WYOMING FREIGHT MOVEMENT AND WIND VULNERABILITY

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June 2005

Acknowledgement

This report has been prepared with funds provided by the United States Department of Transportation to the Mountain Plains Consortium (MPC). The MPC member universities include North Dakota State University, Colorado State University, University of Wyoming, and Utah State University. Matching funds were provided by the Wyoming Department of Transportation.

Executive Summary

The movement of freight in Wyoming is critical to the state's economy as well as the national economy. Wyoming's transportation system provides a vital link for the movement of commodities across the United States in addition to providing access to the mineral, industrial, and agricultural resources of the state. The intent of this research is twofold. First is to get an overall understanding of freight movement within the state including freight vehicle counts, commodity types, and freight vehicle accidents. The second intent is to focus on freight vehicle safety in strong wind conditions. High wind conditions are the frequent cause of freight vehicle rollovers, often forcing the shutdown of roadways and halting the movement of freight through heavily used corridors. The wind research studies the weather station data and looks at the correlation between measured wind speeds and the likelihood of freight vehicle rollover accidents. The focus of this research is on truck and rail freight movement because air and water freight modes represent a very small portion of the goods movement in the state. Pipelines are addressed to a lesser extent.

This report describes a research effort conducted at the University of Wyoming by Dr. R. Young, assistant professor, and graduate students Joel Liesman, David Lucke, and Shane Schieck.

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1. Introduction

1.1 Importance of Freight Planning

The amount of freight being moved by all transportation modes is increasing and this trend is expected to continue in the foreseeable future. Freight planning is needed to handle this additional demand at all types of freight facilities. These needs can be met by increasing the capacity and the efficiency of freight facilities in a timely manner and within the budget constraints of the public and private agencies providing these facilities. According to the Federal Highway Administration's Office of Freight Management and Operations (FHWA, 2004b):

> "Investments are likely to include a mix of approaches, including adding new capacity, improving existing infrastructure, streamlining operation, and using intelligent transportation system (ITS) technologies to provide real-time travel information or gateways clearances to enhance the performance of vehicles and operators."

Freight planning is necessary for public agencies to answer the following critical questions:

- When should current freight infrastructure be upgraded?
- Where should new infrastructure be located?
- Which factors influence the freight transportation decisions made by private shipping parties?
- How can economic development in the region be promoted?

The following discussion provides four important reasons why public transportation agencies should engage in freight-planning activities. First, freight planning is necessary to determine when to upgrade current infrastructure. Planners want to know if their facilities will be able to meet projected demand with a reasonable amount of excess capacity. According to the Federal Highway Administration (FHWA), the amount of domestic freight moved on our nation's highways alone is estimated to increase from 10.4 billion tons in 1998 to 14.9 billion tons in 2010 and to 18.1 billion tons in 2020, increases of 43 percent and 74 percent respectively. (FHWA, 2002b) The value of goods moved nationwide is also expected to increase from a 1998 level of $6.7 trillion to $12.7 trillion in 2010 and $20.2 trillion in 2020, increases of 91 percent and 204 percent respectively.

The FHWA estimates also call for growth in both domestic and international freight shipments. If public agencies adequately prepare for these increases and are able to supply the needed infrastructure in a timely manner, regions can be competitive in attracting new businesses to the area. This, in turn, will improve the local and regional economy. If this growth is not planned for, infrastructure will become congested and prospective businesses may choose to locate elsewhere. If congestion levels degrade to an intolerable level the region may lose existing businesses.

A second reason for freight planning is to know where new facilities and infrastructure should be located. Based on projected increases in freight movement, new facilities and infrastructure will need to be built and existing ones upgraded or expanded. When constructing facilities it is important to have the best planning estimates available because of the consequences for both over- and under-designing a facility. Over-designing a facility results in funds being utilized inefficiently (i.e. money could have been spent on other projects for more public benefit). Under-designing a facility is also inefficient because it results in the need to upgrade sooner than expected. There are also benefits to identifying necessary improvements early on because right-of-way costs can be secured and conflicts with future development avoided.

Third, freight planning helps transportation agencies determine which factors influence the transportation decisions made by freight companies. Once these factors are understood, planners will be equipped with knowledge on how changes in the transportation system influence these private decisions, leading to improvements in how freight movement is modeled. This improved understanding also helps planners encourage private freight companies to make decisions that are beneficial to the entire transportation system.

Often the most important reason that freight planning should be undertaken by public agencies is the role it plays in state and regional economic development. The Federal Highway Administration's Office of Freight Management and Operation said the following about the importance of freight movement (FHWA, 2002a):

> "In 2001, Americans spent over $313 billion on goods and services that were transported over the Nation's highway system. Transportation accounts for a share of the final price of the product, ranging from 1 to 14 percent, depending on the commodity and the distance moved. Thus, changes in the physical condition and operating characteristics of the highway system can have a major effect on the final price of goods and services."

Because the majority of goods are not produced where they are consumed, a freight network is needed to transport the goods between production and market locations. The cost of transportation is a significant portion of the cost of the product, particularly for low-valued goods. If a region has an efficient freight network, that region's commodities will be more attractive to consumers in other areas. As freight movement becomes more efficient and the per-mile cost decreases, companies will be able to serve a larger market area from a single production location. This increased market area will in turn enhance the local and regional economy. Also, when freight transportation infrastructure in a region is efficiently operating, outside companies may consider locating to that region. Often, the economic development potential of freight planning is reason enough for an agency to pursue freight-planning activities.

Freight movement in Wyoming is following the same increasing trend as the rest of the nation. The volume of freight movement originating or terminating in Wyoming by all transportation modes is estimated to increase 42 percent from 377 million tons in 1998 to 534 million tons in 2020 (FHWA, 2002c). Considering highways alone, the estimated increase in tons of goods originating and terminating in Wyoming doubles from 65 million tons in 1998 to 135 million tons in 2020. The value of freight movement originating or terminating in Wyoming by all modes is estimated to increase 228 percent from $50 billion in 1998 to $164 billion in 2020. These numbers do not include freight that is transported through the state, which is the majority of goods given Wyoming's central location and small population base. This will put even greater pressure on the freight routes that travel through the state.

Transportation is important to the Wyoming economy. The transportation sector brought $557 million in revenues and employed over 4,600 people in the state in 1997, excluding revenues and employment in the rail transportation area (US Census Bureau, 2001). With transportation being such a vital part of the economy, state planners need to keep the transportation network in good condition and to be prepared to expand or otherwise increase the supply as the demand rises. In addition, Wyoming needs to adequately plan for freight traffic so that personal transportation needs are not impacted. Wyoming's economy is heavily based on the tourism industry. Many of the same transportation facilities that are projected to be inundated by freight vehicles are the same ones that visitors use to access the many natural wonders of the state. Tourism will be greatly impacted if those facilities are operating at congested levels and dominated by large freight vehicles.

The above discussion set out the reasons for why freight planning in general should be performed by state agencies. This particular research effort focuses on two major sub-areas of freight planning: safety and wind vulnerability; and the identification of critical infrastructure. The following sections discuss the importance of and issues relating to these areas.

1.1.1 Freight Safety and Wind Vulnerability

Freight planning is important for safety reasons. When deciding where to locate new roadways and how to operate existing ones, large trucks require special consideration of factors that are not as prevalent with passenger vehicles. Some of these factors include grades, curvature, and weather conditions. Steep grades can be problematic for large trucks. Downgrades cause problems when, if the driver is not careful, the truck accelerates to unsafe speed and results in the loss of control of the vehicle. Upgrades can also cause problems as trucks are moving significantly slower than the rest of the traffic stream. This impedance by the larger vehicle may cause other drivers to accept higher risks in passing them. Likewise, if curves are too sharp, trucks, because of their high center of gravity, may overturn if their speed is too high. Finally, weather may cause problems such as high wind gusts, which can cause overturning of the vehicle, slick road conditions, and low visibility all of which can cause driving conditions to become unsafe. Because of the time-sensitive nature and economic importance of most cargo, trucks are often forced to travel in severe weather conditions that many other travelers would avoid. The trend from warehoused supply chains to just-in-time delivery systems for production lines increases the time pressures on freight movement.

Freight planners should consider these large vehicle factors when planning a new facility or when making decisions about changing the operations of an existing facility. Planners need to ensure that the road is as safe as possible yet still recognize the economic realities. In Wyoming, freight planners need to be particularly concerned with truck safety because of the large percentage of trucks on its Interstate system. Unpredictable and severe weather conditions along with frequent mountainous terrain also present safety problems. During winter, the roads are frequently slick, icy, and snow-packed, often forcing drivers to reduce their speeds, even given the great time pressures put on them. Highway officials try to keep the roadways open as long as possible and in some cases the pressure to keep the roadway open results in the facility only being closed when serious crashes occur. If more information were available about what type of weather conditions and corresponding traffic speeds cause crashes, officials could make better operational decisions about when to close the road and when to post warnings and speed reduction recommendations. If the affects of weather were better understood, officials could maintain freight movement for longer periods while still maintaining a high level of safety.

1.1.2 Identification of Critical Infrastructure

The identification of critical infrastructure is important in freight planning for several reasons. First, various government agencies, such as the federal and state departments of transportation and private industry, have limited budgets for the operation and maintenance of existing and the construction of new infrastructure. Given these budget constraints, decisions have to be made about the best use of the resources. One tool that can be used to aid in this decision is the identification of which components of the system are most critical. These components would be the most vital segments of the transportation network and would allow funding agencies to direct resources toward projects that would have the largest impact on the operation of these specific facilities.

The identification of critical infrastructure would also be useful in the development of contingency plans for agencies that rely on the network to deliver emergency services. The use of the freight system could come in the form of the delivery of military, personnel and equipment, or the delivery of disaster relief workers and supplies in times of large-scale crisis, or in the conveyance firefighters, law enforcement, and emergency medical personnel during more localized times of need.

Identification of critical infrastructure also benefits the private industries that rely on the freight network. As the business world has become increasingly competitive, the smooth operation of freight networks has taken a more prominent role in daily operations. The identification of critical infrastructure would be an important step to increasing the reliability of the transportation network. Operation, maintenance, and capital construction funds could be prioritized for use on these critical links where the consequences of closure are great.

1.2 Project Objectives

As mentioned previously, this research effort focuses on two main areas; freight safety and wind vulnerability, and the identification of critical infrastructure. This research also tackles another major but less defined task in bringing together information from numerous sources to provide agencies in Wyoming with a general understanding of freight movement in the state. While this sounds unspecific, it is a critical task that must be undertaken before any serious efforts at freight planning can begin. The following sections break the research effort into three major tasks and describe the individual objectives within each of these tasks.

1.2.1 General Understanding of Wyoming Freight Movement

The objective for understanding freight movement in the State of Wyoming is to address the following fundamental questions:

- What is the volume of freight moving to, from, within, and through the state?
- What is the value of freight moving to, from, within, and through the state?
- By what modes is the freight being moved?
- What commodities are being moved?
- What is the impact of freight movement on the state economy?
- What are the future projections for freight commodities and how will this affect the freight infrastructure in Wyoming?
- How can freight infrastructure be improved to increase the competitiveness of Wyoming products and the desirability of the state for new businesses?
- How vulnerable is the infrastructure to disruption?

As would be expected, there is overlap between some of these questions and the two other major tasks in this research effort. The purpose of this particular task is to provide a board overview of what is happening in Wyoming with regard to freight movement. The other tasks are more in-depth probes into particular aspects.

The above questions, except for the last one, will be addressed in Chapter 3 - Background, Chapter 4 - Data Sources, and Chapter 5 – Freight Forecasts. The last question will be addressed in Chapter 7 - Critical Infrastructure.

Each of these questions could be an entire research project on their own. The intent of this research project is to provide a general understanding of freight movement. This understanding will in turn provide a foundation for the other two research tasks as well as for future research work. In addition to its usefulness in other research work, the broad picture created by this task will aid agencies in Wyoming in addressing freight concerns. This effort will also help other state agencies in the region when addressing their freight concerns because freight issues go beyond state jurisdictional boundaries.

1.2.2 Freight Safety and Wind Vulnerability Objectives

The objectives of the freight safety and wind vulnerability task of this project are to develop a methodology for locating high hazard areas for freight vehicles and to use this methodology to perform an analysis of freight vehicle crashes in Wyoming. Currently WYDOT has a safety database that stores crash information for the entire state regardless of the road's jurisdiction. This database also performs various crash analyses and generates summary statistics. The existing database is in the process of being transferred to a new database system compatible with the geographic information system (GIS) environment. The development of the methodology in this research effort is being done with a GIS system so that it can be utilized once this transfer of the safety database has taken place.

The application of the analysis methodology will locate the following: areas with high crash rates, areas with high crash fatality rates, and areas with a high number of crashes involving overturning of trucks in high wind conditions. The crash rates and fatality rates will be calculated using million truck vehicle miles traveled, while the overturning truck crashes will be analyzed using frequency calculations based on the number of overturned trucks on a particular road segment. While the focus of this research is on freight safety, the methodology will not be limited to use in analyzing freight vehicles. It will also apply to general vehicle crashes.

The wind speed from the closest WYDOT weather station will be linked to each overturning truck crash to determine if a correlation between measured wind speeds and overturning crashes can be made. This correlation could then be used to determine what wind conditions are hazardous to trucks. If a large number of trucks were overturning in particular wind conditions, according to the crash data, but the nearest weather station was a considerable distance away, this research effort could also result in recommendations on where new weather stations should be located in order to monitor critical locations more accurately.

In summary, the objectives of the freight safety and wind vulnerability task are:

- Develop a methodology to be used by WYDOT for the analysis of freight vehicle crashes.
- Apply methodology to 10 years of crash data set to determine high-hazard locations for freight vehicle crashes.
- Develop a methodology for linking weather station data, in particular wind speeds, to crash data.
- Apply methodology to determine if correlation exists between weather station wind speeds and freight vehicle overturning crashes.
- Make recommendations regarding whether existing weather stations are adequate and/or properly located to provide good coverage of roadway system with respect to predicting overturning freight vehicle crashes.

These tasks are covered in Chapter 6 - Freight Crash and Wind Vulnerability Analysis.

1.2.3 Identification of Critical Infrastructure Objectives

The final task in this research effort pertains to the identification of critical transportation infrastructure in the State of Wyoming. The intent of this task is not to generate a list of the critical infrastructure, but to propose a methodology for doing so that will be implemented in Phase II of the research effort.

The first step in developing a methodology is to define what transportation infrastructure will be considered and then to define what is meant by the term critical. The second step of the project will be to look at various methods for identifying critical infrastructure. Next, the most appropriate method for the unique conditions in Wyoming will be selected and adapted.

To summarize, the research objectives for the critical infrastructure task are:

- Define critical infrastructure and select what components of the transportation infrastructure that will be considered for this project.
- Review critical infrastructure identification methodologies applied elsewhere and discuss their applicability to Wyoming.
- Select an appropriate methodology and refine to meet the characteristics of Wyoming and the data available.
- Document the procedure for applying the methodology in Phase II of the research project.

These tasks are further discussed in Chapter 8 - Critical Infrastructure. The second task is covered in Chapter 2 - Literature Review.

2. Literature Review

The following chapter provides a review of the literature on the state-of-the-practice for freight planning in general, freight safety, and the identification of critical infrastructure.

2.1 Freight Planning in General

Freight transportation planning methods have historically lagged behind their passenger transportation counterparts. Several reasons are likely for this. One is that freight transportation stakeholders historically have been absent from the planning processes, either because of their own wish for secrecy or because the planning process excluded them. The planning process was designed to get input from the general public, which, for the most part, has concerns with the quality of the passenger transportation system.

Another reason for the lack of freight transportation planning is the complexity in modeling freight movements. Understandably, the processes behind freight transportation are much more complex and less understood than passenger travel. The passenger-demand models are driven by survey data where the general public states their travel behavior and other socioeconomic factors. This type of data is much more difficult to obtain from freight transporters because the freight market is highly competitive. This leads to issues in data confidentiality and the protection of business secrets.

Because of this, most research in the area of transportation-demand modeling has been focused on passenger travel demand rather than freight demand. During the latter part of the 1970s and the early 1980s, there were several research projects aimed at developing models for freight movement. Most of these efforts created large-scale national models as opposed to regional or state-wide demand models (Cambridge Systematics, 1997). Most of the freight planning that did occur during this period was limited to privately operated specialty agencies such as railroads, marine ports, and airports. The models developed during this era were so complex that they were virtually unworkable, causing most of them to be discontinued. One rare successful model was the foundation for the Association of American Railroads' Intermodal Competition Model.

The U.S. Congress realized the need for public-sector freight planning while writing the *Intermodal Surface Transportation Efficiency Act of 1991* (ISTEA). With the passing of this legislation, the emphasis of freight planning within transportation agencies greatly increased and modern freight planning as we know it was born. ISTEA required planning agencies receiving federal funding to incorporate 15 factors into their decision-making process. Two of these 15 factors directly involved freight transportation. In Section 1024 of the ISTEA legislation, modifications were made to the U.S. Code, Title 23, to include the following factors relevant to freight transportation (U.S. Congress, 1991):

- International border crossing and access to ports, airports, intermodal transportation facilities, major freight distribution routes, national parks, recreation areas, monuments and historic sites, and military installations.
- Methods to enhance the efficient movement of freight.

ISTEA was the first major federal government act to mandate state and metropolitan planners to include freight movement in their planning processes. This legislation provided the initial motivation for development of freight-planning techniques and models for public agencies. The passage of ISTEA also began the practice of actively bringing freight stakeholders into the planning process to articulate the needs of this user group.

In 1998, ISTEA expired and the reauthorized transportation bill was entitled the *Transportation Equity Act for the 21st Century* (TEA-21). The factors that planning agencies were required to consider were reduced to seven, but two were explicitly directed towards freight. In Section 1203(f) the following factors are listed (U.S. Congress, 1998):

- Increase the accessibility and mobility options available to people and for freight.
- Enhance the integration and connectivity of the transportation system, across and between modes, for people and freight.

With the passing of TEA-21, the federal government reemphasized the importance of freight planning. It could be said that increased emphasis was put on freight planning in TEA-21 because two of the seven factors dealt with freight compared to two of 15 factors dealt with freight in ISTEA.

Both ISTEA and TEA-21 have made state and metropolitan planning agencies realize not only the necessity of freight planning, but also the social and economic benefits of freight planning. Some of the required management systems, such as the intermodal and the congestion management systems, that were mandated by ISTEA were made optional by the Federal National Highway System Designation Act of 1995. However, many transportation agencies continued to use these management systems in their planning processes (Coogan, 1996).

2.2 Freight Safety

This section covers some previous work relating to truck crashes in general as well as to large truck crashes in strong wind conditions. More recently a higher percentage of the work in the safety area has included the use of geographic information systems (GIS). This review will cover some general background information on crash analyses and the use of GIS in these analyses. Next, it will look at some of the methods of analysis used for investigating truck crashes. Finally, it will cover the research analyzing the affects of winds on high profile vehicles.

2.2.1 General Background

Many traffic accidents occur each year in the United States. A significant portion of these traffic accidents involve freight trucks. According to the National Highway Traffic Safety Administration (NHTSA), one out of nine traffic fatalities in 2002 resulted from a collision involving a large truck (NHTSA, 2002a). In Wyoming, 13 percent of the vehicles involved in a fatal crash in 2002 were large trucks (NHTSA, 2002a). With more than 10 percent of fatalities throughout the nation involving large trucks, it is important to try to improve the safety for both the trucks and for other road users as well. With a significant percentage of crashes involving trucks, it is useful to analyze where these crashes are located. These high crash areas can then be analyzed to determine what common factors they share with the intent of finding ways to make the segments of roads safer.

Injuries from truck crashes are usually more serious than those only involving passenger cars and often are fatal. In 2002, 42,815 people were killed in vehicle crashes, with 4,897 (11%) being killed in crashes that involved large trucks (NHTSA, 2002a and 2002b). (Note that a large truck is defined as a vehicle with a gross vehicle weight greater than 10,000 pounds.) Of these 4,897 fatalities, 684 (14%) were occupants of the large truck, 3,853 (79%) were occupants of other vehicles, and 360 (7%) were nonoccupants (pedestrians, bicyclists, etc.). These numbers show that, very often when a large truck is involved in a crash, it is people other than the large truck occupants that are killed. For the same period, more than 2.9 million people were injured in vehicle crashes with 130,000 (4%) being injured in crashes that involved large trucks. Both the public and government agencies are looking for ways to make the roads safer by reducing the number of crashes that occur. If the factors causing large trucks to be involved in crashes are known, and can be mitigated, then it is possible that a significant reduction in these crashes can be achieved.

Until recently, truck crashes have typically been grouped with auto crashes, particularly at the non-federal reporting level. This has resulted in most crash analyses not addressing issues that relate specifically to trucks or not accounting for factors that affect large trucks more than other vehicles. Some of these factors include roadway geometry, roadway surface conditions, and weather conditions.

The federal government has begun to recognize the need to reduce truck crashes. In 1999, then-Secretary of Transportation Rodney Slater set a goal to reduce the number of fatalities in truck crashes by half within 10 years (Blower and Campbell, 2002). For this goal to be met, areas with high truck crash rates must be located and methods to reduce the number of these crashes must be implemented.

Many state and federal agencies have recently performed studies relating to large truck crashes. One of the first crash analysis performed using geographic information systems used data from the Highway Safety Information System (HSIS) for the year 1999. HSIS is a multi-state safety database that contains crash, roadway inventory, and traffic volume data. HSIS is operated by the University of North Carolina Highway Safety Research Center under contract with the Federal Highway Administration. The project developed a GIS program to enter, edit, manage, and analyze crash data. Specific objectives for the research effort included identifying locations with high rates of truck crashes and exploring the applicability of non-traditional databases (i.e. GIS) for this type of analysis (HSIS, 1999b). This study developed five analysis tools: spot/intersection, strip, cluster, sliding-scale, and corridor analyses. These analysis tools will be discussed later in this chapter.

Regarding the applicability of GIS to safety analysis the research effort found the following advantages over traditional (non-GIS) methods (HSIS, 1999b):

- Ability to quickly milepost a crash that has missing or incorrect locational data.
- Evaluate the problem using spatial relationships.
- Produce presentation graphs and plots within the software itself instead of relying on outputting to other software.
- Develop online capability to respond to concerns about specific locations.
- More accurately report crashes and roadway features when GIS is combined with GPS technology in reporting accident locations.
- Ability to conduct corridor analyses by automatically linking routes.
- Ability to incorporate additional data sources such as land use, zoning ordinances, population characteristics.
- Better access to information such as handwritten crash reports, photographs, and video logs.

Another study, conducted between June 2001 and December 2003, was the national *Large Truck Crash Causation Study* performed by the Federal Motor Carrier Safety Administration and the National Highway Traffic Safety Administration (Blower and Campbell, 2002). This study collected detailed data on truck crashes involving serious or fatal injuries. This study did not use GIS but is notable for the research objective of determining pre-crash events that contributed to the collision being unavoidable. Data collected included information on the vehicle and its condition, driver condition and experience, information about the motor carrier and type of truck operations, and the environment at the scene of the crash. This study used the data and information collected to determine the first critical event, critical reason, and associate factors of each crash.

The critical event is defined by the researchers as the event that immediately led to the crash. The critical event is not the cause of the crash but is the event or action that made the collision unavoidable. The critical reason is defined as the immediate reason for the critical event. The list of critical reasons includes driver decisions, driver conditions, vehicle failures, and environmental conditions including weather, roadway condition, and highway design features. For example, if the critical event was that the truck did not slow down or stop and the critical reason was brake failure, then the cause may have been related to poor vehicle maintenance or vehicle type. Associate factors are other data collected that may or may not be related to the crash. Associate factors were collected for two reasons: first to be able to describe the crash completely and allow analysis to be performed on subsets of the data, and secondly to provide information on a wide range of factors believed to be related to crash risk. The *Large Truck Crash Causation Study* provided statistical methodology for determining what factors influence the cause of the crash.

Many agencies are using GIS to perform spatial analysis on crashes and subsets by crash type such as fatal, head on, overturning, and others. Analyses, such as crash rate per mile or per vehicle miles traveled or crashes within a certain distance of an intersection, may all be performed using GIS tools.

An example of a state utilizing GIS for crash analysis is the Arizona Department of Transportation (ADOT). The Arizona Transportation Research Center, in conjunction with ADOT, began using GIS for its Accident Location Identification Surveillance System (ALISS) in 1997 (Breyer, 2000). The GIS interface allowed for the development of a set of macro- and micro-level tools. The macro (system level) tools allowed for a spatial (grid-based) tools and a network (translated) view. The micro tools investigated individual crashes and their attributes to determine if crashes in the same area contain similar attributes.

The spatial view uses a GIS grid overlaid with the locations from the crash database. The cells in the grid are assigned a value based on the number of crashes that occurred within each cell. The cells are then color-coded based on the number of accidents in that cell. The coding allowed for quick and easy method of spatial cluster analysis. The grid can than be normalized by dividing the number of crashes by the total length of roads contained within each cell to produce a density map with cell values in units of crashes per mile. Grid-based analyses have a disadvantage of including not only arterial roadways but also local streets. This inclusion can result in inaccurate results for crash rates along the corridor of interest. Also, small areas with high crash densities may become segmented at the arbitrary cell boundaries and may not reflect the true crash density of the area.

ADOT also developed the translated-network view to analyze crashes that occurred within a certain distance of the corridor centerline. This system allowed for crashes off of the mainline route to be considered. These crashes may need to be included in the analysis as potentially contributing factors to, or results of, crashes that happened on the mainline. This method also allowed for a continuous corridor to be developed even when the route went through urbanized areas or changed names. This macro tool provided ADOT with an easy-to-use analysis method to identify high-crash routes that warrant further investigation.

ADOT also realized that micro-level tools could be developed using GIS with the ability to attach attributes to individual crashes and to form crash groupings based on criteria such as crash type, weather conditions, or lighting levels. Using attributes allows crashes to be queried based on their attributes, to display only certain types of crashes, or to have different types displayed with different symbology. Using different symbols, however, can be problematic if the crashes occur close to the same location because one symbol may hide other symbols behind it. Thematic grouping addressed this issue by clustering the crashes in an area and utilized a pie, bar, or line graph to show the number of crashes that occurred in that area. These graphs allowed for a concise reporting that allowed the user to visualize the different types of crashes in that area. Thematic grouping also solved the problems associated with the macro tools and individual crash identification (Breyer, 2000).

In 1975, the National Highway Traffic Safety Administration (NHTSA) began the Fatal Accident Reporting System (FARS), the first comprehensive national database of fatal vehicle crashes (Wolfe and Carsten, 1982). Previously all crash data was aggregated, which prevented estimates on subsets of data such as trucks. The FARS data enabled more detailed studies to be performed on crash subsets and allowing for common factors for these crashes to be found.

In 1982, the University of Michigan, Ann Arbor, conducted a study of truck/car crashes (Wolfe and Carsten, 1982). This study examined the frequency of car/truck crashes compared to other crashes and circumstances of car/truck crashes. Part of this study compared the proportion of miles traveled for cars and trucks to the proportion of fatal crashes involving these vehicle types. Based on this comparison, the researchers concluded that "In comparison to the outcome for fatal car-car collision, car-truck collisions are overrepresented by 34 percent and truck-truck collisions by 94 percent" (Wolfe and Carsten, 1982). Part of this overrepresentation could be because this analysis was performed on fatal crashes, which could mean that if a truck is involved in a crash, there is a greater likelihood of a person being killed. This study also analyzed the descriptive statistics relating to the geometric configuration, crash cause, and time of the crash. The researchers found that in 1980, the majority of crashes were on curves, wet roads, and after dark. For the large majority of crashes, the car driver was at fault and the most common factors cited were speeding, improper lane changing, failure to yield the right of way, and driving on the wrong side (Wolfe and Carsten, 1982).

During the early 1980's the *Surface Transportation Act of 1982* legislation was passed and required all states to allow larger trucks to operate on certain roadways such as Interstates and other federal-aid highways (U.S. Congress, 1982). The law specified that states must permit all twin-trailer combinations. This required that trucks that were 102 inches wide and single trailers of 48 feet to be allowed to operate on federally funded highways. The Georgia Institute of Technology in Atlanta conducted a study in 1985 to determine the safety of various types of large trucks and what roadway and traffic characteristics were common in large truck crashes. The researchers used information from the Georgia Department of Transportation (GDOT) Planning Division as well as a survey to determine the types and distribution of trucks on Georgia's highways (Wright, 1985). The survey was conducted to determine how truck operators were taking advantage of the changes in size limitations in to the new federal legislation. The survey found that 18 percent of the operators exceeded the previous size limits and were therefore taking advantage of the new legislation. Two additional surveys were performed to determine the type of cargo the trucks were carrying and what safety violations were most common.

This study also examined the crashes occurring within the state of Georgia during 1984 involving large trucks. The researchers wanted to compare the crash rates for various-sized trucks on different classes of highways throughout the state. However, because of the lack of data for other sizes and configurations of vehicles, only tractor-semitrailers could be evaluated on the different road classes (Wright, 1985). The research found that nearly two-thirds of the crashes occurred in rural areas with 24 percent occurring on rural interstates and 38 percent occurring on other rural roads. An engineering study was also done on the geometrics of the roadway for a one-mile section before the crash site of 200 crashes in the study. The researches found that the crash locations had more two-lane roads, narrower pavements, more horizontal curvature, and more restrictions to passing (Wright, 1985).

2.2.2 Methods of Analyses

In the last several years, there have been two broad categories into which most crash analyses can be divided: the expert or clinical method and the statistical method. In the clinical method, a group of experts from various disciplines determine the main and contributing causes for each crash. Analysts may then use statistical methods to determine association between different factors and crash types, but the cause and other contributing factors have been determined by the experts. While the clinical method has many advantages and may arguably be more accurate, the requirement of experts to review large amounts of crash data makes it infeasible for large scale analyses.

In the statistical method, the cause of a specific crash is never determined, but rather the cause is defined in terms of changes in risk (Blower and Campbell, 2002). The researchers then look for associations between factors and the risk of a crash. Geographic information systems are a powerful tool in applying the statistical method because of their ability to query based on different factors associated with the crash.

GIS is an increasingly popular method to analyze crash data. Before any examination or analysis of crashes can take place using GIS, the crash locations need to be plotted on a map. This can be done in one of two ways. The first would be to identify the latitude and longitude, or some other x-y coordinates, of the crash locations and then use the coordinates to place the crashes on a map containing the roadway network. Unless the authorities responding to the crashes are using a global positioning system (GPS) device, determining the crash coordinates can be challenging. Therefore, most crashes are reported by a route number or street name and milepost. Utilizing this linear referencing system is the second and more common way of plotting crash locations on the map.

Using linear referencing, GIS software can determine the location of a crash on a network given that the crash has associated with it a route and milepost to describe its location. The network must have a route name associated with each link of the network and each line must have a beginning and an ending milepost. The crash points are then plotted by matching the route names and interpolating the distance between the beginning and ending number to match the crash location to the network location.

Once the crashes are located on the network, the method of analysis must be chosen. The following methods will be discussed in the this section: grid analysis; spot/intersection analysis; strip analysis; cluster analysis; sliding scale analysis; and corridor analysis. All of the above analysis tools except the grid analysis were implemented in the tools used with the HSIS study discussed earlier (HSIS 1999b). Some of these tools were developed elsewhere and adapted to this study while others were developed as part of this effort.

A grid analysis is one of the simplest methods for performing a crash analysis. A grid with a uniform cell size is overlain on the crash data and the number of crashes that are contained in each cell is calculated. These values can be normalized by dividing the number of crashes by the total length of roads in each cell. The result is a crash density for each cell. This method is simple to apply but has several important disadvantages. Both major arterials and local roads are included in the same cell, thereby "diluting" the effects of high crash occurrences on the arterial by including the local road length in the normalizing process. Another major disadvantage is that areas with high crash occurrences could be divided among multiple cells by an arbitrary cell boundary. The result would be two cell segments with moderate crash occurrences instead of one cell segment with a high number of crashes.

The spot/intersection analysis method is similar to doing a grid analysis on only a few selected cells around a particular spot or intersection. To perform the analysis, the user selects a spot and enters a search radius. The analysis will return the number of injuries, total crash cost, or other variables selected by the user on the crashes that occurred within the given radius. This analysis is useful when the user wants the summary statistics for a particular area (HSIS, 1999a).

The strip analysis divides each road into segments of a uniform size selected by the user and determines the densities of crashes within each road segment. This method also suffers from forcing arbitrary boundaries on the analysis procedure. The sliding-scale analysis is a more dynamic version of the strip analysis that addresses this issue. A segment length is specified, but in this case, the segment slides along the route in search of the highest crash density thereby eliminating the arbitrary boundary problem. The segment continues to slide along route. If the crash rate of any intermediate segment meets or exceeds a user-defined threshold for a high crash occurrence, the segment is extended by an incremental distance, and the process is repeated (HSIS, 1999a). This process ensures that that the whole segment with a high crash density is determined. The process is terminated after a predetermined number of extensions have occurred without a crash or the end of the route is reached. The sliding scale analysis is more advantageous than the strip analysis but is also more complex computationally.

The cluster analysis is a tool to perform multiple spot analyses around certain roadway features. Crashes that occur within a given radius of a user selected feature such as bridges or railroad crossing will be analyzed. Any areas that have more crashes, fatalities or other criteria above a defined threshold value will be flagged for inclusion in the results. The report then lists the flagged locations and will display other statistics that the user chooses.

A corridor analysis is an extension of the sliding-scale analysis that allows for a corridor consisting of multiple routes to be analyzed in a single process. With the corridor analysis, many routes can be linked together before a single sliding-scale analysis is performed, thus allowing for a complete analysis of an entire corridor rather than a series of analyses of individual routes. This is beneficial when performing an analysis where crashes may occur at intersections, route junctions, or slightly off the main route, and might not be included in the analysis if only a normal sliding-scale analysis were conducted.

When any of the above analyses methods are used, the methodology can be used on the entire data set or a subset of the data. This can be helpful when investigating particular factors in crashes. For example, a query may first be performed to select only crashes that happen during the night or during certain weather conditions. By analyzing subsets of data, it may be possible to determine whether improvements to the roadway could enhance safety and decrease the number of crashes.

The Federal Highway Administration adapted the tools from the HSIS study. The original tools were converted from a UNIX platform to a Windows platform for ArcView GIS software developed by the Environmental Systems Research Institute (ESRI), Incorporated (GIS/Trans, 2000). This effort resulted in the *GIS Safety Analysis Tools* program that is written in ESRI’s specialized programming language, Avenue. This language has since been replaced in ESRI’s current GIS products with more common languages such as Visual Basic and Python. Therefore, the analysis methodology written in the Avenue language is archaic and considered difficult to translate. Also, the *GIS Safety Analysis Tools* program is “hard wired” to the North Carolina data utilized in the original study, and hence the tools would have to be modified to accept alternative data sources. These reasons make the software tool a poor candidate for application in this research effort. However, the program is useful in illustrating different types of analysis that can be performed in GIS and also increases the awareness of these uses to transportation agencies.

2.2.3 Freight Safety and Wind Vulnerability

Winds can be particularly dangerous to high-profile vehicles such as freight trucks and strong winds can overturn trucks. Even light winds can be hazardous with gusts creating forces on the trailer resulting in a resonance that causes the trailer to move hazardously (Summerfield, 2001). This effect has been compared to a child on a swing: if pushed at the maximum extent, only a small force is needed to maintain or increase motion. The University of Manitoba Transportation Institute conducted a computer simulation of gusting winds to determine the effect on large trucks (Summerfield, 2001). Researchers used a 5-degree angle between the trailer and the tractor as the limit of when the truck becomes unstable and is likely to crash. Researchers determined that a light load and slicker road conditions caused the trucks to be more susceptible to winds, while slower speeds reduced the wind effect.

The Federal Highway Administration’s Office of Operations runs the Road Weather Management Program. Through this program much research is being done using Road Weather Information Systems (RWIS) to determine when weather conditions make traveling hazardous. However, most of this research is focused on precipitation, road surface conditions, and fog. Six states are listed on the RWIS website for having best practices related to wind conditions. Two of these six best practices do not directly relate to the affect of high winds on vehicles and will only be mentioned briefly. South Carolina has developed a contraflow plan for hurricane evacuations and reentry operations. Houston, Tex., mentions winds in the environment parameters that are measured and used by traffic managers to warn the public of hazardous conditions.

The other four states, Idaho, California, Montana, and Nevada, have best practices directly relating wind speeds to vehicle safety. Idaho DOT collects road, weather, and traffic conditions for 100 miles along Interstate 84 in the southeast part of the state. This information is transmitted to a central computer in the traffic control center at the Port of Entry. The central computer warns traffic managers when conditions are hazardous and the managers decide what messages should be displayed on the dynamic message signs (DMS).

The effectiveness of the DMS to influence driver behavior was studied between 1993 and 2000. This study evaluated the difference in traffic speeds when no message was displayed and when an advisory message was displayed. During high-wind conditions (more than 20 mph), displaying a warning message decreased the average vehicle speed by 23 percent from 55 mph (with no warnings messages) to 42 mph (with warning messages). When moderate to heavy precipitation was occurring in addition to high winds the speeds were reduced another 12 percent from 47 mph (with no warning messages) to 41 mph (with warning messages). When high winds were present with snow-covered pavement the warning messages reduced speed by 35 percent from 55 to 35 mph.

California DOT (Caltrans) relates high-wind information to travelers in the Stockton-Manteca area on Interstate 5 and State Route 120. Information from environmental sensor stations (ESS), which record weather conditions, and vehicle detection sites, which monitor traffic speed, are transmitted to three central computers at the Stockton Traffic Management Center (TMC). These computers process the data and automatically display warning messages on the DMS on the highways. When the wind speed is greater than 35 mph, the computer shows “High Wind Warning” on the DMS. Operators at the TMC have the ability to override the computer generated message if the need arises. Messages are also displayed when traffic speeds are below 35 mph or visibility is less than 500 feet. When visibility is below 200 feet, the California Highway Patrol uses patrol vehicles with flashing amber lights on top to lead platoons of vehicles at a safe pace through the area with low visibility.

Two of the states have systems in place that restrict high profile vehicles, such as large trucks, during high-wind conditions. The Montana DOT monitors a 27-mile section of Interstate 90 in the Bozeman/ Livingston for high-wind conditions and warns motorists when the wind speeds exceed 20 mph. A warning message, “CAUTION: WATCH FOR SEVERE CROSSWINDS” is displayed on DMS when wind speeds are between 20 and 39 mph. If the wind speeds reach 40 mph or greater, high-profile vehicles are prohibited from that section of Interstate and instructed to exit. The diverted traffic us directed to an alternative route through Livingston. The Montana DOT developed the wind speed criteria through their knowledge and judgment of the area and have found that the currant system works well and is safe.

The Nevada DOT has a high-wind warning system on a seven-mile segment of U.S. 395 (FHWA, 2003). Nevada measures both the average wind speed and the maximum wind gusts and then uses these values to determine when to display messages on DMS to discourage or prohibit high-profile vehicles from traveling on that road. Table 2-1 shows the critical values used to determine what message is displayed by the DMS.

Table 2-1. Nevada DOT High-Wind Warning System Messages

Average Wind Speeds	Maximum Wind Gust Speeds	Displayed Messages
15 mph to 30 mph	20 mph to 40 mph	High-profile vehicles "NOT ADVISED"
Greater than 30 mph (48 kph)	Greater than 40 mph (or 64 kph)	High-profile vehicles "PROHIBITED"

Nevada DOT performed a study to determine these critical wind values (Saiidi and Maragakis, 1995). The study examined what wind force was necessary to cause a vehicle to overturn or slide. The single trailer truck was determined by researchers to be the most vulnerable to overturning and sliding. The dimensions used for the single trailer were the following:

Weight (W): 15000 lb

Wheel Base (b): 3 ft

Length (l): 45 ft

Vehicle Height (h): 14 ft

Wheel Diameter (h_2): 4 ft.

Equation 2-1 and Equation 2-2 were used to find the critical wind speeds for overturning and sliding of different type trucks and recreation vehicles. For a single trailer these equations yield a critical wind speed of 40 mph for overturning and 29 mph for sliding. The sliding equation incorporates a coefficient of friction of 0.1 which is for the critical condition of snowy and icy road surfaces.

$$v = \left\{ W * \frac{b}{\left[0.00666 * l * \left(h - \frac{h_2}{2} \right) * \left(\frac{h}{2} + \frac{h_2}{4} \right) \right]} \right\}^{0.5}$$

Equation 2-1: Critical Wind Speed for Overturning

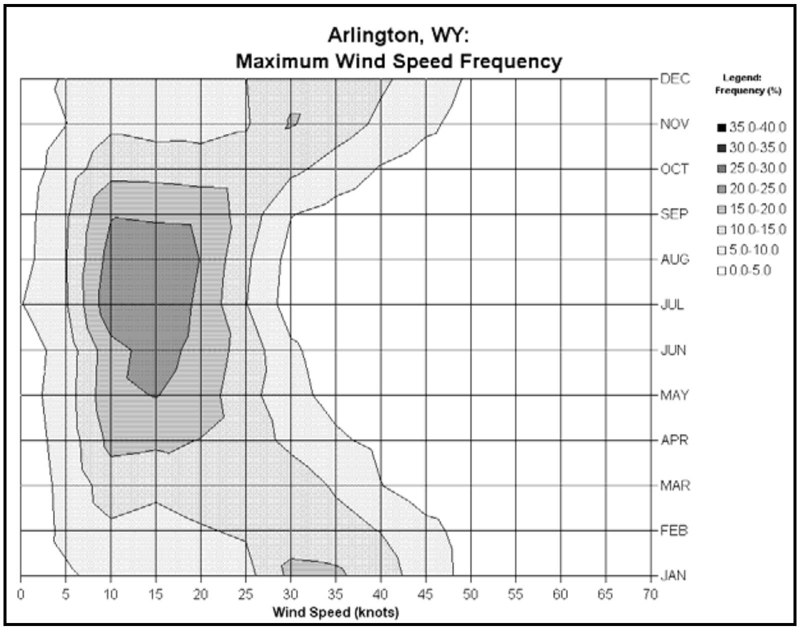
$$v = \left\{ \frac{W}{\left[0.0333 * l * \left(h - \frac{h_2}{2} \right) \right]} \right\}^{0.5}$$

Equation 2-2: Critical Wind Speed for Sliding

It is important to note that the 40 mph critical wind speed is for empty trucks. If the weight of the truck is increased to 35,000 pounds, the formulas from Nevada's study result in a critical wind speed for overturning of 60 mph and 44 mph for sliding.

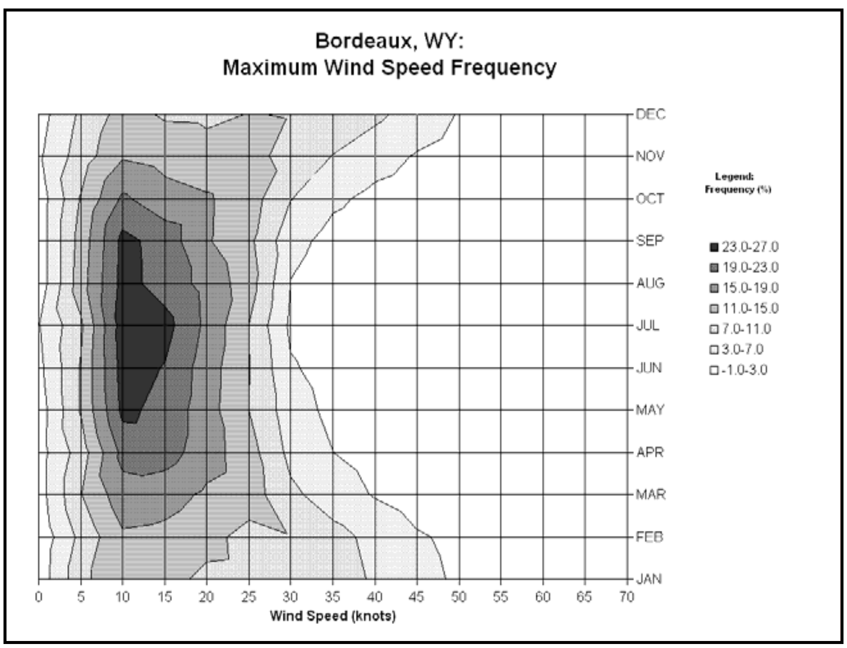
During winter months, Wyoming often experiences wind speeds that are greater than 40 mph. Between the years 1994 and 2001 the weather station along Interstate 80 near Arlington, Wyo., experienced maximum wind speeds in excess of 40 mph 10 percent of the time between the mid October and late February and 15 percent of the time between mid December and mid January (Curtis and Grimes, 2004). The Bordeaux weather station along Interstate 25 south of Wheatland, Wyo., showed a similar trend for the same time period. The winds at Bordeaux had maximum speeds above 40 mph for 7 percent of the time or more from November to mid February. These trends can be seen in Figure 2-1 and 2-2.

If the Wyoming DOT were to close the Interstates to large trucks every time the wind speed were above 40 mph, trucks would be prohibited from traveling at least 7 percent to 10 percent of the time for four months of the year. This equates to approximately three days per month during this time period. There is currently tremendous pressure to keep the Interstates open because of the impact closures have on freight movement and many would feel that three days every month of closures would be unacceptable.



Note: 1 knot = 1.15 mph, 35 knots = 40mph. Source: Wyoming Climate Atlas.

Figure 2-1. Maximum Wind Speeds, Arlington, Wyoming, for 1994-2001



Note: 1 knot = 1.15 mph, 35 knots = 40mph. Source: Wyoming Climate Atlas.

Figure 2-2. Maximum Wind Speed at Bordeaux (South of Wheatland, Wyoming) for 1994-2001

One way to maintain safety while allowing freight to continue traveling would be to have the closures based upon weight and geometry of the truck. A restriction could be placed that would prohibit light, high-profile trucks during strong wind conditions but would allow heavier trucks to continue traveling. This operational issue will be addressed in a follow-up study to be completed in August of 2005.

2.3 Identification of Critical Infrastructure

This section on the identification of critical infrastructure is divided into three subsections. The first defines what is meant by the term critical infrastructure. The second subsection presents the need and importance of this type of planning. The last subsection reviews the literature on the methods for identifying the particular infrastructure assets that are critical.

2.3.1 Definition of Critical Infrastructure

The natural starting point for any effort to identify what constitutes critical infrastructure in general and in Wyoming specifically is the document that is the driving force behind the movement to define, evaluate, and protect critical infrastructure. In July of 1996, Present Clinton issued Executive Order 13010 (Clinton, 1996). This executive order established the President's Commission on Critical Infrastructure Protection (PCCIP) whose charge was to develop a national strategy for protecting critical infrastructure from threats and to assure the continued operation of that infrastructure. The executive order was followed up with another document that was issued in May of 1998 from the White House as *Presidential Decision Directive 63* (PDD-63) and was signed by President Clinton (Clinton, 1998). The subject of PDD-63 is critical infrastructure protection. Although PDD-63 can be viewed as having a focus directed more towards the protection of cyber-based systems, several sections are very relevant to the subject of this research effort, transportation in general and, by extension, freight infrastructure. The following quote from the second paragraph of PDD-63 sets forth a definition of critical infrastructure (Clinton, 1998):

> "Critical infrastructure are those physical and cyber-based systems essential to the minimum operations of the economy and government. They include, but are not limited to telecommuni-cations, energy, banking and finance, transportation, water systems, and emergency services, both governmental and private."

Although this definition is broad in nature, it provides a starting point for further evaluation that will lead to a definition directly tied to the movement of freight in this country. PDD-63 also sets forth a list of the governmental agencies that will be held responsible for overseeing each type of critical infrastructure. This section states that at the Federal level, the Department of Transportation will directly supervise aviation, highways, mass transit, pipelines, railways, and waterborne commerce.

2.3.2 Importance of Critical Infrastructure Identification

The Federal Highway Administration and the American Association of State Highway and Transportation Official (AASHTO) Transportation Security Task Force convened a Blue Ribbon Panel (BRP) on Bridge and Tunnel Security. Recommendations from that Blue Ribbon Panel were released in late 2003 (BRP, 2003). That document stated that the terrorism against American citizens and assets was real and growing. The report went on to say that transportation and related assets made attractive terrorist targets because of their easy accessibility and large potential for impacting human lives and economic activity. The following is a quote from the report's executive summary (BRP 2003).

> "The success and safety of the transportation system, combined with the perceived number of parallel routes, can lead to the conclusion that the transportation system is so robust that it is not susceptible to significant disruption by terrorist attack. In the opinion of the BRP members, the conclusion is incorrect."

While it is easy to believe that the remoteness of Wyoming results in only a small probability to terrorist attack, that does not mean the effort of critical infrastructure identification is not a useful one. This is true for several reasons. The first is that, however small the probability of direct attack may be, there is still a risk. Second, while Wyoming is remote, the state provides a vital link between areas of the country. Significant amounts of goods are moved through the state, not to mention the vital energy resources the state provides. Lastly the identification of critical infrastructure is useful, not only in addressing terrorist risk, but also in assessing natural hazards as well. Increased awareness in the critical links in the state will lead to better maintenance decisions to minimize failures as well as higher standards regarding designing against natural hazards such as floods, earthquakes, land slides, etc.

2.4 Methodologies for Identifying Critical Infrastructure

A review of different methodologies previously employed by other states to identify their critical infrastructure was conducted to aid in developing the approach to be used for identifying the infrastructure that is critical to Wyoming. One of the best starting points is *A Guide to Highway Vulnerability Assessment for Critical Asset Identification and Protection* that was prepared as part of the National Cooperative Highway Research Program (NCHRP) Project 20-07 for the AASHTO Security Task Force (SAIC 2002). This guide was developed as a tool for state departments of transportation for the following purposes (SAIC 2002):

- Assess the vulnerabilities of their physical assets.
- Develop possible countermeasures to deter, detect, and delay the consequences of threats.
- Estimate the capital and operating cost of the countermeasures.
- Improve operational aspects for improved security and protection against threats.

The guide provides agencies with a six-step process for conducting a vulnerability assessment. The six steps in this process are (SAIC, 2002):

- Identify critical assets.
- Assess vulnerabilities.
- Assess consequences.
- Identify countermeasures.
- Estimate countermeasures cost.
- Review operational security planning.

While this document is an excellent resource to state DOTs in providing a framework for administering the process, the actual methodologies for performing some of these steps are not given and are left up to individual DOTs. This is understandable because each DOT represents a unique situation. This research effort is aimed at providing information for steps one through three of the process.

Some of the recently employed methodologies for assessing vulnerabilities and consequences include game theory, Monte Carlo simulation, stochastic user equilibrium, and minimum cut sets (Murray-Tuite and Mahmassani, 2003) as well as hierarchical holographic modeling, multi-objective tradeoff analysis, and risk filtering, ranking, and management (Ferguson and Mondul, 2004). These methodologies can be applied either at the system level or at an asset level depending on whether a statewide or regional scope is desired or if an individual asset needs to be analyzed.

Game theory was used in Texas and Maryland and involved a bi-level mathematical programming formulation where a non-zero sum game between an evil entity and a traffic management agency (TMA) is analyzed to assess the vulnerability of a traffic system (Murray-Tuite and Mahmassani, 2003). In this game scenario, the evil entity seeks to cause as much disruption to the system as possible through malicious acts while the TMA seeks to minimize disruption through redirection and rerouting of traffic in the system.

This method of analysis depends on the development of a disruption index that takes into account the ability of the system to absorb the traffic that is rerouted from the affected link. The disruption index is analyzed for up to four different scenarios. During the first three scenarios each player in the game is allowed only one move. The first scenario is that the evil entity completely surprised the TMA. The second scenario is that the TMA suspects the evil entity's actions will take place although this knowledge is not known to the evil entity. The third scenario is that the evil entity knows that the TMA suspects their future actions. The fourth and final scenario allows multiple moves by each player (Murray-Tuite and Mahmassani, 2003).

Monte Carlo simulation is an analytical method of spreadsheet simulation that is generated by randomly varying an undetermined variable repeatedly in order to produce a model. The stochastic user equilibrium method is a mathematical model that takes the inherent errors that people make while driving and the imperfect knowledge that people have of a traffic system into account when attempting to assign routes taken by motorists to quantify and classify travel by factors such as cost or time. Minimum cut sets attempt to determine the minimum number of arcs in the system that must be cut in order to make traveling from origin to destination improbable (Murray-Tuite and Mahmassani, 2003). All three of these methods are widely used and have proven valid for transportation-related modeling and can be adapted for application to the critical infrastructure problem.

The Virginia Transportation Research Council recently contracted the Center for Risk Management of Engineering Systems at the University of Virginia to develop a risk assessment and management plan for critical highway infrastructure. This group used hierarchal holographic modeling (HHM), multi-objective tradeoff analysis, and risk filtering, ranking, and management (RFRM) to complete this task (Ferguson and Mondul, 2004). The analysis was broken down into two distinct stages. The first stage dealt strictly with the severity of the impact resulting from the loss of the asset while the second stage looked at the overall vulnerability of the asset to attack.

Using these two stages as the basis for the analysis, the group used HHM to model all possible portions of an asset that could be attacked and all possible attack modes. They then used RFRM to filter and rank the likelihood of each possible attack combination and multi-objective tradeoff analysis to help determine possible responses to the attacks. The results of this multi-phase and multi-dimensional analysis provided for a system to rank critical infrastructure based on a combination of the consequences of damage to the asset and the vulnerability of the asset to attack.

3. Background

The purpose of this chapter is to provide background information on the freight system and freight planning in the region. The background information is divided into information on the freight system including highway, rail, and other modes; the commodities being moved on the freight system; and freight-planning efforts in Wyoming and adjoining states.

3.1 Description of Freight Network

Wyoming is a land-locked state in the western portion of the United States. It has a sparse population with the majority of its cities located along the major transportation corridors. Fort Laramie and Fort Bridger were some of the original settlements that developed in Wyoming along the earlier pioneer trails in the 1800s. The construction of transcontinental railroad in the southern portion of the state came in the late 1800s and resulted in major population centers in that part of the state. Later, the Interstate highway system influenced the growth of cities along its corridors.

The four major modes for moving freight in Wyoming are rail, highway, air, and pipeline. Most of the freight travels by railroad or truck with very little being moved by the aviation system. Pipelines are also important and are heavily used by the oil and gas industries. There is no freight moved by water because of a lack of navigable waterways.

The majority of freight tonnage is transported by rail by the two major rail companies in the state, Burlington Northern Santa Fe (BNSF) and the Union Pacific (UP). The second largest amount of freight, by volume, is moved along the state's highways. Motor carriers accounted for 65 million tons of freight moved to, from, and within the state (FHWA, 2004a). Commodities shipped by truck tend to be of lower weight and higher value when compared to railroad freight. In 1998, Wyoming freight had an average highway ton value of $600, while rail freight averaged $32 a ton (FHWA, 2004a).

The following sections will take a closer look at the freight system by breaking it down into highway, rail, and other categories.

3.1.1 Highway

Wyoming's public road system is divided into four functional classifications: interstate, arterial, collector and local roads.The National Highway System (NHS) is a federal designation that consists of approximately 160,000 miles nationwide and is defined as the roadway system that is important to the nation's economy, defense, and mobility (2004c). The NHS includes the following subsections: interstate, other principal arterials, strategic highway network (STRAHNET), major strategic highway network connectors, and intermodal connectors.

The National Highway System in Wyoming consists of 2,952 miles of Interstates, U.S. highways, and state highways (FHWA, 2002d) and is the background of the freight highway network in the state. Figure 3-1 shows the NHS within Wyoming with the Interstate portion of the system in blue and the U.S. and state highways in red.

There are 913 miles of Interstate highways in the state. Construction began on Interstate 25 in 1956 and was completed in 1982 (AARoads, 2002a). Interstate 80 follows the original Lincoln Highway across the southern part of the state and runs parallel to the transcontinental railroad for most of the way. I-80 was completed in 1977 (AARoads, 2002b). Interstate 90 was the last Interstate to be completed in Wyoming and was finished in 1985 (AARoads, 2002c). The speed limit in Wyoming on the Interstate system is currently 75 miles per hour except for a few short urban areas.

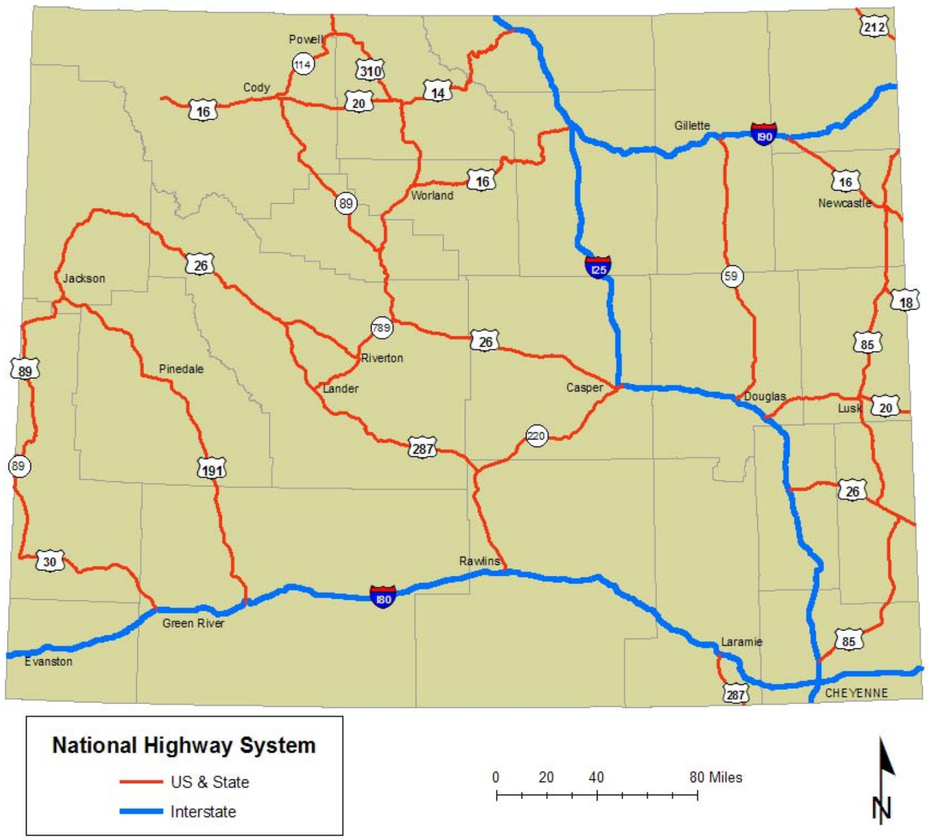


Figure 3-1: National Highway System in Wyoming

I-80 stretches for 403 miles across the southern part of the state and sees much of the country's long haul trucking between the West Coast, Midwest, and Eastern States. I-90 crosses the northern portion of the state connecting Montana and South Dakota at a length of 207 miles. Lastly, I-25 is 301 miles long and runs north-south along the eastern part of the state from Colorado to the I-90 junction near Buffalo, Wyo.

Ninety percent of the miles of rural Interstate in Wyoming are considered to be in good or very good condition (BTS, 2000). This number drops to 62 percent for urban Interstate conditions which represent only a small portion of the system in Wyoming.

The total number of miles of arterials, collectors, and local roads in the state is 3,669; 10,687; and 12,054 respectively. The total public road length including all types of roadways is 27,327 (BTS, 2000).

The STRAHNET system in Wyoming consists of the Interstate system. The major strategic highway network connectors for the STRAHNET includes a road link between Interstate's 25 and 90 that consists of US 18 from Orin, Wyo., through Lusk to Edgemont, S.D. Wyoming is the only state without any official NHS intermodal connectors.

Highway freight in Wyoming is monitored at the 14 ports of entry. The ports of entry are operated by the Wyoming Highway Patrol, which administers the weight, size, and safety regulations for freight vehicles operating in the state. Figure 3-2 shows the locations of these ports of entry.

According to the Wyoming Highway Patrol, approximately 2.7 million commercial vehicles pass through these ports in a typical year (WHP, 2004). The busiest of these ports are the Evanston port for I-80 eastbound and the Cheyenne ports for I-80 westbound and I-25 northbound. These three ports combined handle 72 percent of the total volume for all of Wyoming's Ports of Entry. The total volume through each of the ports is shown in Figure 3-3.

To improve port operations the PrePass system has been installed at some of the busier ports of entry. PrePass allows for automated monitoring of qualified freight carriers. In 1999, approximately 200,000 freight vehicles were passed through the ports using the PrePass system (WHP, 2004). PrePass capability is currently at the two Cheyenne ports of entry (I-80 westbound and I-25 northbound) and at the Evanston port of entry for I-80 eastbound. PrePass is also committed for the new joint port of entry near Sheridan which will be a combined port for Montana and Wyoming that is scheduled for completion in late 2005.

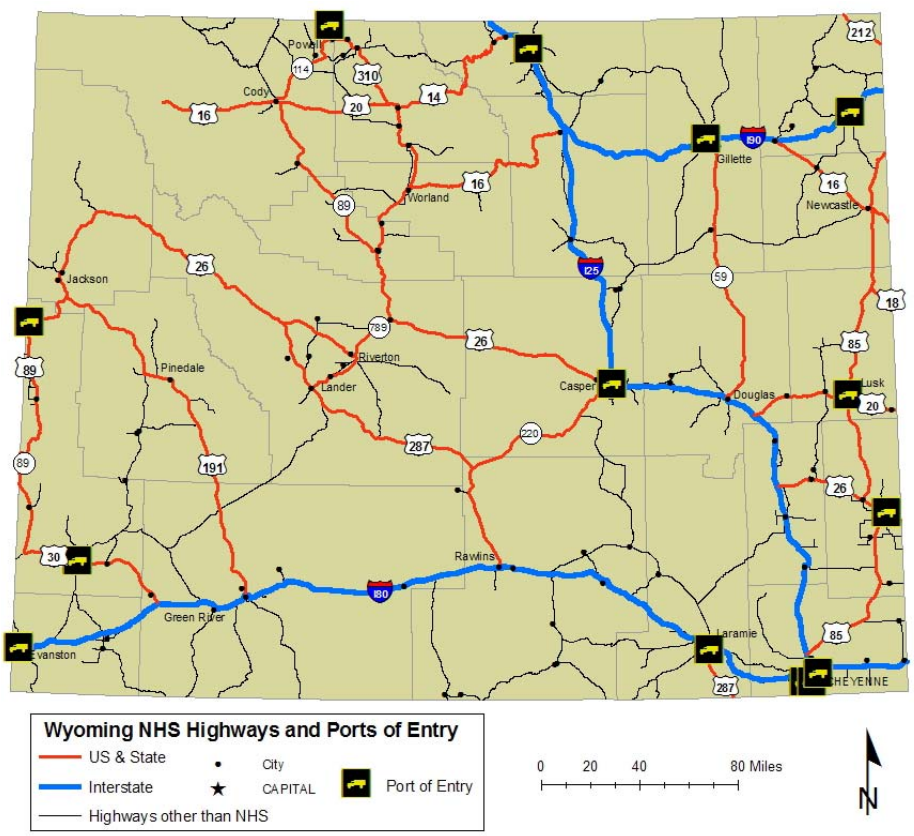


Figure 3-2: Wyoming Ports of Entry

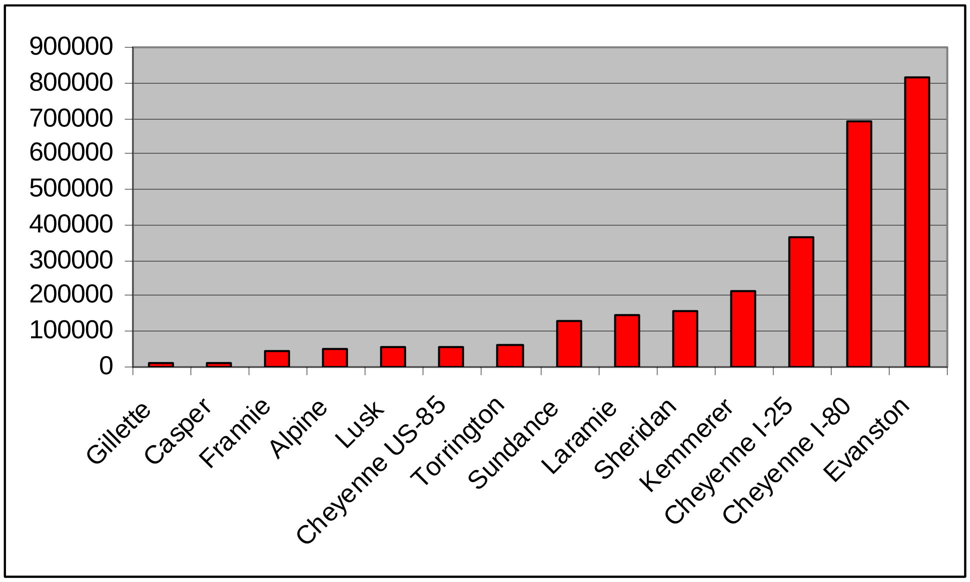


Figure 3-3: Truck Volumes at Wyoming Ports of Entry for 1999

The legal size and weight limits for the State of Wyoming are shown in Table 3-1. (WYDOT, 2003).

Table 3-1: Wyoming Truck Legal Size and Weight Limits

Category	Legal Limits
Width	8 ½ feet
Height	14 feet
Length	60 feet for single unit, or semi-trailer in a truck-tractor semi-trailer combination
	81 feet for semi-trailer, trailer combined in length in truck-tractor, semi-trailer, trailer combination including connecting mechanism
	48 feet maximum for semi trailer
	40 feet maximum for trailer
	85 feet for any combination other than those listed above
	No combination of vehicles shall consist of more than 3 single vehicles
Weight	Single axle: 20,000 pounds
	Tandem axle: 36,000 pounds
	Triple Axle: 42,000 pounds
	Each Wheel: 10,000 pounds
	Each tire: 700 pounds per inch of width on steering tires, 600 pounds per inch of width on other tires

Source: Wyoming Motor Carrier One-Stop-Shop, Wyoming Department of Transportation

The daily average number of trucks traveling on Wyoming's highway system is shown in Figure 3-4. As shown in this figure, the Interstate system, particularly I-80, handles the vast majority of truck traffic.

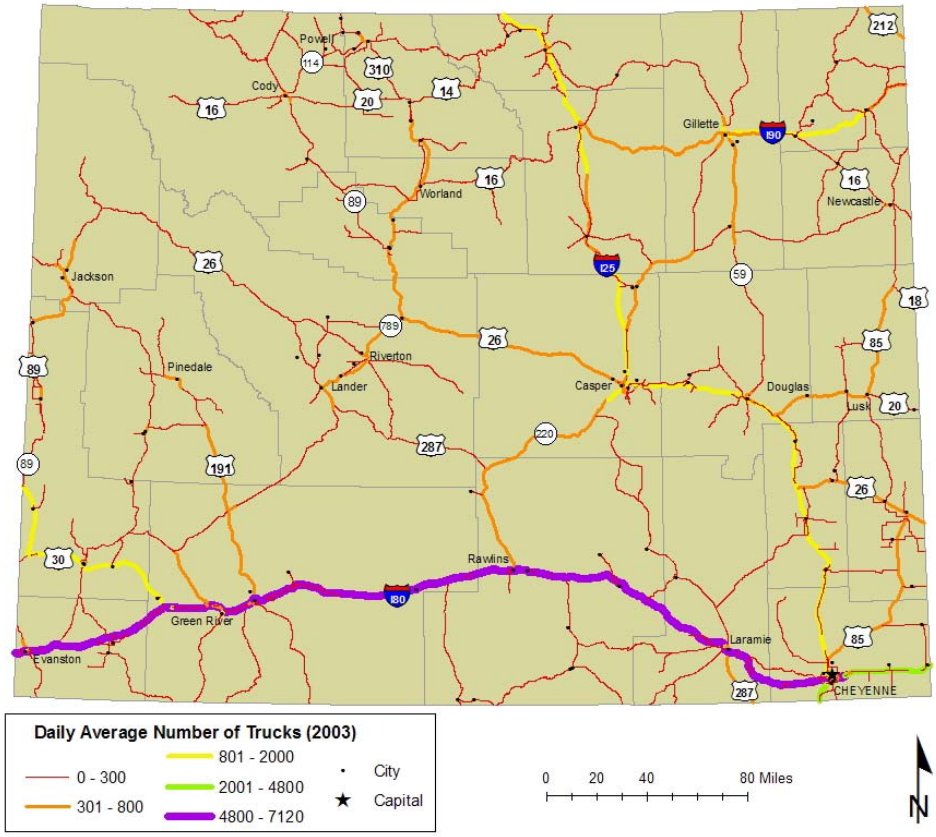


Figure 3-4: Daily Average Number of Trucks on Wyoming Highways

3.1.2 Rail

Any consideration of freight movement in Wyoming must look at the rail network in addition to the highway mode even though all rail lines in Wyoming are privately owned. Not only are the rail lines not owned by public agencies but public agencies are barred from rail investment by the state constitution. Regardless of the inability for public investment in rail it is still important to understand the volume, value, and types of commodities moving by rail because of their impact on freight movement in the state.

Wyoming has two Class I railroads operating in the state, the Burlington Northern Santa Fe Railway (BNSF) and the Union Pacific Railroad (UP). Class I railroads are defined by the Association of American Railroads as line haul freight railroads that have an annual operating revenue above $277.7 million (AAR, 2004). In addition to these two Class I railroads, two short lines operate in Wyoming; the Bighorn Divide and Wyoming (BD&W) and the Wyoming and Colorado Railroad (WYCO). The Dakota, Minnesota and Eastern Railroad (DM&E) is a regional carrier that has proposed additional rail access into Wyoming's Powder River Basin. As can been seen from the mileage-owned chart, Figure 3-5, the railroad tracks in the state are overwhelmingly owned by the two Class I railroads.

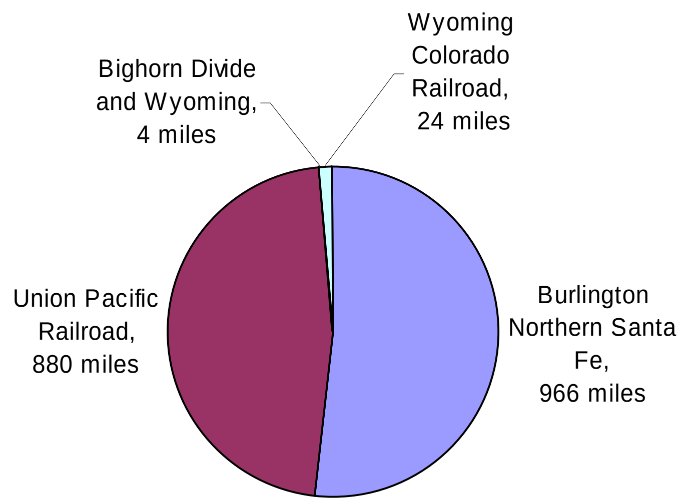


Figure 3-5: Miles of Track Owned by Railroads Operating in Wyoming

The location of the rail lines is shown in Figure 3-6. As can be seen from this figure the concentration of rail lines are in the eastern and southern portion of the state.

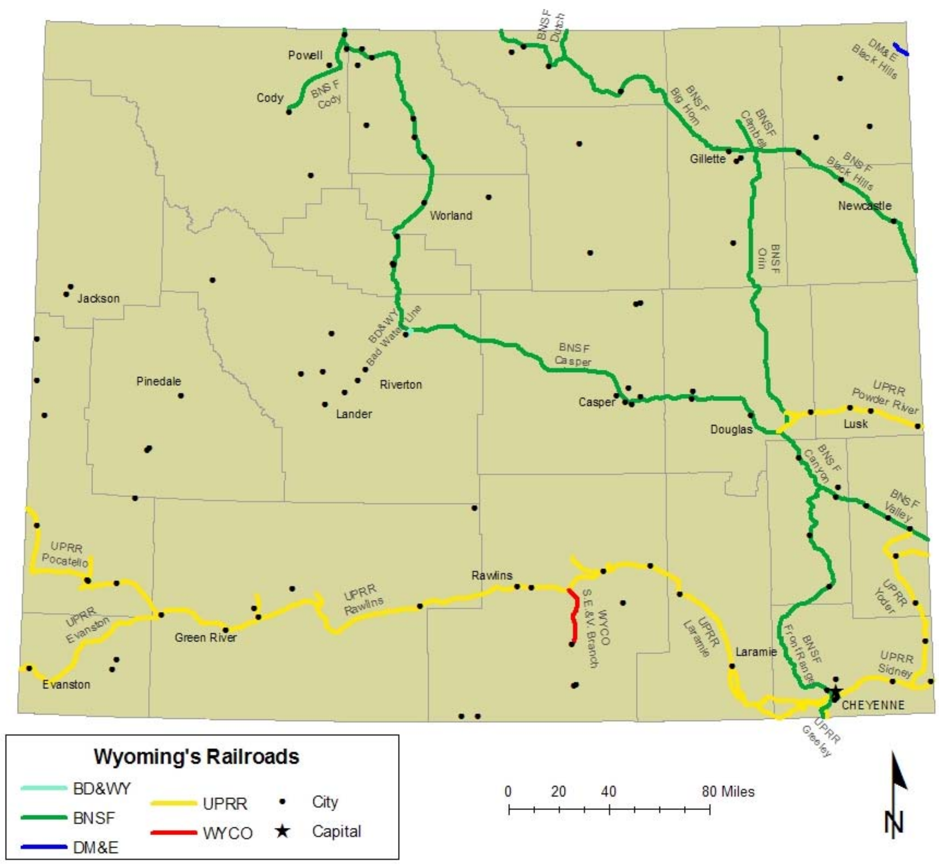


Figure 3-6: Railroad Route Location Ownership

Railroads accounted for 312 million tons of freight shipped to, from, and within Wyoming during 1998 (FHWA, 2004a). About 78 percent of this tonnage consisted of coal being moved out of the Powder River Basin (PRB). BNSF owns the 93 miles of track between Donkey Creek (near Gillette) to Orin (near Douglas) that is used to move this coal out the basin. In 1983, the Interstate Commerce Commission (ICC) ordered Burlington Northern Railroad (now BNSF) to sell half of its share of the PRB coal line, permitting connection with the Chicago and Northwestern Railroad (now owned by UP). The coal contracts in the PRB are highly contested between the two railroads because they represent a large source of revenue. In 2002, BNSF handled 51.4 percent of the coal shipped in Wyoming while UP handled the other 48.6 percent (Wilber Smith, 2004).

The lack of short line railways in Wyoming is representative of the role the state plays in long line-haul operations. Union Pacific moves trains over a major east-west artery following the original transcontinental route across the state. This track through Wyoming carries a very high volume of trains, handling an average of 70 trains per day and moving more than 100 million gross tons per year (Wilber Smith, 2004). Some of this traffic is generated in Wyoming from the coal, soda ash, and other Wyoming industries, but the majority of the track traffic is traveling through the state between the Midwest and West Coast states. This track is double tracked and in some locations triple tracked.

The Burlington Northern Santa Fe Railway also has long line-haul trains traveling in Wyoming. BNSF tracks run in the north-south direction and collect cargo from the local industries. Once again, the majority of the trains are moving through the state from the Northwestern states to the South Central states. The BNSF line is single tracked and sees less volume than the UP transcontinental line and averages about five trains per day (Wilber Smith, 2004).

Union Pacific tracks mentioned above consist of 880 miles of mainline track in the state. The portion of the transcontinental route in Wyoming is made up of four subdivisions; the Sidney Subdivision, the Laramie Subdivision, the Rawlins Subdivision, and the Evanston Subdivision.

Traffic on the UP tracks is controlled by the Harriman Dispatching Center in Omaha, Neb. Signals and switches are remotely controlled under a centralized traffic-control system. UP also operates two additional subdivisions in Wyoming. The Greeley subdivision runs south of Cheyenne toward Denver, Colo. The Yoder subdivision is operated by track warrant control and is located in the southeast part of the state. Track warrant control works by train crews contacting a dispatcher by radio to receive permission to occupy a section of the track. Understandably, tracks do not operate as efficiently under track warrant as compared to centralized traffic control and therefore have less freight moving ability.

The subdivision operated by BNSF in the Powder River Basin is called the Orin Subdivision. This subdivision is operated under centralized traffic control by dispatchers in Fort Worth, Texas. BNSF's Front Range and Greeley Subdivisions make up the north-south freight line that extends from the Colorado border south of Cheyenne north. These tracks, along with the Casper subdivision, operate under track warrant control. BNSF's tracks spread north across Wyoming along two separate routes (see Figure 3.6). The first alignment that passes through Casper, Worland, and north to Montana is called the Casper subdivision. The other route heads north through the Powder River Basin and then to Gillette. This track operates under centralized traffic control.

A major development in the rail network is being proposed by the Dakota, Minnesota and Eastern Railroad (DM&E). This project would connect track in South Dakota to the Powder River Basin and would cost in excess of $2 billion. This project is aimed at tapping into the Powder River Basin's coal market.

Railroad tracks have speed limits similar to those imposed on highways. Different sections of track have maximum speed limits based on track conditions including the grade, curvature, and the type of signaling system. Individual trains also have speed restrictions imposed on them depending on their cargo and equipment. A train's speed is limited either by its maximum authorized speed or by the maximum allowable speed on the particular section of track and must abide by whatever is lower.

The Federal Railroad Administration has nine classes of track with speed limits assigned to each class (USHR, 2001). The classes are determined by track structure and geometry. Each railroad is responsible for assigning their track to a class and then maintaining the track to the appropriate specifications. The nine rail classifications and their associated maximum speeds are listed below (USHR, 2001):

- Class 1: 10 mph freight, 15 mph passenger
- Class 2: 25 mph freight, 30 mph passenger
- Class 3: 40 mph freight, 60 mph passenger
- Class 4: 60 mph freight, 80 mph passenger
- Class 5: 80 mph freight, 90 mph passenger
- Class 6: 110 mph (all)
- Class 7: 125 mph (all)
- Class 8: 160 mph (all)
- Class 9: 200 mph (all)

Figure 3-7 illustrates the maximum speeds found on rail track in the state. Track capacity is both a function of the allowable speeds and the amount of track. Because the UP line in the southern portion of the state is double and triple tracked, has higher maximum speeds, and is operating under centralized traffic control it is possible to understand how the line can carry such a large volume of trains.

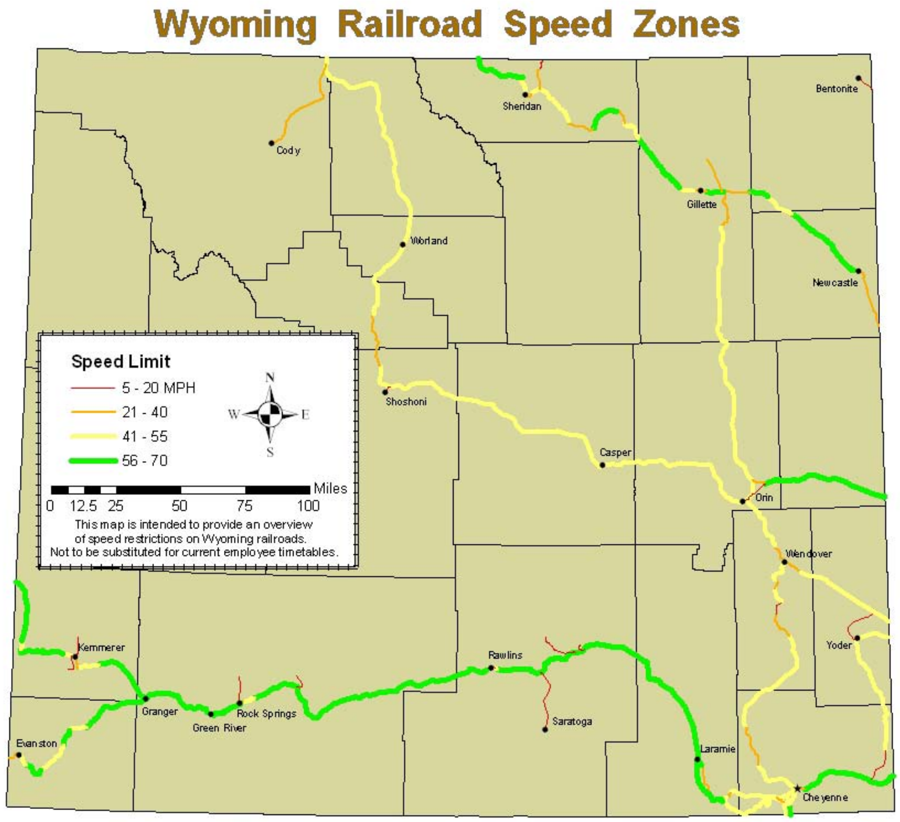


Figure 3-7: Maximum Speeds on Wyoming Railroads

The lowest speed tracks shown in Figure 3-7 are the industrial leads, spurs, and short line railroads. These lines are usually operated under yard limit or restricted limit speeds. Operation on these lines requires crews to communicate with each other and to travel at speeds slow enough to stop within half the distance of their vision.

3.1.3 Other (Air/Water/Pipeline)

The remaining modes that carry freight cargo are air, water, and pipeline. There are 115 airports in Wyoming, 41 of which are publicly-owned airports. There are 50 privately-owned airports of which only two are open to the public (BTS, 2000). Figure 3-8 shows the location of the public and private airports within the state. Even though airports are located throughout the state, less than 1 percent of all freight moves by plane (FHWA, 2004).

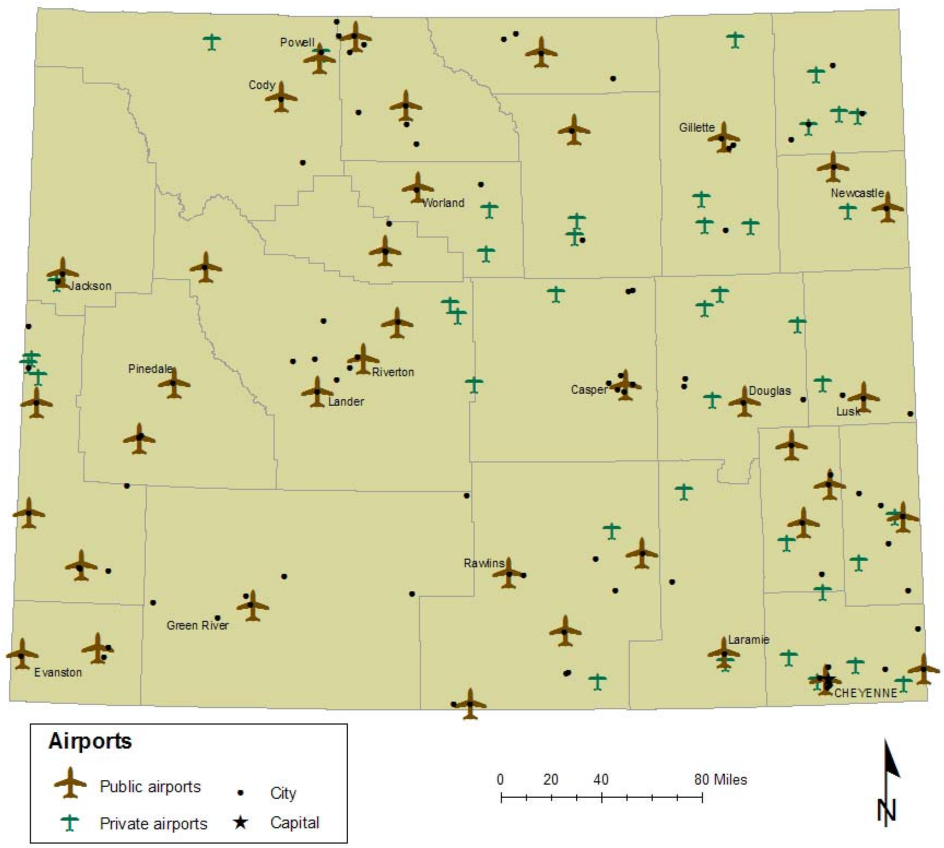


Figure 3-8: Public and Private Airports in Wyoming

As mentioned earlier, Wyoming's lack of significant navigable waters exclude the water mode from consideration in this study.

There is an extensive pipeline system in Wyoming. This system is used to transport oil, natural gas, coal bed methane, and carbon dioxide. There are more than 16,000 miles of pipeline in Wyoming, most of which are operating at capacity (Petroleum Association of Wyoming, 2003). Lack of capacity in the pipeline system may represent a significant issue in trying to get the state's energy products to market. Two main hubs for the pipeline network are near the cities of Cheyenne and Opal. Figure 3-9 shows the pipeline network locations.

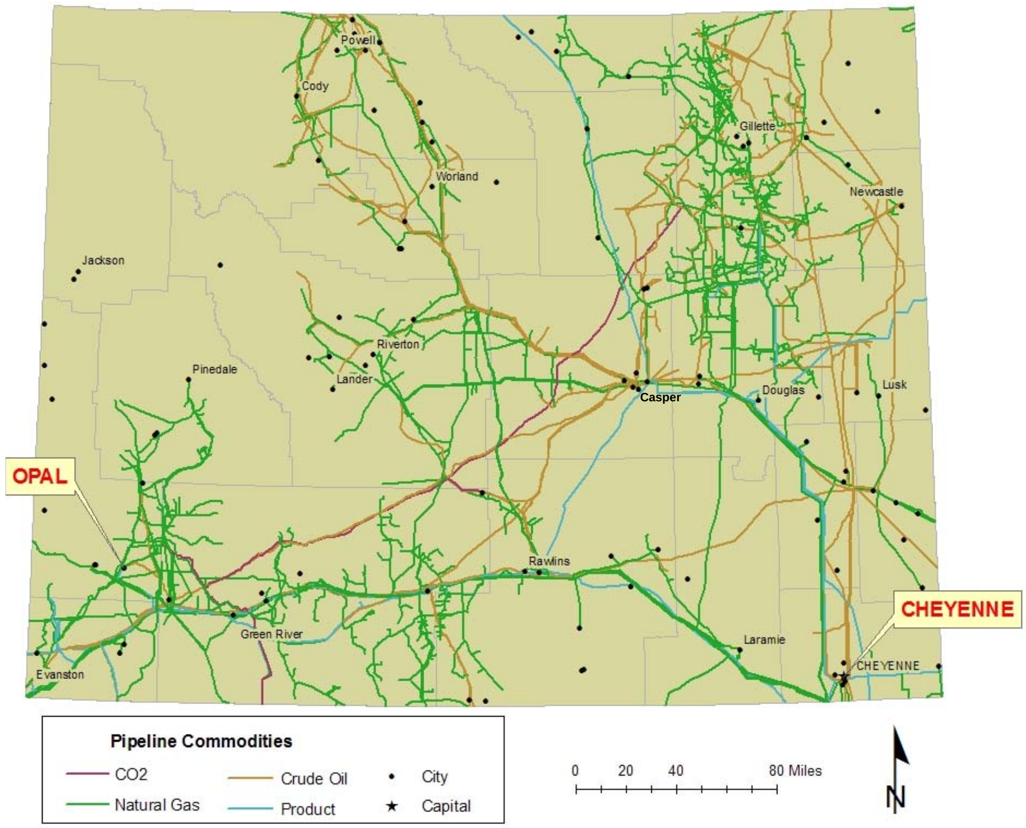


Figure 3-9: Wyoming's Pipeline Network

3.2 Commodities Moved in Wyoming

Commodities are defined as materials or goods that can be traded or sold on a market. Bulk commodities such as coal, oil, livestock, or grain are usually shipped from their point of origin to the market where they are in demand. Wyoming produces commodities for local sale and distribution, as well as producing commodities that must be transported out of state for use in other states or exported to foreign countries. Wyoming also plays a large role in the transportation of commodities between the coastal and interior cities of the United States. Commodities can be transported by any mode or combination of modes necessary to bring a shipment to the intended destination efficiently and safely.

The Federal Highway administration provides estimates to the states on the volume and value of freight commodities moving to, from, and within the state. The estimates on the amount of freight moving through the state are much harder to determine. The following sections will first discuss the available information in the first category and will then discuss the estimates on freight moving through Wyoming.

3.2.1 Commodities Moved To, From, and Within the State

The top five commodity groups shipped to, from and within Wyoming in 1998 by all modes of transportation totaled 357 million tons. Figure 3-10 below shows the top five commodities and the percentage by weight they contribute to the 357 million tons. The five states surrounding Wyoming shipped a combined weight of 542 million tons to, from and within their borders in 1998 (FAF, 2004).

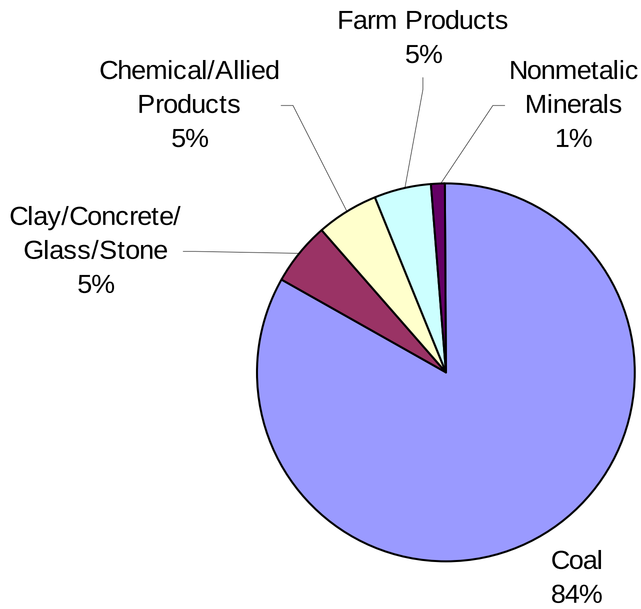


Figure 3-10: Top Five Commodities Shipped To, From, and Within Wyoming by Weight, 1998

Although Wyoming's commodities significantly out weighed its neighboring states, the value of these commodities was low. The top five commodity groups shipped to, from, and within Wyoming in 1998 by all modes of transportation had a total value of $35 billion. Figure 3-11 below shows the top five commodities shipped from Wyoming by value. Colorado, Nebraska and Idaho each had a higher total top five commodity value than did Wyoming (FAF, 2004).

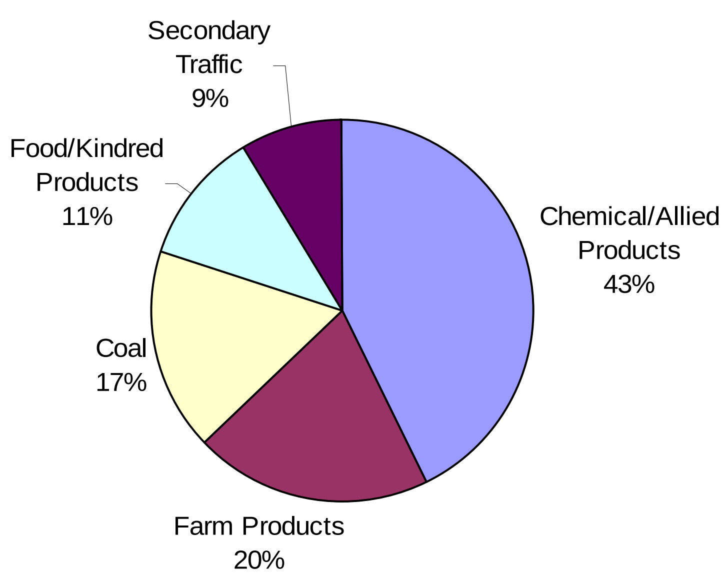


Figure 3-11: Top Five Commodities Shipped To, From and Within Wyoming by Value, 1998

The large tonnage of freight movement attributed to Wyoming is representative of the amount of coal generated in Wyoming. Coal mines located throughout Wyoming can be seen in Figure 3-12. The majority of Wyoming's commodity weight, 297 million tons, was created by the large volume of coal moving from the Powder River Basin (PRB). Coal mines located in the PRB are shown in Figure 3.13. Figure 3.13 also shows the rail volume generated from the coal production at these mines. The lines traveling east through Moorcroft and south out of the basin are both operating at volumes greater than 100 million gross tons.

The other four top commodities in Wyoming are clay, concrete, glass and stone (FAF, 2004). These commodities are all of the bulk variety having a low original value and increasing in value as they are moved to a demand location. The transportation costs of these products can be higher than the cost of the goods themselves.

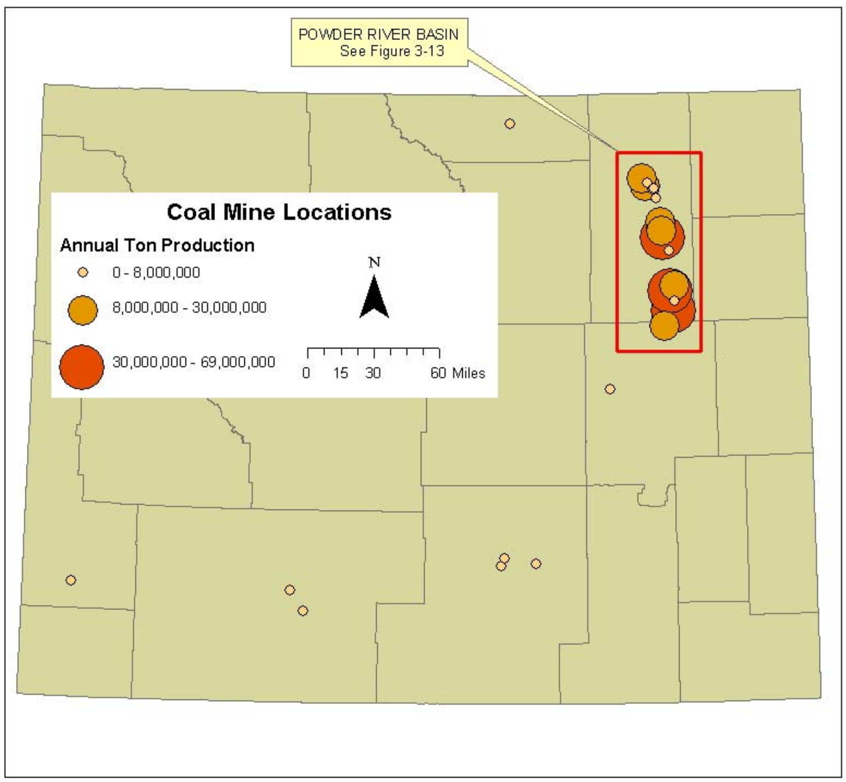


Figure 3-12: Wyoming Coal Mine Locations and Production Rates, 1999

Another way to look at this difference in value is to use an average value per ton ratio. While the top five commodities by weight are not necessarily the same as the top five commodities by value, the ratio will give an idea of the value per ton. Wyoming's top five commodities averaged a one ton value of $98, the total average for the surrounding states was $459 per ton (FAF, 2004).

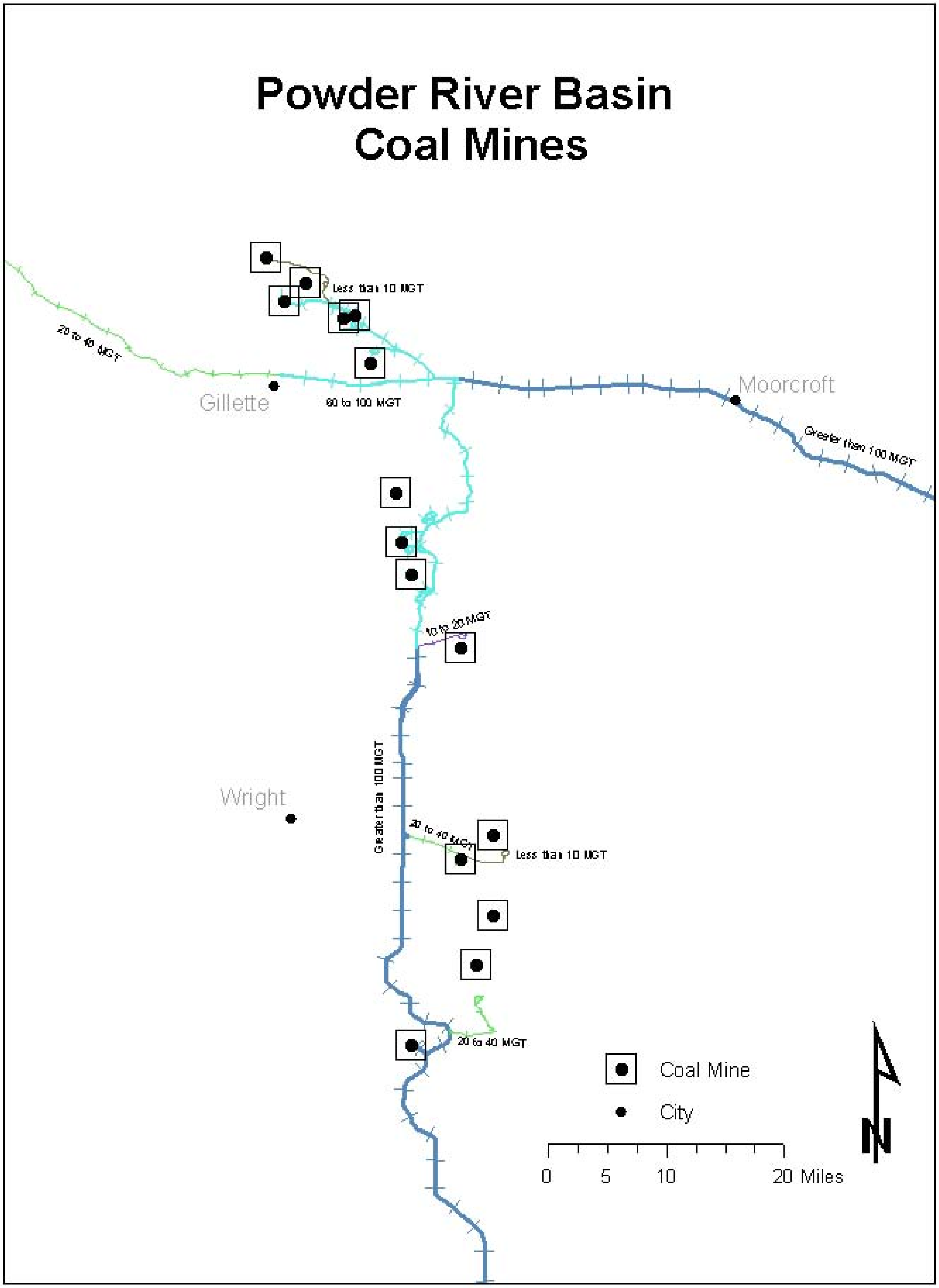


Figure 3-13: Powder River Coal Mine Locations and Rail Volume

Disodium carbonate, or soda ash, is Wyoming's largest export to foreign countries. More than $379 million was exported in 2002 (Wyoming exports, 2004). As shown in Figure 3.14**,** bentonite clay, coal and uranium are also exported but have only a fraction of the value of exported soda ash.

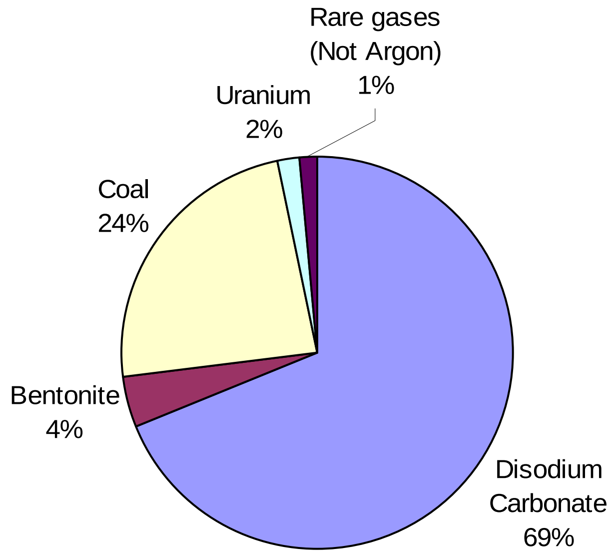


Figure 3-14: Top Five Commodities Exported by Wyoming, 2002

Agricultural commodities in Wyoming make up only 0.5 percent of the total U.S. agriculture commodity value, ranking 44th among states in agricultural exports. The total value for all agricultural commodities was $982,545 in 2001. Figure 3-15 shows the major agricultural commodity types and their percentages in Wyoming. Cattle were the largest contributor of state farm receipts at a value of $757,212 or 84 percent (Agriculture Statistics, 2004).

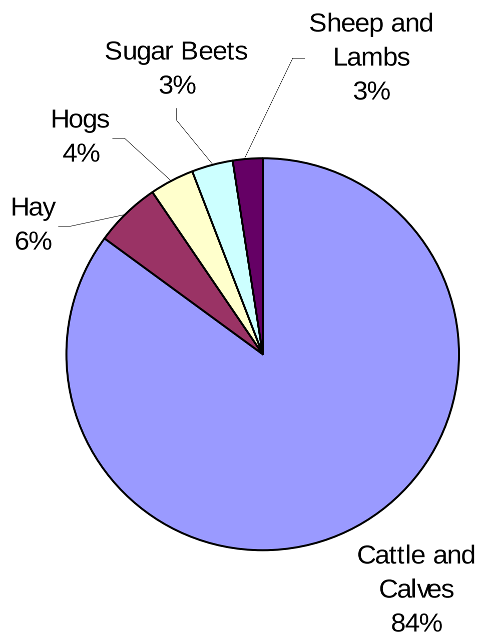


Figure 3-15: Top Five Wyoming Agricultural Commodities, 2001

3.2.2 Commodities Moved Through the State

The top five commodities for Wyoming from the Freight Analysis Framework (FAF) prepared by the Federal Highway Administration (FHWA) do not include freight that is transported from one state, through Wyoming, and into another. This commodity flow plays a significant role in Wyoming's freight traffic. The movement of freight along the southern part of Wyoming is particularly vital to the nation's economy. Two forms of transportation have major east-west arteries in southern Wyoming with the motor carriers using I-80 and the rail transport using the Union Pacific Railroad main line.

While freight movement to and from Wyoming is important for the state's economy, the value and volume of freight moving in the state is overwhelmingly dominated by "through" movements. The Bureau of Transportation statistics estimated that, according to 1993 Commodity Flow Survey data, 92 percent of the freight movement by value in Wyoming involved freight that neither originated nor culminated in the state. This value is reduced to 73 percent when factored by ton-miles instead of freight value; illustrating just how large a factor "through" freight movement is on the transportation network. Figures 3-16 and 3-17 illustrate these values.

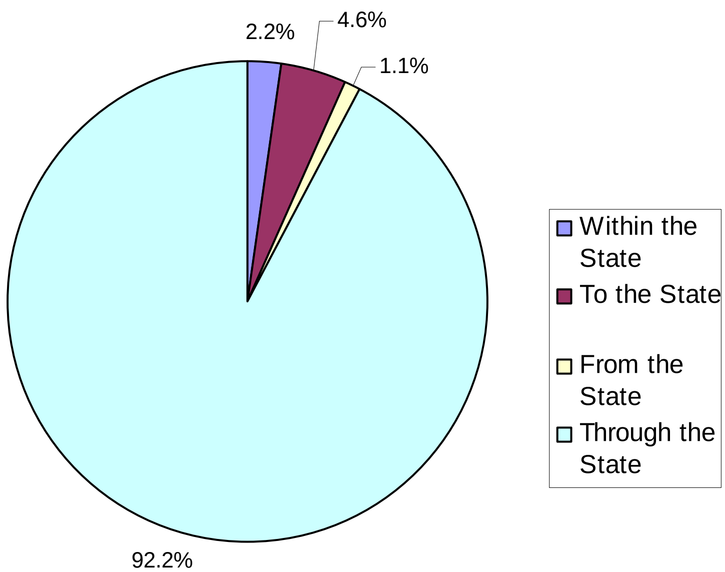


Figure 3-16: Percent Freight Movement Originating, Destined For, Within, or Through Wyoming, by Value

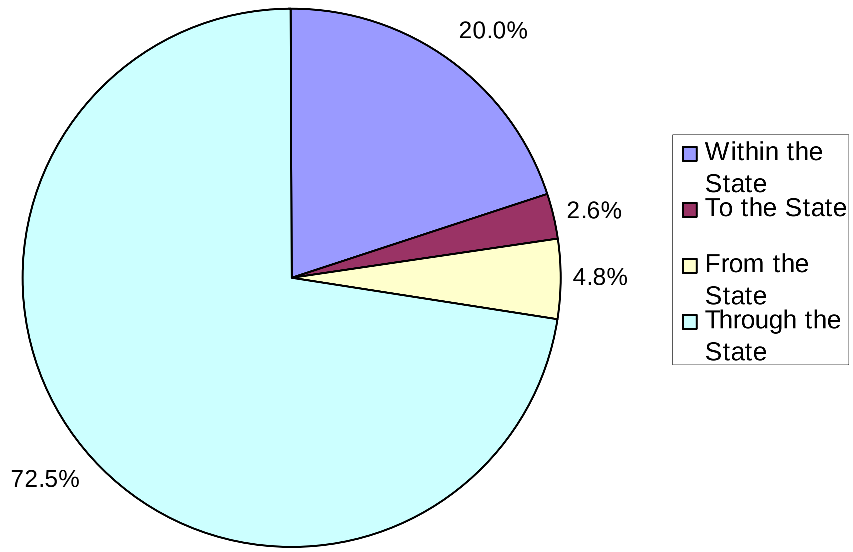


Figure 3-17: Percent Freight Movement Originating, Destined for, Within, or Through Wyoming, by Ton-Miles

3.3 Freight-Planning Efforts in Adjoining States

Freight movement in one state is highly dependent on the freight movement in adjoining states. As shown in the previous section only 2 percent of the freight in Wyoming (by value) has both origin and destination within the state meaning that 98 percent of the freight is passing through at least one of the adjacent states. The following section looks at the adjoining states of; Colorado, Utah, Idaho, Montana, South Dakota, and Nebraska, to see what freight-planning efforts have been undertaken in each state.

3.3.1 Colorado

The 1991 Federal Intermodal Transportation Efficiency Act designated three priority corridors in Colorado: the Ports to Plains Corridor, Heartland Express, and Camino Real. The Ports to Plains Corridor is a joint effort among the states of Colorado, Texas, Oklahoma, and New Mexico. The corridor extends from Laredo, Texas, at the Mexico border north to the I-70/I-25 junction in Denver. The Heartlands Express Corridor goes from Denver, Colo., through Scottsbluff, Neb., to Rapid City, SD. The Camino Real Corridor connects El Paso, Texas, to Sweetgrass, Mont., along Interstates 10 and 25.

The *Eastern Colorado Mobility Study* completed in 2002 used a GIS system and economic models to assess freight mobility and infrastructure needs in eastern Colorado (CDOT, 20002). The results of the study were a list of highway, rail, intermodal, and aviation infrastructure and policy recommendations. Another important component of the study was integration with the Heartland Express and Ports to Plains Corridors.

The study resulted in official designation of the Heartland Express route along I- 76 from Denver to Brush, Colo., then along state highway 71 from Brush to the Colorado border. This route also connects to the Ports to Plains corridor and serves as an alternate route to the congested Comino Real corridor that runs along I-25.

Colorado has a Freight Advisory Council (FAC) that was created in 2003. The 30-member committee meets three times per year to discuss freight movement and infrastructure issues. The FAC works with the State Transportation Advisory Committee to ensure that freight issues are incorporated into transportation planning at the state level.

The draft version of the *2030 Colorado Statewide Plan* is currently being reviewed. The Freight Technology Report is the main document that addresses freight issues in support of the statewide planning effort (CDOT, 2004). The plan is expected to be adopted in 2005.

3.3.2 Utah

Utah Department of Transportation's current long range planning document entitled *Utah Transportation 2030* was adopted in January of 2004 (UDOT, 2004a). The long range plan has a chapter devoted to freight planning that identifies freight mobility projects for trucking and rail movements. The plan also mentions that UDOT is convening a Utah Freight Advisory Committee to address freight issues in the state.

UDOT also addresses freight issues in its Commercial Vehicle and Operations Division of Traffic Operation. Two main areas of this division are the Commercial Vehicle Information System and Network (CVISN) and Intelligent Transportation Systems/Commercial Vehicle Operations (ITS/CVO). Some ITS/CVO projects currently implemented or under evaluation include (UDOT, 2004b):

- Auto-routing system
- Overweight detection
- Weigh-in-motion
- CVO accident reporting and analysis
- Freight mobility
- Hazardous material incident response
- CVO traveler information

3.3.3 Idaho

The current long-range plan in Idaho is the *Idaho Transportation Plan* adopted in 1995. The plan contains no specific sections on freight planning. Most of the references to freight transportation are made to the rail transportation mode. *Idaho State Rail Plan* was adopted in 1996 and serves as the long-range plan for the state's rail system (ITD, 1996). The plan identified the following eight rail-related issues:

- Continuation of passenger rail service
- Repair of flood-damaged rail infrastructure
- Changing rail system with Class I operations spinning off into short line operators
- Rail mergers
- Car shortages
- Grade crossings
- Rail transport of spent nuclear fuel
- Rail project funding

3.3.4 Montana

Montana's current long range plan is the 2002 update to *TranPlan 21*. (MDT, 2002) While this document does not have a specific section devoted to freight transportation, it does identify two issues related to freight:

- Freight's role in economic development.
- Consolidation of the agricultural system has led to increased truck traffic.

The plan goes on to identify action items, two of which are freight related:

- Identify freight mobility needs.
- Identity airport improvements.

The *2000 Montana Rail Plan* updated the earlier *State Rail Plan* (MDT, 2000). The update reviewed the state's role in rail planning and describes the current state of rail planning issues in Montana. The conclusions of the rail study are:

- A number of Montana's rail lines are at risk for abandonment because of low usage.
- Grain handlers and carriers are moving quickly to construct 110-car grain loading facilities. These new facilities may put smaller grain elevators out of business.
- Strong desire exists for additional rail passenger service in southern Montana.
- Montana has suffered impacts from recent rail mergers and restructuring.

Recently, the Governor's Office in Montana released the results from the *Rail Freight Competition Study* that was provided by Montana Senate Bill 315. (MDT, 2004). This was a feasibility study to assess the conditions affecting rail freight competition and to generate recommendations for improving the competition. The report recognized that the federal government's role in rail outweighed the individual state's ability to address problems with competition. The report did offer suggestions for the states including the following recommendations for possible actions:

- Play an active role in opposing future rail mergers if they would harm the state.
- Insist on environmental impact statements for rail closures and abandonment to make these actions more costly.
- Look at the feasibility of building a railroad adjacent to I-15.
- Monitor rates to make sure that carriers are not charging over the maximum allowable rates.
- Invoke the Surface Transportation Board's right to force rail carriers to allow competitors to use their tracks.

3.3.5 South Dakota

South Dakota's *Statewide Intermodal Long Range Plan* is reviewed annually and updated as needed (SDDOT, 2000). The current plan identifies transportation improvement projects for 2000 to 2004 but also includes long-range goals. The long-range plan does not contain a section dedicated to freight planning but three of the five long-range goals include elements of freight planning. These goals are:

- Provide needed access to important facilities like grain elevators, pipeline terminals, airports and intermodal facilities.
- Encourage competition and lower transportation costs within and among transportation modes.

- Support economic development

Freight-related supporting documents to the longs range plan include the *State Highway Needs Analysis*, *Statewide Airport Systems Plan*, *State Rail Plan,* and *Corridor Studies*.

The current rail plan is the *1997 State Rail Plan*. The goals of the rail plan are (SDDOT, 1997):

- To inform the public and transportation officials of the planning process and the importance of rail in an integrated transportation plan.
- To establish goals and objectives to be achieved by the rail planning process.
- To inform about the current rail system.
- To examine the future of rail transportation in the state.

The action items for the current plan include:

- Identify the essential rail system for current and future activities.
- Retain viable core rail system.
- Eliminate non-profitable rail lines that are non-essential.
- Invest trust fund dollars and secure federal funds for improvement and rehabilitation of essential rail lines.
- Assist in establishing regional railroad authorities and provide loans to develop or improve rail facilities.

The corridor studies include the Heartland Express Corridor discussed in the Colorado section of this chapter.

3.3.6 Nebraska

Nebraska's first and current long-range plan is the *Future Transportation in Nebraska: 1995-2015* prepared in 1995 (NDOR, 1995). This document was published in a short Executive Summary format and is currently undergoing an update process. The 1995 document addressed the freight system briefly. A draft version of the goals for the updated plan has been released and includes safety, mobility, and environmental stewardship. Two of the objectives under mobility relate to freight and include:

- Optimize intermodal connections.
- Support stateside economic development.

As illustrated in the previous sections the level of freight-planning integration in the transportation-planning process among the states varies greatly. Colorado and Utah appear to be putting the most effort into freight planning. Montana is also notable for the effort it is putting into the economic development aspect of rail transportation.

4. Data Sources

The following chapter lists data sources used in this study. The chapter breaks the data sources into federal, state, and private sources.

4.1 Federal Data Sources

The federal government is the major source for freight data in the United States. Of particular importance is the Commodity Flow Survey (CFS), the Vehicle Inventory and Use Survey, Carload Waybill Sample, Transborder Surface Freight Data, and the Freight Analysis Framework results data.

4.1.1 Commodity Flow Survey

The Commodity Flow Survey (CFS) is an important data source for freight movement that is obtained by the Census Bureau as part of the Economic Census for the Bureau of Transportation Statistics and the U.S. Department of Commerce. The first CFS was performed in 1963 and is now performed on a five-year cycle. The scope of the CFS was significantly expanded in 1993 to include more data on intermodal shipments. The most recent complete CFS data set is 1997 with the portions of the 2002 data set becoming available in 2004.

The 1997 Commodity Flow Survey represents data obtained from more than 5 million shipment samples including information on zip code of both origin and destination, the five-digit standard classification of the goods, weight, value, and mode of transportation. Additional information includes whether the material transported was containerized, a hazardous material, or exported goods.

4.1.2 Vehicle Inventory and Use Survey

The Vehicle Inventory and Use Survey (VIUS) provides data on the nation’s truck population including physical and operational characteristics. The survey is performed every five years as part of the Census Bureau’s Economic Census. Currently 1997 VIUS data is available but portions of the 2002 data are being released in 2004-2005. At the time of this report writing, 2002 data for Wyoming has not been released. Data for the 1997 VIUS is from a sample of 131,000 trucks registering in the United States in 1997. The total sample size for Wyoming is 2,493. From that sample, 90 percent represented pickup, panel, minivan and sport utility vehicles. The remaining are medium- to heavy-duty trucks applicable to this research effort.

4.1.3 Carload Waybill Sample

The Carload Waybill Sample is administered by the Surface Transportation Board and is a sample of carload waybills for terminated shipments by railroad carriers. For the 2002 sample more than 590,000 waybills were processed. The sample database contains information on origin and destination, type of commodity, number of cars, tons, revenue, length of haul, interchange locations, and uniform rail costing system shipment variable cost estimates. The entire database is used primarily by federal and state agencies and is not available for public use except in the aggregated form that does not violate confidentiality of the rail carriers.

4.1.4 Transborder Surface Freight Data

The Transborder Surface Freight Data contains data on the commodity type and mode of transportation for freight for the United States to and from Canada and Mexico. Modes included in this data set include rail, truck, pipeline, mail and other. This data has been available since 1993 and is updated on monthly basis with a typical lag time of several months.

The dataset is obtained from the Census Foreign Trade Statistics Program. Import and export data is derived from import and export paper documents or electronic information.

4.2 State Data Sources

The following provides a brief description of the key state data sources used in this effort.

4.2.1 Wyoming Geographic Information Science Center

GIS shapefiles containing the spatial and attribute data for Wyoming's boundaries, cities, airports, mines, agricultural use, and much more was downloaded from the Wyoming Geographic Information Science Center (WYGISC) website, www.wygisc.uwyo.edu. There are more than 500 datasets available to the public for downloading at this website. WYGISC is an official "node" of the National Spatial Data Infrastructure (NDSI).

4.2.2 Wyoming State Geological Survey

The Wyoming State Geological Survey (WSGS) provided the shapefile containing location and attribute data for Wyoming's pipeline infrastructure. The GIS section of the WSGS prepares GIS data, maps and reports that are either sold or distributed for free. The Publications or GIS sections of the WSGS can be contacted by visiting www.wsgs.uwyo.edu. Currently GIS data is not available for download at the website. The WSGS is a separate operating agency working under the Executive Branch of Wyoming State Government.

4.2.3 Wyoming Department of Transportation

The Wyoming Department of Transportation (WYDOT) supplied the information for the linear reference system used by the state for its highways and Interstates. The linear referencing system allows data described by route and milepost to be spatially referenced to the GIS highways layer. WYDOT does not have GIS data available to the public for download at this time but its website contains information about GIS applications at http://gis.dot.state.wy.us/.

Crash data was obtained through the WYDOT Safety Office. The Safety Office manages crash data for the entire state of Wyoming regardless of the jurisdiction of the roadway where the crash occurred. Data can be queried from the crash database to obtain subsets of crash data by numerous crash attributes such as vehicle type, crash type, or contributing factors such as weather or alcohol involvement. For this research effort, data for a 10-year period was obtained for all crashes involving heavy trucks.

Traffic volume data was another important component of this research effort. Traffic volume data including vehicle classification was compiled from the Traffic Operations Division of WYDOT.

Weigh-in-motion data was also obtained for the years 1992 to 2002. This data represented 21 locations from portable weigh-in-motion equipment and eight locations from permanent weigh-in-motion equipment. This data contained axle weights and vehicle classification information.

4.2.4 Wyoming Department of Revenue

The most accurate and up-to-date shapefile for Wyoming's railroad network was downloaded from the Wyoming Department of Revenue's website, http://revenue.state.wy.us/. The maps and GIS data page provides access to free downloading of GIS shapefiles. The railroads map shapefile was created using USGS 7.5 minute quad topographic maps at a scale of 1:24,000. Additional information was gathered from aerial photos and mine maps at a scale of 1:400. The agency is responsible for administration and collection of mineral and excise taxes, property valuation and liquor laws.

The Department of Revenue's Division of Economic Analysis also provided data on the manufacturing and agricultural sectors of the state including economic forecast information.

4.2.5 Wyoming State Climatologist Office

Weather station data was obtained from the Wyoming State Climatologist. Some of the data can be down loaded from the Water Resources Data System (WRDS). WRDS is a clearinghouse of hydrological and climatological data for the state of Wyoming and can be accessed at http://www.wrds.uwyo.edu/. It is funded by the Wyoming Water Development Commission.

Additional information on the frequency of certain wind conditions was obtained from the Wyoming Climate Atlas prepared by the Wyoming State Climatologist Office.

4.3 Private Data Sources

While most of the data used for this research were from public agencies there were two private data sources worth noting.

4.3.1 Altamont Press

Railroad speeds, subdivision names and main track authority attributes came from the Mountain Plains Region Timetable published by Altamont Press. The regional timetable was created from railroad timetables, track charts and field checks. Altamont Press maintains a website at www.altamontpress.com.

4.3.2 Transsearch Freight Market Data

Early in this research effort, the cost of obtaining Transsearch Freight Market Data from Reebie and Associates was investigated. The Transsearch data represents the most complete freight data set available and contains truck shipments of manufactured and some nonmanufactured goods, rail shipments including carload and intermodal, waterborne and air shipments, and U.S./Mexico and U.S./Canada shipments for some transportation modes. The data set is available back to 1980 and is purchased at either the county or zip-code level. Pricing for a state DOT is based on whether or not that data will be shared with the regional metropolitan planning organizations within the state.

This dataset is the standard for any in-depth freight analysis. Unfortunately the dataset is also costly and was not feasible for purchase within the budget of this research effort. It is recommended that WYDOT consider purchasing this data in the future if continued freight research and/or planning is desired.

5. Freight Forecasts

5.1 Introduction

When considering freight movements within an area it is important to look both at current and projected volumes. Transportation infrastructure is costly to construct and maintain and transportation planners need long planning horizons to adequately prepare for increased use of the transportation system. This is true for both passenger and freight transportation. When considering passenger-demand forecasts, planners often look at population forecasts to see what the future demand will be. While population is also an indicator for increased freight demand other indicators must also be considered. In Wyoming, for example, future coal demand will have a tremendous impact on the rail volume moving from the Powder River Basin.

As discussed in Chapter 3, most of the freight volume in Wyoming is moving through the state from the Midwest to the West Coast. Forecasts for this freight movement is heavily dependent on large-scale trends in containerized shipping and the increased use of Post Panamax vessels (ships that are too large to use the Panama Canal). This chapter will first look at national freight forecasts that will heavily influence increases in through-movement freight volumes and then look at state economic forecasts for Wyoming commodities that will effect the amount of goods originating and terminating in Wyoming.

5.2 National Freight Forecasts

The Freight Analysis Framework (FAF) was created by the U.S. Department of Transportation and is maintained by the Federal Highway Administration's Freight Management and Operations Division. The FAF is used to help analyze and forecast freight movements within the country and includes data on truck, rail, water, and air freight movements.

Currently, freight volumes and commodity estimates from the FAF are available for the years 1998, 2010, and 2020. Figure 5-1 shows the annual average daily truck traffic (AADTT) from the FAF for the Wyoming roads for the year 1998. Note that the FAF network does not contain all roads in the country only those on the National Highway Planning Network (NHPN). It can be seen from the figure that I-80 represents the major volume of truck flows in Wyoming. From the FAF data tables, the I-80 AADTT values for 1998 range from 7,700 to 10,500 (FHWA, 2002b).

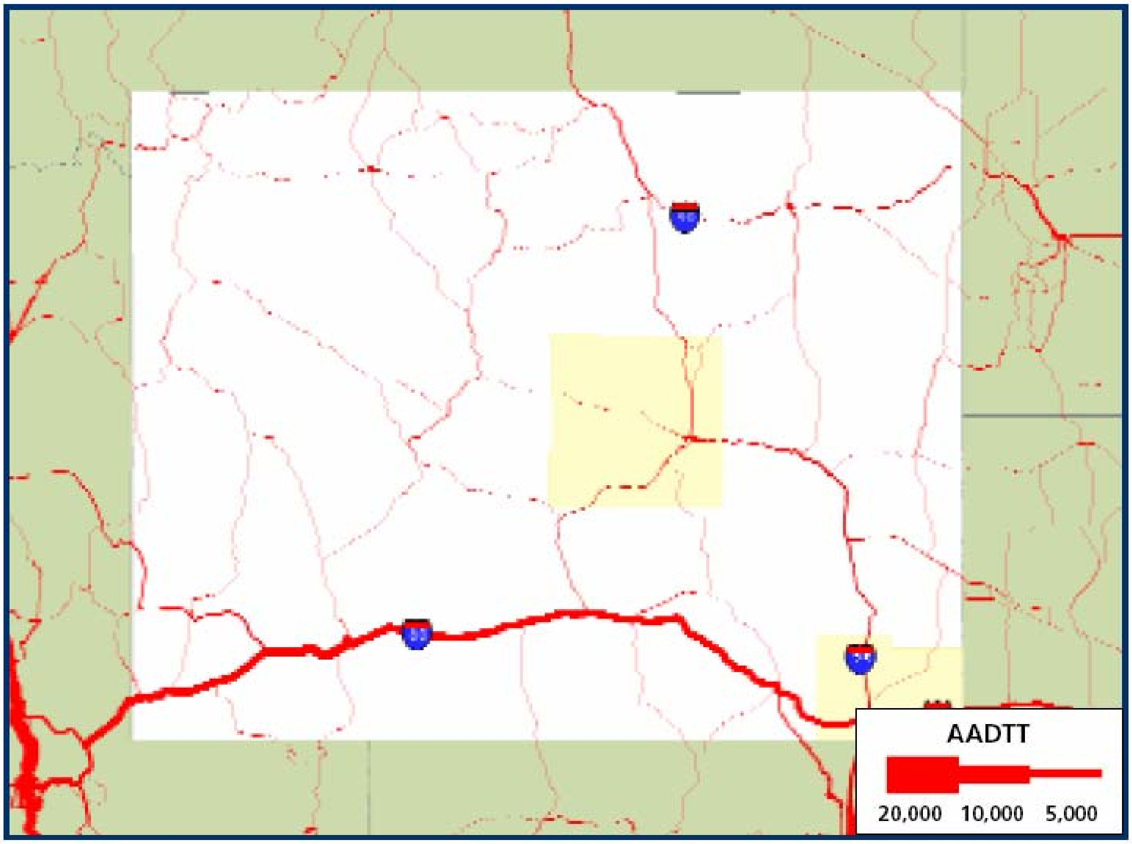


Figure 5-1: Average Annual Daily Truck Traffic, 1998
(Source: Freight Analysis Framework, Federal Highway Administration)

The 2010 volumes for the I-80 corridor from the FAF show increased AADTT's ranging from 11,200 to 15, 100. The 2020 volumes are shown in Figure 5-2. Once again focusing on the I-80 corridor and looking at the FAF data tables, the 2020 volumes range from 15,200 to 16,600, representing an increase of more than 100 percent from the 1998 volumes. Comparing Figures 5-1 and 5-2, significant increases can also been seen in the I-90 corridor as well as roadways serving the Casper area (I-25 south of Casper, Wyoming 220 from Caper to Muddy Gap, and US 287 from Muddy Gap to Rawlins).

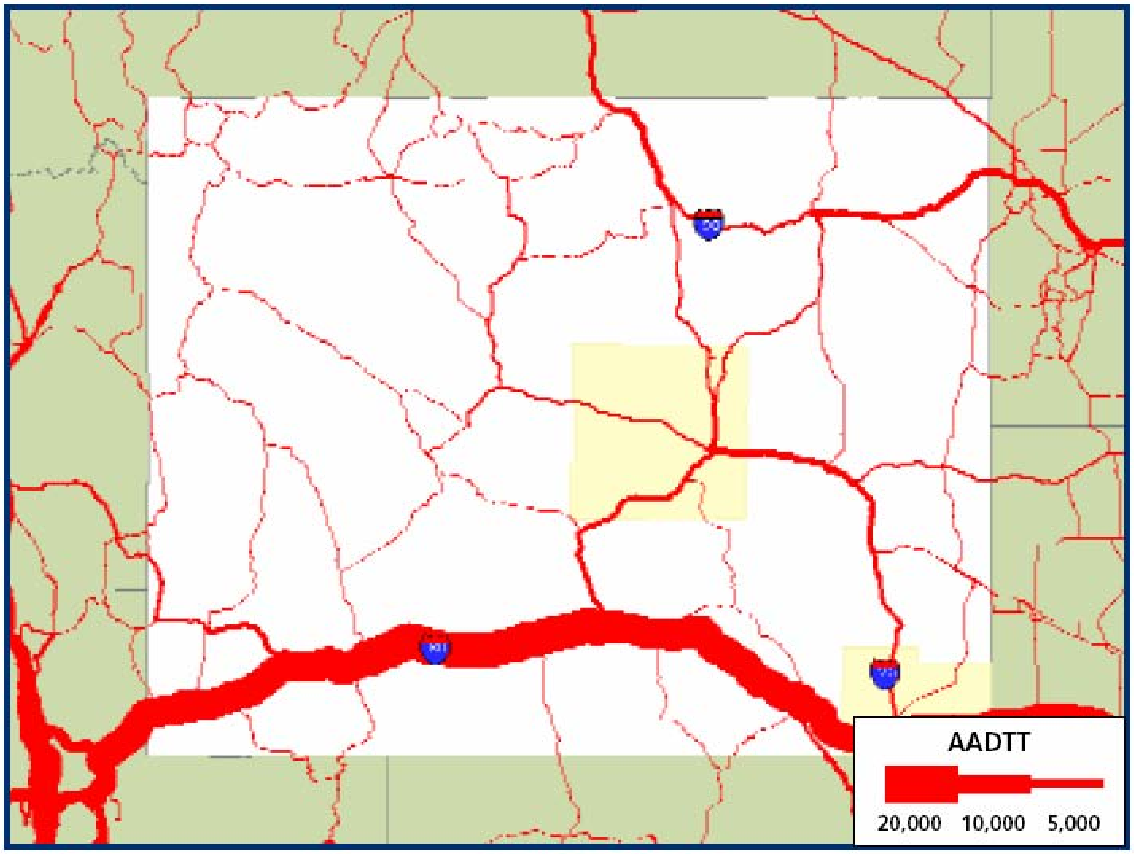


Figure 5-2: Average Annual Daily Truck Traffic, 2020
(Source: Freight Analysis Framework, Federal Highway Administration)

As mentioned previously, the FAF looks at other modes of freight transportation in addition to trucks. Table 5-1 lists the FAF forecast numbers by tons shipped and by value of goods shipped for 1998, 2010, and 2020 for all of the freight modes. As can be seen by the table, the growth by volume and value of goods shipped by truck is expected to far outpace growth in the other freight transportation modes. Note that this table is for freight shipments to, from, and within Wyoming and does not include the large freight volume that moves through the state (see Section 3.2).

Table 5-1: Freight Shipments To, From, and Within Wyoming; 1998, 2010, 2020

	Tons (Millions)			Value (Billions $)		
	1998	2010	2020	1998	2010	2020
State Total	377	475	534	50	98	164
By Mode						
Air	<1	<1	<1	<1	2	3
Highway	65	101	135	39	79	135
Other	<1	<1	<1	<1	<1	<1
Rail	312	374	399	10	18	26
Water	0	0	0	0	0	0
By Destination/Market						
Domestic	376	473	531	49	97	161
International	1	2	3	<1	2	3

Source: Freight Analysis Framework, Federal Highway Administration

5.3 Wyoming Freight Forecasts

The FAF also provides data on the freight forecasts specific to each state. These forecasts once again deal specifically with freight that originates in, is destined for, or travels exclusively within the state. When considering all of the data shown below it must be remembered that through movement of freight is what dominates the Interstate corridors, particularly I-80. The Wyoming freight forecasts have a larger impact on roads other than Interstates.

Table 5-2 lists the top five Wyoming commodities by value and by weight for 1998 along with their estimated growth in 2020. Coal represents the largest increase in tonnage with an expected growth of 63 million annual tons. Clay/concrete/glass/stone has the second largest increase in tonnage with an expected increase of 32 million annual tons. With respect to value, chemicals/allied products has the largest estimated increase with a growth of $43 billion per year.

Table 5-2: Wyoming Freight Commodities by Weight and Volume, 1998 and 2020

	Tons (Millions)			Value (Billions $)	
Commodity	**1998**	**2020**	**Commodity**	**1998**	**2020**
Coal	297	360	Chemicals/Allied Products	15	58
Clay/Concrete/Glass/Stone	19	51	Farm Products	7	12
Chemicals/Allied Products	19	48	Coal	6	9
Farm products	18	22	Food/Kindred Products	4	17
Nonmetallic Minerals	4	6	Secondary Traffic *	3	16

* Secondary traffic is defined as freight flow to and from distribution centers or through intermodal facilities.
(Source: Freight Analysis Framework, Federal Highway Administration)

When considering traffic on Wyoming's freight transportation system, these expected increases in freight volume must be planned for. As discussed in Chapter 3 of this report, coal is moved primarily by rail. Rail planners at Burlington Northern Santa Fe and Union Pacific must adequately plan for an additional 63 million annual tons. WYDOT must also consider how this increase in coal train traffic will affect rail-highway grade crossings and other highway related impacts.

6. Freight Crash Analysis and Wind Vulnerability

6.1 Introduction

According to the National Highway Traffic Safety Administration (NHTSA), "One out of nine traffic fatalities in 2002 resulted from a collision involving a large truck" (NHTSA, 2002a). In Wyoming, 13 percent of the vehicles involved in fatal crashes in 2002 were large trucks (NHTSA, 2002a). Note that for safety data, large trucks are typically defined as tractor-trailers, single-units trucks and heavy cargo vans with gross weight of more than 10,000 pounds. With more than 10 percent of fatalities throughout the nation involving large trucks, it is important to try to improve the safety of the road for both the trucks and for other users of the road.

One of the research objectives for this project is to review different methodologies for using GIS to analyze traffic crashes and to develop some of these methodologies to analyze truck crashes in Wyoming. Currently Wyoming does not have the ability to compute crash rates only crash frequencies. Crash rates account for vehicle exposure using a variable such as average daily truck traffic volumes. Calculating only crash frequencies makes it difficult to determine which roads are truly more hazardous. It would naturally be expected that routes with higher volumes would experience a higher frequency of crashes. Crash rates account for this variation.

While frequency numbers are valuable information, crash rates allow for direct comparison of different types of facilities where the volumes of these facilities may vary greatly. Because of the number of trucks that travel through the state, it is important to determine if trucks are overrepresented in crashes and to try to identify what factors are predominant in truck crashes. This will allow WYDOT to find ways to make it safer for trucks to travel in Wyoming.

Problems can also arise for trucks traveling in Wyoming from the frequent high winds that cause high profile vehicles to become unstable and overturn. This chapter also investigates if a correlation exists between measured wind speed at weather stations and rollover truck crashes.

The remainder of this chapter will cover the data, methodology, results, and future work that will be done in the area of truck crashes.

6.2 Data

This section will review the data that was used in this project. The four different data sets used in the safety analysis are the crash data, highway linear referencing, truck volume, and wind data.

6.2.1 Crash Data

All crash data for the state of Wyoming, regardless of the roadway jurisdiction, is compiled into a single database maintained by the Wyoming Department of Transportation. The crash data, consisting of all 14,700 crashes that involved trucks from 1994 to 2003, was obtained from the Highway Safety Program at WYDOT. This data was split into two files; the information that described the crash was in one file and another file described the trucks involved in each crash. The crash file contained information such as date, time, location, environmental conditions, and the number of people and vehicles involved in each crash.

The vehicle file contained information such as vehicle make and year, speeds, vehicle direction, size and number of axles, and the cargo. A complete list of all the fields in both the crash and vehicle files is given in Table 6-1.

Table 6-1: Data Fields in Crash and Vehicle Files

Crash File	**Vehicle File**
KEY	VKEY
COUNTY	OWNER
HIGHWAY SYSTEM	STATE
CITY	MAKE
STREET CODE	BODY
COUNTY RD	VEHICLE YEAR
ROUTE SIGN	POSTED SPEED
HWY SECTION	ESTIMATED SPEED
MILEPOST	TRAILER STYLE
EQUATION	MECHANICAL DEFECTS
DIVIDED HWY	DAMAGE SEVERITY
SIDE HWY	CARGO
HIGHWAY ELEMENT	HUMAN CONTRIBUTING FACTOR
ACC DATE	ACTIVITY PRIOR
TIME	DIRECTION OF TRAVEL
# DRIV	HAZ MAT
# VEH	HAZ MAT NAME
#INJ	HAZ CLS
#KILLD	HAZ DIV
SURFACE	GVWR
LIGHTING	# AXLES
ROAD	
WEATHER	
ALIGNMENT	
1ST HARMFUL EVENT	
ADVERSE ROAD	
COLLISION TYPE	

6.2.2 Highway Route Referencing

A GIS layer of the state highways and interstates encoded with the necessary information required for linear referencing was acquired from the GIS office at WYDOT. The roads in this file were measured polylines; a special type of line which contains embedded measurement information (beginning number, ending number, and length) rather than having these attributes shown in the attribute table.

As was mentioned above, the crash data provided included route and milepost information. Because the mileposts were given in hundredths of a mile without a decimal, a new field had to be created in the crash data file that divided the milepost field by 100. In the highway layer, the routes were labeled with a unique name that WYDOT uses to distinguish roads. The first two letters of this internal name designate the type of roadway as a main line (used for interstates and highways), ramp (used for on and off ramps), turnouts, and others. The crash database used the common public naming system for the routes, such as I80, US287, and WY210. WYDOT provided a table that listed the relationship between the public names and WYDOT's internal names. However, there was not a one to one relationship for all the roads.

Some of the crashes were time consuming to locate because some of the public highways have the same milepost number in different locations due to highways joining and diverging as they traverse the state. In these instances, the highway section number in the crash database was used and the crash in question was compared to located crashes whose names and highway section numbers were the same. A new field was added to the crash database to add WYDOT's internal name to the crash record.

The crash database included all crashes that happened within the state including those that happened within city limits. For the crashes that happened within city limits, street codes were given to designate where the crash occurred. A macro was written within Excel to match the street names in another file with the street codes in the crash database. These crashes were then manually correlated to route names if they were on state-maintained routes.

The GIS software program, ArcMap, was used to plot the highway layer and the crashes were added using ArcMap's linear referencing capabilities. With linear referencing, GIS programs can determine the location of a point on a network given that the point has associated with it a route and a number that describes the location along the route. The network must have a name (that matches the route names given for the points) associated with each link of the network and each link must by a measured polyline (as in this case) or have a beginning number and an ending number. The points are then plotted by matching the route names and interpolating the distance between the beginning and ending number imbedded in the polyline to match the location measure of the point.

Not all the crashes could be plotted because some of the crashes happened on roads that are not state maintained and therefore not on the highway layer. Out of the 14,700 crashes, 2,013 (14%) of them could not be plotted because of this fact. As WYDOT continues to put more of the county and local roads into their GIS roads layer, more of the crashes will be able to be plotted.

6.2.3 Volume data

To compute crash rates, traffic and truck volume data was obtained from the Planning Program at WYDOT. This data included truck counts and estimates for all of the state-maintained roads in Wyoming between the years of 1993 and 2003. This data was already referenced by WYDOT's internal naming system, which made it easy to link to the highway layer in GIS. This was accomplished in the same manner as the crashes except that the truck volumes were line events rather than point events. A line event has a length associated with it and is plotted on a section of the polyline, rather than just a single point in the same manner as the point events are plotted.

Having the traffic and truck volumes accessible in a GIS environment makes it possible to see the volumes of trucks on the roads and these volumes provide an exposure rate that can be used to calculate a crash rate to determine if trucks are truly overrepresented in crashes or, if compared to the exposure rate, trucks are just as likely to crash as other vehicles.

6.2.4 Wind data

To determine if a correlation existed between wind speed and trucks overturning, wind data from around the state was needed in sub-hourly intervals. This data was obtained from the state climatologist for the 21 weather stations across the state. The 1994 to 2001 data was obtained from the state climatologist on a

CD while the 2002 data was downloaded from the climatologist's website. Data from these stations was available from 1994 through October 2002 in approximately 15-minute intervals.

The truck crashes then had to be associated with the closest weather station. This was accomplished with the ArcInfo command *Near*. The *Near* command found which station was the closest to each crash and then added a field to the crash database with the identification number of that weather station and another field with the straight line distance to the station.

Once the nearest weather station to each crash was known, the wind data for the time of the crash could be added to the crash database. Before the data was linked, the time in the weather data was changed from Greenwich Mean Time to Mountain Standard Time. For the wind data downloaded from the website the wind speeds were change from knots to miles per hour.

Macros were written in Microsoft Excel using Visual Basic for Applications to link the weather data. The macro was written to add wind data for one weather station at a time. The code would loop through the crash database to find a crash that was associated with the current weather station. It would then loop through the weather data to find the date of the crash. After the date of the crash was found, the macro would check the time of each weather data record until the difference between the crash time and the weather time started to increase. When the difference between the two times was at the minimum, this meant that time was the closest time that weather data was recorded to the time of the crash. The macro would then add the wind speed, gust, and direction, as well as the time of the observation to the crash database record.

6.2.5 Other

Other data to enhance the quality of the project and to aid in visual representation of the data, such as county lines and cities, were downloaded from the Wyoming Geographic Information Science Center (WYGISC) at www.wygisc.uwyo.edu. The highway data was projected in the Albers projection with a central meridian of -107.5° and the rest of the data were either not projected or were easily transformed into this projection, therefore the Albers projection was used for the entire project.

6.3 Freight Crash Analysis Methodology

The methodology section will discuss the grid analysis, sliding scale analysis, advanced grid analysis, and the wind speed correlation analysis.

6.3.1 Grid Analysis

Using a grid is one of the simplest methods for large network analysis. A grid with a uniform cell size is overlain on the crash data and the number of crashes that are contained in each cell is determined. These values can be normalized by dividing the number of crashes by the total length of the roads in each cell, which will result in crash density for each cell.

To perform the grid analysis, ArcMap was used to convert both the crash locations and the traffic volumes into a grid layer with each grid cell being square mile. A *density grid* was use for the crash data in which each cell contained the number of crashes that occurred within that square mile radius and assigned that value to individual cell. A *value grid* was used for the truck volumes, in which each cell contained the average daily truck traffic (ADTT) for those cells in which there was a road or *no data* for the cells without a road.

When the density function is used, it creates a circle around the point at the center of the cell and calculated the density of points within the area of the circle, and applies that density value to the cell. This creates a problem trying to select the search radius, because the circle and the square do not cover the same area. As a solution, it was decided to set the area of the circle to one and therefore use a radius of 0.564 miles (2978.9 ft). Using this value, the circle extended beyond the square in the middle of the sides but not at the corners. Because this error is present, one must realize that the grid analysis is only an approximation because some crashes may be missed and others may be counted twice.

Since the cells were one mile square it was assumed that each cell with a road contained one mile of roadway. Therefore, the ADTT also equaled the number of truck miles traveled (TMT); since ADTT times the road length equals TMT.

Doing all the roads in a single grid revealed some problems when there was a high-volume road and a low-volume road within the same cell. The cell value was based on the lower traffic volume, and therefore would calculate an unreasonably high crash rate. Using a density grid also revealed problems because the density function uses a radius to calculate values for the square grid cell. Imposing a circular function onto a square grid imposed errors.

This method is simple but has several disadvantages. The first is that the method includes both major and minor roads in the same cell, which possibly dilutes or magnifies crash problems. The second is that the one-mile grid cells impose arbitrary boundaries and may divide high crash rate areas among multiple cells.

6.3.2 Sliding Scale Analysis

The second type of analysis chosen for this report is the sliding scale analysis. For the sliding scale a segment length is specified and the segment slides along the route, stopping at specified intervals to calculate the crash rate. "If the crash rate of any strip meets or exceeds the user-defined threshold, the segment is extended by the incremental distance, and the process is repeated" (HSIS, 1999a). This will ensure that a whole segment with a high crash density is determined. This process is terminated after a predetermined number of extensions without a crash have occurred or the end of the route is reached. The sliding scale analysis has the advantage over many other types of analysis because the chance of splitting a high-crash area between two analyses sections is eliminated.

The Federal Highway Administration has a GIS Safety Analysis Tools CD available that uses this analysis technique, but the code is written in the obsolete programming language Avenue. To use the analysis tools on data other than the sample data provided on the CD the code needs to be modified. For this research effort, translating the code into a modern programming language was investigated but GIS experts all agreed that the best approach would be to start over.

The code needed to implement the sliding scale is best explained by using pseudo code to describe the process. The pseudo code for the sliding scale analysis is given below.

1. Set the analysis section length, with a default value of one.
2. Set the increment distance, with a default value of one-tenth.
3. Enter the number of years to be analyzed.
4. Set the critical crash rate above which to flag values.
5. Set the maximum number of extensions to lengthen the analysis segment that is above the critical crash rate without finding another crash.

6. Begin looping through each selected road segment or do all road segments if none are selected.
7. Extract the beginning milepost for the segment.
8. Begin looping through each section of the segment until the analysis section reaches the end of the road.
9. Set the analysis section to start at the beginning milepost for a length of the analysis section length.
10. Count the number of crashes in the analysis section. Determine the number of truck vehicle miles traveled (TVMT) on the analysis section from the annual daily truck traffic.
11. Calculate the crash rate by dividing the number of crashes by the TVMT.
12. If the crash rate is above the critical crash rate then do the following: extend the analysis section by the increment distance.
13. Recount the number of crashes, recalculate the TVMT, and determine the new crash rate.
14. If the crash rate is now below the critical crash rate then record this section's location number of crashes and crash rate and exit this loop and continue with the next analysis section.
15. If no new crashes were found then record this.
16. If the number of times this loop is repeated consecutively finding no new crashes reaches the maximum number of extension, then record this section's location number of crashes and crash rate and exit this loop.
17. When the crash rate is greater than the critical crash rate, the new analysis section starts at the end of the old section.
18. If the crash rate for a section is below the critical crash rate then increase the beginning milepost by the increment distance and perform the analysis on the new section of road.
19. Once the entire segment has been analyzed, repeat the analysis for each segment.
20. After all the segments have been analyzed, generate a report showing the segments that were above the critical crash rate sorted by crash rate, showing the worst section first.

It was decided that for this research effort an advanced grid analysis could be performed that addressed the disadvantages of the basic grid analysis method described above. This approach avoided having to write programming code to perform the sliding scale analysis since it could use standard functions within the GIS software.

6.3.3 Advanced Grid Analysis

As mentioned in the grid analysis section several problems and disadvantages were revealed in the basic analysis. These disadvantages are:

- Density function uses a radius value to calculate crash frequencies for the square cell.
- Unreasonably high crash rates because of the grid analysis picking up the volume from the lower volume road and the crash frequencies from both a low- and high-volume road.
- One-mile grid cells impose arbitrary boundaries that may divide high crash rate areas among multiple cells, thereby diluting the crash problem.

The first problem was addressed by using a neighborhood statistic function instead of the more common density function with the software. The neighborhood statistic used a square area instead of the radius to avoid the errors associated with imposing a circle on a square grid cell.

The second problem was corrected by developing multiple grids based on the functional classification of the road. A separate grid was developed for each of the three interstates (functional classification 1), another grid for major roads (functional classification 2), and a final grid for minor roads (functional classifications less than 2). This addressed the problems of major road intersections where the analysis method was picking up on crashes that occurred on adjacent roads.

The arbitrary boundary problem with the one-mile square grid cells was addressed by increasing the grid resolution from one mile squares to a tenth of a mile squares. A tenth of a mile square resolution was determined to be adequate because crash reports typically identify crash locations down to a tenth of a mile. The arbitrary boundary problems are inherent in the crash reporting and therefore in the original data. Since the original data was reported at this scale, an analysis performed at this scale would be suitable.

Another issue not previously discussed but addressed in the advanced analysis is the issue of the time period for the analysis. The data sets being utilized are for a 10-year period. For crash analyses, a trade-off needs to be made by the analyst between the increased accuracy of adequately describing the crash problems provided by longer time period data sets and decreased accuracy of the data caused by changes in the roadway features that affect accident rates. Safety analysts typically recommend three to five years as an ideal time period that balances these two issues. Therefore the advanced grid analysis was performed three times, each using a five year period. The three time periods analyzed were 1994-1998, 1997-2001, and 1999-2003.

The last issue addressed in the advanced grid analysis is one that deals with crashes on very-low-volume roads. If the truck volume on a particular road is low enough, just one crash within the analysis period can show up with a high crash rate. To screen out these types of road, a threshold of one crash per year on average was used to remove these from being identified as a high hazard location. This threshold was deemed reasonable by the research team but should be discussed by the agency before implementation because it can have dramatic affects on the results.

6.3.4 Wind-Speed Correlation Analysis

It is logical that true wind speed at the location of the crash would influence whether or not that crash was of the overturning type. What is not known is how well measured wind speeds at weather stations are a good predictor of the likelihood of an overturning crash. The objective of the wind-speed correlation is to determine this. If a strong correlation exists then measured wind speeds could be used to make operational decisions about the roadway.

To analyze whether the measured wind speed influenced a truck overturning, a model that could predict discrete outcomes was needed. A binary logit model was used because there were only two discrete outcomes — overturning crash or not. A new binary variable was added to the crash data set labeled overturn. It contained a one if the crash was overturning and a zero otherwise.

The statistical software program SAS with the *Logistic* procedure was used to estimate the maximum likelihood probability function. It was decided that all reasonable variables would be put into the model at the beginning and variables that were not found to be statistically significant would be removed. A variable was considered significant if its coefficient was statistically different from zero. This is accomplished by testing the hypothesis of H_0: $\beta_j = 0$, where β_j is the coefficient of the k^{th} variable.

The output from SAS includes the Wald chi-squared test and the associated p-value. The p-value is a measure of the confidence of the hypothesis being tested is true. A p-value of 0.05 was chosen to serve as the criteria for whether a variable would remain in the model. A p-value of less than 0.05 gives a 95 percent confidence that the coefficient is not zero. Using this decision rule any variables with a p-value greater than 0.05 would be removed from the model and any with a p-value less the 0.05 would remain. Variables were removed one at a time by selecting for removal the one with highest p-value above 0.05. The model was then rerun and the next variable with the highest p-value above 0.05 would be removed. This would be repeated until all the variables had a p-value below 0.05.

The general form for the logistic model used in this analysis is shown in Equation 6-1:

$$P = \frac{e^{\bar{\beta}}}{1 + e^{\bar{\beta}}}$$

$$\bar{\beta} = \beta_0 + \beta_1 x_1 + \cdots + \beta_k x_k$$

Equation 6-1: General Equation for Logistic Model

Where,

P = Probability of the crash being an overturning crash
β_0 = Constant value
β_k = Coefficient value for the k^{th} variable
x_k = Value of the k^{th} variable

The form of this formula will ensure that the probability (*P*) will be a value between 0 and 1. As $\bar{\beta}$ becomes larger or more positive; *P* will approach one and the probability of a success (in this case, a truck overturning) will increase.

This general model formulation will be used to created different models for the state. A statewide model will be created along with models for some of the individual weather stations. Models will also be developed for individual weather stations based upon the number of rollover crashes near that weather station and the public's perception of whether a location is known to have numerous trucks overturning. It is believed that models for individual weather stations would be a better predictor for overturning crashes than a generalized statewide model.

6.4 Results

The results section will discuss what was found in the grid and wind speed correlation analyses.

6.4.1 Advanced Grid Analysis Results

Overall, the advanced grid analysis is a good tool for performing a crash analysis. It can be done using standard GIS tools and produces quick visual results of crash rates or frequencies for a large analysis area. One major drawback was that reports identifying the top crash rate locations had to be generated by hand and were time consuming. If this methodology was adopted by WYDOT, programming scripts could be created that would automate this process.

Before discussing the results of the advanced grid analysis the point should be made that the objective of this research effort was to review methodologies for identifying high-hazard locations and was not to point out the high-hazard locations themselves. The following graphs and tables listing these areas are meant to describe the output types and the typical conclusions that can be made from this output and is not to point out areas of concern. There are still issues to be addressed in the methodology that may affect the results.

One of these issues is that the intersection of minor roads has still not been addressed. The methodology may still be over representing the crash rates at the intersection of these minor roads since the neighborhood function could pick up crashes on nearby roads and attribute them to the cell being analyzed. This was addressed on major roads by separating out the analysis by functional classification. A solution to address this problem may be to separate out roads by direction (east-west and north-south) instead of by functional classification so that all intersection locations are addressed.

Figures 6-1 through 6-3 show the results of the advanced grid analysis for the three time periods. The figures show the crash rate in crashes per million truck miles traveled (MTMT) as well as the average daily truck traffic (ADTT) for the roadways. Tables 6-2 through 6-4 list the top crash rate locations along with the route description. As can be seen from the figures and the tables the high-crash locations are spread throughout the state but in general are located within urban areas. This is reasonable given the higher likelihood for crashes in urban areas but also may be an indicator of the minor road intersection issue described above.

The figures and tables illustrate the typical output from a grid analysis using GIS. As these figures and tables show, GIS is a useful tool in spatially identifying high-hazard crash locations. The figures that can be generated using GIS are easy to interpret and can be highly valuable tools for a statewide safety program.

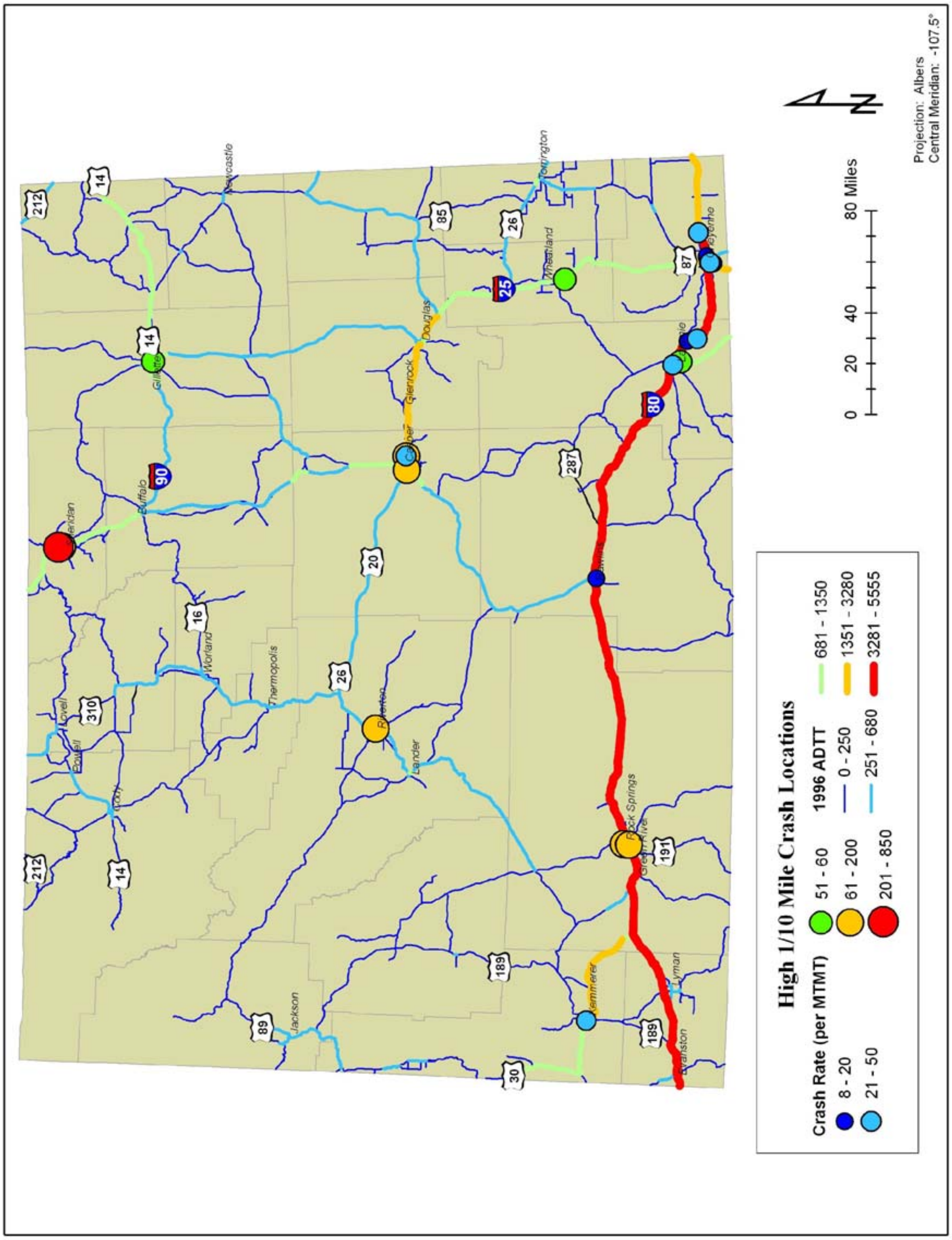


Figure 6-1: Wyoming Truck Crash Grid Analysis, 1994-1998

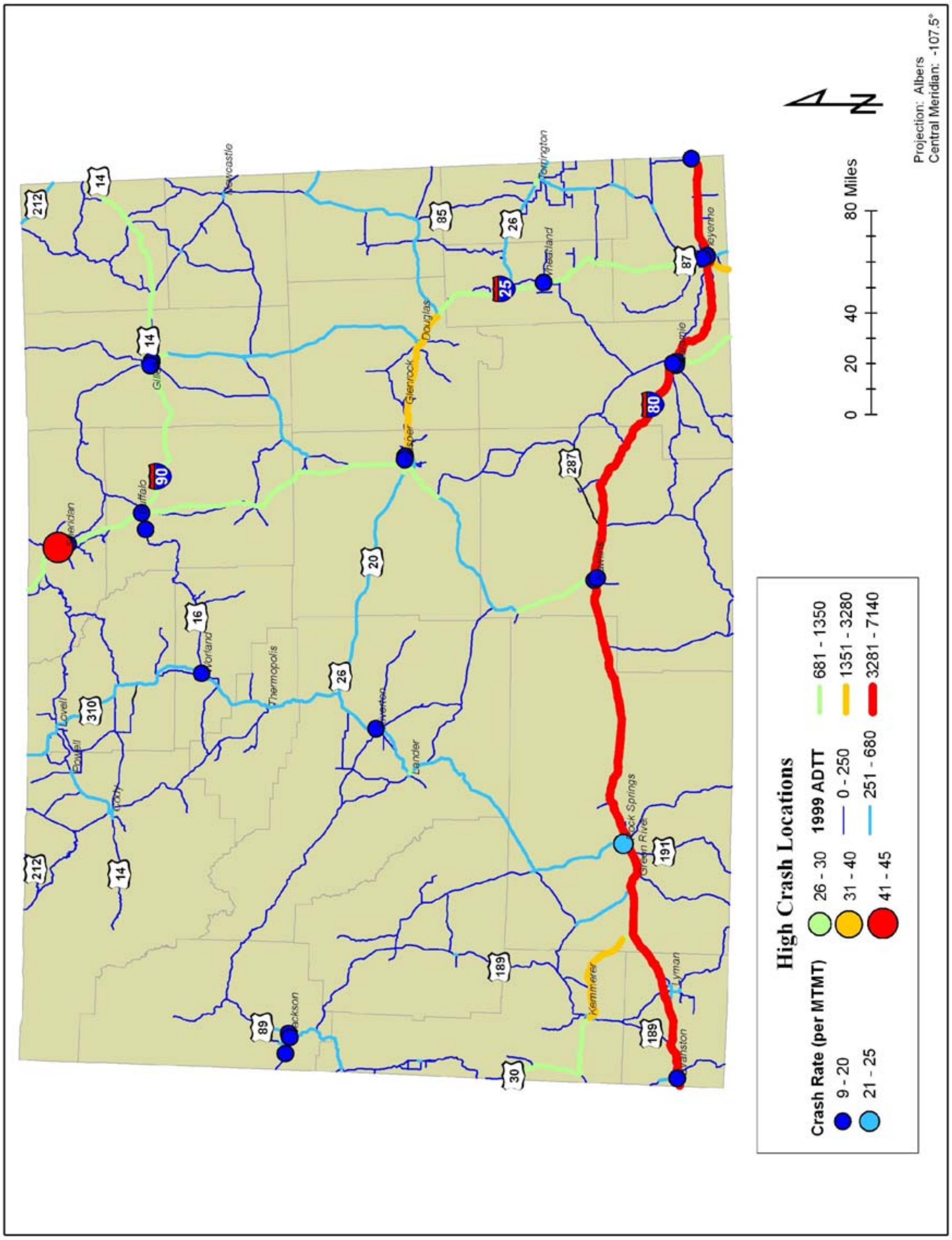


Figure 6-2: Wyoming Truck Crash Grid Analysis, 1997-2001

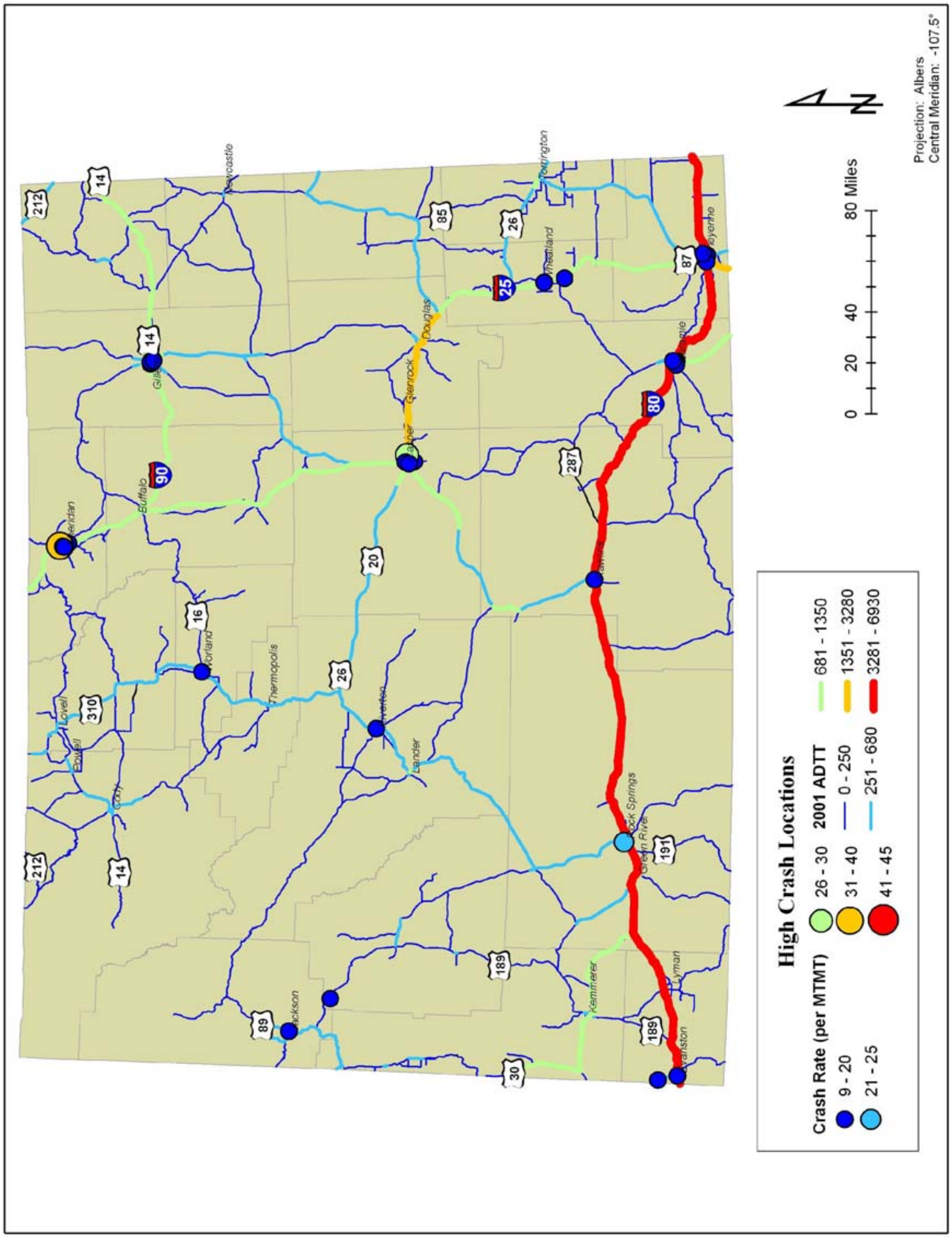


Figure 6-3: Wyoming Truck Crash Grid Analysis, 1999-2003

Table 6-2: Top Truck Crash Rate Locations, 1994-1998

Rank	Crash Rate (per MTMT)	Number of Crashes	ADTT	Route	Mile Post	Location
1	42	44	320	I 90 BUS/US 14	21.5	North of Sheridan, I 90 & Main St. Interchange
2	26	27	410	US 191	1.2	Rock Springs I 90 & WY 191 Interchange
3	22	24	360	US 59	112.5	I 90 - Douglas Hwy Interchange in Gillette
4	21	23	320	US 20	186.8	Casper, I 25 and Wyoming Blvd.
5	20	22	190	US 20	187.3	Casper, I 25 and Yellowstone
6	17	17	580	US 191/89/26	154.5	Jackson US 191/89/26
6	17	10	195	US 30/287	327.2	Laramie, Intersection of 3rd St. & Clark
6	17	13	160	I 180/US 85	10.3	Cheyenne, Intersection of Central Av & Lincoln Way
6	17	22	320	WY 258	18.0	Casper, WY 253 & Wyoming Blvd.
6	17	17	380	US 287	400.3	Laramie. Intersection of 3rd St. and Grand Ave.
11	16	7	170	US 30/287	320.5	7 Miles North of Laramie US 30/287
11	16	8	160	US 20/26	0.2	Casper, Yellowstone Hwy.
13	15	21	730	US 26/WY 789	105.4	Riverton, Junction US 26 & WY 789
13	15	17	260	US 30/287	328.1	Laramie, Intersection of 3rd St. and Snowy Range
13	15	15	380	US 87 BUS/US 14 BUS	22.9	Sheridan, Intersection of Main and 5th Streets
16	14	14	410	US 189 BUS	3.6	Evanston, Intersection of Old US 30 & Overthrust
16	14	7	290	US 16	100.5	Buffalo, I 80 & US 16 Interchange
16	14	8	150	F Street (U 4136)	0.5	Casper, F St.
19	13	15	365	US 287	0.4	Lander, Junction of US 287 & WY 131
19	13	7	250	WY 130/230	1.6	Laramie, I 80 & Snowy Range Interchange
21	12	9	75	WY 78	0.6	Rawlins, I 80 & Higley Blvd. Interchange
21	12	8	185	US 20/26	1.5	Casper, Intersection of Center and Yellowstone
23	10	16	550	I 180/US 85	8.1	Cheyenne, I 80 & US 85 Interchange
23	10	17	545	US 14/16/WY 59	114.8	Junction of US 16/14 and WY 50, Gillette
23	10	7	220	I 180/US 85	12.0	Cheyenne, I 80 & Central Ave. Interchange

Table 6-3: Top Truck Crash Rate Locations, 1997-2001

Rank	Crash Rate (per MTMT)	Number of Crashes	ADTT	Route	Mile Post	Location
1	44	41	250	WY 338	0.4	Sheridan, Decker Rd. & I 90
2	24	34	900	US 191	1.5	Rock Springs, I 90 & Elk St. Interchange
3	19	5	110	US 16	86.2	6 miles west of Buffalo
4	18	20	220	US 20/26	187.0	Casper, I80 & Yellowstone Ave. Interchange
4	18	5	100	WY 22	8.1	10 miles northwest of Jackson
6	17	17	580	US 26/89/191	154.5	Jackson, Intersection of Broadway & Cache
7	16	5	110	US 30	402.2	Pine Bluffs
7	16	17	160	I 180/US 85	10.3	Cheyenne, Intersection of Lincolnway & Central Ave.
9	15	12	310	US 189 BUS	3.6	Evanston, I80 & I 80 BUS/US 189 BUS Interchange
10	14	12	90	WY 330	0.3	Sheridan, Intersection of 5th St. & Main
11	13	10	230	US 87 BUS	79.2	Wheatland, I 25 & WY 312 Interchange
11	13	14	410	US 287	400.3	Laramie, 3rd St. & Grand Ave.
11	13	9	110	US 14	0.4	Sheridan, I 90 & US 14 Interchange
11	13	14	360	WY 59	112.5	Gillette, I 90 & WY 59 Interchange
11	13	14	380	US 87/14 BUS	23.0	Sheridan, Intersection of Main St. & Loucks St.
11	13	16	240	US 14/16	1.4	Gillette I 90 & US 14/16 Interchange
17	12	10	80	WY 78	0.6	Rawlins, I 80 & WY 78 Interchange
17	12	9	230	Curtis St. (U4200)	0.6	Laramie, Intersection of 3rd St. & Curtis St.
19	11	17	550	I 25 BUS/US 85	8.1	Cheyenne, I 80 & US 85 Interchange
19	11	6	250	WY 130/230	1.6	Laramie, I 80 & Snowy Range Interchange
19	11	6	255	US 16	100.4	Buffalo, Junction I 25 & US 16
19	11	6	150	F St. (U4136)	0.5	Casper, F St.
23	10	16	650	US26/89/191	152.8	South of Jackson, Junction US 26/89/191& WY 22
23	10	13	475	US 16	0.1	Worland, Intersection of Bighorn Ave. & 10th St.
23	10	14	630	WY 789	105.1	Riverton, Intersection of Main St. & Federal Blvd.
23	10	12	220	US30/287	213.7	Rawlins, Intersection of 3rd St. and Cedar

Table 6-4: Top Truck Crash Rate Locations, 1999-2003

Rank	Crash Rate (per MTMT)	Number of Crashes	ADTT	Route	Mile Post	Location
1	36	38	300	I 90 BUS/US 14	21.5	North of Sheridan, I 90 & Main St. Interchange {I90BUS/US14}
2	26	25	340	WY 258	17.7	Casper, I 25 & Wyoming Blvd. Interchange
3	23	30	480	US 191	1.2	Rock Springs, I 80 & Elk St. Interchange
4	16	13	120	WY 255	0.6	Casper, I 25 & Center St. Interchange
4	16	14	90	WY 330	0.4	Sheridan, Intersection of Main St. & 5th St.
6	14	13	440	US 287	400.3	Laramie, Intersection of 3rd St. and Grand Ave.
6	14	10	250	WY 220	115.3	Casper, Intersection of CY Ave. & Poplar St.
8	13	13	160	I 180/US 85	10.3	Cheyenne, Central Ave. {I 180/US 85}
8	13	12	350	US 189 BUS	3.6	Evanston, I 80 & US 30 Interchange
8	13	6	50	US 87 BUS	79.0	Wheatland, Junction of I 25 & WY 312
11	12	23	650	US 14/16	114.4	Gillette, Junction I 90 & US 14/16
11	12	65	1900	US 87	9.3	Cheyenne, I 25 & Lincolnway Interchange {I 25}
11	12	8	120	US 14	0.4	Sheridan, Intersection of Coffeen Ave. & Brundage Ln.
14	11	11	220	WY 130/230	0.1	Laramie, Intersection of 3rd St. and Snowy Range {WY 130/230}
14	11	19	1000	WY 59	111.9	Gillette, I 90 & Douglas Hwy Interchange
16	10	5	180	US 189/191	148.8	25 miles south of Jackson {US 189/191}
16	10	10	500	US 26/89/191	154.5	Jackson, Intersection of Broadway & Cache Dr. {US 26/89/191}
16	10	7	430	US 26	133.1	Riverton, Intersection of Main St. & Federal Blvd.
16	10	5	280	WY 258	13.1	Casper, Wyoming Blvd.
16	10	5	170	WY 89	8.3	9 miles north of Evanston
16	10	13	490	US 14/16/WY 59	113.6	Gillette, Intersection of 2nd St. & Douglas Hwy.
16	10	33	1100	US 87	70.6	9 miles south of Wheatland
16	10	5	270	US 30	363.8	Cheyenne, Lincolnway {US 30}
16	10	6	80	WY 331	0.5	Sheridan, Intersection of Main St. & Loucks St.
25	9	16	550	I 25 BUS/US 85	8.1	Cheyenne, Greeley Hwy (US 85)
25	9	12	480	US 16	0.1	Worland, Intersection of Bighorn Ave. & 15th St.
25	9	13	310	US 30	213.6	Rawlins, Intersection of Cedar St. & 3rd St.
25	9	5	270	WY 130/230	1.7	Laramie, Snowy Range Road
25	9	7	280	Curtis St. (U4200)	1.2	Laramie, Intersection of 3rd St. and Curtis St.

After identifying high-hazard locations, the next step in a safety analysis program would be to do site investigation and in-depth crash analyses on the full crash data set to see what the likely causes of the crashes are. From these causes, a list of countermeasures for each site would be developed to correct any deficiencies found at the site.

A grid analysis was also performed for the overturning truck crashes throughout the state. The results of this analysis are shown in Figure 6-4. This map illustrates the frequency of overturning crashes. As can been seen in the figure, there are high overturning-crash frequencies on I-80 west of Laramie near Arlington and on I-25 north of Cheyenne and south of Wheatland. This map illustrates how the grid analysis can also be used as a quick tool to find areas where there are high frequencies of crashes.

Figure 6-4 was used in the wind correlation analysis to identify areas of particular concern for overturning crashes.

6.4.2 Wind Correlation Results

After looking at the grid analysis for the overturning crashes (Figure 6-4), it was decided that two local models and the statewide model would be developed. The two local models are for the Arlington and the south Wheatland weather stations where high overturning-crash frequencies were found.

The model that was developed for the Arlington weather station will be looked at first. A total of 1,436 crashes occurred where the Arlington weather station was the closest weather station to the site of the crash. Of these crashes 310 (22%) were classified by the crash report as overturning crashes. Only 1,275 of the total crashes were analyzed (275 or 22% overturn crashes) since weather data was not available from the weather station for the other crashes.

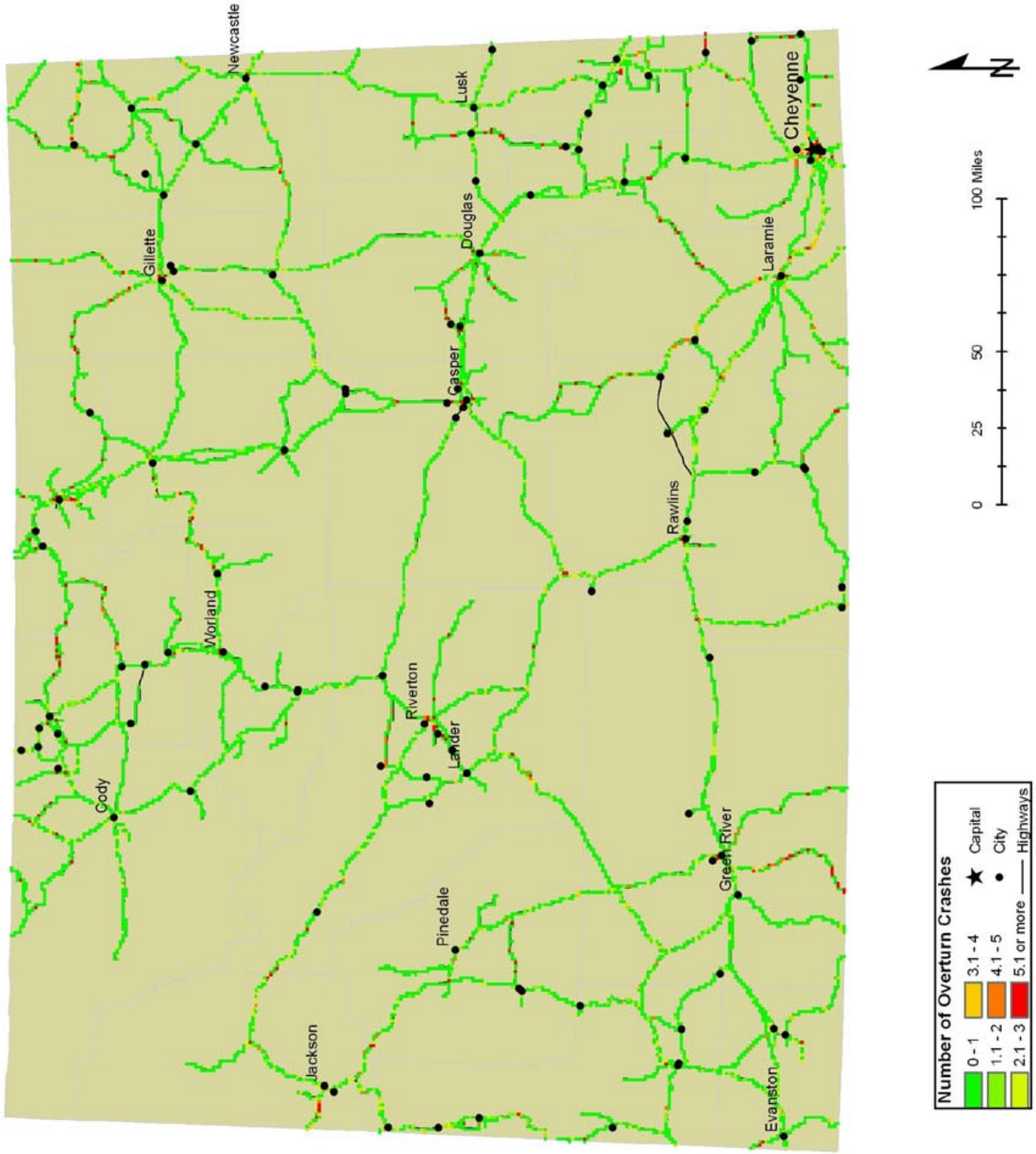


Figure 6-4: Wyoming Grid Analysis of Overturning Truck Crashes

The variables that were originally considered in the model included wind speed, gust, direction, and distance to the weather station. The basic form (Equation 6-1) of the model and the coefficient estimates for this first model are shown in Table 6-5. The model estimates the probability of an overturning accident occurring, P, given the values of the model parameters, β.

$$P = \frac{e^{\bar{\beta}}}{1 + e^{\bar{\beta}}}$$

$$\bar{\beta} = \beta_0 + \beta_1 x_1 + \cdots + \beta_k x_k$$

Equation 6-1: General Equation for Logistic Model

Table 6-5: Parameter Coefficients for the 1st Arlington Model

Parameter	Estimate	P-value
Intercept (β_0)	-1.8786	<0.0001
Wind Speed (β_1)	-0.1018	0.0051
Wind Gust (β_2)	0.1182	0.0002
Wind Direction (β_3)	-0.00171	0.1878
Distance (β_4)	-0.00834	0.2734

The wind-speed coefficient in this model was negative which is unrealistic because it is not reasonable to suppose that increases in wind speed would decrease the probability of an overturning accident occurring. Therefore, a new variable based on the difference between the wind gust and the wind speed was created. Also, for this station, it was found that the wind direction and distance to the weather station were not statistically significant at the 0.05 level. Models with the wind speed and the difference, and the wind gust and the difference were created and yielded similar results.

The coefficients for the model using only the wind speed and the difference between the wind gust and the wind speed is shown in Table 6-6.

Table 6-6: Parameter Coefficients for the Final Arlington Model

Parameter	Estimate	P-value
Intercept (β_0)	-2.0997	<0.0001
Wind Speed (β_1)	-0.1592	<0.0001
Wind Gust (β_2)	0.1592	<0.0001

The likelihood ratio for this model had a chi-squared value of 66.84 and a p-value of less than 0.0001. Since the p-value is less than 0.05 that means this model is much better at determining, given a crash occurred, the probability of that crash being a rollover crash given the wind speed and wind gust than just the overall probability of a rollover crash.

The area for the south Wheatland weather station had 348 crashes and 119 (34%) of these were rollovers. Weather data was available to analyze 279 (106, 38% overturn) of these crashes. Once again the first model was run with the four variables of wind speed, gust, direction, and distance to the weather station. The same basic form of the model was used and the coefficients for the parameters are shown in Table 6-7.

Table 6-7: Parameter Coefficients for the 1st Wheatland Model

Parameter	Estimate	P-value
Intercept (β_0)	-2.7058	0.0006
Wind Speed (β_1)	-0.1626	0.0993
Wind Gust (β_2)	0.2135	0.0127
Wind Direction (β_3)	0.00168	0.5635
Distance (β_4)	-0.0504	0.0001

Variables whose p-values were higher than 0.05 were removed one at a time until all the p-values were below 0.05. The final model included the following two parameters: wind gust and distance from the weather station. The values for the final model for this weather station are shown in Table 6-8.

Table 6-8: Parameter Coefficients for the Final Wheatland Model

Parameter	Estimate	P-value
Intercept (β_0)	-2.4883	<0.0001
Wind Speed (β_1)	0.0784	<0.0001
Distance (β_2)	-0.0461	0.0003

This model had a chi-squared value of 167.32 with a p-value of less than 0.0001 for the likelihood ratio. As with the previous model, this model does well at providing the probability of an overturn crash occurring.

The statewide model was the final model developed. Out of the 14,700 truck crashes throughout the state, 2,095 (14%) were overturning crashes. A total of 9,917 crashes (1,445, 15%) had the associated wind data and were used in the analysis. The same procedure was used and the model with all four variables produced the values for the coefficients shown in Table 6-9.

Table 6-9: Parameter Coefficients for the 1st Statewide Model

Parameter	Estimate	P-value
Intercept (β_0)	-2.5898	<0.0001
Wind Speed (β_1)	-0.0204	0.2892
Wind Gust (β_2)	0.0525	0.0015
Wind Direction (β_3)	-0.00030	0.4087
Distance (β_4)	-0.00807	<0.0001

Once again insignificant variables were removed from the model based on their p-values. The final statewide model included wind gust and distance to the weather station. The coefficients are shown in Table 6-10.

Table 6-10: Parameter Coefficients for the Final Statewide Model

Parameter	Estimate	P-value
Intercept (β_0)	-2.5436	<0.0001
Wind Gust (β_1)	0.0324	<0.0001
Distance (β_2)	0.00535	0.0003

This model also has a high chi-square value of 288.61 and a p-value of less than 0.0001. These high chi-squared values for all three models show that the probability of a truck crash being an overturning crash can be well estimated if some information is known about the wind speeds at the time of the crash.

Since all of the models can give the probability of an overturning crash better than the average probability there does seem to be a definite correlation between the wind gust and trucks overturning. This is an important result that leads to the possibility of developing operational rules for the roadways similar to those used by Nevada and Montana and discussed in the literature review section.

6.5 Future Work

This research will be continued to more fully implement the methodology given above. This will include additional work on the crash analysis and the wind vulnerability.

The crash analysis section will be continued by writing the sliding scale code in Visual Basic to be used in Arc Map. The code will then be used to perform the sliding scale analysis on the crashes in Wyoming. The high-crash locations will then be reported to WYDOT so it can decide how to best treat these problematic locations.

For the wind vulnerability, models will be developed and refined for the Arlington and south Wheatland areas as well as a statewide model. These models will also investigate the use of a new variable of wind gust minus wind speed. This was decided because the coefficients of the two parameters were close to the same absolute value but had opposite signs. These three probability models will then be converted into a predictive model that will tell at what wind speed and/or gusts it is hazardous for large trucks to travel. This information can then be used to determine at what wind speeds the road should be closed to truck travel.

7. Critical Infrastructure

7.1 Introduction

This report's first objective dealing with critical infrastructure is to define what constitutes critical infrastructure in Wyoming as it relates to the movement of freight. As mentioned in the literature review, the document that is, in essence, the driving force behind the national movement to define, evaluate, and protect critical infrastructure is PDD-63. The following quote from the second paragraph of PDD-63 sets forth a definition of critical infrastructure that will be used as the base from which to start:

> "Critical infrastructure are those physical and cyber-based systems essential to the minimum operations of the economy and government. They include, but are not limited to telecommunications, energy, banking and finance, transportation, water systems and emergency services, both governmental and private."

This broad definition will now be examined and refined to focus on the areas relating to the movement of freight in Wyoming. The portions of this definition that were deemed to be directly linked to the movement of freight included the minimum operations of the economy and government, energy, transportation, and emergency services.

The minimum operations of the economy can be broken down into two levels, economy of the state and the national economy. The reliance of the economy of the state on freight movement is demonstrated by the $50 billion of freight that was moved to, from, or within Wyoming in 1998 by trucks, railroads, or pipelines, which was discussed earlier in this report. The importance to the national economy can be seen by estimating the amount of freight that moves through the state but does not have an origin or a destination inside the state. In 1993, it was estimated that 92.2 percent of the movements of freight transported by truck in Wyoming were "through" movements (Bureau of Transportation Statistics, 1997). Relating this to the 1998 value of $50 billion of to, from, and within freight movements, of which 78 percent was transported by truck, an annual estimate of $500 billion in through freight movements by truck transport can be determined.

Although the previous estimate of the economic impact of transported freight is significant, it does not fully consider the impact of items such as coal, natural gas, and petroleum products that predominantly rely on rail and pipelines as modes of transportation. These importance of these items falls under the energy portion of the definition of critical infrastructure. In 2003, Wyoming was the nation's leading producer of coal with approximately 35 percent of the nation's total coal production. (Energy Information Administration, 2003). Numbers for 2002 show that 92.5 percent of the coal produced was shipped out of state and 92 percent of all coal produced was shipped by rail. (Energy Information Administration, 2002). Additionally, 98.5 percent of the coal produced was used in the production of electricity (Energy Information Administration, 2002a). Given that 57 percent of the nations production of electricity comes from coal-fired plants (Power Scorecard, 2004), Wyoming produces 35 percent of the nation's coal, and 98.5 percent of Wyoming's coal is used to produce electricity, it can be derived that Wyoming coal is responsible for approximately 20 percent of the electricity generated in the United States. Therefore, any long-term disruption to the rail mode of the freight transportation system in Wyoming would hinder the delivery of coal to the nation's power plants and would have far-reaching effects.

The oil and gas industries must also be considered when looking at the energy portion of Wyoming's critical infrastructure. In 2002 Wyoming was the fifth largest producer and the third largest exporter of natural gas (Energy Information Administration, 2002b) and the seventh largest producer of oil

(Petroleum Association of Wyoming, 2003). Wyoming gas plants processed 97 percent of the gas produced in the state while oil refineries processed 135,000 barrels of crude everyday (Petroleum Association of Wyoming, 2003). More than 16,000 miles of pipelines carried oil and gas through all 23 counties in Wyoming and these pipelines are running at or near capacity (Petroleum Association of Wyoming, 2003). The pipelines responsible for exporting Wyoming's natural gas have two main hubs, one outside of Opal in southwestern Wyoming that ships gas to the west and one outside of Cheyenne in southeastern Wyoming that ships gas to the east (Associated Press, 2003). With only two main hubs and a lack of redundancy in the pipeline system, long-term disruption to this mode of freight transportation could have a very negative impact on the state and on the consumers of these products.

Another way to tie the energy resources which are transported in the state to the definition of critical infrastructure is the minimum operations of government clause. While the government is not directly responsible for the production of coal, oil, or gas in the state, it is extremely dependant on their production, transportation, and subsequent sale. In 2002, the Wyoming government received just over $1 billion in property taxes, severance taxes, and royalties from these three industries (Petroleum Association of Wyoming, 2003).

The relationship between transportation as a segment of critical infrastructure and the movement of freight in Wyoming is self-evident. The transportation aspect, just like the economic operations, relies heavily on the highway system. Not only is the majority of the value of freight transported over the state highways, the people of this very sparsely populated state rely on highway system for their quality of life. Those who live in the smaller towns, which predominate Wyoming, must often travel to seek health care, for basic shopping needs, and for entertainment purposes. The vast majority of travel is conducted in private vehicles on the state highways as public transportation and rail travel are almost non-existent in Wyoming.

A section of the transportation field that delves into the cyber-based realm is the advent of intelligent transportation systems (ITS). ITS is just now getting a foothold in Wyoming with variable message signs, web cameras, and automated road closure gates. However, the possibilities for ITS are numerous and include many aspects that could deal directly with freight movements such as weigh-in-motion technologies and the wind vulnerability data collection efforts discussed earlier in this paper. As ITS applications become more predominant in the transportation field, steps will need to be taken to ensure their protection from outside attack; however this is not yet a major concern for Wyoming.

The delivery of emergency services is also inextricably tied to the economic operations and the transportation aspects of the critical infrastructure because of its reliance on the highway system. The majority of the roads connecting Wyoming cities are part of the National Highway System (NHS). The two main components of the NHS that are found in Wyoming are the Eisenhower Interstate System and the Strategic Highway Network (STRAHNET). The NHS is composed of highway infrastructure that supports national security in peacetime and war, economy, and mobility (FHWA, 2001a). The NHS also contains sections that have been determined to be "high priority corridors" (HPC) that are critical to the operation of the system. The Camino Real HPC runs approximately from the border with Mexico around El Paso, Texas, to the Canadian border and runs through Wyoming. The Wyoming section consists of I-25 from the Colorado border to the I-90 junction in Buffalo, Wyo., and then continues up I-90 to the Montana border (FHWA, 2001b). It is curious to note that although I-80 carries the bulk of the traffic in Wyoming, it is not designated as an HPC. The NHS and STRAHNET systems are critical for the delivery of emergency services and for the movement of troops and equipment especially given the lack of redundancy in the infrastructure available to carry out these functions in Wyoming.

Taking all of the previous discussion into account, the following more refined definition of the state's critical infrastructure was developed:

> Critical infrastructures are those highway, railway, or pipeline systems essential to the minimum operations of the economy and government. They include, but are not limited to systems linked directly or indirectly to energy, transportation, or the delivery of emergency services, both governmental and private.

This definition sufficiently narrows the scope of critical infrastructure that will be analyzed to the physical infrastructure directly responsible for the movement of freight. It also limits the analysis to the three prevalent modes of transportation used in Wyoming, which include highway, railway, and pipelines. This also eliminates the need to analyze aviation, mass transit, and waterborne commerce, as they are not extensively used to move freight in Wyoming. This definition also confirms that the Wyoming Department of Transportation will be the governmental agency with primary responsibility for all phases of oversight for any critical infrastructure identified.

7.2 Methodology

As stated in the literature review section, a host of modeling techniques such as game theory, Monte Carlo simulation, stochastic user equilibrium, and minimum cut sets, hierarchical holographic modeling, multi-objective tradeoff analysis, and risk filtering, ranking, and management were considered. Although all of these had points that were relevant to the modeling of critical infrastructure as it applies to this research, none of them completely captured the essence of what this research was striving for. Therefore, to fully meet the objectives set forth earlier in this paper, the methodology that was determined to best suit the purpose of identifying the critical infrastructure in regards to the movement of freight in Wyoming is a combination of the disruption index developed by Texas and Maryland and the stage one severity of impact analysis used by Virginia.

This decision was made for a variety of reason, the first being the desire to focus on an easily reproducible and readily transferable critical infrastructure index (CII) that could be easily communicated to and understood by various groups throughout the state. The need to be reproducible stems from the desire to be able to do periodic reviews of the CII as the systems change with time, new construction of assets, and continuing improvement efforts. The transferable nature is important because of the vast differences in the three modes of freight transport, highway, rail, and pipeline. As the CII will be used by various groups, all with differing levels of expertise, the CII needs to be easy to communicate and easy to understand to assure that it would be implemented by the various groups. The decision was made to have the CII focus primarily on the impact or severity that the loss of an asset would have on the system and let the various entities responsible for the maintenance and operation of the individual assets evaluate the unique vulnerability of each asset.

7.3 Results

Because the highway mode carries the majority of the monetary value of freight, it will be the first mode to be analyzed. It was determined that the most straight-forward way to address this problem would be a penalty function. With this in mind, the CII for the highway mode will be developed by using shortest path network algorithms with and without particular network segments with a penalty accessed for any delay that occurs within the system. The delay will be the difference, in hours, between the shortest path time with and without any given segment. This delay will then be assigned to every passenger vehicle and truck vehicle on the segment normally. Time value for each vehicle type will be applied to the delay. Time values will not vary by network so that the delay component is based solely on network volumes. The following equation will be used for the analysis:

$$CII = w_{Delay}[(ADTT * D * TTV) + ((ADT - ADTT) * D * TV)] + w_{value}[ADTT * D * GV]$$

Equation 7-1: Critical Infrastructure Index for Highways

Where,

CII = critical infrastructure index
wDelay = weighting factor for delay
wValue = weighting factor for goods value/importance
ADT = average daily traffic (veh/day)
ADTT = average daily truck traffic (truck/day)
D = delay per vehicle due to loss of segment (hours)
TV = time value for passenger vehicles (~$10/hr)
TTV = time value for trucks (~$50/hr)
GV = time value for delayed goods ($/hr, varies by segment)

The value component will incorporate a measure of the value or importance of goods on a particular network segment. For example, I-80 is critical for manufacturers and suppliers and disruption of the roadway has serious consequences on supply-chain logistics. Other segments might also be carrying high-value or highly time-dependent goods. The GV will be assigned based on the types of commodities being carried. By doing this, it allows for goods or services with national importance to be weighted heavier than goods of limited local importance. The weighting factors, w_{delay} and w_{value}, will vary between 0 and 1 with their sum equal to 1. This weighting factor will be used in scenario analyses to see how critical infrastructure changes with these factors. Ultimately, WYDOT planning staff would set the final weighting values to reflect the agency's planning goals.

The railway mode carries the next highest monetary value of freight so it will be the next mode to be analyzed. The CII for the railway mode will be developed by using the same penalty-type function and the shortest path network algorithms with and without particular network segments. The delay again will be the difference, in hours, between the shortest path time with and without that segment. This delay will then be assigned to every ton of freight normally transported on the segment. The equation for the railway mode will differ from the highway mode in several ways. First it will not account for passenger traffic on the network because of the relative lack of such traffic on Wyoming railways. Secondly, it will also include a penalty for additional mileage added to the route. This ton-mile penalty will be assessed for each additional mile of travel incurred due to the rerouting of the freight. The following equation, which was modified from the original equation presented, will be used for the analysis of the rail mode:

$$CII = w_{Delay}[ATT * D] + w_{value}[ATT * D * GV] + [PPTM * (Lr - Ln)]$$

Equation 7-2: Critical Infrastructure Index for Railroads

Where,

CII = critical infrastructure index
wDelay = weighting factor for delay
wValue = weighting factor for goods value/importance
ATT = average tons transported
D = delay per vehicle due to loss of segment (hours)
GV = time value for delayed goods ($/hr, varies by segment)
PPTM = price per ton mile ($/ton-mile, varies by segment)
Lr = length of rerouted path
Ln = length of normal path

As in the previous model, the value component will incorporate a measure of the value or importance of goods on a particular network segment. For example, the Powder River Basin produces the majority of Wyoming's coal and disruption of this segment of the railway network has serious consequences on supply-chain logistics for the nation's power plants. Other segments might also be carrying high-value or highly time-dependent goods. Again, by doing this it allows for goods or services with national importance to be weighted heavier than goods of limited local importance. The GV will be assigned based on the types of commodities being carried. The weighting factors, w_{delay} and w_{value}, will vary between 0 and 1 with their sum equal to 1. This weighting factor will be used in scenario analyses to see how critical infrastructure changes with these factors. Ultimately, the final weighting values would be adjusted by the railway operators with help from WYDOT to reflect the concerns and the planning goals of both agencies.

The mode to be analyzed next will be the pipelines. The CII for the pipeline mode will be developed by using the same penalty type function and the shortest path network algorithms with and without particular network segments. The delay again will be the difference, in hours, between the shortest path time with and without that segment. This delay will then be assigned to every million cubic feet of natural gas or every barrel of petroleum-based product normally transported in that segment of the pipeline.

The equation for the pipeline mode will differ from the highway and railway modes significantly. First, because most of Wyoming's pipelines are running at or near capacity, the delay portion of the equation will have the ability to go to infinity if additional capacity in system is not available to transport the disrupted flow. Therefore, the delay portion may become a measure of time required to repair the network instead of a measure of additional time transporting the product via a different route. Secondly, it will also include a penalty for additional miles the product must travel in the pipeline. This pumping cost penalty will be assessed for each additional mile of travel incurred because of the rerouting of the freight. The following equation, which is another modification of the original equation presented, will be used for the analysis of the pipeline mode:

$$CII = w_{Delay}[UT * D] + w_{value}[UT * D * GV] + [PCPM * (Lr - Ln)]$$

Equation 7-3: Critical Infrastructure Index for Pipelines

Where,

CII = critical infrastructure index
wDelay = weighting factor for delay
wValue = weighting factor for goods value/importance
UT = average unit of measure (MMCF or Barrel) transported
D = delay per vehicle due to loss of segment (hours)
GV = time value for delayed goods ($/hr, varies by segment)

PCPM = pump cost per mile ($/mile, varies by segment)
Lr = length of rerouted path
Ln = length of normal path

As in the previous model, the value component will incorporate a measure of the value or importance of goods on a particular network segment. For example, the natural gas hub at Opal ships enough gas to heat 13.3 million homes and disruption of this segment of the pipeline network would have serious consequences (Billings Gazette). Other segments, such as those that transport gasoline to various distribution points, also carry high-value or highly time-dependent goods. Again, by doing this it allows for goods or services with national importance to be weighted heavier than goods of limited local importance. The GV will be assigned based on the types of commodities being carried. The weighting factors, w_{delay} and w_{value}, will vary between 0 and 1 with their sum equal to 1. This weighting factor will be used in scenario analyses to see how critical infrastructure changes with these factors. Ultimately, the final weighting values would be adjusted by the energy producers, the refineries, and WYDOT to reflect the concerns and the planning goals of both agencies.

7.4 Future Work

Now that preliminary equations for the CII for each of the modes of Wyoming's freight transportation network have been derived, the next step will be to conduct a pilot study to collect experimental data for each mode. To accomplish this, the pilot study will analyze a limited number of segments of varying types and different unique situations that are found in highway, railway, and pipeline freight transportation. The data collected during this pilot can then be used to calibrate the w_{delay} and the w_{value} variables for the formulas derived for each of the modes. Once the equations have had their initial calibrations, input will be sought from personnel at WYDOT and representatives of the railway and energy production entities to further refine the equations. During this period of input and evaluation, GIS technology will be used to create an updatable database for all segments of all three of the modes of freight transportation. When the database of the segments is complete and the CII equations have been finalized, system-wide evaluations can be made for each mode. These evaluations will lead to reproducible rankings for the critical infrastructure for each mode. These rankings will then be communicated to the various entities and ways to implement the new knowledge into future decisions in operations, maintenance, and capital investments and be examined. Additionally, once the CII is proven to work reliably, the database can be turned over to the individual entities so that they can evaluate their systems as improvements are made.

One of the challenges with modeling critical infrastructure will be to attempt to model inter-modal connections and impacts between the major freight modes. For example, if a disruption was made to the highway network, what is the ability of the other modes to compensate for this disruption? Would disruption in one mode then have a rippling effect that would spur disruptions in other modes? The answer to these questions would be modeled by allowing products to transfer between modes at designated inter-modal locations. The extent to which these inter-modal transfers could be made would rely on the excess capacity of the various modes and be subject to the capacities of those connector facilities.

8. Results and Conclusions

8.1 Summary of Research Results

The research objectives were divided into three categories: general understanding of freight movement, freight safety and wind vulnerability, and identification of critical infrastructure. The results of each of these categories were discussed in their respective chapters but a brief summary is also provided here.

The general understanding of freight movement was presented as a list of critical questions. These are listed below:

- What is the volume of freight moving to, from, within, and through the state?
- What is the value of freight moving to, from, within, and through the state?
- How is the freight being moved?
- What commodities are being moved?
- What is the economic impact of freight movement to the state?
- What are the future projections for freight commodities and how will this affect the freight infrastructure in Wyoming?
- How can freight infrastructure be improved to increase the competitiveness of Wyoming products and the desirability of the state for new businesses?
- How vulnerable is the infrastructure?

It was found that the majority of freight based on value (more than 90%) was moving through the state. For freight moving to, from, or within the state, the majority by volume is moved by rail. When compared by value this percentage is significantly reduced because a large portion of the rail shipments is low-value coal. Coal makes up the vast majority of products exported based on volume. When comparing by value, chemical and allied products and farm products are the top two commodities.

Growth is predicted in the energy and mineral fields, particularly bentonite clay. This, coupled with large growths in the freight moving through the state, may cause growing pressure on the freight infrastructure system.

The main questions left to address are the vulnerability of the infrastructure and how freight improvements can aid economic development. The infrastructure vulnerability will be discussed separately below. The link between economic development and transportation infrastructure was addressed in earlier sections by determining the number of jobs and the value of the freight goods movement.

The second major task was to investigate freight safety and wind vulnerability of freight vehicles. The research objectives for this task are summarized below:

- Develop a methodology to be used by the Wyoming Department of Transportation for the analysis of freight-vehicle accidents.
- Application of the safety methodology to determine high-hazard locations for freight-vehicle accidents.
- Develop a methodology for linking weather station data, in particular wind-speed data, to crash data.

- Apply methodology to determine if correlation exists between weather data wind speeds and freight-vehicle overturning accidents.
- Make recommendations on whether existing weather stations are adequate and/or properly located to provide good coverage of the roadway system with respect to predicting overturning freight vehicle accidents.

The methodology for identifying freight-vehicle accidents was completed for the grid analysis. This method has the benefit of being computationally straightforward but may miss high-hazard locations because of the arbitrary grid pattern it imposes. The sliding scale methodology requires more intensive programming but promises greater accuracy.

Both of these methods are an improvement because of the GIS platform they operate within and their use of accident rates over accident frequencies employed by WYDOT's current system.

The wind vulnerability aspect of this research task linked rollover accident data with wind speeds from the closest weather station. Initial results showed that the correlation between the two was better than expected. Wind speeds are thought to be highly localized and it is surprising to see that high levels of correlation exist. This brings greater hope that weather station data could be used for developing operational guidelines for freight vehicles using the roadways. This will be addressed in follow-up research.

The last task was regarding the identification of critical infrastructure. The research objectives are shown below:

- Define critical infrastructure and state what transportation infrastructure will be considered in this project.
- Review critical infrastructure methodologies that have been applied elsewhere and discuss their applicability to Wyoming.
- Select an appropriate methodology and refine to meet the characteristics of Wyoming.
- Document the procedure for applying the methodology in Phase II of the research project.

The methodology was developed for identification and link to the larger effort of quantifying the freight volumes from the first task. Application of the methodology will take place in the second phase of this research.

8.2 Phase II Research

The next year of the research effort will wrap up the tasks from the first year as well as develop each task further. The objectives of the safety task will be to develop predictive models for wind speeds and rollover accident potential. This predictive model will then be used to develop operational guidelines for applying this model to freeway operations.

The critical infrastructure methodology developed in the first phase will be applied to the freight network. The results of this will lead to operational and maintenance strategies as well as homeland security plans. Applying the critical infrastructure methodology will require additional work in the general freight understanding area as volumes and freight values will need to be more accurately quantified.

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