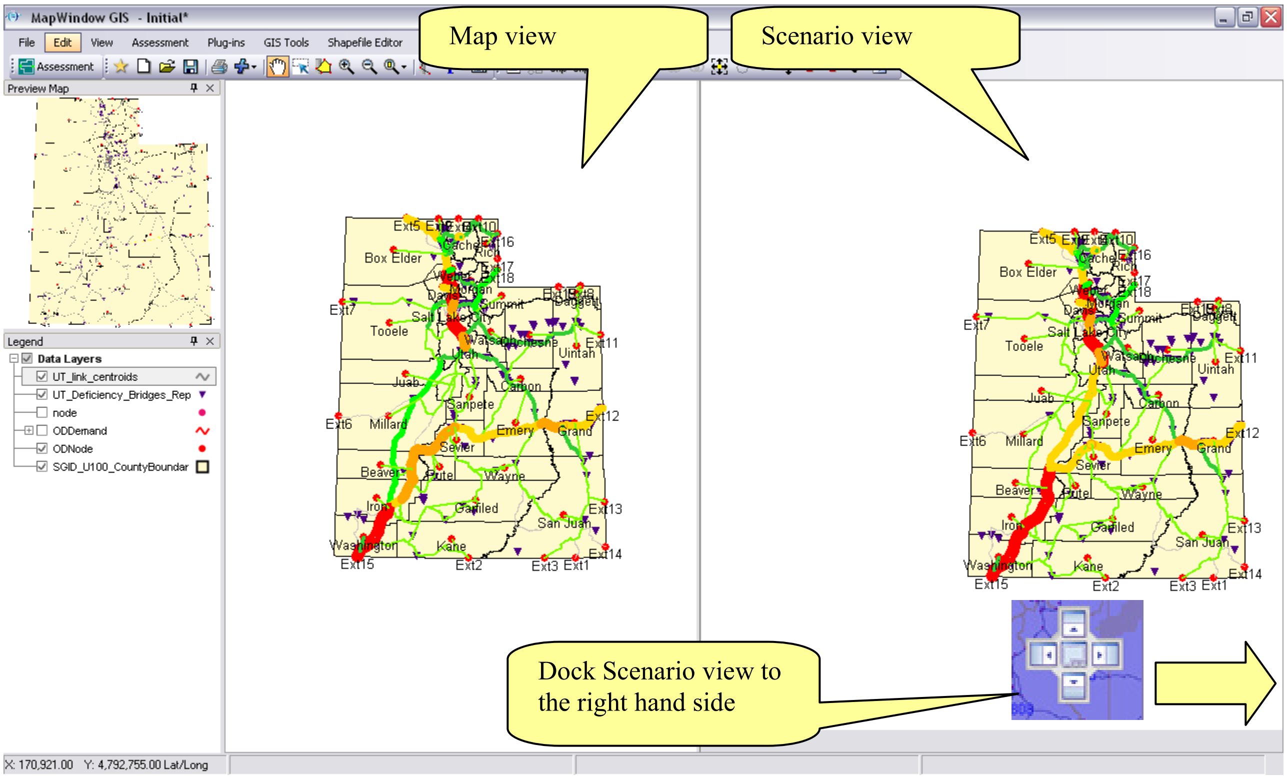


Figure 5.31 Thematic Map

Step 5: Scenario View

To compare scenarios and show them in the different panels, click **Display Map** button in step 5. Program will snap the extent view of the current GIS map to the Scenario View panel. (see Figure 5.32) At the same time, it generates bitmap picture (*.bmp) in the Bin folder. Note that the scenario view window can be docked at the desired locations on the main window.

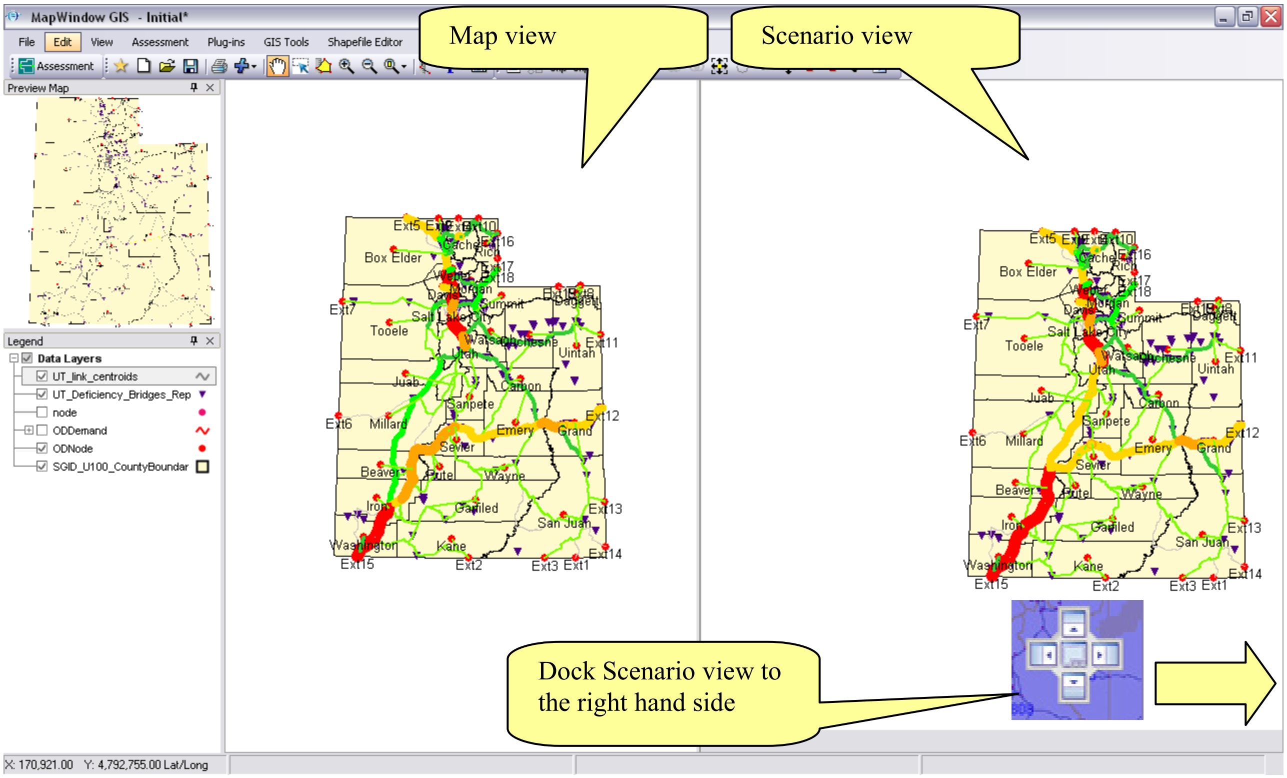


Figure 5.32 Scenario View

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6. CASE STUDY AND RESULTS

The objective of this chapter is to illustrate the usage of the freight chokepoint analysis tool via a case study using the Utah freight transportation network. The case study adopts a "what-if" analysis approach by generating chokepoint disruption scenarios for the assessment of transportation vulnerability. Results of the vulnerability assessment in terms of O-D connectivity and freight flow pattern change are summarized in this chapter. The organization of this chapter includes the following sections:

- Scenario generation for freight chokepoint analysis
- Vulnerability assessment measures
- Result and analysis

6.1 Scenario Generation for Freight Chokepoint Analysis

A scenario here refers to the disruption of a set of links (or chokepoints) in the transportation network. In this case study, the objective is to assess the vulnerability of bridges in the State of Utah due to an earthquake. Figure 6.1 provides a schematic depicting the vulnerability assessment process using the FCAT described in Chapter 5.

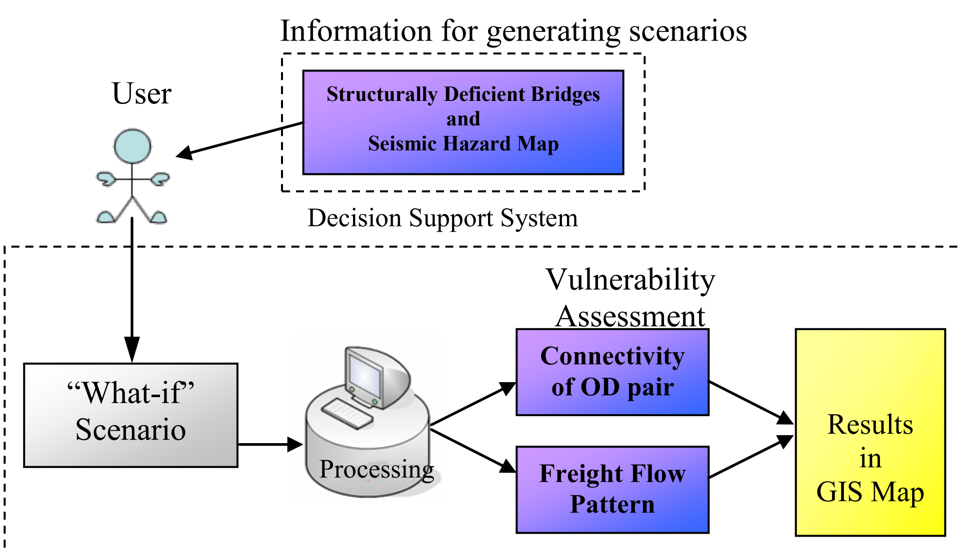

Figure 6.1 Schematic of the vulnerability assessment process

6.1.1 Information for scenario generation

The scenarios considered in the case study are the disruptions of structurally deficient bridges in the Utah highway network due to an earthquake. To generate the scenarios, two information sources were used:

1. Structurally deficient bridges from the National Bridge Inventory (NBI) database (year 1995-2004), and
2. Utah seismic hazard map created by the structural group at Utah State University.

- Structurally Deficient Bridges

According to the NBI database, there are a total of 2,854 bridges in Utah. The NBI uses the condition rating to describe the existing in-place bridge compared to the as-built condition. The NBI condition rating is determined from the physical condition of following components:

- *Deck Condition Rating (NBI Item 58):* This item describes the overall condition rating of the deck.
- *Superstructure Condition Rating (NBI Item 59):* This item describes the physical condition of all structural members.
- *Substructure Condition Rating (NBI Item 60):* This item describes the physical condition of piers, abutments, piles, fenders, footings, or other components.
- *Culvert Condition Rating (NBI Item 62):* This item evaluates the alignment, settlement, joints, structural condition, scour, and other items associated with culverts. The rating code is intended to be an overall condition evaluation of the culvert.

Figure 6.2 provides an illustration of these four components. The NBI condition rating varies from 0–9 and they are described in Table 6.1. According to the FHWA definition, a structurally deficient bridge refers to a bridge which has a condition rating less than or equal to 4 for at least one of the four major components (i.e., deck, superstructure, substructure, or culvert). The FHWA definition was applied and the structurally deficient bridges were located in the Utah highway network. In Utah, there are about 221 bridges classified as structurally deficient bridges and the locations of these bridges are shown in Figure 6.3. For details of these 221 structurally deficient bridges in Utah, see Appendices E and F.

Superstructure

Deck

Substructure

Culvert

Source: Structure and Bridge Division, Virginia Department of Transportation and http://www.lmnoeng.com/Pipes/hds.htm

Figure 6.2 Illustration of the four components of a bridge

Table 6.1 National bridge inventory (NBI) condition rating

Code	Description
N	*Not Applicable*
9	*Excellent Condition*
8	*Very Good Condition*—no problems noted.
7	*Good Condition*—some minor problems.
6	*Satisfactory Condition*—structural elements show some minor deterioration.
5	*Fair Condition*—all primary structural elements are sound but may have minor section loss, cracking, spalling, or scour.
4	*Poor Condition*—advanced section loss, deterioration, spalling, or scour.
3	*Serious Condition*—loss of section, deterioration, spalling, or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present.
2	*Critical Condition*—advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present, or scour may have removed substructure support. Unless the condition is closely monitored, it may be necessary to close the bridge until corrective action is taken.
1	*"Imminent" Failure Condition*—major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic, but corrective action may put it back in light service.
0	*Failed Condition*—out of service and beyond corrective action.

Source: Office of Engineering Bridge Division, U.S. Department of Transportation, FHWA, 1995

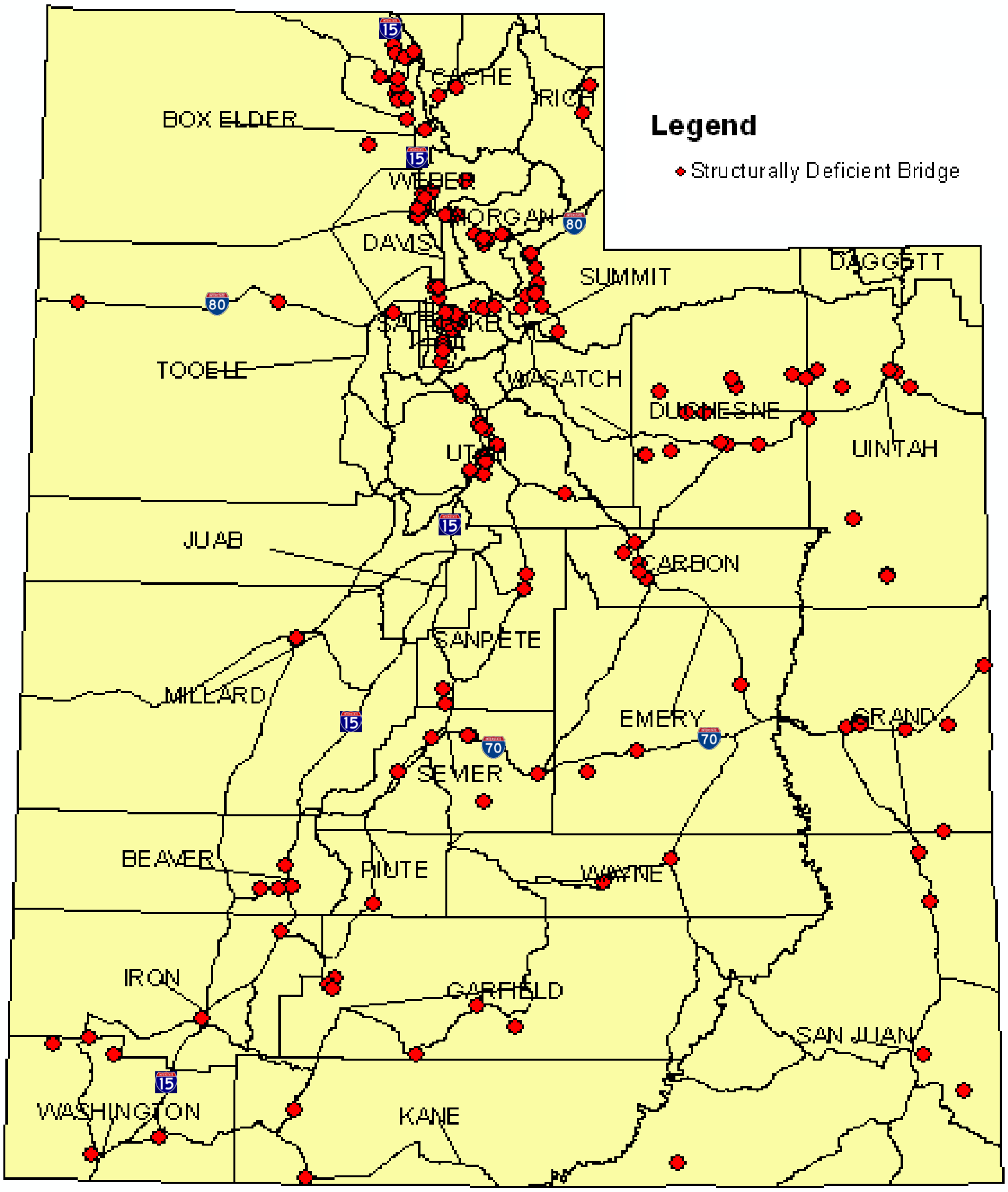

Figure 6.3 Locations of structurally deficient bridges[5] in Utah

The structurally deficient bridges categorized by the NBI condition rating and bridge's components are shown in Figure 6.4. For this study, the bridges are further classified by the highway functional class and area type. Figures 6.5 and 6.6 show the number of structurally

5 Structurally deficient bridges were selected from the NBI condition rating of deck, superstructure, substructure or culvert less than or equal to 4

deficient bridges in rural and urban areas. For the interstate, there are about 27 bridges in the rural area and 32 bridges in the urban area that are considered to be structurally deficient.

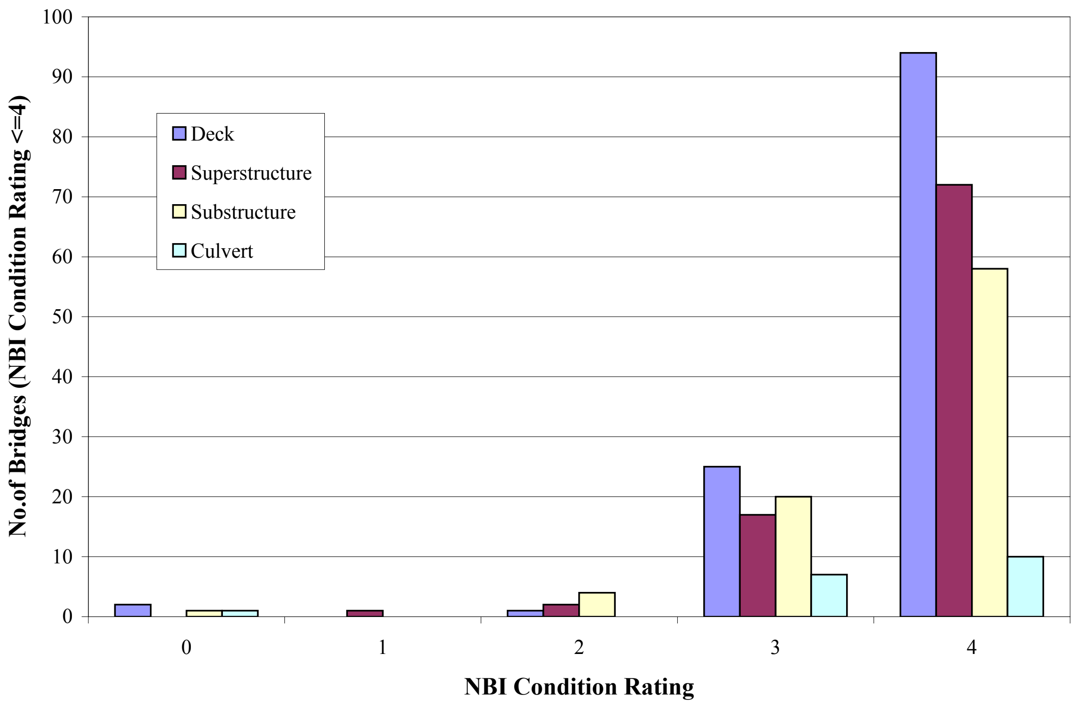

Figure 6.4 Number of structurally deficient bridges classified by bridge's components

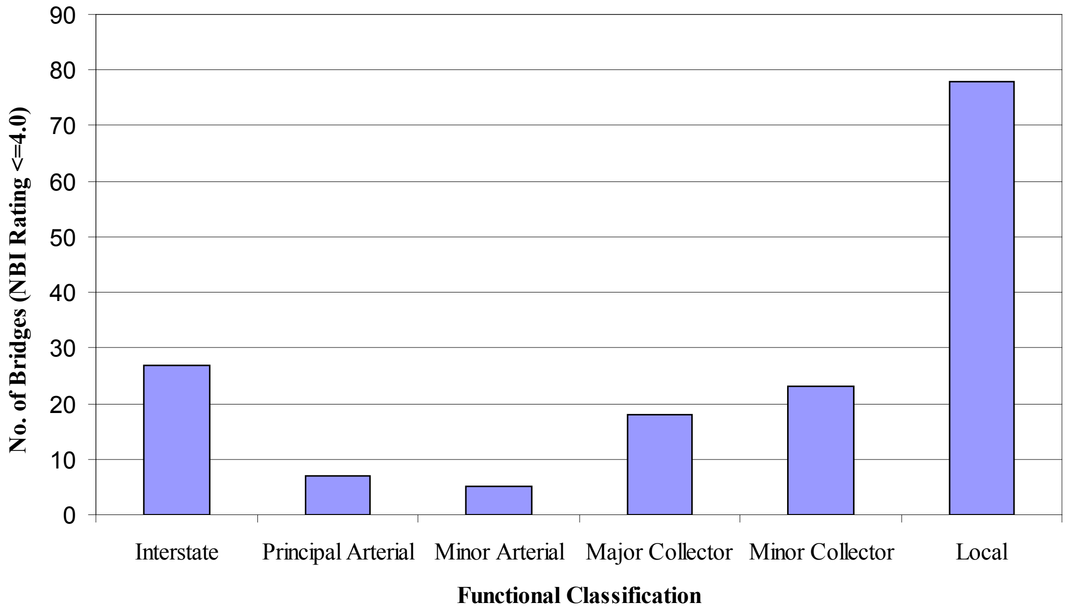

Figure 6.5 Number of structurally deficient bridges in rural area classified by highway functional class

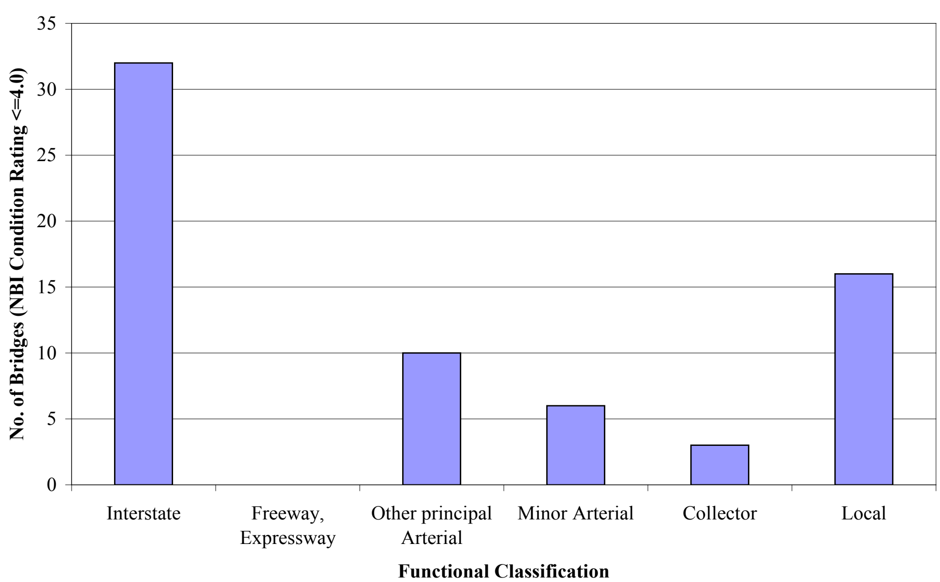

Figure 6.6 Number of structurally deficient bridges in urban area classified by highway functional class

- Utah Seismic Hazard Map

To conduct the case study due to assumed bridge failures in an earthquake, the seismic hazard map developed by the structural group at Utah State University (Halling et al., 2002) was used. The seismic hazard map for Utah is based on the deterministic maximum peak bedrock acceleration determined by the length of fault rupture and slip type expected in an earthquake. The acceleration is measured in terms of peak ground acceleration (PGA), which indicates how hard the earth shakes in a given geographical area. Figure 6.7 provides a GIS map of the seismic hazard superimposed with the locations of structurally deficient bridges in Utah. The contour lines show the various levels of PGA intensity. As can be seen, many of the structurally deficient bridges (denoted with the red dots) are in the high PGA intensity areas which indicate that these bridges are highly vulnerable to an earthquake.

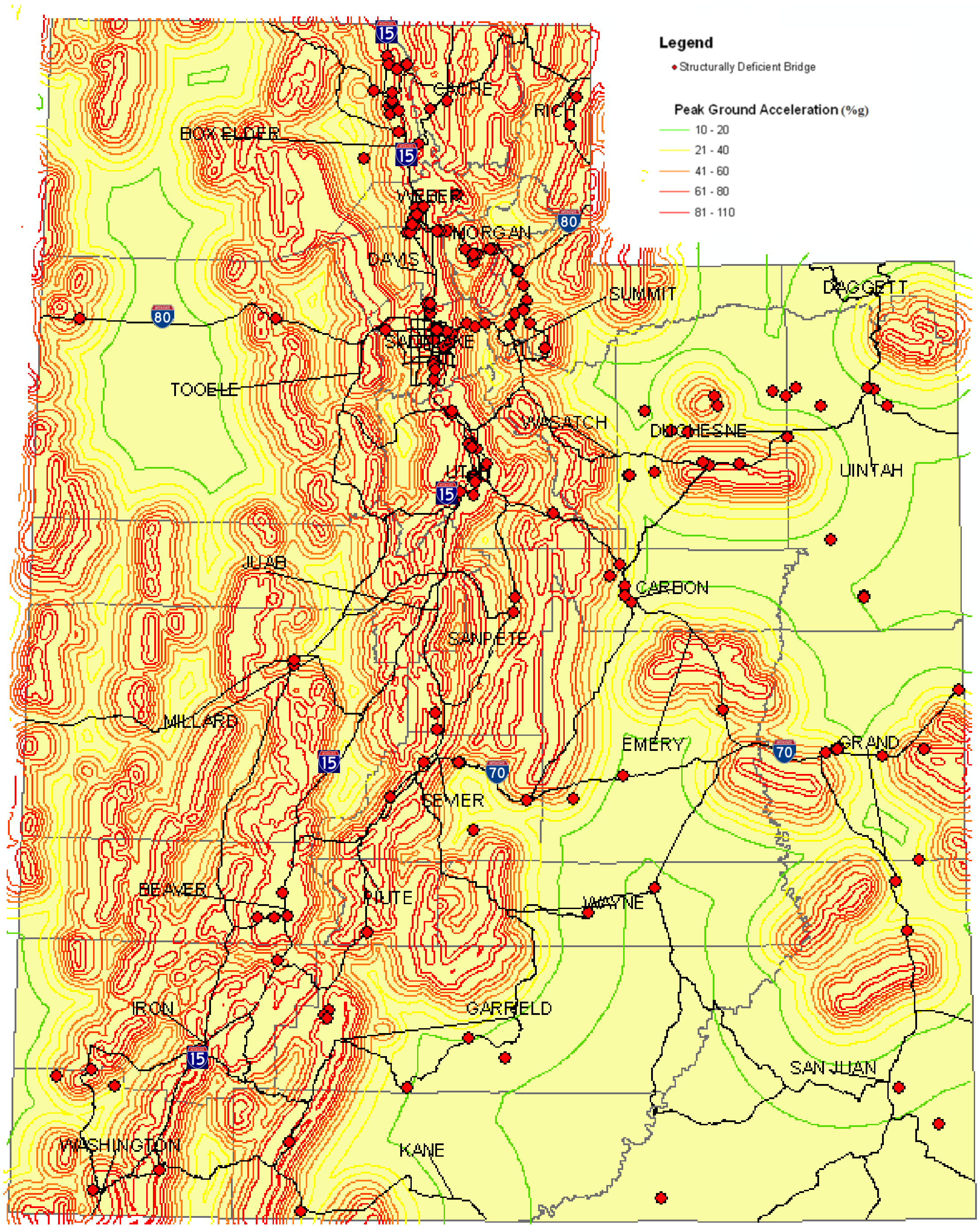

Figure 6.7 Deterministic maximum peak bedrock acceleration[6] map and locations of the structurally deficient bridges in Utah

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[6] Developed by Halling et al. (2002) for Utah.

6.1.2 Scenario Generation

As mentioned above, the "what-if" scenarios generated for the freight chokepoint analysis case study are the disruptions of structurally deficient bridges due to an earthquake. It assumes that the disrupted bridges will result in a shut down of its serviceability. For the scenarios, two groups of bridges are considered: rural and urban.

- Rural Interstate Bridges

Rural interstate bridges are important for interregional freight. Disruptions to these bridges could cause long detour and significantly increase travel distance (or travel time). In the rural interstate bridge case, the following three scenarios are considered for vulnerability assessment:

- Scenario A: Bridge at Eagle Canyon, Rural Interstate 70
- Scenario B: Bridge at Silver Creek, Rural Interstate 80
- Scenario C: Bridge near Beaver County, Rural Interstate 15

These three structurally deficient bridges are located in the relatively high seismic hazard area, and they are critical for interstate (or long-haul truck) freight transportation.

- Urban Interstate Bridges

Urban interstate bridges are vital for moving people and goods in the metropolitan area due to high traffic volumes. Disruptions to these bridges could have an adverse impact on the population living in the urban areas. In the urban interstate bridge case, the following two scenarios are considered for vulnerability assessment:

- Scenario D: Bridge at Roy (5600 South), Weber County, Urban Interstate 15
- Scenario E: Bridge at Salt Lake City (Near 2300 N. and Beck St.), Salt Lake County Urban Interstate 15

These two structurally deficient bridges are also located in the relatively high seismic hazard area. Disruptions to these bridges could have a major impact on economic productivity as well as making peoples' daily lives more difficult.

- Combined Rural and Urban Interstate Bridges

In addition to the above single bridge failure scenarios (both rural and urban), the following multiple bridge failure scenarios are considered:

- Scenario F: Disruption of Scenarios A+B+C (Rural Interstate Bridges)
- Scenario G: Disruption of Scenarios D+E (Urban Interstate Bridges)
- Scenario H: Disruption of Scenarios A+B+C+D+E (Both Rural and Urban Interstate Bridges)

See Figure 6.8 for the locations of both rural and urban interstate bridges for all scenarios. The red solid dots denote the rural interstate bridges and the blue solid dots are the urban interstate bridges.

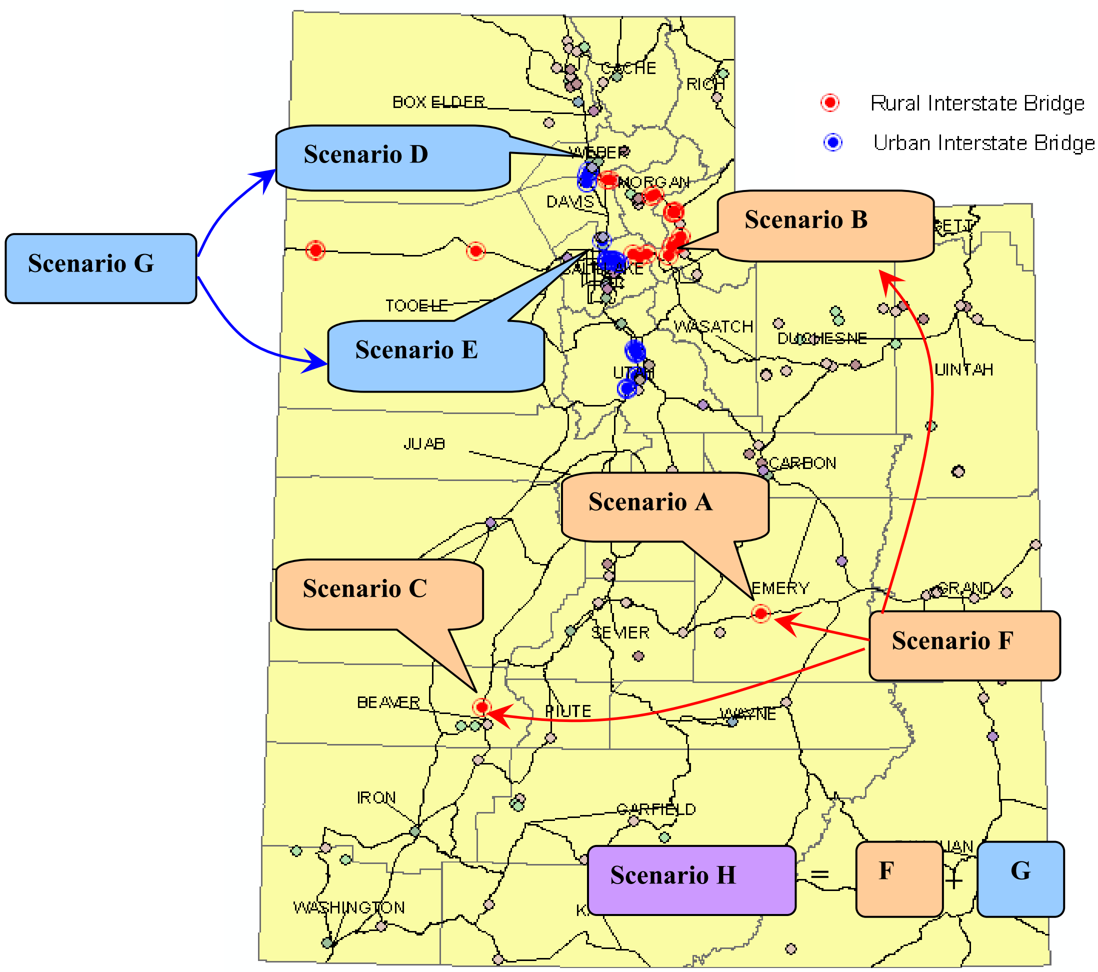


Figure 6.8 Locations of the disrupted bridges in scenarios A to H

6.2 Vulnerability Assessment Measures

This section briefly describes the measures used to assess the transportation network vulnerability and the methods used to present the results. For more details, please refer to the vulnerability assessment methods described in section 5.4 of Chapter 5. The vulnerability assessment measures include:

- O-D connectivity
- Freight flow pattern change

6.2.1 O-D connectivity

This measure is used to examine the connectivity between origin and destination nodes when a chokepoint (or a group of chokepoints) is disrupted. The shortest path algorithm is used to evaluate the impacts of bridge disruption (i.e., connectivity and detour route). The detour route is evaluated based on the increased travel distance computed before and after network disruption. For each scenario, the increased travel distances from all origins to all destinations are summarized in a table format. In the table, the impacts are color-coded to indicate the severity level as described in Table 6.2. Low impact level with an increased travel distance of less than 5 miles is color-coded in green, medium impact level with an increased travel distance of 5 to 10 miles is color-coded in yellow, and high impact level with an increased travel distance of more than 10 miles is color-coded in red. In addition, the top three O-D pairs with the highest impact in terms of increased travel distance are displayed in GIS maps.

Table 6.2 Impact levels of increased travel distance

Increased travel distance	Impact	Color legend
Less than 5 miles	Low	Green
Between 5-10 miles	Medium	Yellow
More than 10 miles	High	Red

6.2.2 Freight flow pattern change

To measure the freight flow pattern change, VMT is used as the impact measure defined as follows:

$$VMT\ (veh\text{-}mile/day) = travel\ distance\ (mile) \times daily\ truck\ flows\ (veh/day)$$

Note that VMT is calculated based on the All-or-Nothing (AON) traffic assignment process described in Chapter 5. For each scenario, the increased VMT from all origins to all destinations are summarized in a table format. Similar to the O-D connectivity measure, the impacts of freight flow pattern change are also color-coded to indicate the severity level as described in Table 6.3. In addition, the top three O-D pairs with the highest impact in terms of increased VMT are displayed in GIS maps

Table 6.3 Impact levels of increased VMT

Increased VMT	Impact	Color legend
Less than 50 veh-miles/day	Low	Green
Between 50-100 veh-miles/day	Medium	Yellow
More than 100 veh-miles/day	High	Red

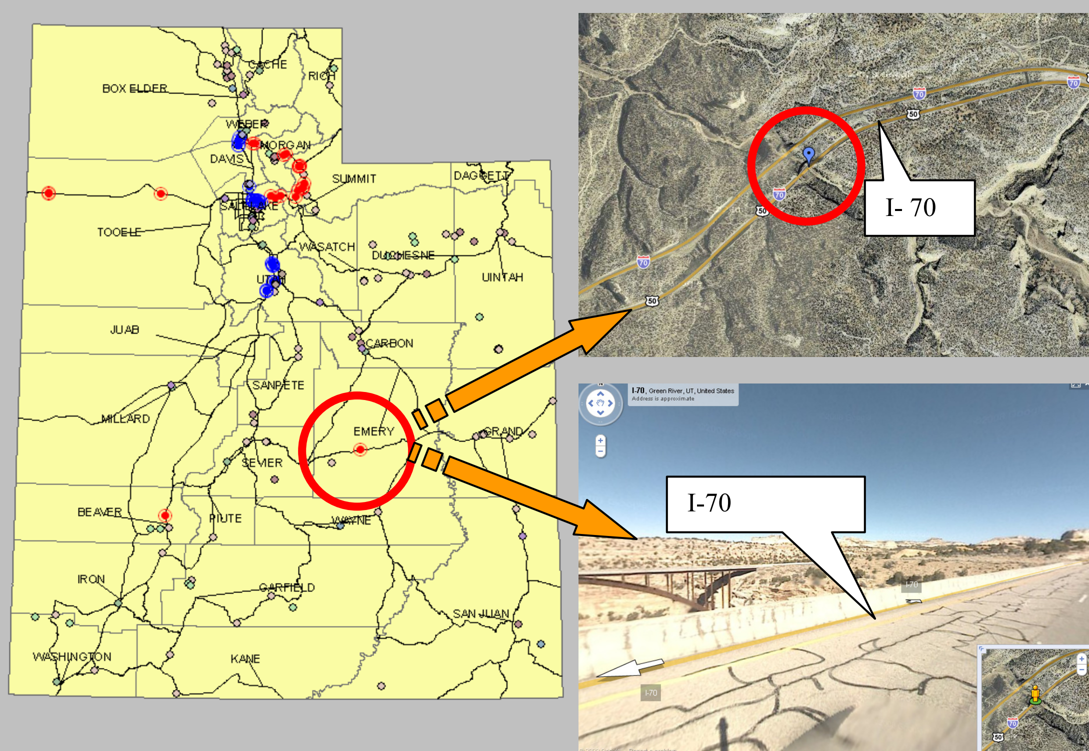
6.3 Results and Analysis

This section provides the results of the what-if scenarios by running the FCAT decision support tool. In each scenario, the following results are reported:

- Profile of each bridge (location, functional class, span length, and pre-earthquake NBI condition rating)
- Increased travel distance table and the top three O-D pairs impacted by the scenario
- Increased VMT table and the top three O-D pairs impacted by the scenario
- Increased travel distance and VMT by zone
- Summarized key findings of the scenario

Scenario A: Bridge at Eagle Canyon, Rural Interstate 70 (I-70)

Figure 6.9 shows the profile of the bridge at Eagle Canyon on I-70. This bridge is located in the rural area with limited alternative routes. It is classified as a structurally deficient bridge, because the NBI rating for the deck is 4, which indicates the deck is in poor condition. The results of O-D connectivity and freight flow pattern change of scenario A are provided in Figure 6.10 and 6.11. Table 6.4 summarizes the impact in terms of total increased travel distance and total increased VMT by zone of scenario A.



Profile of Bridge at Eagle Canyon (I-70):
Functional class: rural interstate
Length of span: 375 feet
NBI condition rating (Deck/Superstructure/Substructure/Culvert): 4/6/5/N

Figure 6.9 Bridge on I-70 at Eagle Canyon and its profile

	Ext9	Ext4	Ext11	Ext12	Ext13	Ext14	Ext7	Ext6	Ext15	Ext2	Ext3	Ext1	Ext17	Ext18	Ext16	Ext19	Ext8	Ext5	Ext.10	Box Elder	Summit	Davis	Tooele	Juab	Millard	Beaver	Iron	Washington	Kane	Garfield	Wayne	Sevier	Puite	Emery	San Juan	Carbon	Wasatch	Duchesne	Uintah	Utah	Salt Lake City	Weber	Grand	Rich	Cache	Daggett	Morgan	Sanpete	SUM
Ext9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext12	0	0	0	0	0	0	0	0	52.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22.43	0	52.6	52.6	52.6	0	0	0	59.99	51.38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24.93	369.13
Ext13	0	0	0	0	0	0	0	0	36.73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22.43	0	36.73	36.73	36.73	0	0	0	55.18	35.51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24.93	284.97
Ext14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.02	0	0	0	0	0	0	0	5.26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.02	7.3
Ext7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext15	0	0	0	52.6	36.73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	52.6	0	0	0	0	0	141.93
Ext2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.02	0	0	0	0	0	0	0	5.26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.02	7.3
Ext1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.02	0	0	0	0	0	0	0	5.26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.02	7.3
Ext17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext.10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Box Elder	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Summit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Davis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tooele	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Juab	0	0	0	22.43	22.43	1.02	0	0	0	0	1.02	1.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.02	0	0	0	0	0	0	0	22.43	0	0	0	0	0	71.37
Millard	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Beaver	0	0	0	52.6	36.73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	52.6	0	0	0	0	0	141.93
Iron	0	0	0	52.6	36.73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	52.6	0	0	0	0	0	141.93
Washington	0	0	0	52.6	36.73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	52.6	0	0	0	0	0	141.93
Kane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Garfield	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wayne	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sevier	0	0	0	59.99	55.18	5.26	0	0	0	0	5.26	5.26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.26	0	0	0	0	0	0	0	59.99	0	0	0	0	0	196.2
Puite	0	0	0	51.38	35.51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51.38	0	0	0	0	0	138.27
Emery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
San Juan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.02	0	0	0	0	0	0	0	5.26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.02	7.3
Carbon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wasatch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Duchesne	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uintah	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Utah	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Salt Lake City	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Weber	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grand	0	0	0	0	0	0	0	0	52.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22.43	0	52.6	52.6	52.6	0	0	0	59.99	51.38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24.93	369.13
Rich	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cache	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Daggett	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Morgan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sanpete	0	0	0	24.93	24.93	1.02	0	0	0	0	1.02	1.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.02	0	0	0	0	0	0	0	24.93	0	0	0	0	0	78.87
SUM	0	0	0	369.13	284.97	7.3	0	0	141.93	0	7.3	7.3	0	0	0	0	0	0	0	0	0	0	0	71.37	0	141.93	141.93	141.93	0	0	0	196.2	138.27	0	7.3	0	0	0	0	0	0	0	369.13	0	0	0	0	78.87	

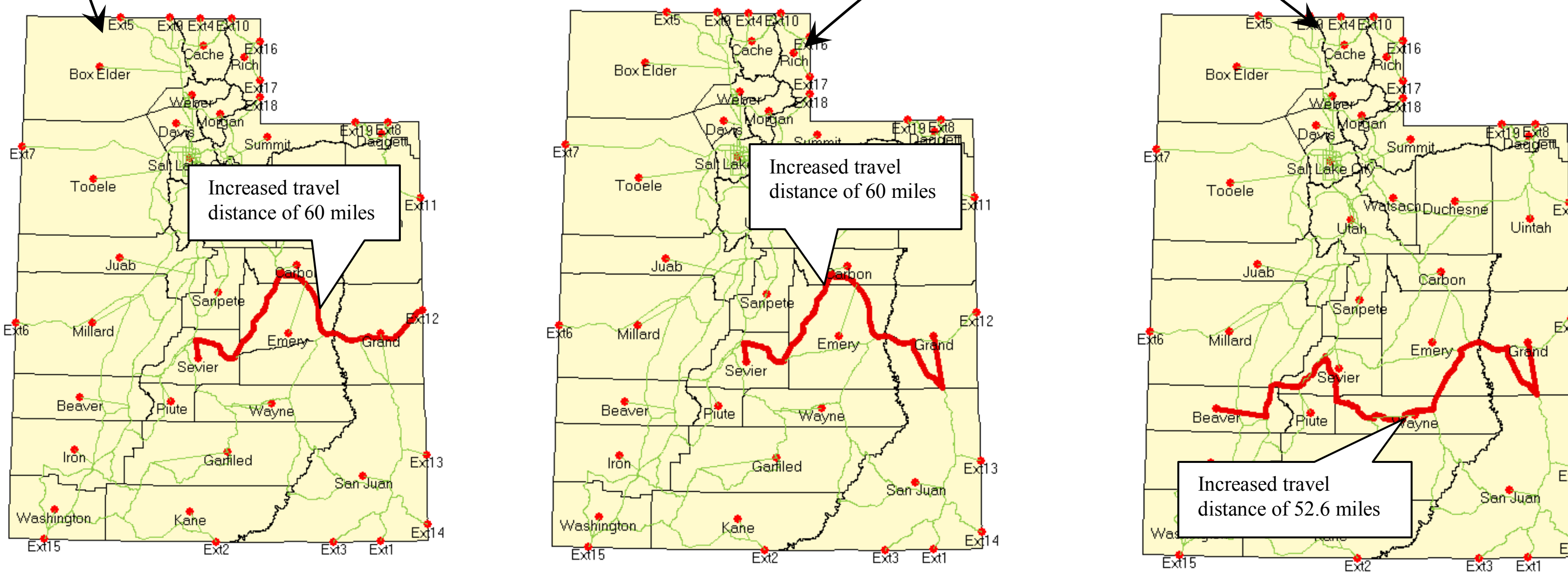


Figure 6.10 Increased travel distance table and the top three O-D pairs impacted by scenario A

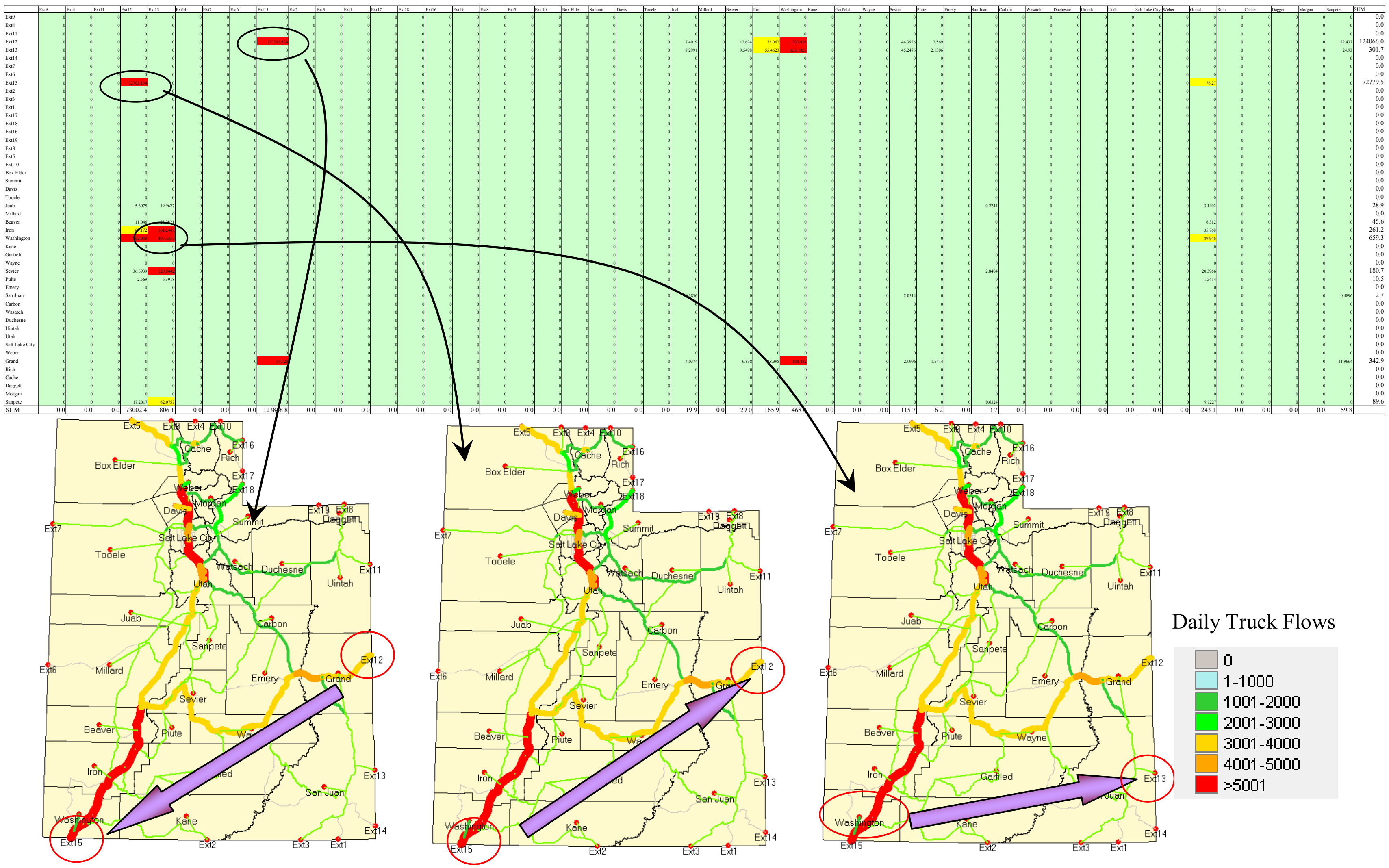


Figure 6.11 Increased VMT table and the top three O-D pairs impacted by scenario A

Table 6.4 Total increased travel distance and total increased VMT by zone of scenario A

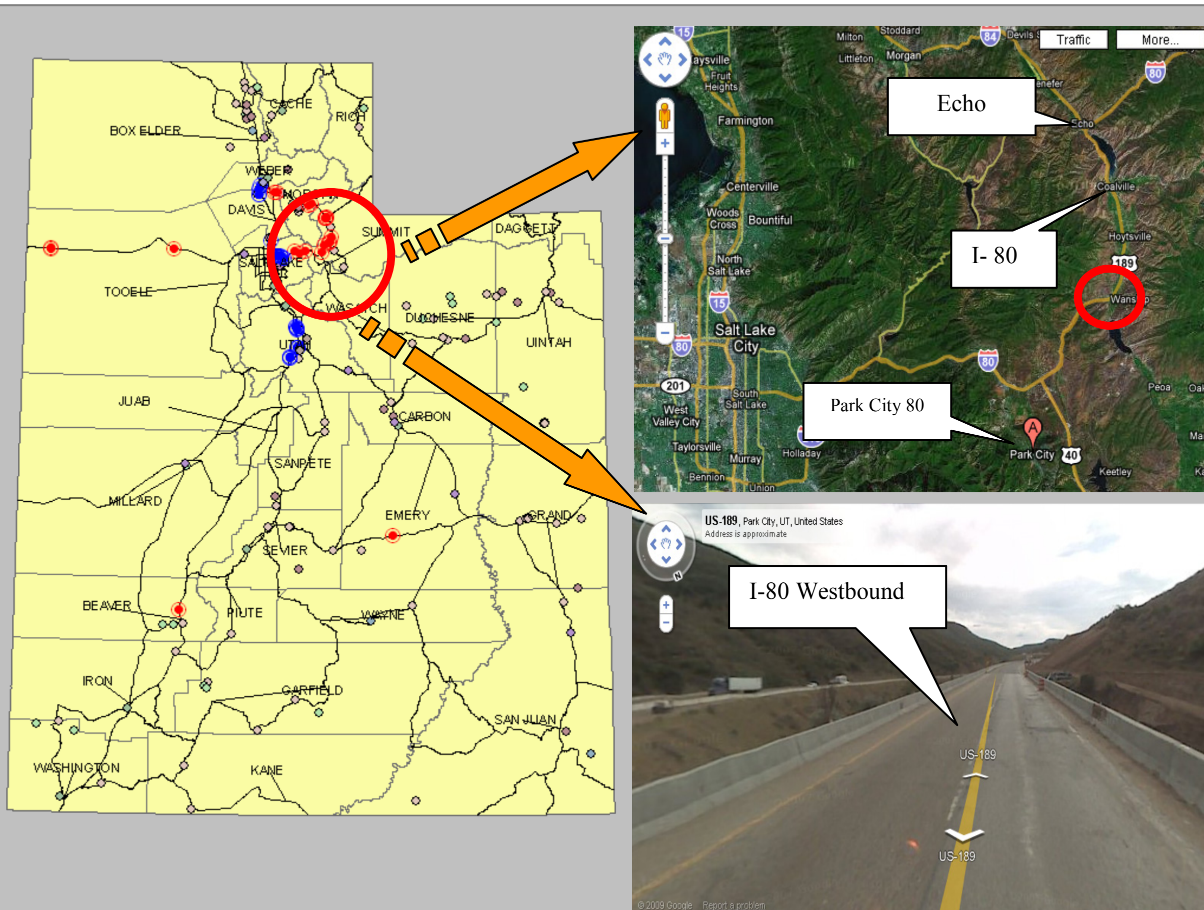
From	Total Increased Travel Distance (Mile)	Total Increased Vehicle-Miles Traveled (Veh-Mile)
Beaver	141.93	45.64
Box Elder	-	-
Cache	-	-
Carbon	-	-
Daggett	-	-
Davis	-	-
Duchesne	-	-
Emery	-	-
Garfield	-	-
Grand	369.13	342.94
Iron	141.93	261.18
Juab	71.37	28.93
Kane	-	-
Millard	-	-
Morgan	-	-
Puite	138.27	10.50
Rich	-	-
Salt Lake City	-	-
San Juan	7.30	2.72
Sanpete	78.87	89.63
Sevier	196.20	180.68
Summit	-	-
Tooele	-	-
Uintah	-	-
Utah	-	-
Wasatch	-	-
Washington	141.93	659.29
Wayne	-	-
Weber	-	-
Ext 1	7.30	-
Ext 2	-	-
Ext 3	7.30	-
Ext 4	-	-
Ext 5	-	-
Ext 6	-	-
Ext 7	-	-
Ext 8	-	-
Ext 9	-	-
Ext 10	-	-
Ext 11	-	-
Ext 12	369.13	124,066.05
Ext 13	284.97	301.72
Ext 14	7.30	-
Ext 15	141.93	72,779.46
Ext 16	-	-
Ext 17	-	-
Ext 18	-	-
Ext 19	-	-
Total	2,104.86	198,768.76

The key findings of scenario A are summarized as follows:

- The top three O-D pairs with the highest increased travel distance are:
    - Sevier County and external station 12 = 60.0 miles
    - Sevier County and Grand County = 60.0 miles
    - Beaver County and Grand County = 52.6 miles
- The top three O-D pairs with the highest increased VMT are:
    - External station 12 and external station 15 = 123,702.0 veh-miles/day
    - External station 15 and external station 12 = 72,703.0 veh-miles/day
    - Washington County and external station 13 = 407.3 veh-miles/day
- The zone with the worst impact is:
    - Grand County = 369.13 miles
    - External station 12 = 124,066.05 veh-miles/day
- The total impacts of scenario A for all zones are:
    - Total increased travel distance = 2,104.85 miles
    - Total increased VMT = 198,768.76 veh-miles/day

Scenario B: Bridge at Silver Creek, Rural Interstate 80 (I-80)

Figure 6.12 shows the profile of the bridge at Silver Creek on I-80. This bridge is located on the rural interstate 80 between Park City and the interchange at Echo Junction. It is classified as a structurally deficient bridge, because the NBI rating for the deck is 3, which indicates the deck is in serious condition. The results of O-D connectivity and freight flow pattern change of scenario B are provided in Figure 6.13 and 6.14. Table 6.5 summarizes the impact in terms total increased travel distance and total increased VMT by zone of scenario B.



Profile of Bridge at Silver Creek (I-80):
Functional class: rural interstate
Length of span: 78 feet
NBI condition rating (Deck/Superstructure/Substructure/Culvert): 3/7/7/N

Figure 6.12 Bridge on I-80 at Silver Creek and its profile

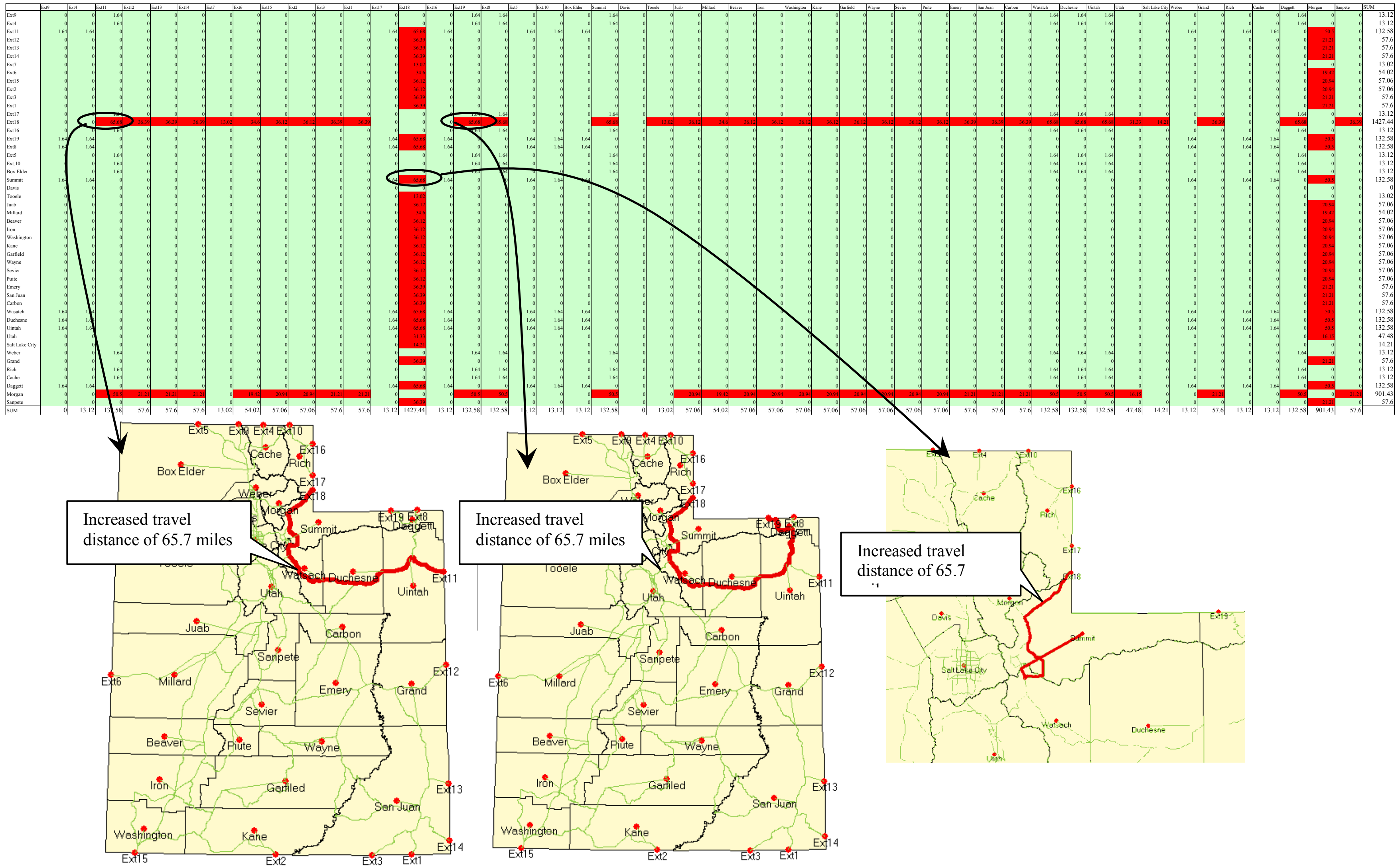


Figure 6.13 Increased travel distance table and the top three O-D pairs impacted by scenario B

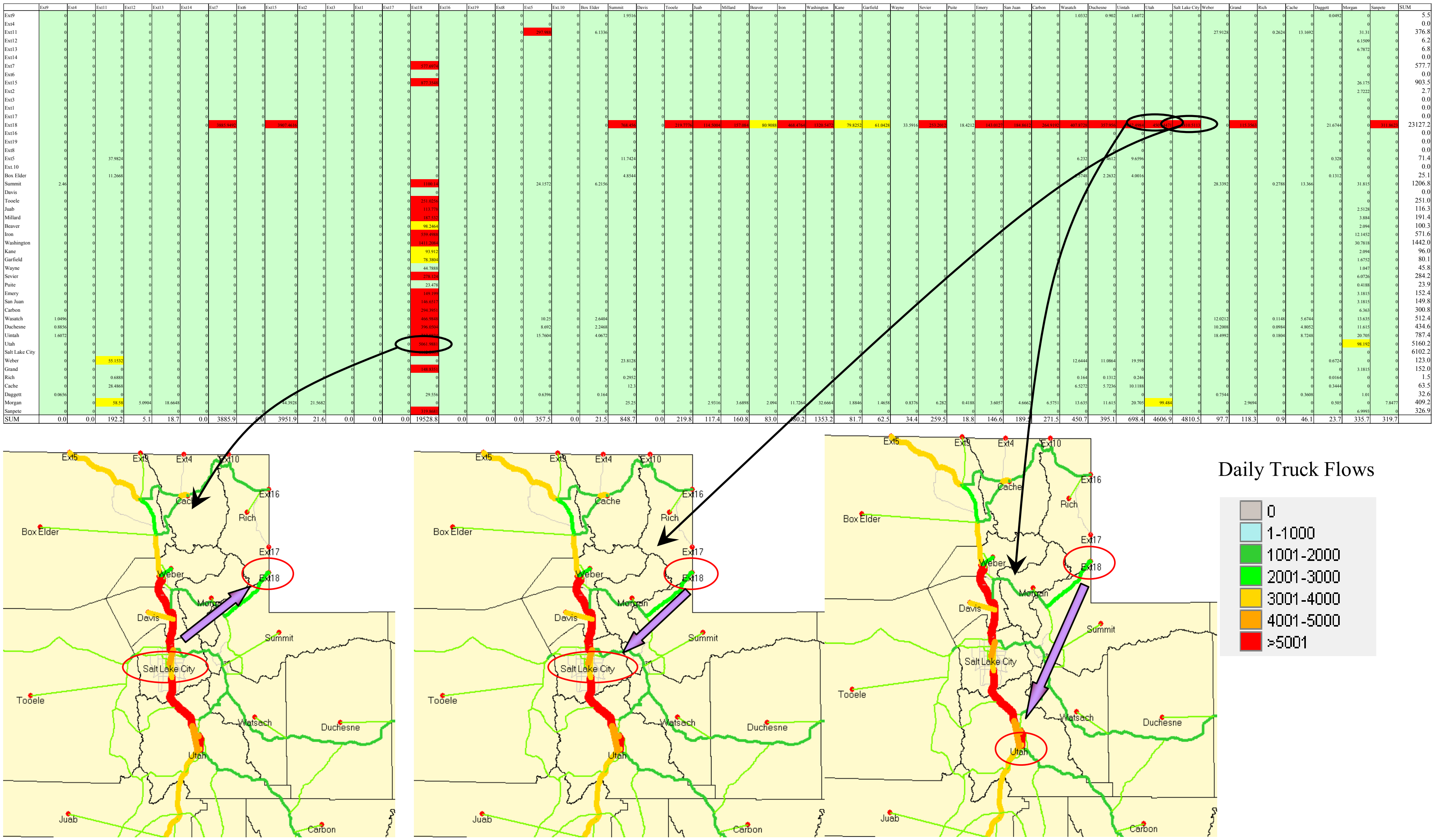


Figure 6.14 Increased VMT table and the top three O-D pairs impacted by scenario B

Table 6.5 Total increased travel distance and total increased VMT by zone of scenario B

From	Total Increased Travel Distance (Mile)	Total Increased Vehicle-Miles Traveled (Veh-Mile)
Beaver	57.06	100.34
Box Elder	13.12	25.09
Cache	13.12	63.50
Carbon	57.60	300.76
Daggett	132.58	32.55
Davis	-	-
Duchesne	132.58	434.59
Emery	57.60	152.38
Garfield	57.06	80.06
Grand	57.60	152.02
Iron	57.06	571.64
Juab	57.06	116.29
Kane	57.06	96.01
Millard	54.02	191.42
Morgan	901.43	409.15
Puite	57.06	23.90
Rich	13.12	1.54
Salt Lake City	14.21	6,102.20
San Juan	57.60	149.83
Sanpete	57.60	326.87
Sevier	57.06	284.20
Summit	132.58	1,206.77
Tooele	13.02	251.03
Uintah	132.58	787.43
Utah	47.48	5,160.18
Wasatch	132.58	512.37
Washington	57.06	1,441.99
Wayne	57.06	45.84
Weber	13.12	122.97
Ext 1	57.60	-
Ext 2	57.06	2.72
Ext 3	57.60	-
Ext 4	13.12	-
Ext 5	13.12	71.41
Ext 6	54.02	-
Ext 7	13.02	577.70
Ext 8	132.58	-
Ext 9	13.12	5.54
Ext. 10	13.12	-
Ext 11	132.58	376.78
Ext 12	57.60	6.15
Ext 13	57.60	6.79
Ext 14	57.60	-
Ext 15	57.06	903.53
Ext 16	13.12	-
Ext 17	13.12	-
Ext 18	1,427.44	23,127.21
Ext 19	132.58	-
Total	4,920.14	44,220.73

The key findings of scenario B are summarized as follows:

- The top three O-D pairs with the highest increased travel distance are:
  - External station 18 and external station 11 = 65.7 miles
  - External station 18 and external station 19 = 65.7 miles
  - Summit County and external station 18 = 65.7 miles
- The top three O-D pairs with the highest increased VMT are:
  - External station 12 and external station 15 = 123,702.0 veh-miles/day
  - External station 15 and external station 12 = 72,703.0 veh-miles/day
  - Washington County and external station 13 = 407.3 veh-miles/day
- The zone with the worst impact is:
  - External station 18 = 1,427.44 miles
  - External station 18 = 23,127.21 veh-miles/day
- The total impacts of scenario B for all zones are:
  - Total increased travel distance = 4,920.14 miles
  - Total increased VMT = 44,220.73 veh-miles/day

Scenario C: Bridge near Beaver County, Rural Interstate 15 (I-15)

Figure 6.15 shows the profile of the bridge near Beaver County on I-15. This bridge is located on the rural interstate 15, about 20 miles to I-70 interchange at Cove Fort. It is classified as a structurally deficient bridge, because the NBI ratings for both deck and superstructure are 4, which indicate the bridge is in poor condition. The results of O-D connectivity and freight flow pattern change of scenario C are provided in Figure 6.16 and 6.17. Table 6.6 summarizes the impact in terms total increased travel distance and total increased VMT by zone of scenario C.

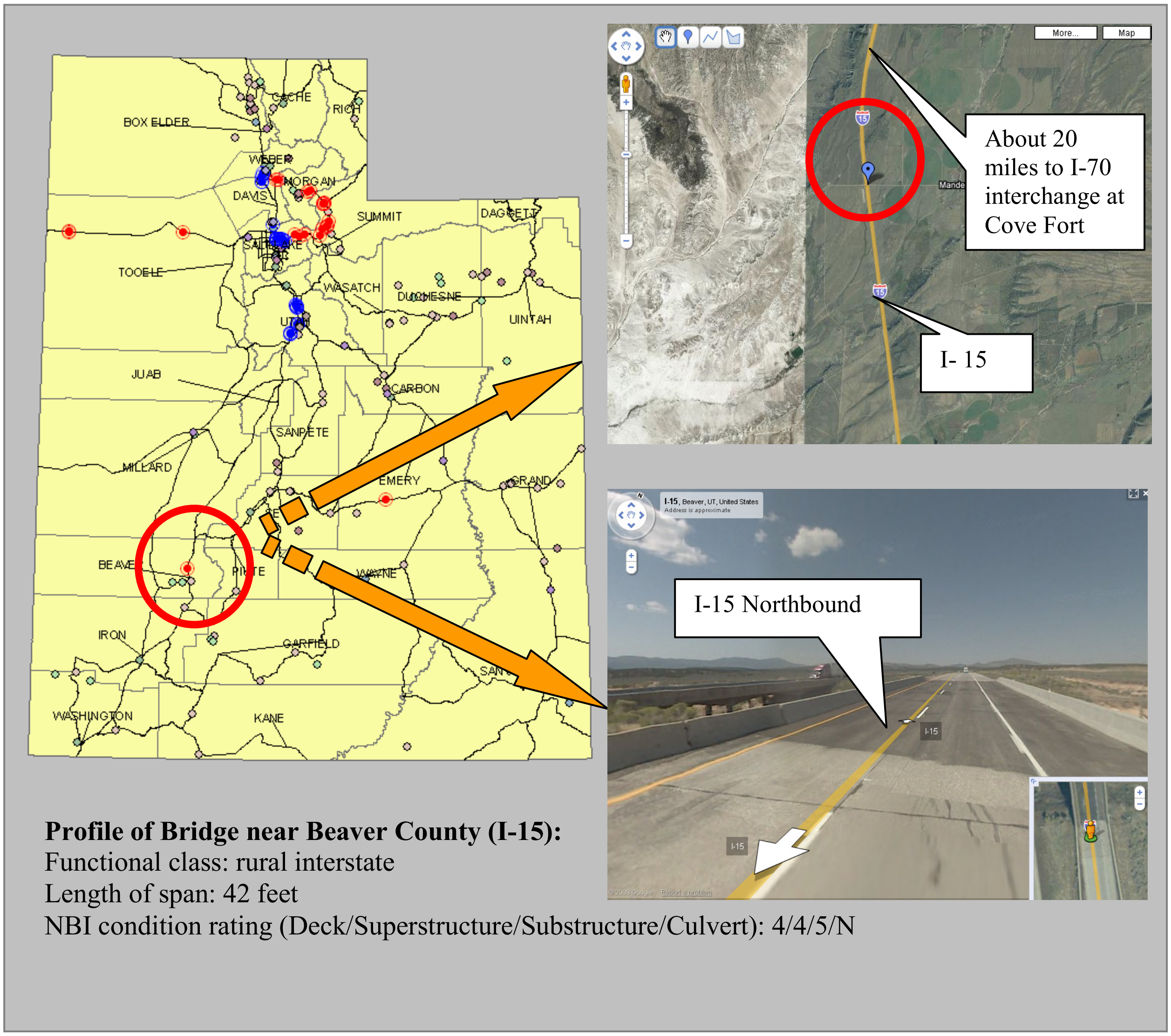


Figure 6.15 Bridge on I-15 near Beaver County and its profile

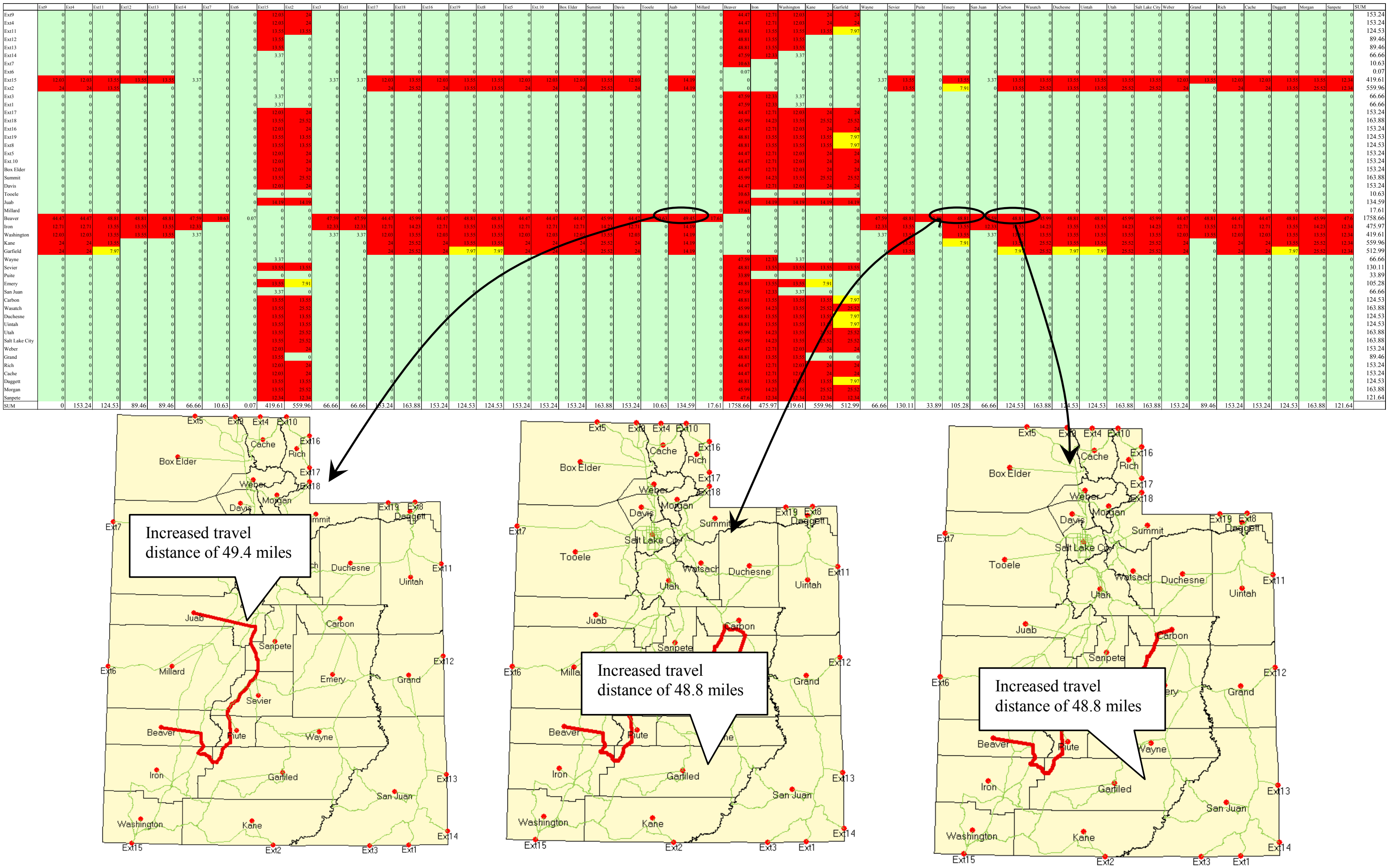


Figure 6.16 Increased travel distance table and the top three O-D pairs impacted by scenario C

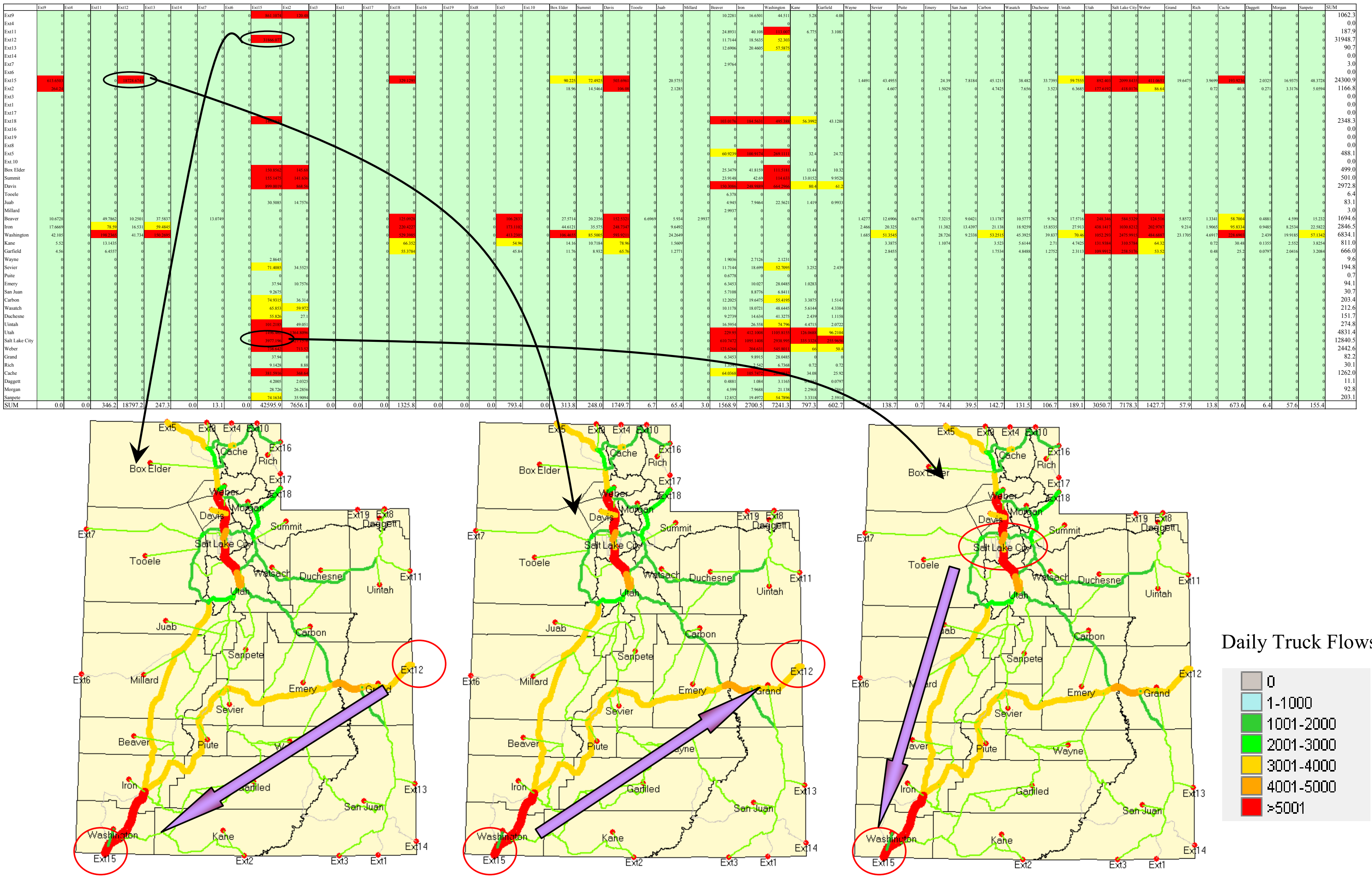


Figure 6.17 Increased VMT table and the top three O-D pairs impacted by scenario C

Table 6.6 Total increased travel distance and total increased VMT by zone of scenario C

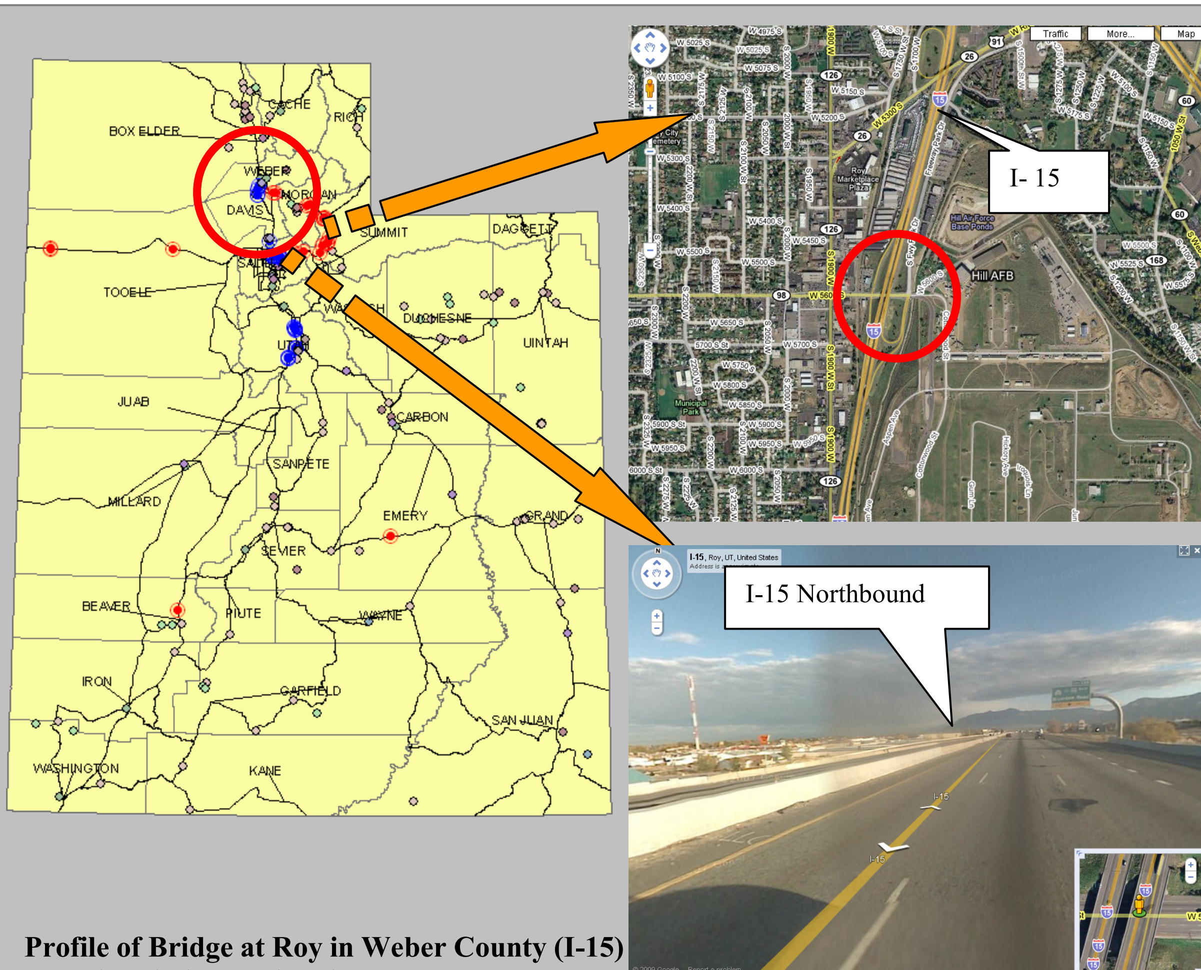
From	Total Increased Travel Distance (Mile)	Total Increased Vehicle-Miles Traveled (Veh-Mile)
Beaver	1,758.66	1,694.56
Box Elder	153.24	498.98
Cache	153.24	1,262.00
Carbon	124.53	203.42
Daggett	124.53	11.14
Davis	153.24	2,972.76
Duchesne	124.53	151.72
Emery	105.28	94.15
Garfield	512.99	666.04
Grand	89.46	82.23
Iron	475.97	2,846.50
Juab	134.59	83.13
Kane	559.96	811.01
Millard	17.61	2.99
Morgan	163.88	92.80
Puite	33.89	0.68
Rich	153.24	30.08
Salt Lake City	163.88	12,840.54
San Juan	66.66	30.70
Sanpete	121.64	203.13
Sevier	130.11	194.77
Summit	163.88	500.99
Tooele	10.63	6.38
Uintah	124.53	274.76
Utah	163.88	4,831.42
Wasatch	163.88	212.61
Washington	419.61	6,834.08
Wayne	66.66	9.60
Weber	153.24	2,442.62
Ext 1	66.66	-
Ext 2	559.96	1,166.80
Ext 3	66.66	-
Ext 4	153.24	-
Ext 5	153.24	488.07
Ext 6	0.07	-
Ext 7	10.63	2.98
Ext 8	124.53	-
Ext 9	153.24	1,062.34
Ext. 10	153.24	-
Ext 11	124.53	187.89
Ext 12	89.46	31,948.66
Ext 13	89.46	90.74
Ext 14	66.66	-
Ext 15	419.61	24,300.89
Ext 16	153.24	-
Ext 17	153.24	-
Ext 18	163.88	2,348.34
Ext 19	124.53	-
Total	9,413.52	101,482.47

The key findings of scenario C are summarized as follows:

- The top three O-D pairs with the highest increased travel distance are:
  - Beaver County and Juab County = 49.4 miles
  - Beaver County and Emery County = 48.8 miles
  - Beaver County and Carbon County = 48.8 miles
- The top three O-D pairs with the highest increased VMT are:
  - External station 12 and external station 15 = 31,866.0 veh-miles/day
  - External station 15 and external station 12 = 18,728.0 veh-miles/day
  - Salt Lake County and external station 15 = 3,977.2 veh-miles/day
- The zone with the worst impact is:
  - Beaver County = 1,758.66 miles
  - External station 12 = 31,948.66 veh-miles/day
- The total impacts of scenario C for all zones are:
  - Total increased travel distance = 9,413.52 miles
  - Total increased VMT = 101,482.47 veh-miles/day

Scenario D: Bridge at Roy, Weber County, Urban Interstate 15 (I-15)

Figure 6.18 shows the profile of the bridge at Roy in Weber County on I-15. This bridge is located on the urban interstate 15 with many alternative routes. It is classified as a structurally deficient bridge, because the NBI rating for the deck is 4, which indicate the deck is in poor condition. The results of O-D connectivity and freight flow pattern change of scenario D are provided in Figure 6.19 and 6.20. Table 6.7 summarizes the impact in terms total increased travel distance and total increased VMT by zone of scenario D.



Profile of Bridge at Roy in Weber County (I-15)
Functional class: urban interstate
Length of span: 86 feet
NBI condition rating (Deck/Superstructure/Substructure/Culvert): 4/6/7/N

Figure 6.18 Bridge on I-15 at Weber County and its profile

Increased travel distance
less than 5 miles

	Ext9	Ext4	Ext11	Ext12	Ext13	Ext14	Ext7	Ext6	Ext15	Ext2	Ext3	Ext1	Ext17	Ext18	Ext16	Ext19	Ext8	Ext5	Ext.10	Box Elder	Summit	Davis	Tooele	Juab	Millard	Beaver	Iron	Washington	Kane	Garfield	Wayne	Sevier	Puite	Emery	San Juan	Carbon	Wasatch	Duchesne	Uintah	Utah	Salt Lake City	Weber	Grand	Rich	Cache	Daggett	Morgan	Sanpete	SUM
Ext9	0	0	0	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0	0	0	0.44	0.44	0	0.44	0	0	0	0	0.44	12.32
Ext4	0	0	0	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0	0	0	0.44	0.44	0	0.44	0	0	0	0	0.44	12.32
Ext11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext12	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Ext13	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Ext14	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Ext7	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Ext6	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Ext15	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Ext2	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Ext3	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Ext1	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Ext17	0	0	0	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0	0	0	0.44	0.44	0	0.44	0	0	0	0	0.44	12.32
Ext18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext16	0	0	0	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0	0	0	0.44	0.44	0	0.44	0	0	0	0	0.44	12.32
Ext19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext5	0	0	0	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0	0	0	0.44	0.44	0	0.44	0	0	0	0	0.44	12.32
Ext.10	0	0	0	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0	0	0	0.44	0.44	0	0.44	0	0	0	0	0.44	12.32
Box Elder	0	0	0	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0	0	0	0.44	0.44	0	0.44	0	0	0	0	0.44	12.32
Summit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Davis	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Tooele	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Juab	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Millard	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Beaver	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Iron	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Washington	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Kane	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Garfield	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Wayne	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Sevier	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Puite	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Emery	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
San Juan	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Carbon	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Wasatch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Duchesne	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uintah	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Utah	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Salt Lake City	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Weber	0	0	0	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0	0	0	0.44	0.44	0	0.44	0	0	0	0	0.44	12.32
Grand	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Rich	0	0	0	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0	0	0	0.44	0.44	0	0.44	0	0	0	0	0.44	12.32
Cache	0	0	0	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0	0	0	0.44	0.44	0	0.44	0	0	0	0	0.44	12.32
Daggett	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Morgan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sanpete	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
SUM	0	12.32	0	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	12.32	0	12.32	0	0	12.32	12.32	12.32	0	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	0	0	0	4.4	4.4	12.32	4.4	12.32	12.32	0	0	4.4	

Figure 6.19 Increased travel distance table of scenario D

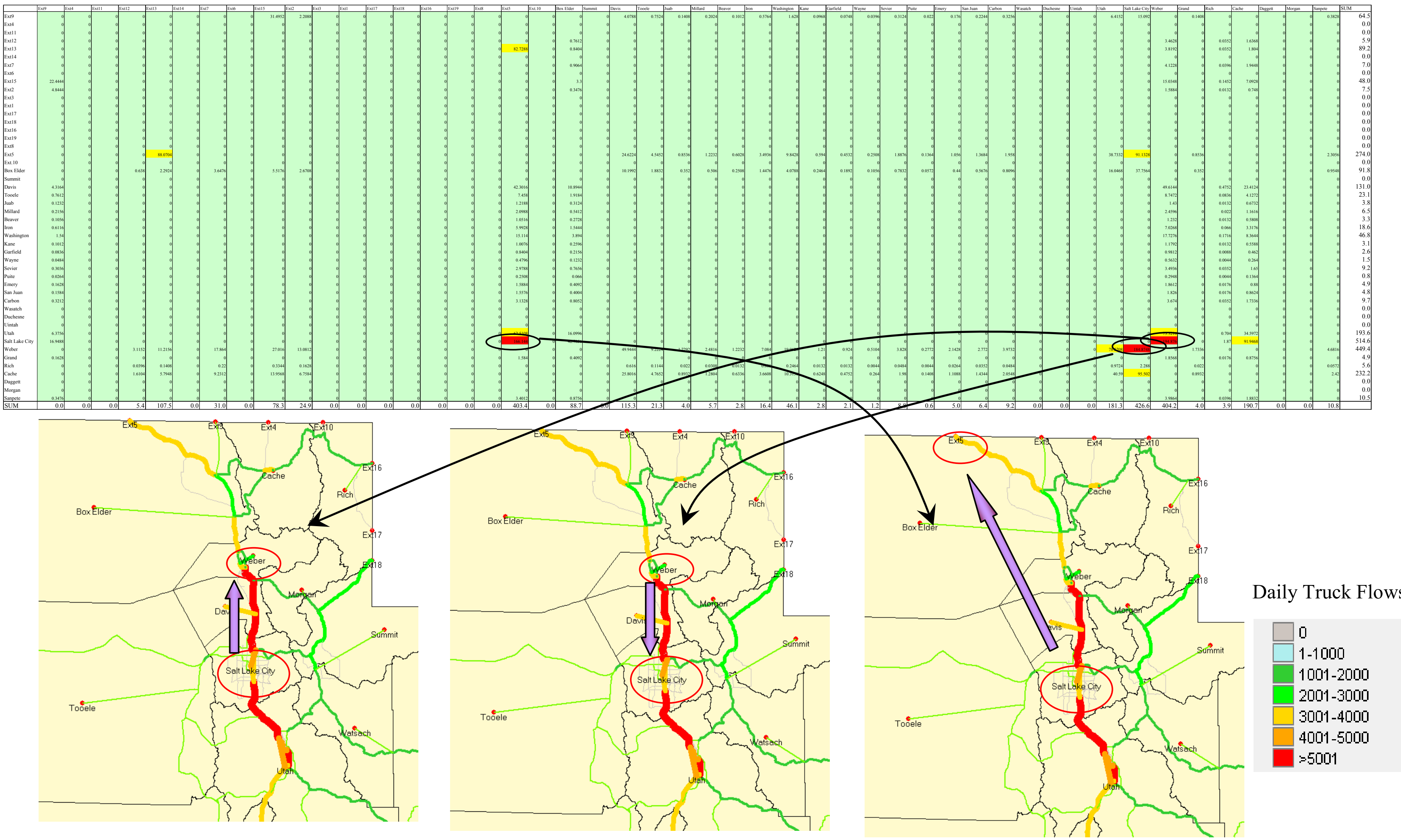


Figure 6.20 Increased VMT table and the top three O-D pairs impacted by scenario D

Table 6.7 Total increased travel distance and total increased VMT by zone of scenario D

From	Total Increased Travel Distance (Mile)	Total Increased Vehicle-Miles Traveled (Veh-Mile)
Beaver	4.40	3.26
Box Elder	12.32	91.79
Cache	12.32	232.19
Carbon	4.40	9.70
Daggett	-	-
Davis	4.40	131.01
Duchesne	-	-
Emery	4.40	4.92
Garfield	4.40	2.59
Grand	4.40	4.91
Iron	4.40	18.56
Juab	4.40	3.77
Kane	4.40	3.12
Millard	4.40	6.50
Morgan	-	-
Puite	4.40	0.78
Rich	12.32	5.56
Salt Lake City	4.40	514.57
San Juan	4.40	4.82
Sanpete	4.40	10.53
Sevier	4.40	9.23
Summit	-	-
Tooele	4.40	23.10
Uintah	-	-
Utah	4.40	193.61
Wasatch	-	-
Washington	4.40	46.81
Wayne	4.40	1.48
Weber	12.32	449.44
Ext 1	4.40	-
Ext 2	4.40	7.54
Ext 3	4.40	-
Ext 4	12.32	-
Ext 5	12.32	273.98
Ext 6	4.40	-
Ext 7	4.40	7.01
Ext 8	-	-
Ext 9	12.32	64.49
Ext. 10	12.32	-
Ext 11	-	-
Ext 12	4.40	5.90
Ext 13	4.40	89.23
Ext 14	4.40	-
Ext 15	4.40	48.02
Ext 16	12.32	-
Ext 17	12.32	-
Ext 18	-	-
Ext 19	-	-
Total	246.40	2,268.42

The key findings of scenario D are summarized as follows:

- Since there are many alternative routes in the urban area, the disruption of this bridge has low impact. The detour distance for all O-D pairs are less than 5 miles.
- The top three O-D pairs with the highest increased VMT are:
    - Salt Lake County and Weber County = 194.9 veh-miles/day
    - Weber County and Salt Lake County = 184.9 veh-miles/day
    - Salt Lake County and external station 5 = 166.1 veh-miles/day
- The zone with the worst impact is:
    - The longest increased travel distance is about 12.32 miles (many counties and external stations have the same increase, see Table 6.7)
    - Salt Lake County = 514.57 veh-miles/day
- The total impacts of scenario D for all zones are:
    - Total increased travel distance = 246.40 miles
    - Total increased VMT = 2,268.42 veh-miles/day

Scenario E: Bridge at Salt Lake City (Near 2300 N. and Beck St.), Salt Lake County, Urban Interstate 15 (I-15)

Figure 6.21 shows the profile of the bridge in the Salt Lake City near 2300 N. and Beck Street on I-15. Similar to scenario D, this bridge is located on the urban interstate 15 with many alternative routes. It is classified as a structurally deficient bridge, because the NBI ratings for both deck and superstructure are 4, which indicate the bridge is in poor condition. The results of O-D connectivity and freight flow pattern change of scenario E are provided in Figure 6.22 and 6.23. Table 6.8 summarizes the impact in terms of total increased travel distance and total increased VMT by zone of scenario E.

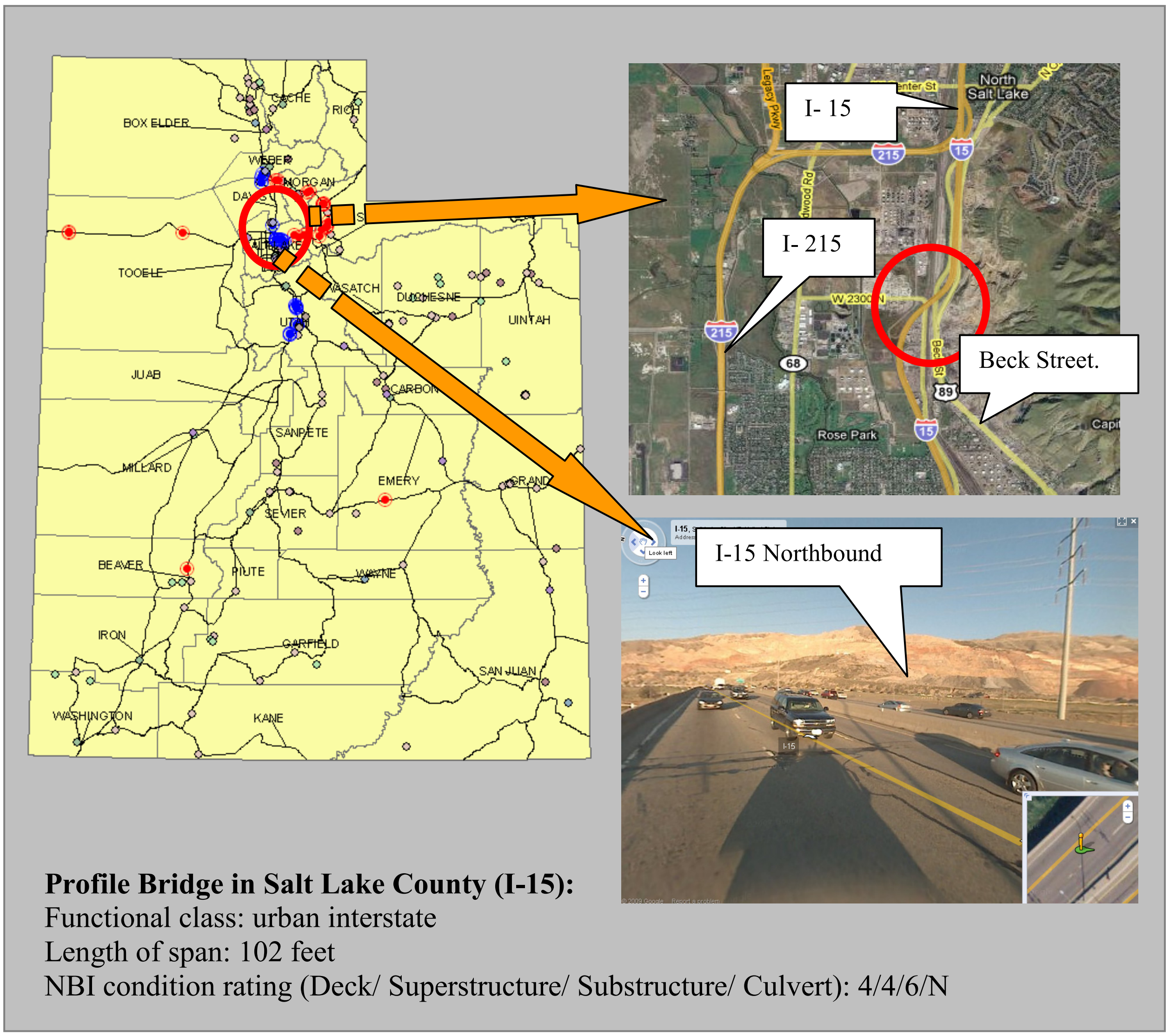


Figure 6.21 Bridge on I-15 at Salt Lake City and its profile

Increased travel distance less than 5 miles

	Ext9	Ext4	Ext11	Ext12	Ext13	Ext14	Ext7	Ext6	Ext15	Ext2	Ext3	Ext1	Ext17	Ext18	Ext16	Ext19	Ext8	Ext5	Ext.10	Box Elder	Summit	Davis
Ext9	0	0	0	2.65	2.65	2.65	0	0	2.65	2.65	2.65	2.65	0	0	0	0	0	0	0	0	0	0
Ext4	0	0	0	2.65	2.65	2.65	0	0	2.65	2.65	2.65	2.65	0	0	0	0	0	0	0	0	0	0
Ext11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Ext12	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
Ext13	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
Ext14	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
Ext7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext15	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
Ext2	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
Ext3	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
Ext1	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
Ext17	0	0	0	2.65	2.65	2.65	0	0	2.65	2.65	2.65	2.65	0	0	0	0	0	0	0	0	0	0
Ext18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext16	0	0	0	2.65	2.65	2.65	0	0	2.65	2.65	2.65	2.65	0	0	0	0	0	0	0	0	0	0
Ext19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Ext8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Ext5	0	0	0	2.65	2.65	2.65	0	0	2.65	2.65	2.65	2.65	0	0	0	0	0	0	0	0	0	0
Ext.10	0	0	0	2.65	2.65	2.65	0	0	2.65	2.65	2.65	2.65	0	0	0	0	0	0	0	0	0	0
Box Elder	0	0	0	2.65	2.65	2.65	0	0	2.65	2.65	2.65	2.65	0	0	0	0	0	0	0	0	0	0
Summit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Davis	0	0	2.9	2.65	2.65	2.65	0	0	2.65	2.65	2.65	2.65	0	0	0	2.9	2.9	0	0	0	2.9	0
Tooele	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Juab	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
Millard	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Beaver	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
Iron	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
Washington	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
Kane	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
Garfield	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
Wayne	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
Sevier	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
Puite	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
Emery	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
San Juan	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
Carbon	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
Wasatch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Duchesne	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Uintah	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Utah	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
Salt Lake City	2.9	2.9	0	0	0	0	0	0	0	0	0	0	2.9	0	2.9	0	0	2.9	2.9	2.9	0	2.9
Weber	0	0	0	2.65	2.65	2.65	0	0	2.65	2.65	2.65	2.65	0	0	0	0	0	0	0	0	0	0
Grand	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
Rich	0	0	0	2.65	2.65	2.65	0	0	2.65	2.65	2.65	2.65	0	0	0	0	0	0	0	0	0	0
Cache	0	0	0	2.65	2.65	2.65	0	0	2.65	2.65	2.65	2.65	0	0	0	0	0	0	0	0	0	0
Daggett	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Morgan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sanpete	2.65	2.65	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	0	0	2.65	2.65	2.65	0	2.65
SUM	0	61.2	2.9	29.15	29.15	29.15	0	0	29.15	29.15	29.15	29.15	61.2	0	61.2	2.9	2.9	61.2	61.2	61.2	2.9	84.4

	Tooele	Juab	Millard	Beaver	Iron	Washington	Kane	Garfield	Wayne	Sevier	Puite	Emery	San Juan	Carbon	Wasatch	Duchesne	Uintah	Utah	Salt Lake City	Weber	Grand	Rich	Cache	Daggett	Morgan	Sanpete	SUM
Ext9	0	2.65	0	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	0	0	0	2.65	2.9	0	2.65	0	0	0	0	2.65	61.2
Ext4	0	2.65	0	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	0	0	0	2.65	2.9	0	2.65	0	0	0	0	2.65	61.2
Ext11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Ext12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
Ext13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
Ext14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
Ext7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
Ext2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
Ext3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
Ext1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
Ext17	0	2.65	0	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	0	0	0	2.65	2.9	0	2.65	0	0	0	0	2.65	61.2
Ext18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext16	0	2.65	0	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	0	0	0	2.65	2.9	0	2.65	0	0	0	0	2.65	61.2
Ext19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Ext8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Ext5	0	2.65	0	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	0	0	0	2.65	2.9	0	2.65	0	0	0	0	2.65	61.2
Ext.10	0	2.65	0	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	0	0	0	2.65	2.9	0	2.65	0	0	0	0	2.65	61.2
Box Elder	0	2.65	0	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	0	0	0	2.65	2.9	0	2.65	0	0	0	0	2.65	61.2
Summit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Davis	0	2.65	0	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.9	2.9	2.9	2.65	2.9	0	2.65	0	0	2.9	0	2.65	84.4
Tooele	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Juab	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
Millard	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Beaver	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
Iron	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
Washington	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
Kane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
Garfield	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
Wayne	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
Sevier	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
Puite	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
Emery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
San Juan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
Carbon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
Wasatch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Duchesne	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Uintah	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Utah	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
Salt Lake City	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9	0	2.9	2.9	0	0.97	0	32.87
Weber	0	2.65	0	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	0	0	0	2.65	2.9	0	2.65	0	0	0	0	2.65	61.2
Grand	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
Rich	0	2.65	0	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	0	0	0	2.65	2.9	0	2.65	0	0	0	0	2.65	61.2
Cache	0	2.65	0	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	0	0	0	2.65	2.9	0	2.65	0	0	0	0	2.65	61.2
Daggett	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Morgan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.97	0	0	0	0	0	0	0	0.97
Sanpete	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.65	0	2.65	2.65	0	0	0	29.15
SUM	0	29.15	0	29.15	29.15	29.15	29.15	29.15	29.15	29.15	29.15	29.15	29.15	29.15	2.9	2.9	2.9	29.15	32.87	61.2	29.15	61.2	61.2	2.9	0.97	29.15	

Figure 6.22 Increased travel distance table of scenario E

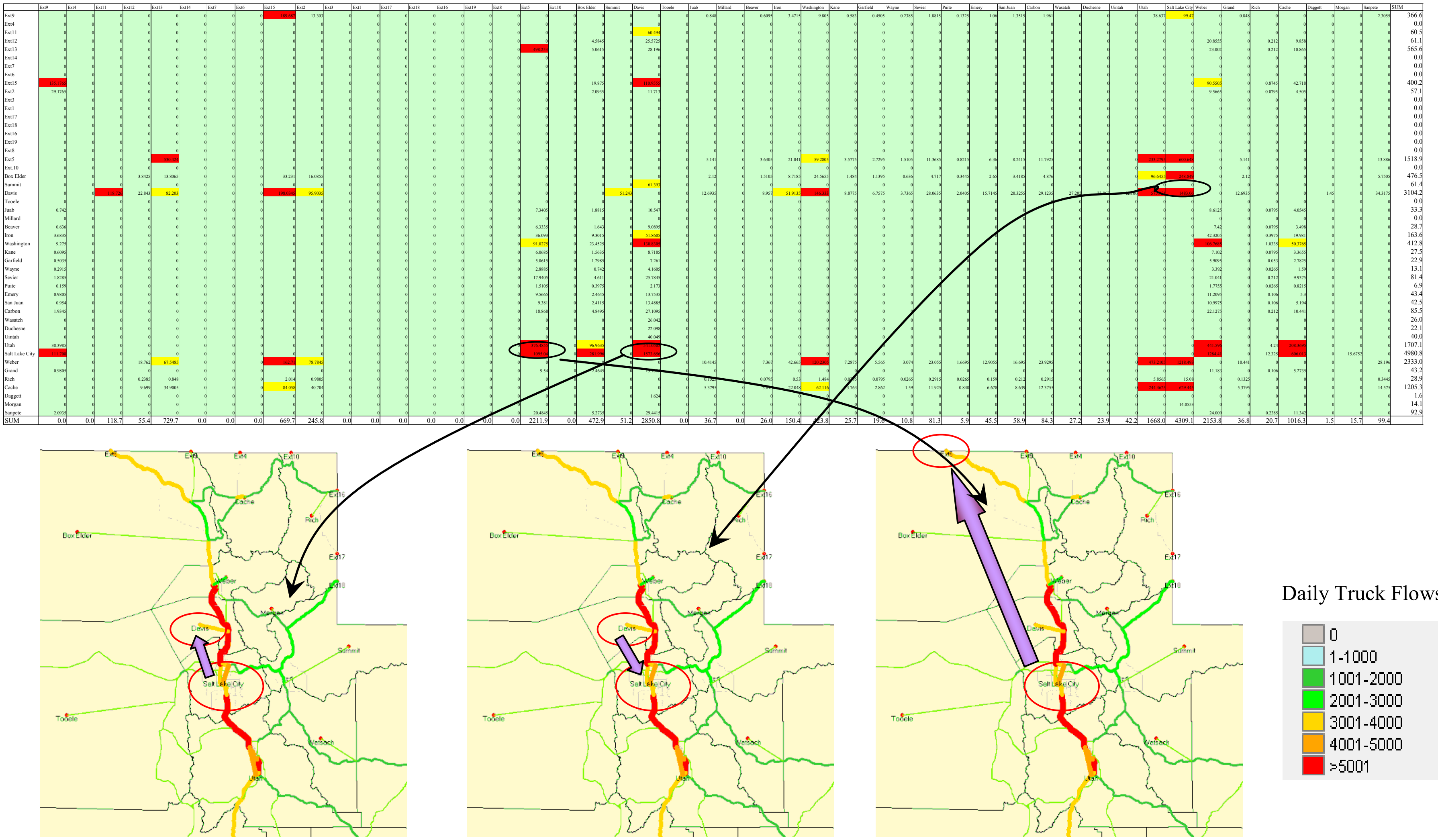


Figure 6.23 Increased VMT table and the top three O-D pairs impacted by scenario E

Table 6.8 Total increased travel distance and total increased VMT by zone of scenario E

From	Total Increased Travel Distance (Mile)	Total Increased Vehicle-Miles Traveled (Veh-Mile)
Beaver	29.15	28.70
Box Elder	61.20	476.51
Cache	61.20	1,205.26
Carbon	29.15	85.54
Daggett	2.90	1.62
Davis	84.40	3,104.20
Duchesne	2.90	22.10
Emery	29.15	43.38
Garfield	29.15	22.87
Grand	29.15	43.25
Iron	29.15	163.64
Juab	29.15	33.26
Kane	29.15	27.51
Millard	-	-
Morgan	0.97	14.06
Puite	29.15	6.86
Rich	61.20	28.89
Salt Lake City	32.87	4,980.82
San Juan	29.15	42.53
Sanpete	29.15	92.88
Sevier	29.15	81.36
Summit	2.90	61.39
Tooele	-	-
Uintah	2.90	40.05
Utah	29.15	1,707.10
Wasatch	2.90	26.04
Washington	29.15	412.76
Wayne	29.15	13.09
Weber	61.20	2,333.00
Ext 1	29.15	-
Ext 2	29.15	57.13
Ext 3	29.15	-
Ext 4	61.20	-
Ext 5	61.20	1,518.87
Ext 6	-	-
Ext 7	-	-
Ext 8	2.90	-
Ext 9	61.20	366.64
Ext. 10	61.20	-
Ext 11	2.90	60.49
Ext 12	29.15	61.08
Ext 13	29.15	565.59
Ext 14	29.15	-
Ext 15	29.15	400.15
Ext 16	61.20	-
Ext 17	61.20	-
Ext 18	-	-
Ext 19	2.90	-
Total	1,394.74	18,128.64

The key findings of scenario E are summarized as follows:

- Similar to scenario D, the disruption of this bridge has low impact. The detour distance for all O-D pairs are less than 5 miles.
- The top three O-D pairs with the highest increased VMT are:
    - Salt Lake County and Davis County = 1573.6 veh-miles/day
    - Davis County and Salt Lake County = 1483.0 veh-miles/day
    - Salt Lake County and external station 5 = 1095.0 veh-miles/day
- The zone with the worst impact is:
    - Davis County = 84.4 miles
    - Salt Lake County = 4,980.82 veh-miles/day
- The total impacts of scenario D for all zones are:
    - Total increased travel distance = 1,397.74 miles
    - Total increased VMT = 18,128.64 veh-miles/day

Scenario F: Rural Interstate Bridges (scenario A+B+C)

In this scenario, the impacts of disrupting multiple rural interstate bridges are assessed. Figure 6.24 shows the locations of these rural interstate bridges. The results of O-D connectivity and freight flow pattern change of scenario F are provided in Figure 6.25 and 6.26. Table 6.9 summarizes the impact in terms of total increased travel distance and total increased VMT by zone of scenario F.

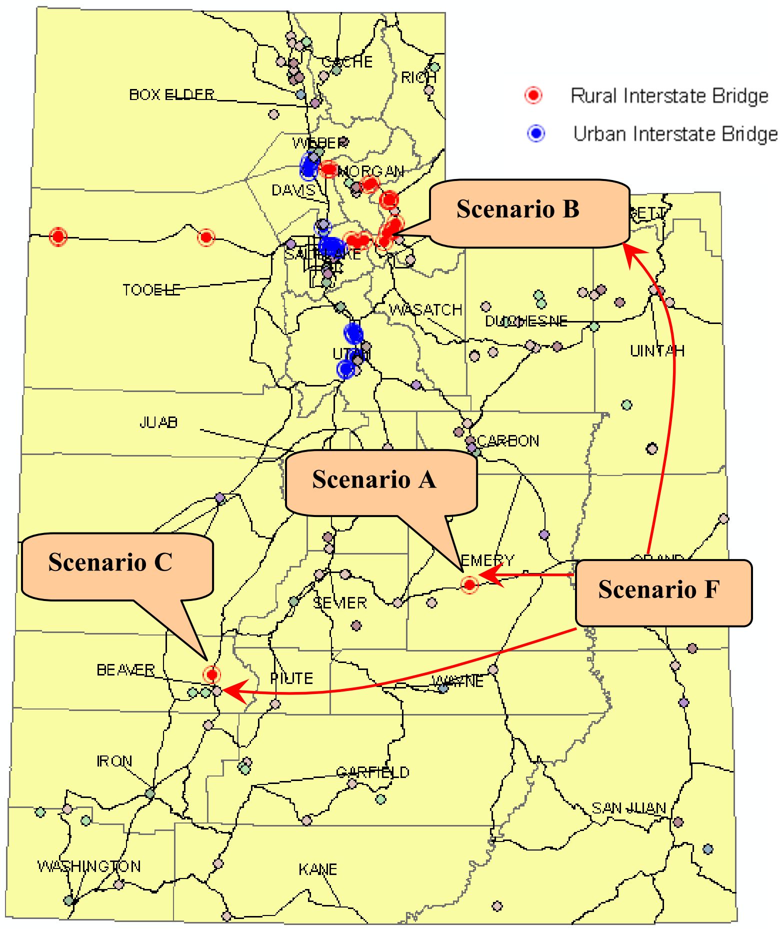


Figure 6.24 Locations of the rural interstate bridges in scenario F

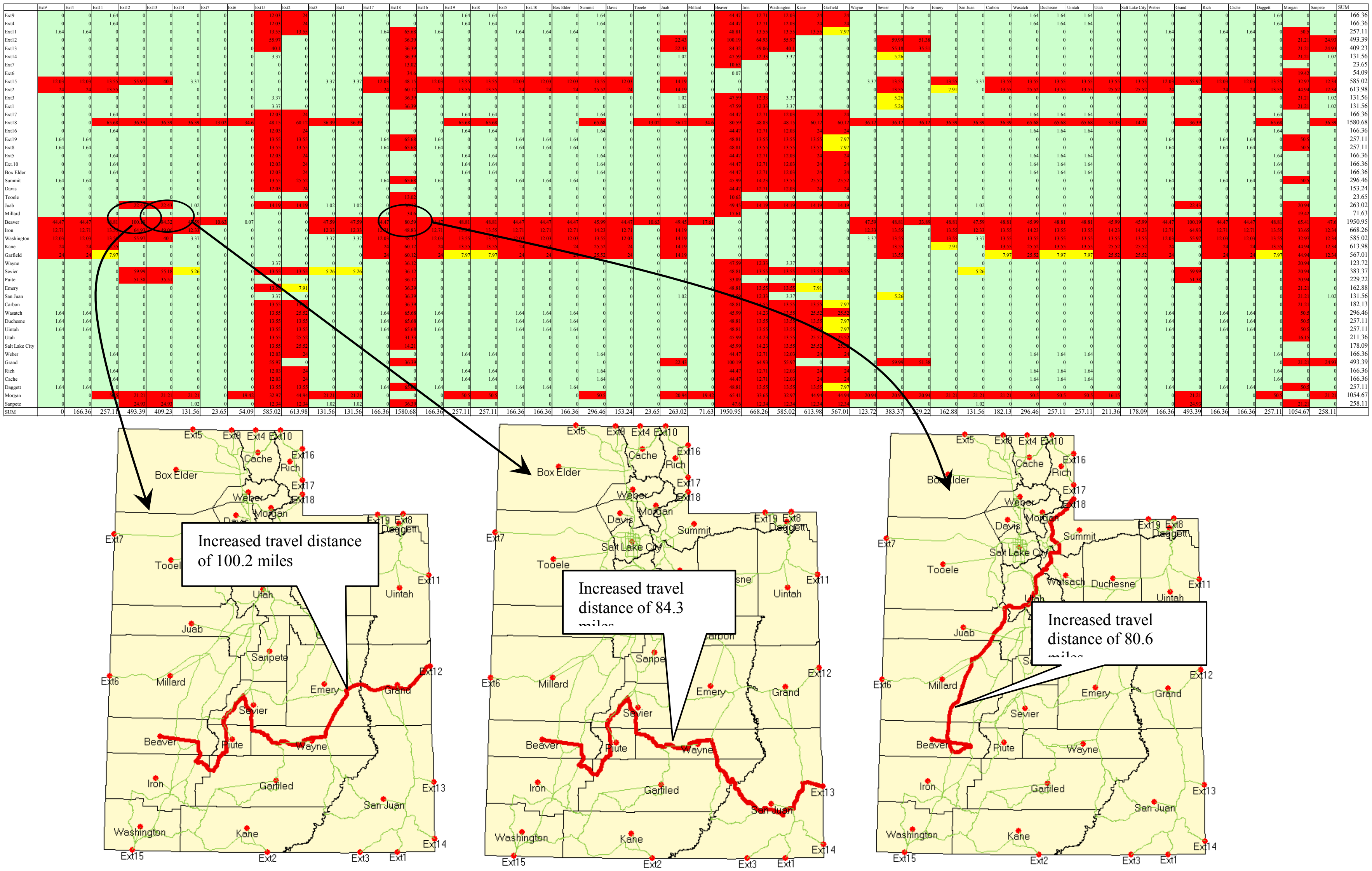


Figure 6.25 Increased travel distance table and the top three O-D pairs impacted by scenario F

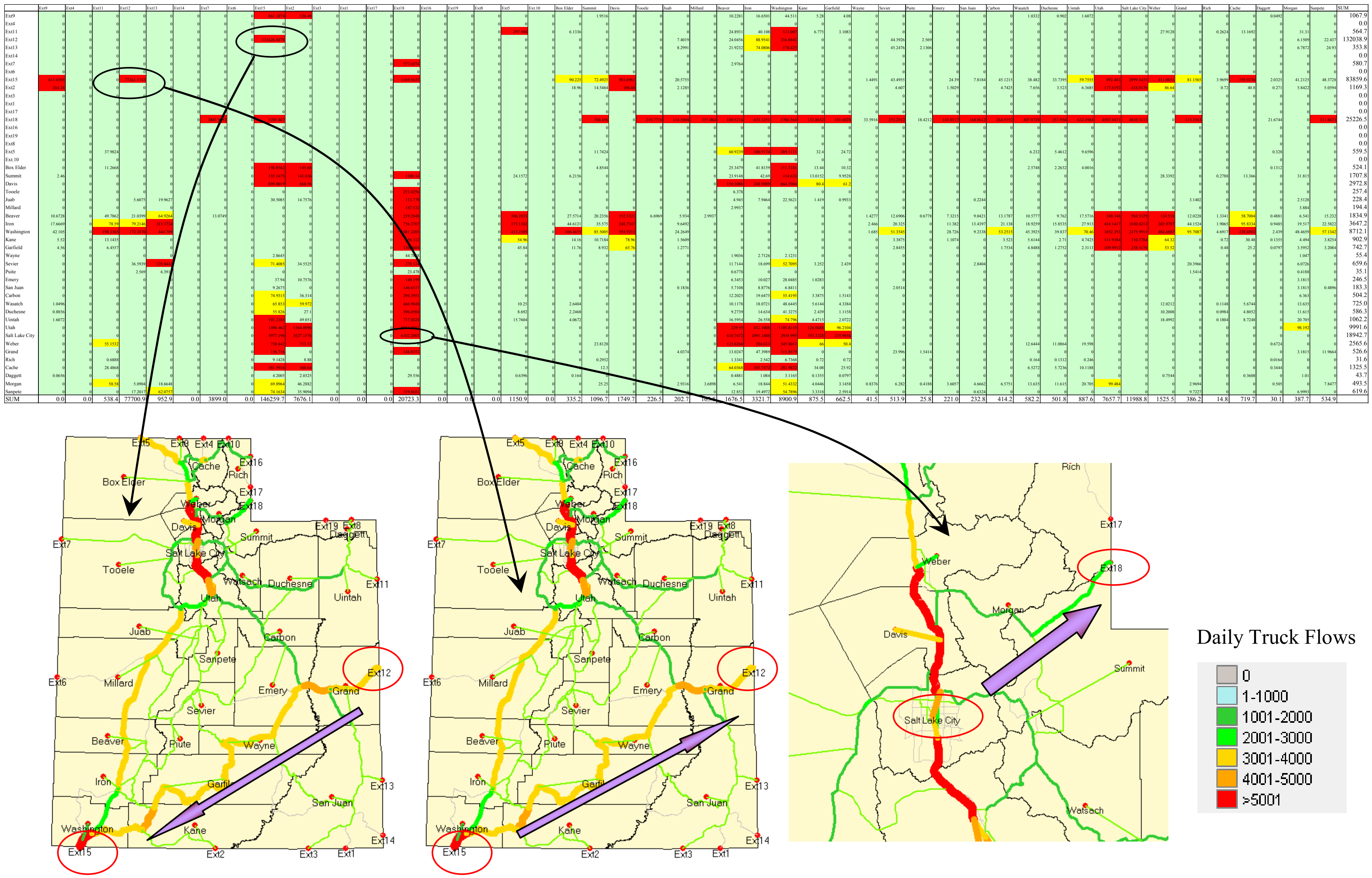


Figure 6.26 Increased VMT table and the top three O-D pairs impacted by scenario F

Table 6.9 Total increased travel distance and total increased VMT by zone of scenario F

From	Total Increased Travel Distance (Mile)	Total Increased Vehicle-Miles Traveled (Veh-Mile)
Beaver	1,950.95	1,834.92
Box Elder	166.36	524.07
Cache	166.36	1,325.50
Carbon	182.13	504.17
Daggett	257.11	43.69
Davis	153.24	2,972.76
Duchesne	257.11	586.31
Emery	162.88	246.53
Garfield	567.01	742.67
Grand	493.39	526.56
Iron	668.26	3,647.23
Juab	263.02	228.36
Kane	613.98	902.91
Millard	71.63	194.41
Morgan	1,054.67	493.55
Puite	229.22	35.08
Rich	166.36	31.62
Salt Lake City	178.09	18,942.74
San Juan	131.56	183.25
Sanpete	258.11	619.63
Sevier	383.37	659.65
Summit	296.46	1,707.76
Tooele	23.65	257.40
Uintah	257.11	1,062.19
Utah	211.36	9,991.60
Wasatch	296.46	724.98
Washington	585.02	8,712.08
Wayne	123.72	55.44
Weber	166.36	2,565.59
Ext 1	131.56	-
Ext 2	613.98	1,169.32
Ext 3	131.56	-
Ext 4	166.36	-
Ext 5	166.36	559.48
Ext 6	54.09	-
Ext 7	23.65	580.67
Ext 8	257.11	-
Ext 9	166.36	1,067.88
Ext. 10	166.36	-
Ext 11	257.11	564.67
Ext 12	493.39	132,038.88
Ext 13	409.23	353.82
Ext 14	131.56	-
Ext 15	585.02	83,859.61
Ext 16	166.36	-
Ext 17	166.36	-
Ext 18	1,580.68	25,226.50
Ext 19	257.11	-
Total	16,259.16	305,743.47

The key findings of scenario F are summarized as follows:

- The top three O-D pairs with the highest increased travel distance are:
  - Beaver County and external station 12 = 100.2 miles
  - Beaver County and external station 13 = 84.3 miles
  - Beaver County and external station 18 = 80.6 miles
- The top three O-D pairs with the highest increased VMT are:
  - External station 12 and external station 15 = 131,626.9 veh-miles/day
  - External station 15 and external station 12 = 77,361.2 veh-miles/day
  - Salt Lake County and external station 18 = 6,102.2 veh-miles/day
- The zone with the worst impact is:
  - Beaver County = 1,950.95 miles
  - External station 12 = 132,038.88 veh-miles/day
- The total impacts of scenario F for all zones are:
  - Total increased travel distance = 16,259.16 miles
  - Total increased VMT = 305,743.47 veh-miles/day

Scenario G: Urban Interstate Bridges (scenario D+E)

In this scenario, the impacts of disrupting multiple urban interstate bridges are assessed. Figure 6.27 shows the locations of these urban interstate bridges. The results of O-D connectivity and freight flow pattern change of scenario G are provided in Figure 6.28 and 6.29. Table 6.10 summarizes the impact in terms of total increased travel distance and total increased VMT by zone of scenario G.

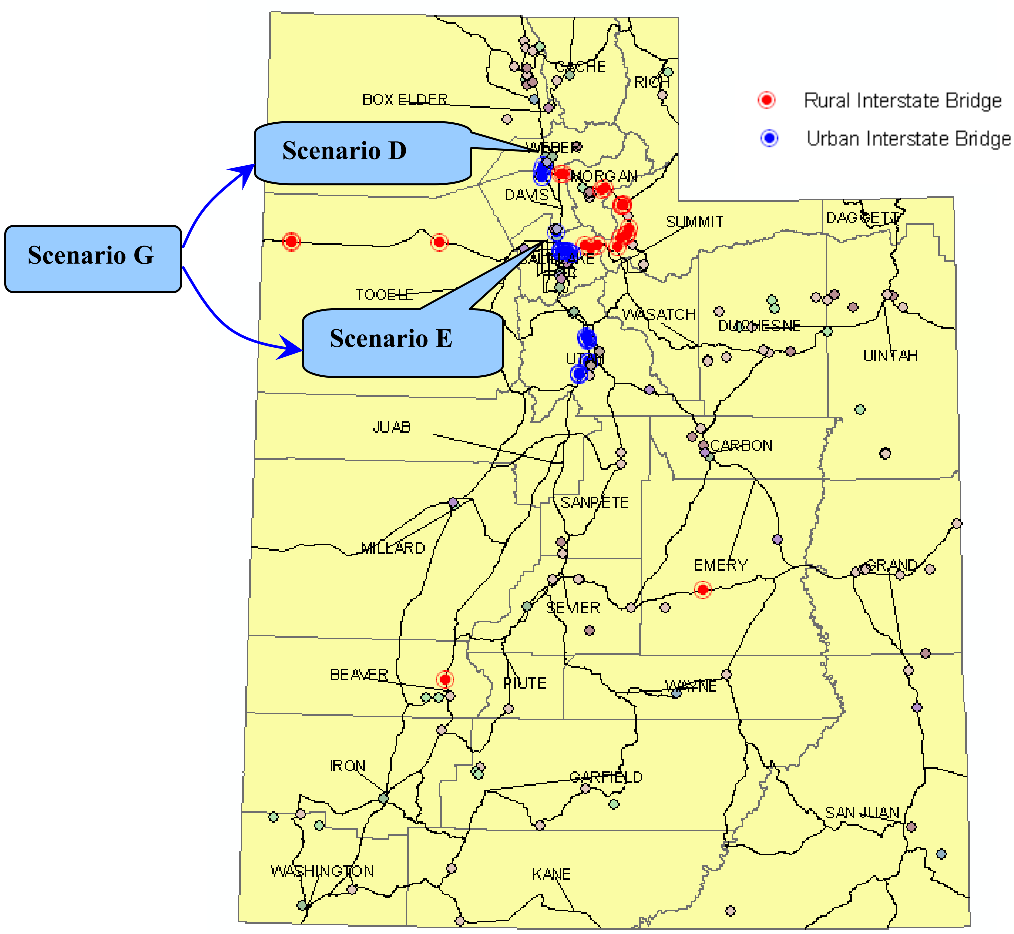


Figure 6.27 Locations of the urban interstate bridges in scenario G

	Ext9	Ext4	Ext11	Ext12	Ext13	Ext14	Ext7	Ext6	Ext15	Ext2	Ext3	Ext1	Ext17	Ext18	Ext16	Ext19	Ext8	Ext5	Ext.10	Box Elder	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Sevier	Puite	Emery	San Juan	Carbon	Wasatch	Duchesne	Uintah	Utah	Salt Lake City	Weber	Grand	Rich	Cache	Daggett	Morgan	Sanpete	SUM
Ext9	0	0	0	3.09	3.09	3.09	0.44	0.44	3.09	3.09	3.09	3.09	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.09	3.09	3.09	3.09	3.09	3.09	0	0	0	3.09	3.34	0	3.09	0	0	0	0	3.09	73.52
Ext4	0	0	0	3.09	3.09	3.09	0.44	0.44	3.09	3.09	3.09	3.09	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.09	3.09	3.09	3.09	3.09	3.09	0	0	0	3.09	3.34	0	3.09	0	0	0	0	3.09	73.52
Ext11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Ext12	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
Ext13	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
Ext14	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
Ext7	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Ext6	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	[illegible]	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Ext15	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	3.09	0	[illegible]	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
Ext2	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	3.09	0	[illegible]	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
Ext3	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	3.09	0	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
Ext1	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	3.09	0	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
Ext17	0	0	0	3.09	3.09	3.09	0.44	0.44	3.09	3.09	3.09	3.09	0	0	0	0	0	0	0	0	0	[illegible]	0.44	3.09	0.44	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	0	0	0	3.09	3.34	0	3.09	0	0	0	0	3.09	73.52
Ext18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext16	0	0	0	3.09	3.09	3.09	0.44	0.44	3.09	3.09	3.09	3.09	0	0	0	0	0	0	0	0	0	0.44	0.44	3.09	0.44	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	0	0	0	3.09	3.34	0	3.09	0	0	0	0	3.09	73.52
Ext19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Ext8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Ext5	0	0	0	3.09	3.09	3.09	0.44	0.44	3.09	3.09	3.09	3.09	0	0	0	0	0	0	0	0	0	0.44	0.44	3.09	0.44	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	0	0	0	3.09	3.34	0	3.09	0	0	0	0	3.09	73.52
Ext.10	0	0	0	3.09	3.09	3.09	0.44	0.44	3.09	3.09	3.09	3.09	0	0	0	0	0	0	0	0	0	0.44	0.44	3.09	0.44	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	0	0	0	3.09	3.34	0	3.09	0	0	0	0	3.09	73.52
Box Elder	0	0	0	3.09	3.09	3.09	0.44	0.44	3.09	3.09	3.09	3.09	0	0	0	0	0	0	0	0	0	0.44	0.44	3.09	0.44	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	0	0	0	3.09	3.34	0	3.09	0	0	0	0	3.09	73.52
Summit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Davis	0.44	0.44	2.9	2.65	2.65	2.65	0	0	2.65	2.65	2.65	2.65	0.44	0	0.44	2.9	2.9	0.44	0.44	0.44	2.9	0	0	2.65	0	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.9	2.9	2.9	2.65	2.9	0.44	2.65	0.44	0.44	2.9	0	2.65	88.8
Tooele	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Juab	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	3.09	0	2.65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
Millard	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0	0	0.44	0.44	0.44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.44	0	0.44	0.44	0	0	0	4.4
Beaver	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	3.09	0	2.65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
Iron	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	3.09	0	2.65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
Washington	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	3.09	0	2.65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
Kane	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	3.09	0	2.65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
Garfield	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	3.09	0	2.65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
Wayne	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	3.09	0	2.65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
Sevier	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	3.09	0	2.65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
Puite	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	3.09	0	2.65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
Emery	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	3.09	0	2.65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
San Juan	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	3.09	0	2.65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
Carbon	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	3.09	0	2.65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
Wasatch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Duchesne	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Uintah	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Utah	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	3.09	0	2.65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
Salt Lake City	3.34	3.34	0	0	0	0	0	0	0	0	0	0	3.34	0	3.34	0	0	3.34	3.34	3.34	0	2.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.34	0	3.34	3.34	0	0.97	0	37.27
Weber	0	0	0	3.09	3.09	3.09	0.44	0.44	3.09	3.09	3.09	3.09	0	0	0	0	0	0	0	0	0	0.44	0.44	3.09	0.44	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	0	0	0	3.09	3.34	0	3.09	0	0	0	0	3.09	73.52
Grand	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	3.09	0	2.65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
Rich	0	0	0	3.09	3.09	3.09	0.44	0.44	3.09	3.09	3.09	3.09	0	0	0	0	0	0	0	0	0	0.44	0.44	3.09	0.44	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	0	0	0	3.09	3.34	0	3.09	0	0	0	0	3.09	73.52
Cache	0	0	0	3.09	3.09	3.09	0.44	0.44	3.09	3.09	3.09	3.09	0	0	0	0	0	0	0	0	0	0.44	0.44	3.09	0.44	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	3.09	0	0	0	3.09	3.34	0	3.09	0	0	0	0	3.09	73.52
Daggett	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.9
Morgan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.97	0	0	0	0	0	0	0	0.97
Sanpete	3.09	3.09	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	0	0	3.09	3.09	3.09	0	2.65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.09	0	3.09	3.09	0	0	0	33.55
SUM	0	73.52	2.9	33.55	33.55	33.55	4.4	4.4	33.55	33.55	33.55	33.55	73.52	0	73.52	2.9	2.9	73.52	73.52	73.52	2.9	88.8	4.4	33.55	4.4	33.55	33.55	33.55	33.55	33.55	33.55	33.55	33.55	33.55	33.55	33.55	2.9	2.9	2.9	33.55	37.27	73.52	33.55	73.52	73.52	2.9	0.97	33.55	

Increased travel distances less than 5 miles

Figure 6.28 Increased travel distance table of scenario G

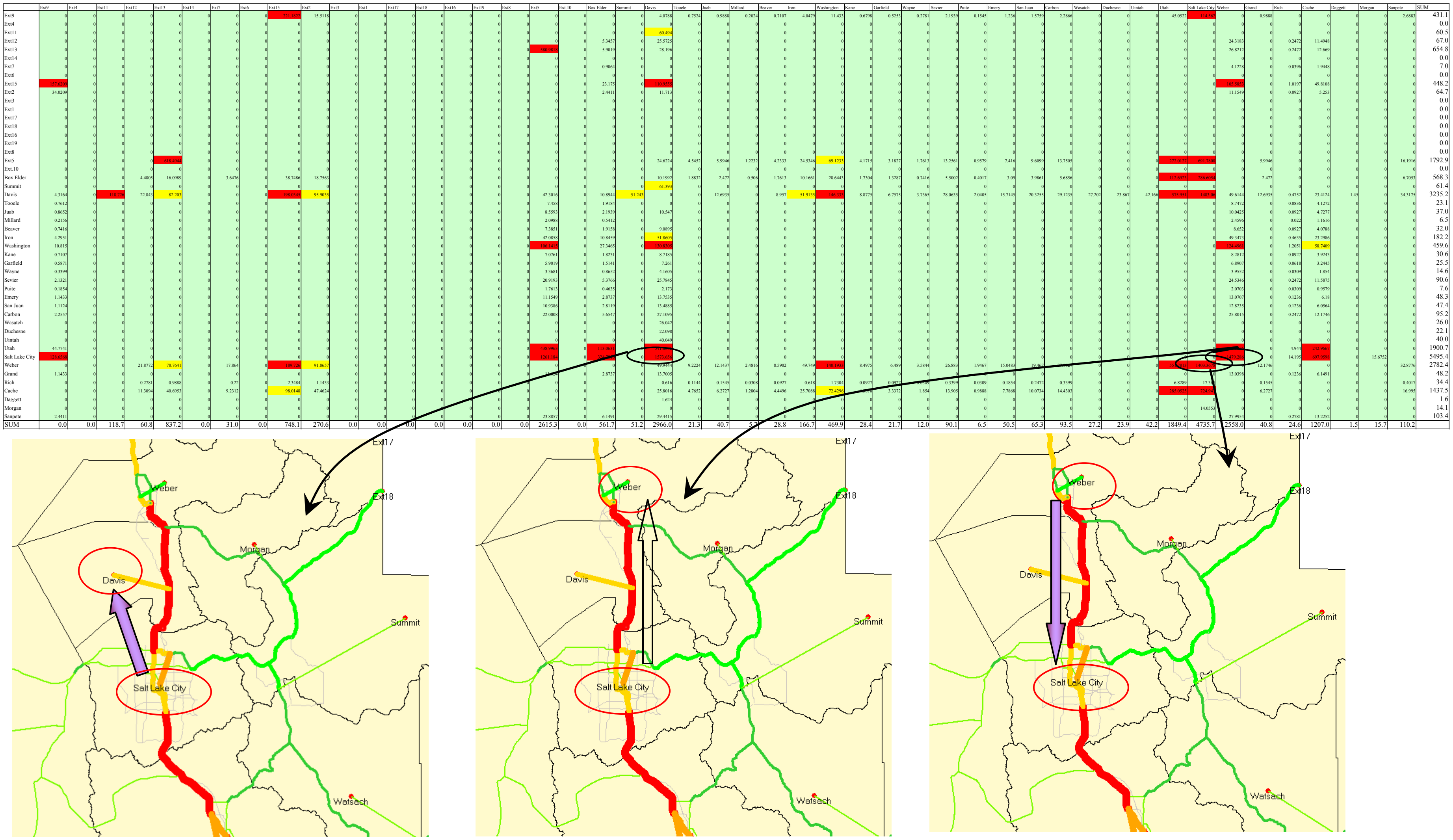


Figure 6.29 Increased VMT table and the top three O-D pairs impacted by scenario G

Table 6.10 Total increased travel distance and total increased VMT by zone of scenario G

From	Total Increased Travel Distance (Mile)	Total Increased Vehicle-Miles Traveled (Veh-Mile)
Beaver	33.55	31.96
Box Elder	73.52	568.30
Cache	73.52	1,437.45
Carbon	33.55	95.24
Daggett	2.90	1.62
Davis	88.80	3,235.21
Duchesne	2.90	22.10
Emery	33.55	48.30
Garfield	33.55	25.46
Grand	33.55	48.15
Iron	33.55	182.20
Juab	33.55	37.03
Kane	33.55	30.63
Millard	4.40	6.50
Morgan	0.97	14.06
Puite	33.55	7.64
Rich	73.52	34.45
Salt Lake City	37.27	5,495.39
San Juan	33.55	47.35
Sanpete	33.55	103.42
Sevier	33.55	90.58
Summit	2.90	61.39
Tooele	4.40	23.10
Uintah	2.90	40.05
Utah	33.55	1,900.71
Wasatch	2.90	26.04
Washington	33.55	459.58
Wayne	33.55	14.57
Weber	73.52	2,782.44
Ext 1	33.55	-
Ext 2	33.55	64.68
Ext 3	33.55	-
Ext 4	73.52	-
Ext 5	73.52	1,792.86
Ext 6	4.40	-
Ext 7	4.40	7.01
Ext 8	2.90	-
Ext 9	73.52	431.13
Ext. 10	73.52	-
Ext 11	2.90	60.49
Ext 12	33.55	66.98
Ext 13	33.55	654.82
Ext 14	33.55	-
Ext 15	33.55	448.17
Ext 16	73.52	-
Ext 17	73.52	-
Ext 18	-	-
Ext 19	2.90	-
Total	1,641.14	20,397.06

The key findings of scenario G are summarized as follows:

- Similar to scenario D and scenario E, the disruption of both urban interstate bridges has low impact. The detour distance for all O-D pairs are less than 5 miles:
- The top three O-D pairs with the highest increased VMT are:
  - Salt Lake County and Davis County = 1,573.7 veh-miles/day
  - Salt Lake County and Weber County = 1,479.3 veh-miles/day
  - Weber County and Salt lake County = 1,403.4 veh-miles/day
- The zone with the worst impact is:
  - Beaver County = 88.8 miles
  - Salt Lake County = 5,495.39 veh-miles/day
- The total impacts of scenario G for all zones are:
  - Total increased travel distance = 1,641.14 miles
  - Total increased VMT = 20,397.06 veh-miles/day

Scenario H: Rural and Urban Interstate Bridges (scenario F+G)

In this scenario, the impacts of disrupting multiple rural and urban interstate bridges are assessed. Figure 6.30 shows the locations of these rural and urban interstate bridges. The results of O-D connectivity and freight flow pattern change of scenario H are provided in Figure 6.31 and 6.32. Table 6.11 summarizes the impact in terms total increased travel distance and total increased VMT by zone of scenario H.

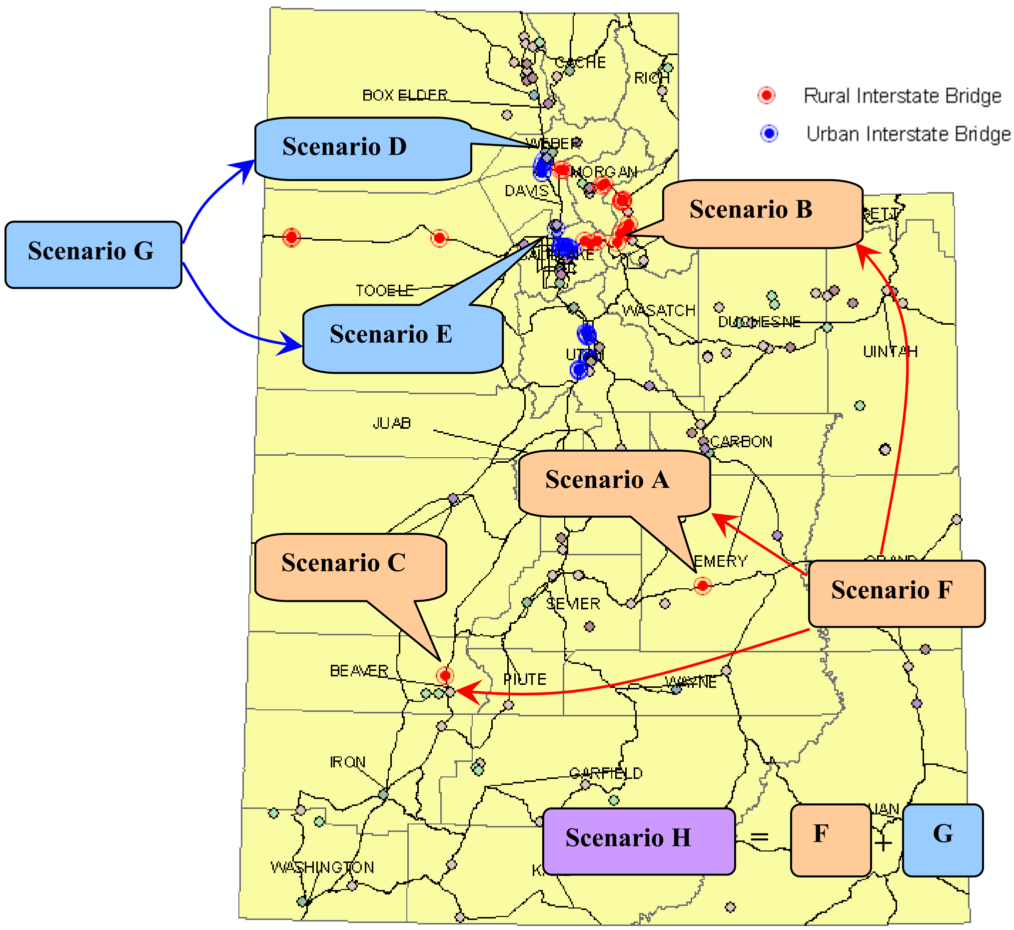


Figure 6.30 Locations of the rural and urban interstate bridges in scenario H

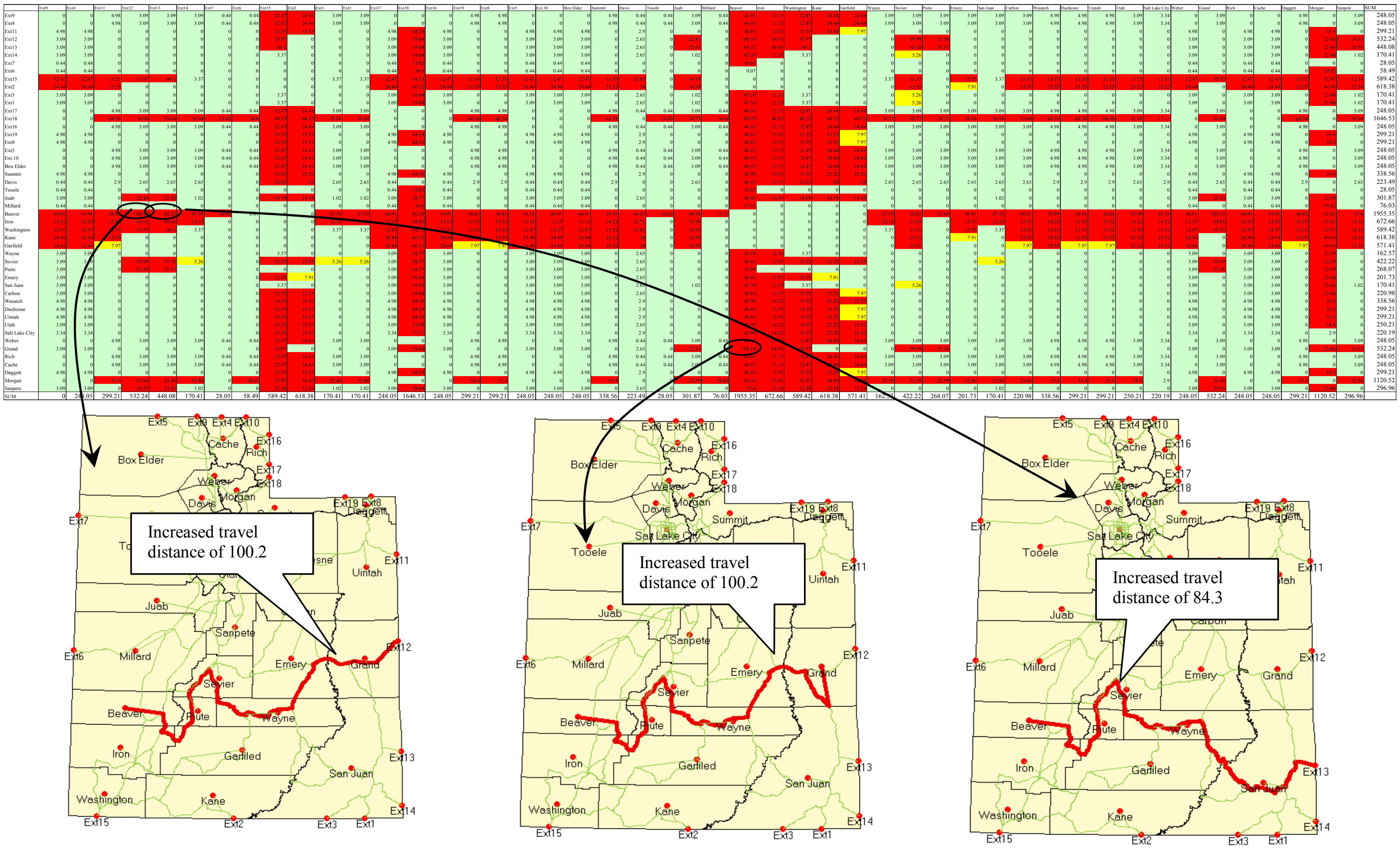


Figure 6.31 Increased travel distance table and the top three O-D pairs impacted by scenario H

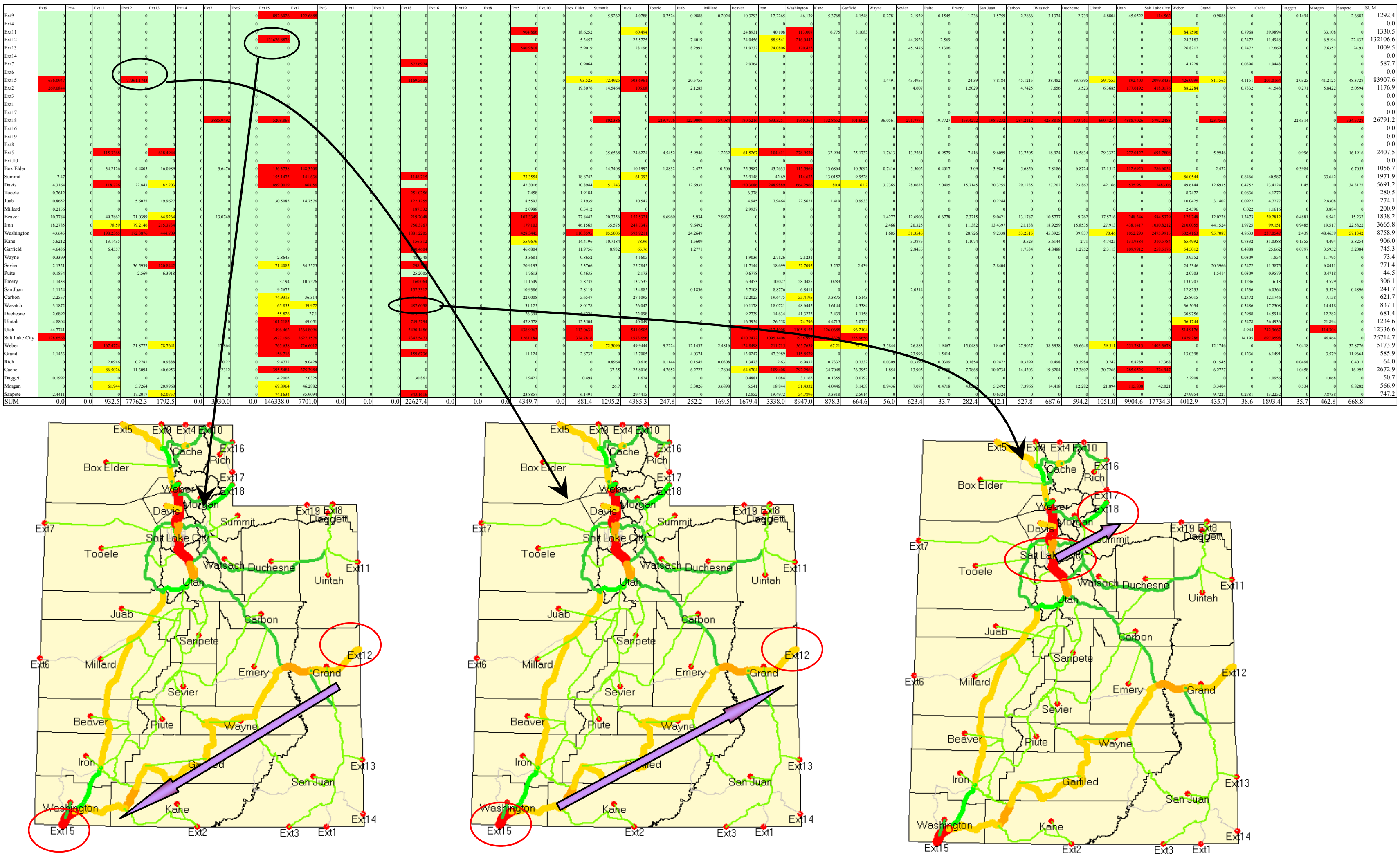


Figure 6.32 Increased VMT table and the top three O-D pairs impacted by scenario H

Table 6.11 Total increased travel distance and total increased VMT by zone of scenario H

From	Total Increased Travel Distance (Mile)	Total Increased Vehicle-Miles Traveled (Veh-Mile)
Beaver	1,955.35	1,838.17
Box Elder	248.05	1,056.74
Cache	248.05	2,672.91
Carbon	220.98	621.65
Daggett	299.21	50.72
Davis	223.49	5,691.19
Duchesne	299.21	681.41
Emery	201.73	306.09
Garfield	571.41	745.26
Grand	532.24	585.95
Iron	672.66	3,665.79
Juab	301.87	274.05
Kane	618.38	906.03
Millard	76.03	200.91
Morgan	1,120.52	566.87
Puite	268.07	44.49
Rich	248.05	63.96
Salt Lake City	220.19	25,714.67
San Juan	170.41	241.69
Sanpete	33.55	747.22
Sevier	422.22	771.40
Summit	338.56	1,971.93
Tooele	28.05	280.50
Uintah	299.21	1,234.59
Utah	250.21	12,336.58
Wasatch	338.56	837.09
Washington	589.42	8,758.90
Wayne	162.57	73.43
Weber	248.05	5,173.85
Ext 1	170.41	-
Ext 2	618.38	1,176.87
Ext 3	170.41	-
Ext 4	248.05	-
Ext 5	248.05	2,407.50
Ext 6	58.49	-
Ext 7	28.05	587.69
Ext 8	299.21	-
Ext 9	248.05	1,292.39
Ext. 10	248.05	-
Ext 11	299.21	1,330.53
Ext 12	532.24	132,106.63
Ext 13	448.08	1,009.49
Ext 14	170.41	-
Ext 15	589.42	83,907.63
Ext 16	248.05	-
Ext 17	248.05	-
Ext 18	1,646.53	26,791.19
Ext 19	299.21	-
Total	18,024.65	328,723.93

The key findings of scenario H are summarized as follows:

- The top three O-D pairs with the highest increased travel distance are:
    - Beaver County and external station 12 = 100.2 miles
    - Beaver County and Grand County = 100.2 miles
    - Beaver County and external station 13 = 84.32 miles
- The top three O-D pairs with the highest increased VMT are:
    - External station 12 and external station 15 = 131,626.9 veh-miles/day
    - External station 15 and external station 12 = 77,361.2 veh-miles/day
    - Salt Lake County and external station 18 = 7,347.5 veh-miles/day
- The zone with the worst impact is:
    - Beaver County = 1,955.35 miles
    - External station 12 = 132,106.63 veh-miles/day
- The total impacts of scenario H for all zones are:
    - Total increased travel distance = 18,024.65 miles
    - Total increased VMT = 328,723.93 veh-miles/day

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7. FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

7.1 Findings and Conclusions

The primary objective of this research is to develop a decision support tool for assessing vulnerability of transportation networks. The key findings and conclusions of each chapter are summarized as follows:

- The trends of freight movements in the nation and the State of Utah were analyzed using the FAF database. In Utah, the demand of truck transportation has been rising steadily and the forecasted trend shows the continuous growth at least over the next two decades. The projection of freight growth in Utah appears to increase at a faster rate than the national average. By 2035, freight volume will be more than double while freight value will be more than triple.
- The bottlenecks/chokepoints in the Utah transportation network were reviewed using the delay measures in the GeoFreight Visual Display Tool. In Utah, majority of bottlenecks/chokepoints are the intersections and highway interchanges in the Salt Lake City area.
- The state-specific commodity flows within, out of, into and through Utah were extracted from the FAF database and then converted into truck trips to generate a truck O-D trip table. The estimated truck flows were compared with selected truck counts provided by the Utah statewide traffic counting program. The results were encouraging in the sense that the commodity flow data from the FAF database could be used to estimate the spatial movements of trucks. However, the accuracy of the truck O-D trip table requires significant improvements in order to close the gap between the estimated truck flows and observed truck counts at selected locations in the urban area. Also see recommendations for data improvement.
- The Freight Chokepoint Analysis Tool (FCAT) was developed as a decision support tool with full GIS functionalities. FCAT provides a graphical user interface (GUI) to facilitate user inputs, vulnerability assessment, and visualization of the outputs. A copy of the FCAT research software may be obtained through the UDOT Research Division or the authors of this report.

- The usage of FCAT was demonstrated via a case study based on the disruption scenarios of highway bridges using the Utah highway network. Results of the vulnerability assessment in terms of O-D connectivity and freight flow pattern change were reported for each scenario. In general, disruptions to the rural bridges could significantly increase the travel distance (taking a long detour) due to the limited alternative routes in the rural area, while disruptions to urban bridges would alter the freight flow pattern as indicated by the increase in VMT in the urban area. In addition, disruptions to multiple bridges could have a much higher impact in terms of travel distance and VMT compared to the single bridge failure scenarios.

7.2 Recommendations

Potential recommendations for future research include the following:

- Data Improvement
    - Input network

      The input highway network for Utah was extracted from FAF (version year 2002). The network used in FCAT could be updated using the up-to-date UDOT network shapefiles to reflect the current network configuration.
    - Truck surveys

      Truck surveys at freight companies and distribution centers for each county and state border (e.g., WIM stations) should be conducted to understand the freight movements in Utah.
    - Structurally deficient bridges

      The latest inspection of structurally deficient bridges in Utah should be updated.
    - Truck O-D trip table

      The current truck O-D trip table is estimated purely from the commodity flow data from FAF. It should be updated using the updated truck counts collected by the UDOT traffic counting program, the TRANSEARCH database from Global Insight, Inc., and the newly developed Utah Statewide Travel Model (USTM) to improve the accuracy and quality of the truck O-D trip table.

- FAF Version 3.0

  The latest version of FAF 3.0, which is expected to release in summer 2010, should be used to update the truck O-D commodity flow database for Utah.

- Decision support tool enhancement
  - The decision support tool should be enhanced according to the feedback from UDOT users to make it more user friendly,
  - FCAT should be upgraded to the core engine of MapWinGIS ActiveX control (current version is version 6.0) to take advantage of the latest developments in MapWindow.
- Potential applications of FCAT include:
  - Prioritizing the structurally deficient bridges for maintenance and retrofitting,
  - Integrating FCAT and vulnerability analysis to the newly developed Utah statewide planning model,
  - Estimating the economic impacts based on commodity values (e.g., values by top ten commodity flows).

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Appendix A Commodity codes based on the Standard Classification of Transported Goods (SCTG)

Table A-1 Commodity codes based on the SCTG

SCTG	BTS/Census Full Commodity Name
1	Live Animals and Fish
2	Cereal Grains (including seed)
3	Other Agricultural Products, except for Animal Feed
4	Animal Feed and Products of Animal Origin, n.e.c.[7]
5	Meat, Fish, and Seafood, and Their Preparations
6	Milled Grain Products and Preparations, and Bakery Products
7	Other Prepared Foodstuffs, and Fats and Oils
8	Alcoholic Beverages
9	Tobacco Products
10	Monumental or Building Stone
11	Natural Sands
12	Gravel and Crushed Stone
13	Non-Metallic Minerals, n.e.c.
14	Metallic Ores and Concentrates
15	Coal
16	Crude Petroleum Oil
17	Gasoline and Aviation Turbine Fuel
18	Fuel Oils
19	Coal and Petroleum Products, n.e.c.
20	Basic Chemicals
21	Pharmaceutical Products
22	Fertilizers
23	Chemical Products and Preparations, n.e.c.
24	Plastics and Rubber
25	Logs and Other Wood in the Rough
26	Wood Products
27	Pulp, Newsprint, Paper, and Paperboard
28	Paper or Paperboard Articles
29	Printed Products
30	Textiles, Leather, and Articles of Textiles or Leather
31	Non-Metallic Mineral Products

[7] n.e.c. = not elsewhere classified

Table A-1 (Continued) Commodity codes based on SCTG

SCTG	BTS/Census Full Commodity Name
32	Base Metal in Primary or Semi-Finished Forms and in Finished Basic Shapes
33	Articles of Base Metal
34	Machinery
35	Electronic and Other Electrical Equipment and Components, and Office Equipment
36	Motorized and Other Vehicles (including parts)
37	Transportation Equipment, n.e.c.
38	Precision Instruments and Apparatus
39	Furniture, Mattresses and Mattress Supports, Lamps, Lighting Fittings, and Illuminated Signs
40	Miscellaneous Manufactured Products
41	Waste and Scrap
42	Mixed Freight
43	Commodity unknown

Appendix B Disaggregated Production-Attraction of Utah

Table B-1 Disaggregated Production-Attraction within Utah (I-I) (1x1)

	Utah (KT)	
From	2002	2035
Utah	97,312.79	197,055.48

Table B-2 Disaggregated Production-Attraction from Utah to Other States (I-E) (1x48)

		Destination								
	Year	AL	AR	AZ	CA	CO	CT	DC	DE	FL
Utah	2002	84.92	38.22	2,102.62	4,342.58	2,356.61	14.80	0.15	0.42	143.19
	2035	557.66	96.17	1,797.83	24,834.83	2,677.29	28.50	0.62	1.17	396.71

		Destination								
	Year	GA	IA	ID	IL	IN	KS	KY	LA	MA
Utah	2002	87.97	179.51	4,173.91	191.35	27.54	21.55	242.04	33.36	9.70
	2035	541.02	92.46	5,442.84	268.40	86.89	57.43	286.04	123.58	29.59

		Destination								
	Year	MD	ME	MI	MN	MO	MS	MT	NC	ND
Utah	2002	25.09	2.90	28.68	146.89	45.09	40.97	570.00	92.08	2.37
	2035	241.80	3.47	36.90	137.46	53.73	109.06	1,134.10	131.15	2.92

		Destination								
	Year	NE	NH	NJ	NM	NV	NY	OH	OK	OR
Utah	2002	141.24	12.48	40.97	979.23	2,872.49	43.88	226.60	160.86	500.23
	2035	90.62	31.13	105.91	1,302.23	8,934.87	76.81	320.69	162.55	338.06

		Destination								
	Year	PA	RI	SC	SD	TN	TX	VA	VT	WA
Utah	2002	85.13	2.77	54.47	143.92	52.47	823.90	69.24	0.24	912.71
	2035	200.78	2.73	63.12	200.55	126.87	1,918.52	76.42	0.62	1,326.37

		Destination		
	Year	WI	WV	WY
Utah	2002	55.87	34.21	4,295.15
	2035	103.02	191.77	4,249.50

Table B-3 Disaggregated Production-Attraction from Other States to Utah (E-I) (48x1)

		Origin								
	Year	AL	AR	AZ	CA	CO	CT	DC	DE	FL
Utah	2002	143.57	101.49	255.15	2,413.04	1,119.15	4.21	0.52	0.88	19.49
	2035	254.03	113.40	878.55	11,620.00	6,594.38	15.37	1.43	0.96	29.19

		Origin								
	Year	GA	IA	ID	IL	IN	KS	KY	LA	MA
Utah	2002	708.93	54.61	2,443.95	309.44	80.93	82.87	131.32	147.46	11.94
	2035	1,102.72	89.06	17,184.15	710.66	295.20	143.83	918.27	121.44	36.50

		Origin								
	Year	MD	ME	MI	MN	MO	MS	MT	NC	ND
Utah	2002	4.70	6.80	78.29	188.67	456.50	86.91	534.24	115.94	3.99
	2035	9.11	23.32	420.34	657.16	1,127.46	233.90	1,876.78	215.17	12.11

		Origin								
	Year	NE	NH	NJ	NM	NV	NY	OH	OK	OR
Utah	2002	99.88	15.39	138.53	47.89	662.02	78.51	256.31	58.24	411.95
	2035	217.33	83.20	126.87	137.43	1,785.42	67.14	467.85	109.91	2,155.08

		Origin								
	Year	PA	RI	SC	SD	TN	TX	VA	VT	WA
Utah	2002	124.98	2.02	75.62	5.90	111.23	564.94	40.34	2.03	368.62
	2035	154.93	5.00	105.89	22.60	400.46	1,096.07	44.38	3.94	476.33

		Origin		
	Year	WI	WV	WY
Utah	2002	200.17	14.62	1,946.27
	2035	353.45	69.26	6,253.91

Appendix C Utah Demographic Statistics

Table C-1 Utah Population

	Utah Population (Year)				
County	2000	2010	2020	2030	2035[8]
Beaver County	6,005	6,674	9,178	13,293	13,661
Box Elder County	42,745	49,953	59,215	70,393	74,018
Cache County	91,391	117,758	149,322	181,921	195,729
Carbon County	20,422	20,317	24,843	27,106	28,088
Daggett County	921	992	1,076	1,155	1,193
Davis County	238,994	323,087	369,467	390,159	430,402
Duchesne County	14,371	17,336	20,130	21,533	23,199
Emery County	10,860	10,698	12,673	13,119	13,588
Garfield County	4,735	5,092	5,843	6,823	7,026
Grand County	8,485	9,693	11,007	11,827	12,521
Iron County	33,779	50,601	68,315	87,644	95,947
Juab County	8,238	10,519	14,158	18,004	19,317
Kane County	6,046	6,893	8,746	10,394	10,999
Millard County	12,405	13,863	16,868	19,682	20,672
Morgan County	7,129	10,589	16,756	24,478	26,381
Piute County	1,435	1,396	1,526	1,690	1,691
Rich County	1,961	2,235	2,606	2,842	3,014
Salt Lake County	898,387	1,079,679	1,273,929	1,468,615	1,561,139
San Juan County	14,413	15,053	15,319	16,653	16,757
Sanpete County	22,763	27,557	31,519	36,120	38,296
Sevier County	18,842	21,249	23,583	25,177	26,481
Summit County	29,736	42,320	61,738	83,252	90,255
Tooele County	40,735	63,777	91,849	119,871	132,154
Uintah County	25,224	31,379	37,950	40,638	44,360
Utah County	368,536	560,511	727,718	907,210	997,640
Wasatch County	15,215	24,950	36,181	48,693	53,593
Washington County	90,354	168,078	279,864	415,510	455,902
Wayne County	2,509	2,698	2,912	3,395	3,453
Weber County	196,533	232,696	278,256	320,634	340,602

[8] Extrapolated from Counties of Utah - Population Projections provided by Utah Office of Planning and Budget

Table C-2 Utah Employment

County	Year						
	2000	2005	2010	2015	2020	2030	2035[9]
Beaver County	3,188	3,398	3,738	4,054	4,289	4,710	5,208
Box Elder County	23,854	26,208	29,598	32,708	35,046	38,750	41,699
Cache County	53,821	59,614	67,440	75,125	79,953	85,648	97,460
Carbon County	11,415	12,409	13,508	14,637	15,424	16,034	17,108
Daggett County	624	688	733	789	835	877	977
Davis County	110,752	122,522	137,537	151,507	161,617	178,066	199,118
Duchesne County	7,387	8,056	8,679	9,408	9,979	10,601	11,309
Emery County	5,025	5,310	5,681	6,054	6,281	6,367	6,449
Garfield County	3,060	3,351	3,745	4,128	4,428	4,992	5,248
Grand County	5,577	5,929	6,345	6,777	7,051	7,168	8,094
Iron County	18,399	19,910	22,720	25,492	27,841	32,293	35,566
Juab County	3,533	4,131	4,777	5,450	6,043	6,859	7,291
Kane County	3,824	4,684	5,727	6,803	7,797	9,790	10,218
Millard County	6,040	6,540	6,892	7,258	7,501	7,590	8,573
Morgan County	2,837	2,882	3,141	3,376	3,528	3,753	4,149
Piute County	501	521	552	574	588	593	619
Rich County	1,089	1,122	1,193	1,253	1,281	1,308	1,468
Salt Lake County	646,003	696,595	779,843	857,292	913,143	1,002,915	1,115,663
San Juan County	5,410	5,901	6,502	7,123	7,580	8,006	8,635
Sanpete County	10,166	11,049	12,087	13,175	14,050	14,983	16,930
Sevier County	9,816	10,647	11,652	12,686	13,531	14,428	15,933
Summit County	23,115	26,558	31,232	35,702	39,273	45,318	51,325
Tooele County	14,536	16,759	19,704	22,518	24,761	28,566	29,364
Uintah County	13,004	13,679	14,313	15,130	15,698	16,125	17,982
Utah County	195,169	217,906	254,702	288,166	310,925	350,741	392,489
Wasatch County	7,234	8,612	10,427	12,130	13,388	15,640	17,118
Washington County	45,465	55,897	68,513	81,636	93,763	118,024	126,291
Wayne County	1,697	1,958	2,236	2,526	2,775	3,106	3,439
Weber County	107,568	117,264	134,421	150,681	163,165	183,790	198,974

[9] Extrapolated from State of Utah Employment Projections By County and Multi-County District provided by the U.S. Bureau of Economic Analysis; Utah Department of Work Force Services

Table C-3 Disaggregation Factor for Year 2002

County	Population Factor	Employment Factor
Beaver County	0.0026	0.0026
Box Elder County	0.0192	0.0178
Cache County	0.0413	0.0451
Carbon County	0.0085	0.0079
Daggett County	0.0004	0.0004
Davis County	0.1071	0.1063
Duchesne County	0.0064	0.0059
Emery County	0.0046	0.0040
Garfield County	0.0020	0.0021
Grand County	0.0037	0.0040
Iron County	0.0152	0.0151
Juab County	0.0037	0.0031
Kane County	0.0026	0.0025
Millard County	0.0053	0.0053
Morgan County	0.0032	0.0030
Piute County	0.0006	0.0006
Rich County	0.0008	0.0011
Salt Lake County	0.3966	0.4173
San Juan County	0.0059	0.0039
Sanpete County	0.0100	0.0085
Sevier County	0.0082	0.0075
Summit County	0.0137	0.0163
Tooele County	0.0198	0.0187
Uintah County	0.0113	0.0106
Utah County	0.1685	0.1570
Wasatch County	0.0073	0.0069
Washington County	0.0428	0.0380
Wayne County	0.0011	0.0012
Weber County	0.0874	0.0873
Total	1.0000	1.0000

Table C-4 Disaggregation Factor for Year 2035

County	Population Factor	Employment Factor
Beaver County	0.0029	0.0021
Box Elder County	0.0156	0.0170
Cache County	0.0413	0.0397
Carbon County	0.0059	0.0070
Daggett County	0.0003	0.0004
Davis County	0.0908	0.0811
Duchesne County	0.0049	0.0046
Emery County	0.0029	0.0026
Garfield County	0.0015	0.0021
Grand County	0.0026	0.0033
Iron County	0.0203	0.0145
Juab County	0.0041	0.0030
Kane County	0.0023	0.0042
Millard County	0.0044	0.0035
Morgan County	0.0056	0.0017
Piute County	0.0004	0.0003
Rich County	0.0006	0.0006
Salt Lake County	0.3295	0.4545
San Juan County	0.0035	0.0035
Sanpete County	0.0081	0.0069
Sevier County	0.0056	0.0065
Summit County	0.0190	0.0209
Tooele County	0.0279	0.0120
Uintah County	0.0094	0.0073
Utah County	0.2106	0.1599
Wasatch County	0.0113	0.0070
Washington County	0.0962	0.0514
Wayne County	0.0007	0.0014
Weber County	0.0029	0.0811
Total	1.0000	1.0000

Appendix D Tonnage to Truck Conversion Factors (Tons per Truck)

Table D-1 STCC Tonnage to Truck Conversion Factors (Tons per Truck)

		Distance Class				
Two-Digit STCC Codes	Two-Digit STCC Commodity Name	Local (<50 Miles)	Short (50 to 100 Miles)	Short-Medium (100 to 200 Miles)	Long-Medium (200 to 500 Miles)	Long (>500 Miles)
1	Farm products	12.04	18.37	19.10	18.71	17.67
8	Forest products	13.36	11.64	13.27	13.27	13.27
9	Fresh fish or marine products	8.20	8.13	14.42	15.89	16.11
10	Metallic ores	16.98	18.81	25.77	25.77	25.77
11	Coal	16.98	18.81	25.77	25.77	25.77
13	Crude petroleum or natural gas	14.43	19.58	17.84	17.84	17.84
14	Nonmetallic minerals	16.98	18.81	25.77	25.77	25.77
19	Ordnance or accessories	7.05	4.42	11.47	9.84	11.30
20	Food or kindred products	8.20	8.13	14.42	15.89	16.11
21	Tobacco products	11.50	16.25	16.03	11.47	15.96
22	Textile mill products	1.34	3.57	18.18	18.16	17.48
23	Apparel or related products	1.34	3.57	18.18	18.16	17.48
24	Lumber or wood products	10.33	12.35	17.50	17.61	17.83
25	Furniture or fixtures	2.92	3.25	11.02	11.26	11.38
26	Pulp, paper, or allied products	4.07	7.67	15.66	15.17	14.59
27	Printed matter	4.07	7.67	15.66	15.17	14.59
28	Chemicals or allied products	5.18	15.39	19.55	19.25	19.25
29	Petroleum or coal products	14.43	19.58	17.84	17.84	17.84
30	Rubber or misc. plastics	7.05	4.42	11.47	9.84	11.30
31	Leather or leather products	1.34	3.57	18.18	18.16	17.48
32	Clay, concrete, glass, or stone	10.69	14.47	18.53	18.63	18.81
33	Primary metal products	11.82	14.73	19.96	20.14	20.13
34	Fabricated metal products	4.00	11.33	14.49	14.49	14.49
35	Machinery	6.97	12.55	17.42	17.21	17.21
36	Electrical equipment	4.05	7.42	14.81	14.62	14.62
37	Transportation equipment	2.48	14.12	17.21	16.92	14.18
38	Instruments, photo equipment, optical equipment	6.97	12.55	17.42	17.21	17.21
39	Misc. manufacturing products	5.48	5.40	11.63	13.04	14.23
50	Drayage, warehousing, distribution	7.05	9.67	14.85	14.98	14.93

Source: Freight Impacts on Ohio's Roadways , 2002

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Appendix E Description of Bridge Data Item in the NBI Database

Item 9 - Location

This item contains a narrative description of the bridge location.

Item 21 - Maintenance Responsibility

The actual name(s) of the agency(s) responsible for the maintenance of the structure shall be recorded on the inspection form. The codes below shall be used to represent the type of agency that has primary responsibility for maintaining the structure.

Code	Description
01	State Highway Agency
02	County Highway Agency
03	Town or Township Highway Agency
04	City or Municipal Highway Agency
11	State Park, Forest, or Reservation Agency
12	Local Park, Forest, or Reservation Agency
21	Other State Agencies
25	Other Local Agencies
26	Private (other than railroad)
27	Railroad
31	State Toll Authority
32	Local Toll Authority
60	Other Federal Agencies (not listed below)
61	Indian Tribal Government
62	Bureau of Indian Affairs
63	Bureau of Fish and Wildlife
64	U.S. Forest Service
66	National Park Service
67	Tennessee Valley Authority
68	Bureau of Land Management
69	Bureau of Reclamation
70	Corps of Engineers (Civil)
71	Corps of Engineers (Military)
72	Air Force
73	Navy/Marines
74	Army
75	NASA
76	Metropolitan Washington Airports Service
80	Unknown

Item 26 - Functional Classification of Inventory Route

For the inventory route, code the functional classification using one of the following codes:

Code	Description
Rural	
01	Principal Arterial - Interstate
02	Principal Arterial - Other
06	Minor Arterial
07	Major Collector
08	Minor Collector
09	Local
Urban	
11	Principal Arterial - Interstate
12	Principal Arterial - Other Freeways or Expressways
14	Other Principal Arterial
16	Minor Arterial
17	Collector
19	Local

Item 43A - Structure Type, Kind of Material and/or Design

Code	Description
1	Concrete
2	Concrete continuous
3	Steel
4	Steel continuous
5	Prestressed concrete *
6	Prestressed concrete continuous *
7	Wood or Timber
8	Masonry
9	Aluminum, Wrought Iron, or Cast Iron
0	Other

* Post-tensioned concrete should be coded as prestressed concrete

Items 58 through 60 - Indicate the Condition Ratings of Deck (Item 58), Superstructure (Item 59), and Substructure (Item 60).

Code	Description
N	NOT APPLICABLE
9	EXCELLENT CONDITION
8	VERY GOOD CONDITION - no problems noted.
7	GOOD CONDITION - some minor problems.

6 SATISFACTORY CONDITION - structural elements show some minor deterioration.
5 FAIR CONDITION - all primary structural elements are sound but may have minor section loss, cracking, spalling or scour.
4 POOR CONDITION - advanced section loss, deterioration, spalling or scour.
3 SERIOUS CONDITION - loss of section, deterioration, spalling or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present.
2 CRITICAL CONDITION - advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken.
1 "IMMINENT" FAILURE CONDITION - major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put back in light service.
0 FAILED CONDITION - out of service - beyond corrective action.

Item 62 - Indicate the Condition Ratings of Culvert

This item evaluates the alignment, settlement, joints, structural condition, scour, and other items associated with culverts. The rating code is intended to be an overall condition evaluation of the culvert. Integral wingwalls to the first construction or expansion joint shall be included in the evaluation.

Code Description
N Not applicable. Use if structure is not a culvert.
9 No deficiencies.
8 No noticeable or noteworthy deficiencies which affect the condition of the culvert. Insignificant scrape marks caused by drift.
7 Shrinkage cracks, light scaling, and insignificant spalling which does not expose reinforcing steel. Insignificant damage caused by drift with no misalignment and not requiring corrective action. Some minor scouring has occurred near curtain walls, wingwalls, or pipes. Metal culverts have a smooth symmetrical curvature with superficial corrosion and no pitting.
6 Deterioration or initial disintegration, minor chloride contamination, cracking with some leaching, or spalls on concrete or masonry walls and slabs. Local minor scouring at curtain walls, wingwalls, or pipes. Metal culverts have a smooth curvature, non-symmetrical shape, significant corrosion or moderate pitting.
5 Moderate to major deterioration or disintegration, extensive cracking and leaching, or spalls on concrete or masonry walls and slabs. Minor settlement or misalignment. Noticeable scouring or erosion at curtain walls, wingwalls, or pipes. Metal culverts have significant distortion and deflection in one section, significant corrosion or deep pitting.

4	Large spalls, heavy scaling, wide cracks, considerable efflorescence, or opened construction joint permitting loss of backfill. Considerable settlement or misalignment. Considerable scouring or erosion at curtain walls, wingwalls or pipes. Metal culverts have significant distortion and deflection throughout, extensive corrosion or deep pitting.
3	Any condition described in Code 4 but which is excessive in scope. Severe movement or differential settlement of the segments, or loss of fill. Holes may exist in walls or slabs. Integral wingwalls nearly severed from culvert. Severe scour or erosion at curtain walls, wingwalls or pipes. Metal culverts have extreme distortion and deflection in one section, extensive corrosion, or deep pitting with scattered perforations.
2	Integral wingwalls collapsed, severe settlement of roadway due to loss of fill. Section of culvert may have failed and can no longer support embankment. Complete undermining at curtain walls and pipes. Corrective action required to maintain traffic. Metal culverts have extreme distortion and deflection throughout with extensive perforations due to corrosion.
1	Bridge closed. Corrective action may put back in light service.
0	Bridge closed. Replacement necessary.

Appendix F Structurally Deficient Bridges in Utah

(NBI database, year 1995-2004)

No	Item 9	Item 21	Item 26	Item 43A	Item 58	Item 59	Item 60	Item 62
1	Scofield Dam	69	06	1	5	4	5	N
2	0.25 MILES SE. of BEAVER	02	09	3	7	6	4	N
3	SOUTH of ADAMSVILLE	02	08	3	6	6	4	N
4	NAVAJO TRAIL OVER BEVER R	02	09	3	5	6	4	N
5	1 MILE EAST of GREENVILLE	02	08	3	N	N	N	3
6	4 MILES WEST OF TREMONTON	02	09	3	7	4	4	N
7	850 NORTH 6800 WEST	02	08	1	5	7	4	N
8	1.0 MILES SW. OF PLYMOUTH	02	09	5	7	8	4	N
9	1.0 MILES SW. OF PLYMOUTH	02	09	3	6	4	4	N
10	2.0 MILES NW. OF FIELDING	02	09	3	6	5	4	N
11	2.5 MI. EAST OF FIELDING	02	08	5	7	7	3	N
12	0.1 MILE E. OF FIELDING	02	08	3	6	4	5	N
13	0.3 MILE SE. OF FIELDING	02	09	3	5	5	4	N
14	5200 W.8000 NO.IN ELWOOD	03	08	3	4	4	5	N
15	SOUTH SIDE OF ELWOOD	03	08	5	6	6	4	N
16	SOUTH SIDE OF ELWOOD	03	08	3	N	N	N	3
17	5200 W.8800 NO.IN ELWOOD	03	09	3	5	4	4	N
18	5200 W.9600 NO.IN ELWOOD	03	09	3	4	4	4	N
19	W.OF I-15 INT. IN ELWOOD	03	07	3	5	4	5	N
20	WEST OF CUTLER DAM	02	08	4	4	5	4	N
21	1 MI.WEST BEAR RIVER CITY	02	07	3	6	4	5	N
22	WELLSVILLE CITY	04	09	1	4	4	5	N
23	WEST EDGE OF MILLVILLE	02	19	1	4	6	3	N
24	SO. PRICE ON 300 W. ST.	04	19	3	0	3	0	N
25	3.5 MILES WEST OF HELPER	02	07	1	4	4	3	N
26	1 MILE NW OF CASTLE GATE	02	09	3	4	3	5	N
27	950 W.800 N.in CLINTON	04	17	3	6	7	4	N
28	2 MILES NW. OF TABIONA	02	09	4	3	5	3	N
29	7 MILES SW. OF TALMAGE	02	09	7	4	4	3	N
30	3 MILES WEST OF ALTONAH	02	08	1	8	8	3	N
31	3.5 MI. NE. MOUNTAIN HOME	02	08	5	7	7	3	N
32	2 MILES NW. OF ALTAMONT	02	09	3	5	7	4	N
33	2 MILE NORTHWEST of NEOLA	02	09	3	4	4	5	N
34	24 MILES WEST OF DUCHESNE	02	09	3	4	4	2	N
35	23 MILES WEST OF DUCHESNE	02	09	3	5	6	2	N
36	12 MILE WEST of DUCHESNE	02	09	7	5	4	4	N
37	SO. SIDE OF DUCHESNE CITY	04	09	7	5	4	5	N
38	IN BRIDGELAND	02	07	3	4	4	6	N
39	GREEN RIVER MISSILE BASE	04	09	3	N	N	N	4
40	7 MI.S.OF S.SALT WASH INT	02	09	3	5	3	6	N
41	3 MI. NORTH OF PANQUITCH	02	09	3	N	N	N	4
42	2 MILES NO.OF PANGUITCH	02	08	3	4	6	6	N
43	1 MILE NE. OF PANGUITCH	02	08	3	4	6	7	N
44	4.5 MI. WEST OF ESCALANTE	02	09	1	4	5	5	N
45	SOUTH SIDE OF HENRIEVILLE	02	09	2	N	N	N	3
46	10 MILES E. OF ESCALANTE	02	08	3	N	N	N	4
47	3.9 MI. WEST OF THOMPSON	02	09	7	4	5	4	N
48	1.5 MI. WEST OF THOMPSON	02	09	7	5	4	4	N
49	WEST END OF THOMPSON	02	09	4	4	3	2	N
50	1.5 MI. SW. OF THOMPSON	02	09	3	4	7	7	N

Appendix F: Structurally Deficient Bridges in Utah (Cont.)

No	Item 9	Item 21	Item 26	Item 43A	Item 58	Item 59	Item 60	Item 62
51	13 MI. EAST OF THOMPSON	02	09	3	4	5	3	N
52	3 MI. SOUTHEAST OF CISCO	02	09	3	4	4	5	N
53	4.5 MI. NE.OF HARLEY DOME	02	09	2	5	3	6	N
54	1 MILE NW. of CEDAR CITY	04	19	5	4	8	8	N
55	0.5 MI.NO.BEAR VALLEY INT	02	09	3	4	5	5	N
56	5 MI.SOUTH OF YUBA INTCHG	02	07	2	3	4	4	N
57	SOUTH SIDE OF KANAB	04	09	3	N	N	N	3
58	CENTER STREET IN GLENDALE	03	09	3	4	4	4	N
59	3 MILES SW. OF DELTA	02	08	5	6	8	4	N
60	EAST OF RICHVILLE	02	09	3	3	4	5	N
61	EAST OF MORGAN	02	09	3	7	4	4	N
62	NEAR TOWN OF MILTON	02	08	3	4	4	5	N
63	SOUTHWEST SIDE OF MORGAN	02	07	1	5	4	5	N
64	2 MI WEST OF DEVILS SLIDE	02	09	1	5	3	7	N
65	SOUTH OF MTN. GREEN INT.	25	09	3	6	4	6	N
66	SO. END OTTER CREEK RES.	02	09	7	5	4	5	N
67	2 MILES SOUTH OF JUNCTION	02	09	1	5	4	6	N
68	6 MILES SOUTH OF RANDOLPH	02	09	3	6	4	4	N
69	5 MILES NE. OF RANDOLPH	02	08	4	6	7	4	N
70	4220 SO.MAIN ST.,MURRAY	04	19	1	3	3	6	N
71	200 EAST 8800 SO., SANDY	04	19	3	3	4	6	N
72	150 WEST 8710 SO., SANDY	04	19	5	6	3	5	N
73	450 WEST 12950 SO.,DRAPER	04	19	5	4	5	5	N
74	1900 EAST 5600 SO.,SL.CO.	04	16	1	6	4	6	N
75	5 MI.SOUTHEAST BLANDING	02	07	3	7	5	3	N
76	10 MILES NORTH LASAL JCT.	02	09	3	0	6	5	N
77	12 MILES EAST JCT. SR-191	02	07	1	5	4	7	N
78	2.5 MILES W. OF AXTELL	02	09	3	4	2	5	N
79	2.5 MILES W. CENTERFIELD	02	07	5	4	4	5	N
80	400 E. MAIN MT. PLEASANT	04	09	7	5	3	6	N
81	1 MILE SO. OF FAIRVIEW	02	09	3	7	2	6	N
82	0.5 MI. SOUTHEAST AURORA	02	09	3	5	5	4	N
83	1 MI.NO. of JOHNSON RESV.	02	07	7	4	5	6	N
84	0.5 MI.E.GOOSEBERRY INTCH	02	09	7	4	6	4	N
85	700 W.300 NO.in RICHFIELD	04	19	3	4	5	7	N
86	EAST OF GOOSEBERRY INTCH.	02	09	1	N	N	N	4
87	IVIE CREEK AT RED CREEK	02	09	1	4	4	6	N
88	100 NO.200 WEST IN KAMAS	04	09	5	4	5	7	N
89	125 WEST 200 NO. IN KAMAS	04	09	5	4	3	5	N
90	W.Of I-80 INT.ON 2ND.S.St	04	09	5	4	5	6	N
91	225 NO.100 WEST IN KAMAS	04	09	5	4	4	5	N
92	9750 NORTH 1500 EAST ST.	02	09	7	4	7	5	N
93	2.5 MI S.E. OF ROOSEVELT	04	08	3	5	6	4	N
94	1550 EAST 500 NORTH ST.	02	07	3	5	5	3	N
95	4.5 MILES NW. OF JENSEN	02	09	5	7	8	4	N
96	4.5 MI.S.BUCK CYN.RD.JCT.	02	09	3	7	4	4	N
97	1320 NORTH 500 WEST ST.	02	09	5	7	7	4	N
98	4 MI.S.BUCK CYN.RD.JCT.	02	09	3	7	5	4	N
99	12.5 MI.S.BUCK CYN.RD.JCT	02	09	3	5	4	3	N
100	13 MI.S.BUCK CYN.RD.JCT.	02	09	3	7	5	4	N

Appendix F: Structurally Deficient Bridges in Utah (Cont.)

No	Item 9	Item 21	Item 26	Item 43A	Item 58	Item 59	Item 60	Item 62
101	13.5 MI.S.BUCK CYN.RD.JCT	02	09	3	5	5	4	N
102	200 S. 100 E. AMER. FORK	04	19	2	5	4	5	N
103	250 SO.400 E.,SPRINGVILLE	04	17	1	6	5	4	N
104	10800 S.800 W., SO.SALEM	02	09	3	5	6	4	N
105	450 N.400 E.AMERICAN FORK	04	19	1	N	N	N	4
106	NORTHEAST OF HURRICANE	02	09	3	4	1	3	N
107	SE. SIDE OF ST. GEORGE	04	19	3	N	N	N	3
108	6 MILE WEST OF ENTERPRISE	02	08	4	6	4	3	N
109	4 MILE EAST OF ENTERPRISE	02	09	3	N	N	N	0
110	PINTO WASH IN PINTO	02	08	7	7	5	4	N
111	1450 E. Foremaster Dr.	04	19	3	N	N	N	3
112	1.5 MILE NORTH HANKSVILLE	02	09	3	7	4	4	N
113	2350 SO. 400 WEST, OGDEN	04	19	5	3	4	5	N
114	1800 SO.GRAMERCY AV.OGDEN	04	19	1	5	4	6	N
115	2.3 MI. NO. of HUNTSVILLE	02	07	1	5	7	4	N
116	1.5 MI.NORTH OF DUCHESNE	01	09	3	4	6	6	N
117	IN MORGAN CITY	01	07	3	4	5	5	N
118	ENTRANCE TO ROCKPORT PARK	01	09	3	3	4	6	N
119	WEST SIDE OF PROVO	01	16	4	4	4	6	N
120	3.3 MILES WEST OF DELTA	01	02	3	4	7	4	N
121	3.5 MI.WEST OF CAINSVILLE	01	06	3	6	4	5	N
122	14.8 MI.EAST OF THISTLE	01	02	4	3	4	6	N
123	9 MILES SO.OF LASAL JCT	01	02	3	6	7	4	N
124	APPROX.800 W.800 NO.,SLC.	01	19	3	2	5	5	N
125	1 MILE EAST OF CORINNE	01	06	3	3	5	4	N
126	RIVERDALE RD.INTERCHANGE	01	14	4	3	4	5	N
127	NORTH HILL AFB GATE	01	19	3	4	5	4	N
128	0.6 MI. W. SPANISH FORK	01	16	3	7	4	5	N
129	2300 NO. BECK ST. IN SLC	01	11	3	4	4	6	N
130	SW. OF NORTH SALT LAKE	01	16	4	4	6	5	N
131	WEST CENTER ST.IN PROVO	01	14	2	4	5	4	N
132	AT HAWS CORNER	01	07	1	5	5	4	N
133	RIVERDALE RD.INTERCHANGE	01	14	2	3	4	5	N
134	0.5 MILES EAST OF LAPOINT	01	07	1	4	4	5	N
135	SPRING GLEN,SO.OF HELPER	01	07	2	N	N	N	4
136	4.8 MILES WEST OF LOGAN	01	06	2	N	N	N	4
137	APPROX. 9750 SO.STATE ST.	01	14	1	N	N	N	4
138	HONEYVILLE INTERCHANGE	01	07	5	4	6	6	N
139	3300 SOUTH INTERCHANGE	01	14	5	5	5	4	N
140	600 SO.UNIV.AVE.IN PROVO	01	14	5	4	5	5	N
141	1.2 MI.EAST TAGGARTS INT.	01	01	5	4	5	5	N
142	4430 SOUTH WASATCH BLVD.	01	14	5	4	3	3	N
143	7 MI.SOUTHEAST OF TABIONA	01	08	5	5	4	7	N
144	9 MILES SOUTH OF WOODSIDE	01	02	5	4	6	6	N
145	300 E.10600 SO., SANDY	01	16	5	5	4	6	N
146	5 MILE NORTHWEST OF PRICE	01	02	3	N	N	N	3
147	1.1 MI NO OF PROVO INTER	01	11	3	4	7	4	N
148	1 MI.NO.OF PROVO INTERCHG	01	11	3	4	6	4	N
149	PROVO INTERCHANGE	01	11	3	7	6	3	N
150	900 WEST 1100 NORTH SLC	01	11	3	3	4	4	N

Appendix F: Structurally Deficient Bridges in Utah (Cont.)

No	Item 9	Item 21	Item 26	Item 43A	Item 58	Item 59	Item 60	Item 62
151	4.6 MI.NO.NO.BEAVER INTER	01	01	2	4	4	5	N
152	HILL AIR FORCE BASE INT	01	11	2	4	6	7	N
153	1.7 MI.SW.SPANISH FK.INT.	01	11	5	4	7	7	N
154	1.5 MI SW SPANISH FK INT	01	11	5	4	7	7	N
155	WEST SIDE OF PAYSON	01	11	5	4	5	6	N
156	IN PAYSON	01	11	5	4	7	7	N
157	1.5 MI.EAST BRIGHAM CITY	01	16	5	6	5	4	N
158	1.4 MI.E.SILVER CREEK INT	01	01	4	4	5	6	N
159	PROVO INTERCHANGE	01	11	3	7	7	4	N
160	PROVO INTERCHANGE	01	11	3	6	5	4	N
161	NEAR KCC ARTHUR MILL	01	02	3	4	7	6	N
162	1.1 MI.NO.RIVERDALE INT.	01	11	4	3	7	5	N
163	BELOW UP&L RESERVOIR	01	01	4	3	6	6	N
164	BY POWER PLANT WEBER CYN.	01	01	4	3	5	6	N
165	31ST STREET INTCHG. OGDEN	01	14	4	3	5	5	N
166	29 MI.E.FREMONT JCT.INT.	01	01	4	4	6	5	N
167	MT.DELLE INTERCHANGE	01	01	3	4	6	5	N
168	ECHO INTERCHANGE	01	01	2	4	4	5	N
169	WEST OF ECHO TOWN	01	01	2	4	4	7	N
170	WANSHIP INTERCHANGE	01	01	5	4	3	5	N
171	2400 SOUTH 300 EAST SO.SL	01	11	5	4	6	6	N
172	2400 SOUTH 500 EAST SLC	01	11	5	4	6	6	N
173	2400 SOUTH HIGHLAND DRIVE	01	11	5	5	4	5	N
174	2500 SO.& 2300 EAST,SLC.	01	11	5	4	7	7	N
175	2400 SOUTH 600 EAST SLC	01	11	5	4	6	4	N
176	3.2 MI.NORTHEAST WANSHIP	01	01	5	5	4	3	N
177	0.8 MI.EAST TAGGARTS INT.	01	01	5	4	7	5	N
178	LAMBS CANYON INTERCHANGE	01	01	5	4	7	7	N
179	12 miles east of Wedover.	01	01	9	N	N	N	4
180	SO. OF NO. SALT LAKE CITY	01	14	3	5	7	4	N
181	PROVO INTERCHANGE	01	11	3	6	6	4	N
182	HILL AIR FORCE BASE INT	01	11	2	4	6	6	N
183	PARLEYS INTERCHANGE	01	11	5	7	4	5	N
184	ROY-5600 SOUTH INTCHG.	01	11	5	4	6	7	N
185	1.7 MI.SW.SPANISH FK.INT.	01	11	5	4	7	7	N
186	1.5 MI.SW.SPANISH FK.INT.	01	11	5	4	7	7	N
187	WEST SIDE OF PAYSON	01	11	5	4	5	7	N
188	IN PAYSON	01	11	5	4	7	6	N
189	1.9 MILE EAST of DELLE	01	01	3	5	4	6	N
190	5.5 MI.E.SILVER CREEK INT	01	01	3	3	7	7	N
191	NEAR KCC ARTHUR MILL	01	02	3	4	6	5	N
192	31ST STREET INTCHG. OGDEN	01	14	4	3	5	5	N
193	SOUTH SPANISH FORK	01	17	1	5	4	4	N
194	0.6 MILE EAST of WANSHIP	00	01	2	3	3	5	N
195	ECHO INTERCHANGE	01	01	2	4	4	5	N
196	WEST OF ECHO TOWN	01	01	2	4	4	7	N
197	WANSHIP INTERCHANGE	01	01	5	4	4	6	N
198	2400 SOUTH 300 EAST SO.SL	01	11	5	3	5	6	N
199	2400 SOUTH 500 EAST SLC	01	11	5	4	6	6	N
200	2400 SOUTH HIGHLAND DRIVE	01	11	5	4	4	5	N

Appendix F: Structurally Deficient Bridges in Utah (Cont.)

No	Item 9	Item 21	Item 26	Item 43A	Item 58	Item 59	Item 60	Item 62
201	2400 SO. & 2000 EAST	01	11	5	6	4	6	N
202	2500 SO.& 2300 EAST,SLC.	01	11	5	3	5	5	N
203	2400 SOUTH 600 EAST SLC	01	11	5	4	6	5	N
204	ECHO JCT. INTERCHANGE	01	01	5	4	6	5	N
205	3.2 MI.NORTHEAST WANSHIP	01	01	5	4	3	3	N
206	SUMMIT PARK INTCHG.	01	01	5	4	5	5	N
207	12 miles east of Wendover	01	01	9	N	N	N	4
208	0.9 MI E OF WHITEROCKS UT	62	07	2	3	4	3	N
209	11.9 MI S OF OURAY	62	08	3	4	3	4	N
210	21.7 MI S OF OURAY	62	08	7	3	4	3	N
211	0.4MI SOUTH OF HATCH T.P.	62	06	5	4	8	4	N
212	10 MI NE NAVAJO MT SCHOOL	62	09	5	7	8	3	N
213	BEAR RIVER MBR	63	09	5	6	4	6	N
214	7.1 MI NW JCT US-191	64	09	7	3	3	4	N
215	15.3 MI NW JCT US-191	64	09	7	4	4	5	N
216	10 MI N MT HOME, UTAH	64	09	3	4	7	5	N
217	.5 MI. N. BRYCE AIRPORT	64	09	7	7	4	7	N
218	NO DATA ENTERED	64	09	7	4	5	2	N
219	3.5 MI SO OF U-150	26	09	7	4	5	5	N
220	21 MI N OF LOGAN V RT 89	64	09	7	4	5	7	N
221	.1 MILE OFF U S 89	26	09	7	3	3	7	N

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