MOUNTAIN-PLAINS CONSORTIUM

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Incorporating Tourism Data in Traffic Estimation on Wyoming Low-Volume Roads

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16. Abstract

This report explains the various data inputs and outputs associated with the travel demand model (TDM) developed for estimating traffic volumes on low-volume roads in Wyoming. This study incorporated tourism-related data into the TDM and developed methods to estimate traffic volume on low-volume roads in Wyoming. The new tourism-based model shared many features with the previously developed model, including geography, traffic analysis zone structure, and networks. The newly developed model was then verified by comparing actual traffic volumes to those predicted by the model. The model implementation required several data inputs, including Wyoming local road network and tourism data. The output results were in the form of geographic data, indicating the various roads and their traffic volumes. This document describes the various data utilized and produced in the model. It also explains how to interpret the traffic volume data from the output map. State departments of transportation, local transportation administrators along with other stakeholders concerned with transportation planning are among the audiences interested in this report.

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Incorporating Tourism Data in Traffic Estimation on Wyoming Low-Volume Roads

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ABSTRACT

This report explains the various data inputs and outputs associated with the travel demand model (TDM) developed for estimating traffic volumes on low-volume roads in Wyoming. This study incorporated tourism-related data into the TDM and developed methods to estimate traffic volume on low-volume roads in Wyoming. The new tourism-based model shared many features with the previously developed model, including geography, traffic analysis zone (TAZ) structure, and networks. The newly developed model was then verified by comparing actual traffic volumes to those predicted by the model. The model implementation required several data inputs, including Wyoming local road network and tourism data. The output results were in the form of geographic data, indicating the various roads and their traffic volumes. This document describes the various data utilized and produced in the model. It also explains how to interpret the traffic volume data from the output map. State departments of transportation (DOTs), local transportation administrators along with other stakeholders concerned with transportation planning are among the audiences interested in this report.

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EXECUTIVE SUMMARY

This study is the third phase (Phase III) of a continuing study of developing travel demand models (TDMs) that estimate traffic volumes on low-volume roads in Wyoming. This study incorporated tourism-related data into the previously developed TDM and developed methods to estimate tourism-related traffic volumes on low-volume roads in Wyoming. This report provides a general summary of the key procedures to develop a tourism-based TDM for low-volume roads in Wyoming. This report also describes the required input data sets for the model development. The purpose of this report is to provide the Wyoming Department of Transportation (WYDOT) and consultants with information about the tourism-based TDM, and to provide direction on the preparation of model input data sets.

1. INTRODUCTION

1.1 Background

Phase I of this study developed traffic estimating models for four counties in Southeast Wyoming: Laramie, Converse, Goshen, and Platte. Regression models were developed to estimate traffic volumes using pavement type; whether the road has direct access to a highway (coded as 1) or not (coded as 0); population in the census block group where the road is located; and land use (categorized into pastureland, cropland, industrial land, and subdivisions). A TDM (a person trip model) was also developed to estimate traffic volumes on the low-volume roads. Finally, the accuracy of traffic volume estimates from the TDM was compared to the accuracy of the regression model estimates. Phase I concluded that the TDMs were more suitable and accurate for estimating traffic volumes on low-volume roads (Apronti et al., 2016). Therefore, Phase I recommended a second phase of the study to improve the TDM and implement the model for the entire State of Wyoming.

Phase II of this study reviewed the model developed in the earlier phase and streamlined the transportation analysis zone (TAZ) delineation process with rules that ensured the process could be replicated across the state (Apronti and Ksaibati, 2018). In addition to the person trips generated in Phase I, additional trip generation sources — agricultural crop production related freight trips and oil production related freight trips — were included in an updated model for estimating traffic volumes. Input data for the model was collected from the U.S. Census, the U.S. Department of Agriculture (USDA), and the Wyoming Oil and Gas Conservation Commission (WOGCC). Wyoming was divided into four regions and delineation of TAZs for each region was done concurrently to stay ahead of schedule. Figure 1.1 shows the four regions as used in the study. A four-step TDM was implemented for Wyoming with a modification that excluded the traditional mode choice step. Figure 1.2 presents the research methodology implemented in Phase II. The person trip model was based on the model developed in Phase I that utilized demographic and employment data to estimate traffic volumes. In the case of the freight trips (crop production related trips and oil production related trips), crop production in each TAZ was computed in tons and the result was divided by the hauling capacity of a truck to determine the truck trips required to haul the crop produced in the TAZ to the crop elevator. For oil production, an estimate of oil produced in each TAZ and the associated wastewater production and water demands were computed in barrels. The capacity of a typical truck was then used to convert the barrels of product produced in a day into truck trips. The model outputs from Phase II were adequate for estimating traffic volumes on low-volume roads in Wyoming. However, the model outputs indicated lower efficiency in estimating traffic volumes in Region 3, where Yellowstone and Grand Teton National Parks are located and many tourism activities take place. The study therefore recommended a third phase of the study to include tourism activities in the model for more accurate traffic volume estimation. Figure 1.3 shows the locations of these two parks.

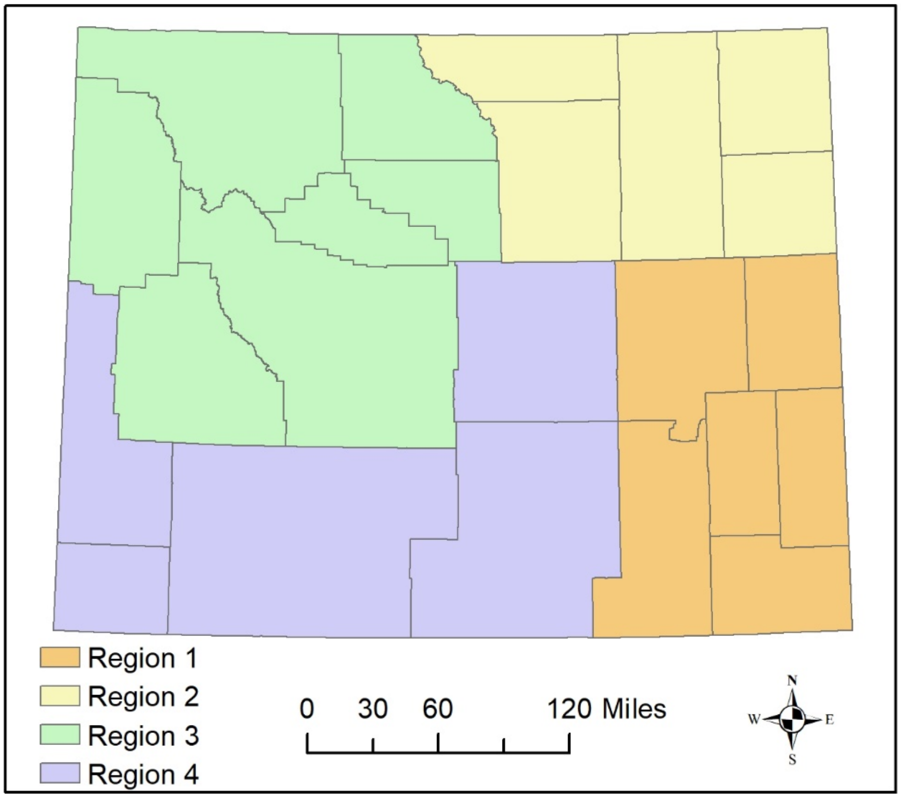

Figure 1.1 Wyoming Divided into Four Regions

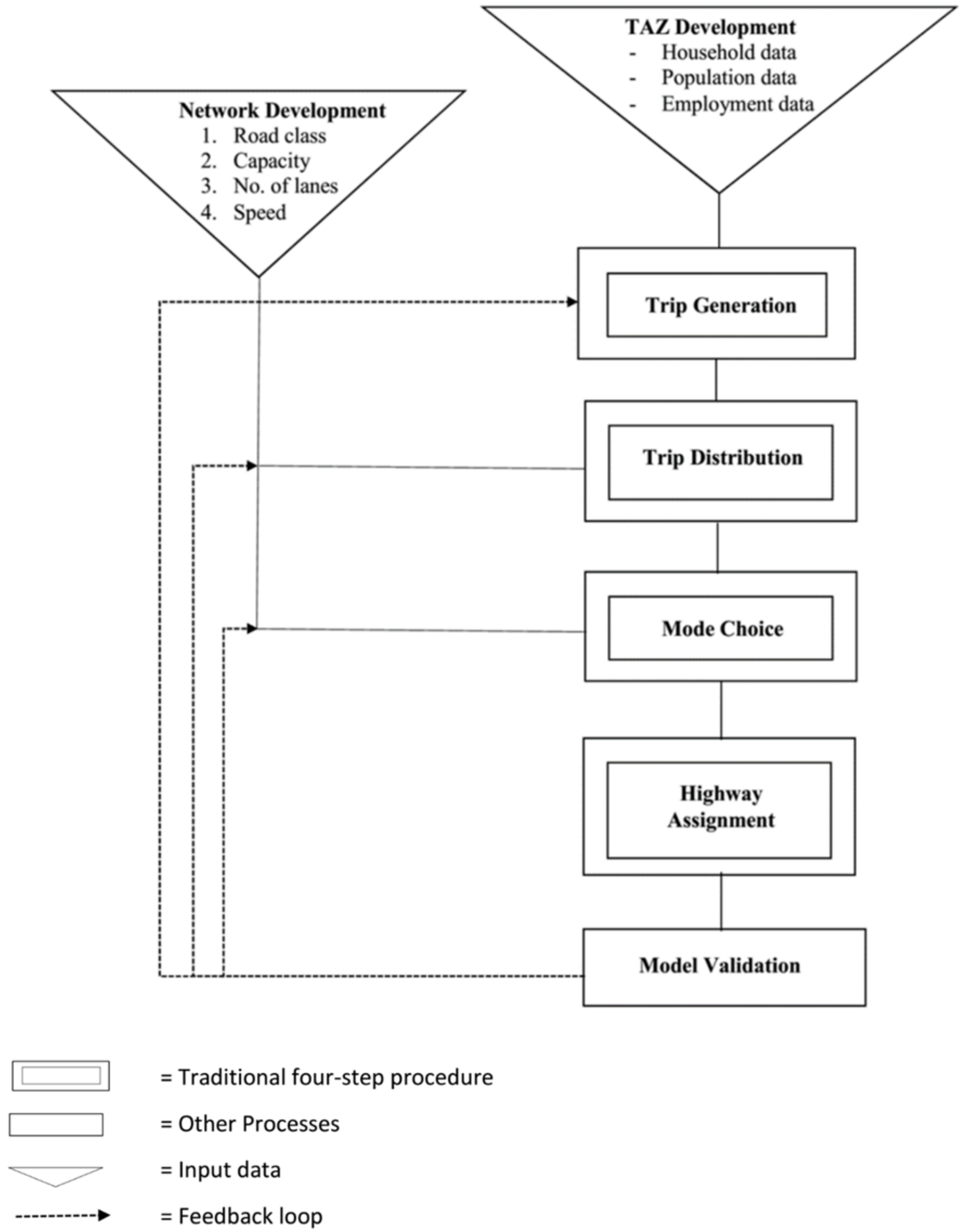

Figure 1.2 Research Methodology Implemented in Phase II

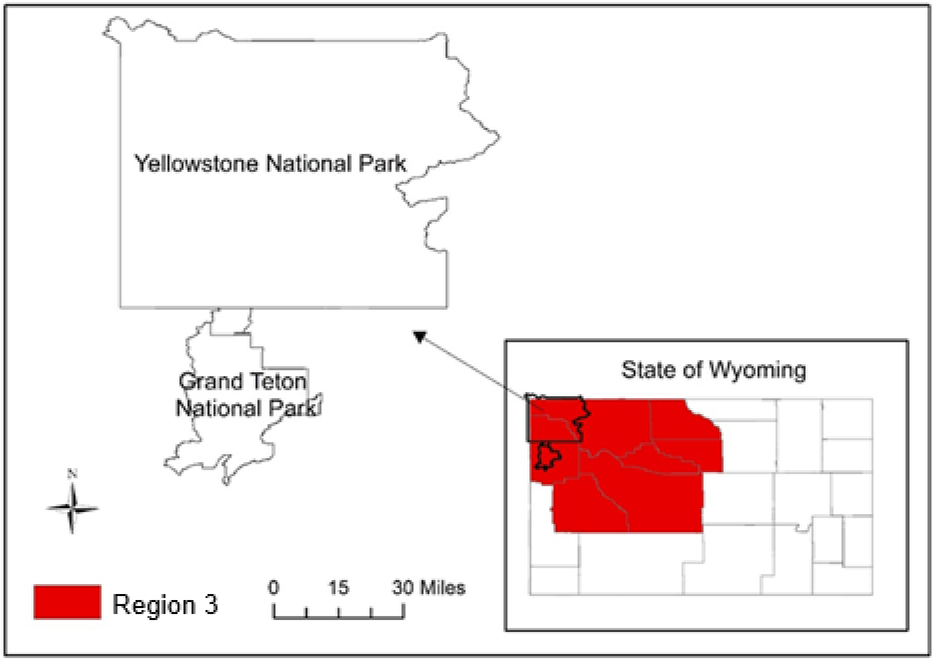

Figure 1.3 Locations of Yellowstone and Grand Teton National Parks

Phase III of this study incorporated tourism-related parameters into the previously developed TDM to estimate traffic volumes on Wyoming low-volume roads. The input tourism data was obtained from the NPS and the WSPHST. The tourism trip model utilized average daily traffic (ADT) at park entrances, park areas, and a number of campsites in each park as model inputs. Results suggested that the proposed method can be used to predict traffic volumes on local and rural roads near tourism destinations. The predicted values can then be compared to actual traffic volume data to locate areas that may have underestimated traffic flows. The models are recommended for use by local governments and national and state parks for transportation planning in related areas. The resulting trips for personal travel, crop production, oil production, and tourism were then combined to obtain the estimated total traffic volumes in the network.

1.2 Problem Statement

Tourism is the second largest industry in Wyoming. Wyoming welcomed 8.5 million visitors in 2016 (Wyoming Office of Tourism, 2017). Yellowstone and Grand Teton National Parks were among the top 10 most-visited national parks in 2016. In addition, based on a recent survey, Wyoming ranked 16 for best road-trip U.S. states for summer. As one of the least populated states in the United States, Wyoming is famous for wilderness landscapes, historic towns, ranches, and cowboy cultures. Tourism-related activities in Wyoming include but are not limited to outdoor adventure, recreation, and entertainment. The combination of low population density and natural scenery makes Wyoming a good place for epic road trips. Figure 1.4 shows the road trip itineraries in Wyoming recommended by the Wyoming Office of Tourism. The itineraries include: Salt to Stone, which covers Flaming Gorge National Recreation Area and Fossil Butte National Monument; Rockies to Tetons, which covers some mountain ranges and Grand Teton National Park; Park to Park, which covers some state parks and historic towns; Black to Yellow, which covers the Black Hills National Forest, Devils Tower National Monument, and Bighorn Canyon National Recreation Area.

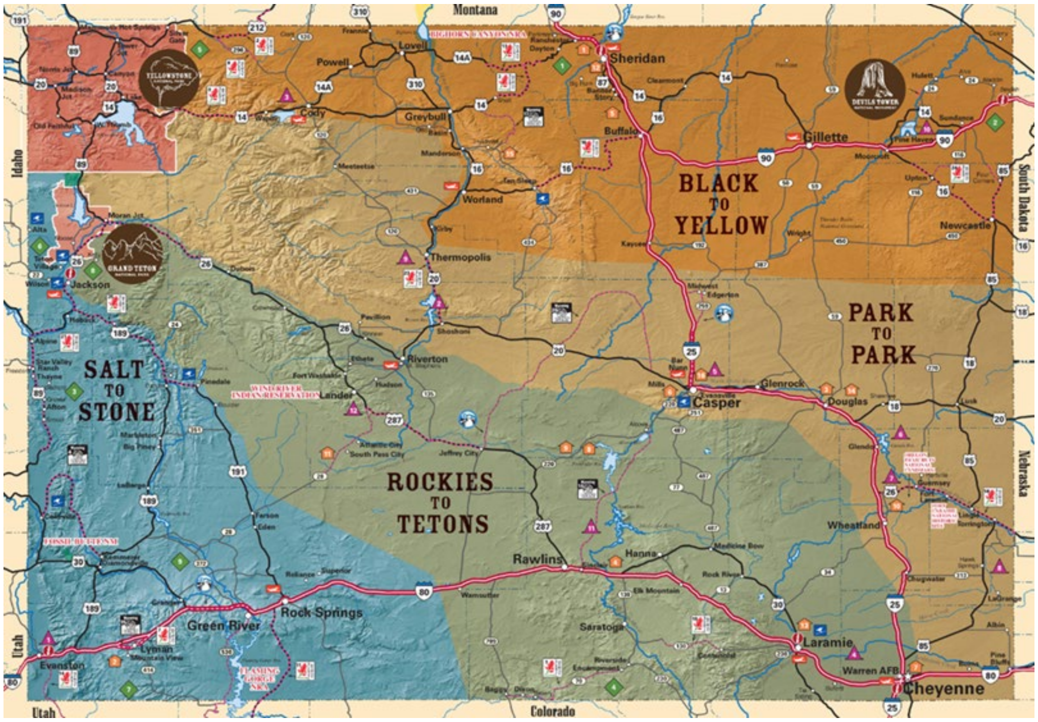

Figure 1.4 Road Trip Itineraries (Wyoming Office of Tourism, 2017)

There are five national parks and historic sites in Wyoming: Yellowstone National Park, Grand Teton National Park, Devils Tower National Monument, Fossil Butte National Monument, and Fort Laramie National Historic Site. Figure 1.5 shows annual total visitors to all five national parks and historic sites from 2000 to 2017. Yellowstone and Grand Teton National Parks have experienced increasing visitors in recent years. They are a place known and loved by local, regional, national, and international visitors. Annual visitors to Yellowstone National Park have increased from three million before 2000 to more than four million in 2017, and annual visitors to Grand Teton National Park have increased from 2.5 million before 2000 to more than 3.3 million in 2017 (National Park Service, 2016). Transportation is a key element in tourism, and it is crucial to estimate traffic volumes on rural roads near the parks and improve road network to enhance visitor experience.

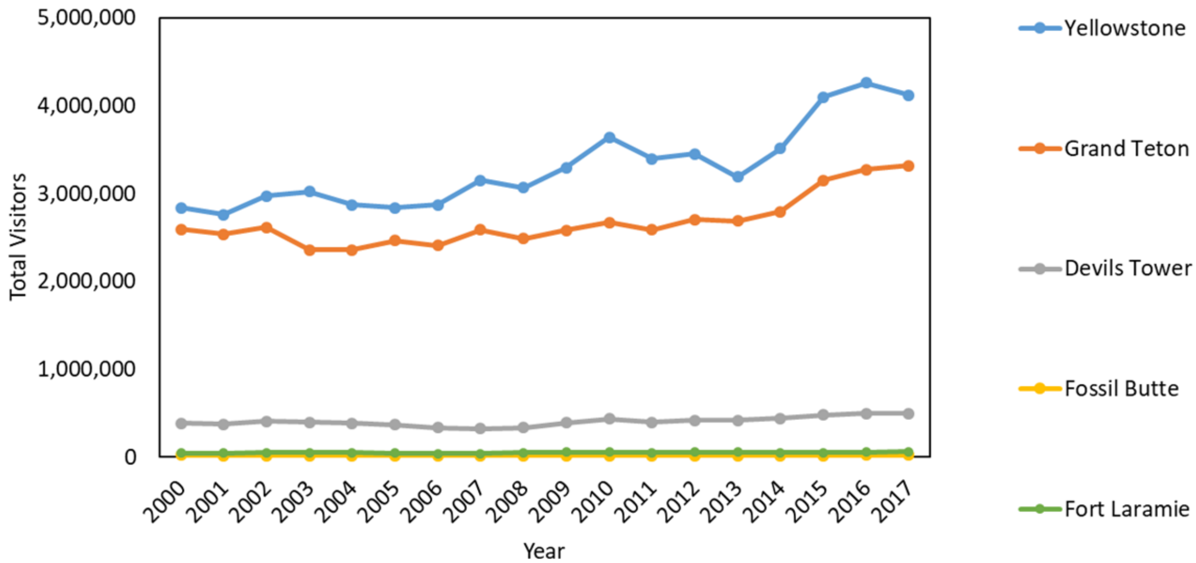

Figure 1.5 Annual Visitors to All Five National Parks and Historic Sites in Wyoming

In addition to national parks, the Wyoming State Parks and Historic Sites (WSPHST) are also popular destinations and stops for leisure tourists. Figure 1.6 shows the locations of WSPHSTs. Starting in 2013, the WSPHST began collecting visitation data year round. Visitation to the WSPHST has steadily increased over the last 20 years. In 2014, 3.6 million visitors came to state parks and 300,000 visitors came to state historic sites. Over two-thirds of the visitors to Wyoming state parks and historic sites are traveling with family members. According to a visitor survey in 2014, visiting state parks continues to be the most influential motivator for Wyoming tourists. Enjoying scenery, hiking, wildlife watching, and visiting historical sites round out the top activities motivating travel. In the 2016 visitor report, the WSPHST served nearly four million visitors representing approximately 70,000 more visitors than the previous year. Figure 1.7 shows annual total visitors to all Wyoming state parks and historic sites from 2006 to 2016.

Figure 1.6 Locations of WSPHSTs (Wyoming State Parks and Historic Sites, 2014)

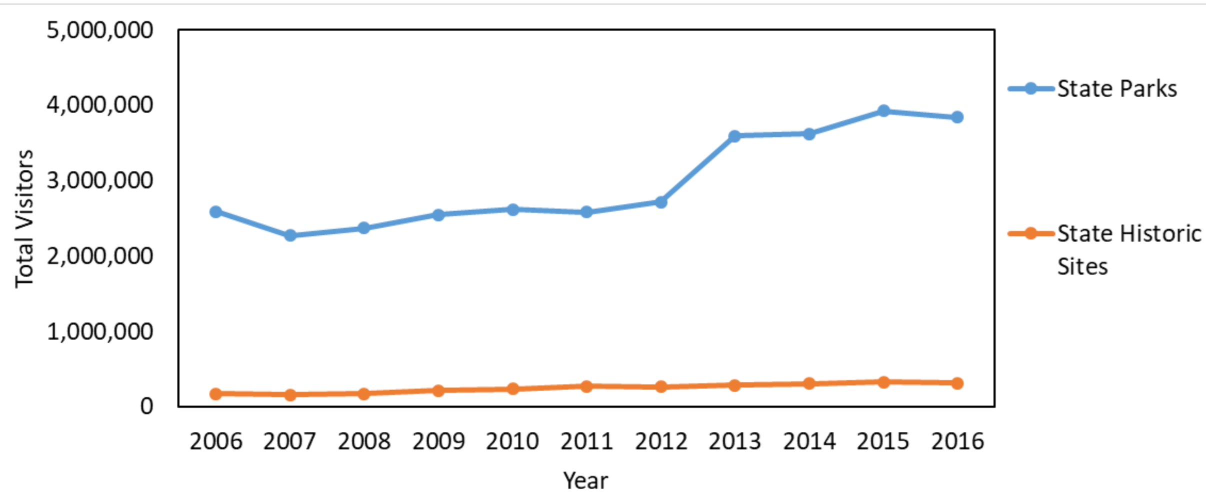

Figure 1.7 Annual Visitors to All State Parks and Historic Sites in Wyoming

The installation of traffic counters on roads is an effective way to estimate traffic volumes. However, it would be prohibitive to install traffic counters on all roads, particularly for rural low-volume roads (Zhong and Hanson, 2009). An alternative to the traffic counters is to develop a travel demand model to estimate traffic volumes. A four-step travel demand model, including trip generation, trip distribution, mode choice, and trip assignment, is the traditional procedure for transportation forecasting. In a travel demand model, traffic volumes are estimated through the interaction of travel supply and demand (McNally, 2007). The outputs of a travel demand model include a variety of traffic-related parameters, such as ADT, travel time, and congestion levels. ADT values from travel demand models are rough estimates based on the input parameters used in models. They can be used in many areas of transportation applications such as design, forecasting, planning, and policy making (Wang and Kockelman, 2009). Most state Departments of Transportation (DOTs) have developed and implemented four-step travel demand models for large metropolitan areas. However, some of those advanced models are not applicable for most county or rural roads which carry a low ADT. Therefore, a travel demand model designed for low-volume roads is needed for local agencies (Mohamad et al. 1998).

1.3 Objectives

The State of Wyoming is facing a tourism industry development in rural areas. A transportation management plan is needed to accommodate the rural roads with higher traffic volumes. This study met three objectives: enhance the TDMs developed in Phase I and II by including tourism inputs in the model; implement the model for the whole State of Wyoming to estimate traffic volumes on low-volume roads; and conduct an analysis to determine the seasonality in tourism travel demand and the impact of tourism travel on local transportation system.

The model outputs will support a wide variety of design, planning, and management functions on the state and county road networks. Using improved models will make better traffic volume estimates possible with the same data, thereby lowering costs and improving the quality of traffic information. By taking advantage of better software and models, more and higher quality information may be provided, leading to improvements in safety and other planning efforts.

1.4 Report Organization

This report includes six parts. Section 2 reviews the literatures on tourism TDM development. Section 3 describes the input data sources and collection procedures. Section 4 describes the TDM development procedures. Section 5 presents model outputs and model validation procedures. Section 6 performs a seasonality analysis to evaluate seasonal tourism traffic. Section 7 provides the summary and conclusions.

2. LITERATURE REVIEW

2.1 Introduction

This section reviews previous literature and studies that focus on tourism-related TDM development. In this literature review, the background, relationship between tourism and transportation, models developed by other state are described to make the reader aware of current conditions related to this study.

2.2 Low-volume Roads in Transportation Systems

Low-volume roads, defined as less than 400 vehicles per day, are crucial parts of transportation systems. They serve as important links between rural areas and markets (Keller and Sherar, 2003). Traffic volume estimation on high-volume roads has received attention from transportation engineers and researchers. Low-volume roads in rural areas have been largely ignored by transportation planning and maintenance compared to high-volume roads. However, in recent years, there has been a need for reliable traffic volume estimation on low-volume roads focusing on road maintenance and safety issues (Seaver et al., 2000). Rural tourism has gained attention from tourists, policy-makers, and investors in different regions of the world (Sharpley, 2002). For example, Hernández et al. (2016) compared the main features in rural and mass tourism in Catalonia, Spain, and made recommendations for rural tourism development in that area. Rural tourism also has been developed rapidly in China. Some traditional agricultural towns in China recently have been transformed into tourism destinations (Chen, 2017). In Africa, rural tourism industry is considered as a potential way to promote local economic development (Rid et al., 2014). A well-designed and maintained low-volume road network is essential for regional development and resource management. When determining cost-effective solutions for low-volume road maintenance, it is important to understand factors that affect the road environment. Figure 2.1 shows these factors, which include natural (uncontrolled) and human (controlled) factors. Together, these factors will influence the performance of low-volume roads. From Figure 2.1 it can be seen that traffic is one of the controllable factors in the low-volume road environment.

Better traffic estimation models on low-volume roads will allow more information to be collected with minimal additional data and perhaps, more information may be provided with less data. These improved models would allow for more cost-effective management of county and secondary state roads. The comprehensive traffic models to the state's low-volume roads will provide decision-makers and planners with more effective planning on transportation network (Apronti et al., 2015). Two recent motivating factors for increased low-volume road traffic counting and estimating efforts relate to their roles in air quality and safety mitigation. It is widely recognized that traffic fatality rates on rural roads are higher than on other roads. With better estimates of traffic on low-volume county and secondary state roads, better targeted and more effective safety improvement efforts can be made. In broader terms, better estimates of traffic volumes on low-volume roads will allow for more effective planning and more efficient operations.

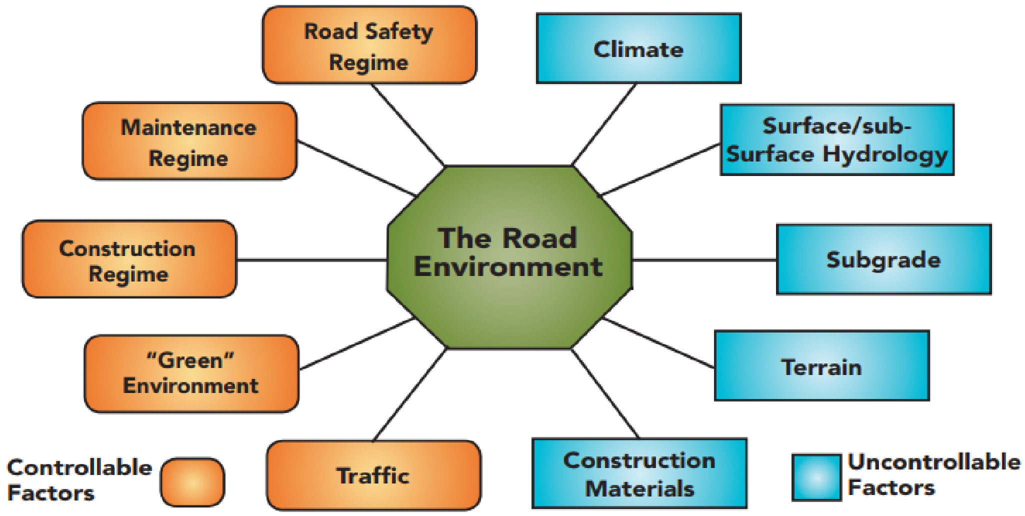

Figure 2.1 Low-Volume Road Design Principles (U.K. Roads Authority, 2016)

2.3 Impact of Tourism on Transportation

Tourism travel poses some transportation planning considerations, which typically differ from commuter travel and commercial transport issues. Transportation is a key to accessing major tourism attractions and it can be a critical element of the operation of visitor attractions. The integration of effective management into well-designed road networks can reduce total travel time (Litman, 2008). Effective transportation planning on low-volume roads for tourism can produce appropriate solutions for balancing the traffic needs of different traveler groups during peak tourism seasons or special events (National Cooperative Highway Research Program, 2012). The National Cooperative Highway Research Program (NCHRP) has conducted a survey on improved accessibility of tourism destinations by developing the road network. The survey covered state DOTs, state tourism/parks departments, and regional agencies. A total of 41 responses were received, including 32 state DOTs (11 western states, five central states, nine southeastern states, and seven northeastern states) and other agencies. Not surprisingly, the survey confirmed that tourism is recognized as a major interest among many transportation and tourism agencies. Figure 2.2 indicates that both types of agencies see a similar set of joint interests. These findings confirm a wide range of common interests spanning transportation and tourism planning and indicate that differences in institutional mandates are also a factor. The most notable differences are that state DOTs are more likely to see road design and safety as issues high on their list of joint interests, and less likely to put tourism promotion high on that list. It is also notable that access and tourism facilities appear to be the two areas of high interest with the smallest differential in interest between the two types of agencies—indicating a potential for converging interests.

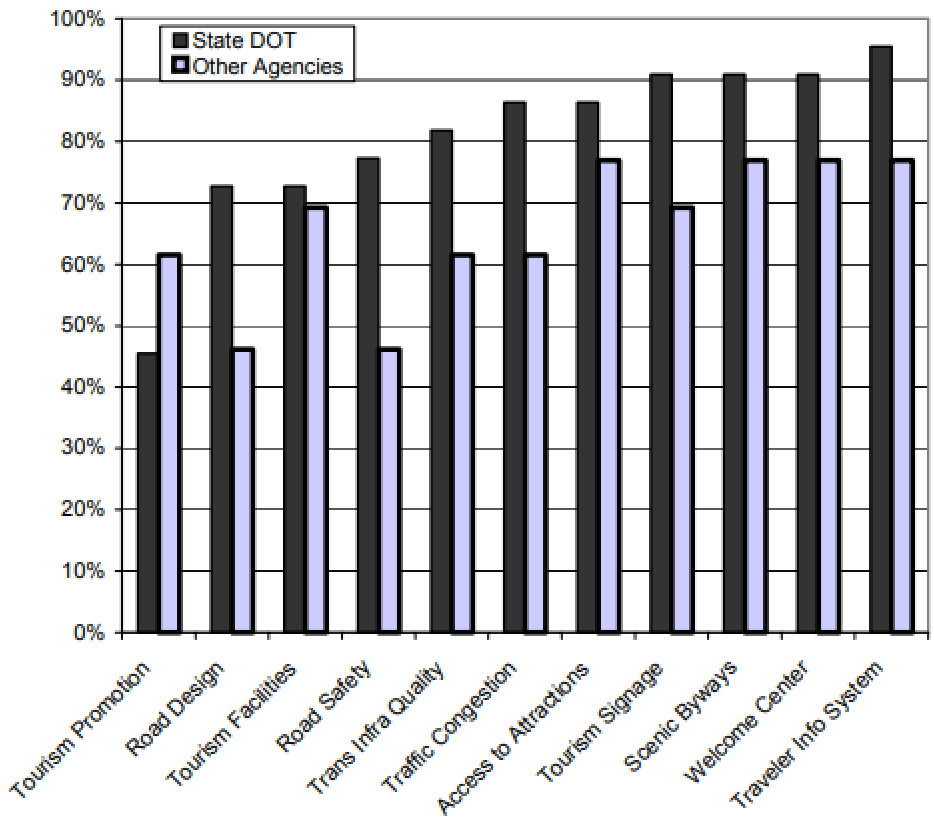

Figure 2.2 Issues Considered in Transportation and Tourism Planning (National Cooperative Highway Research Program, 2012)

2.4 Traffic Volume Estimation

Traffic flows and volumes are primary pieces of information when making transportation design, planning, safety, administration and management decisions (Wang and Kockelman, 2009; Sharma et al., 2001; Seaver et al., 2000). Unfortunately, resource constraints often restrict agencies from conducting counts at all areas of interest (Pulugurtha and Kusam, 2012). As part of the federally mandated Highway Performance Management System (HPMS), each state is required to provide summary data for their rural minor collector and local road networks. A primary element of this summary data is the total vehicle miles traveled on these roads. The State of Wyoming used actual traffic recorders (ATRs) to monitor traffic volumes on rural and local roads. Figure 2.3 shows the traffic monitoring sites across the state.

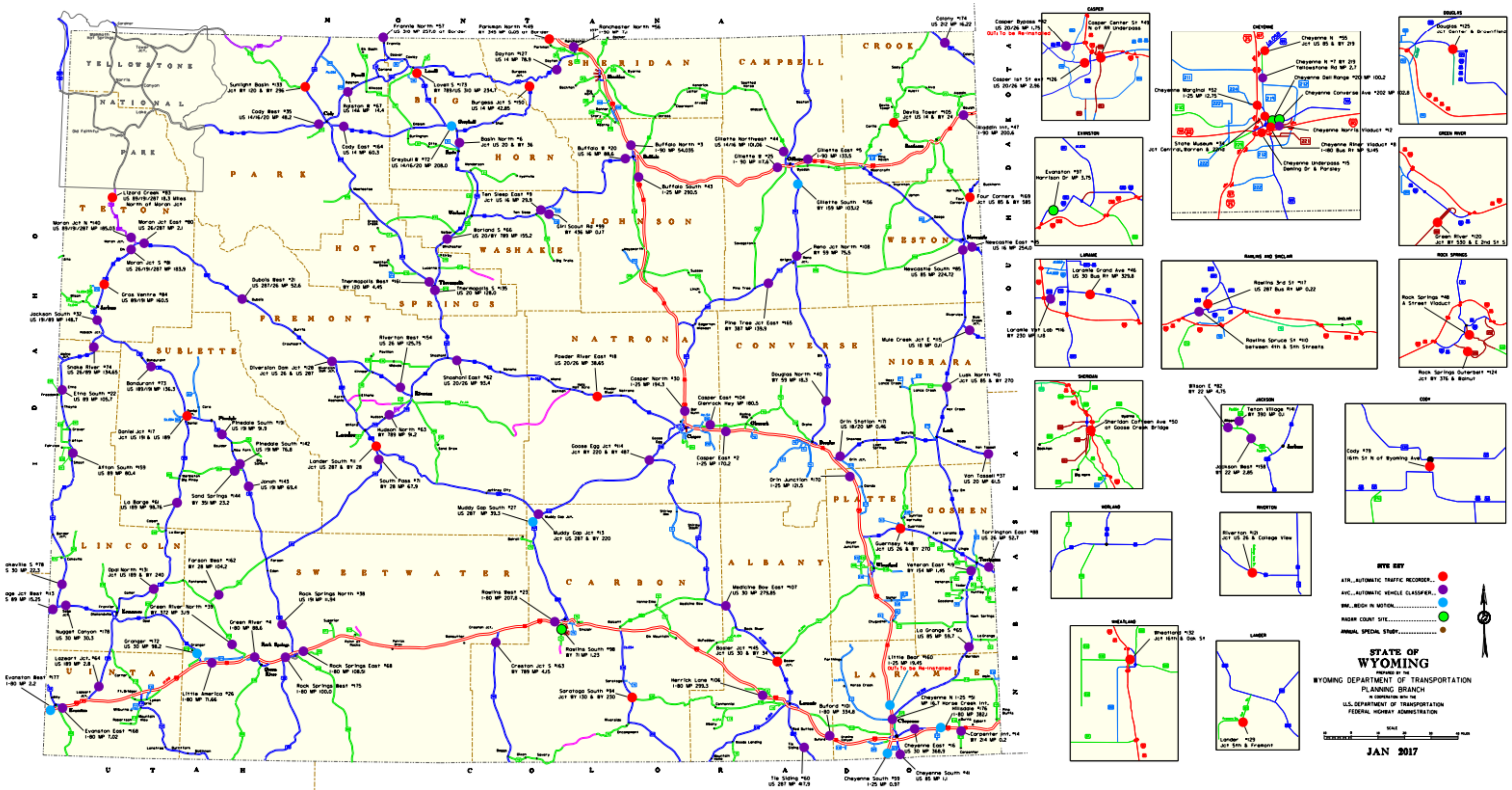

Figure 2.3 Wyoming Actual Traffic Recorder Locations (Wyoming Department of Transportation, 2017)

In Florida, improved estimates of travel on local roads are used to "apportion federal funds, estimate vehicle emissions, determine crash rates, and prepare bridge condition ratings" (Blume et al., 2005). The utility of traffic flow information, combined with the prohibitive expense of counting traffic on a high percentage of the many low-volume roads, makes an easy, inexpensive method for estimating low-volume road traffic highly desirable. The American Association of State Highway and Transportation Officials (AASHTO) recognizes a number of benefits from traffic data; some are relevant to low-volume roads, while others are not. Those that may be relevant to low-volume roads include: project selection, pavement design, safety analysis, pavement and bridge management systems, traffic simulation, traffic forecasting, air quality, and implementation of access controls. In addition to these direct agency benefits, further benefits identified affect: commerce and economic development, motel and service station chains, chambers of commerce, and litigation tort claims (American Association of State Highway and Transportation Officials, 1992).

Many studies have focused on the estimation of traffic volumes and the various factors affecting the values. Zhan et al. (2017) developed a hybrid framework to estimate citywide traffic volumes. Their results indicated the effectiveness of the proposed framework in traffic volume estimation. Kwon et al. (2003) proposed an algorithm to estimate real-time truck traffic volumes from single loop detectors on Interstate 710 near Long Beach, California. The algorithm captured the daily patterns of truck traffic volumes and mean effective vehicle length with only 5.7% error. In addition to urban areas and interstate highways, the issues of traffic volumes on low-volume roads have also been addressed in some research. Sharma et al. (2001) applied artificial neural networks to estimate average annual daily traffic (AADT) on low-volume rural roads in Alberta, Canada. They found a number of advantages of the neural network approach in AADT estimation compared to the traditional approach. Karlaftis and Golias (2002) developed a statistical methodology to assess the relationship between rural road geometric characteristics and traffic volumes on rural roadway accident rates. The methodology they developed allowed for the explicit prediction of accident rates on rural roads. Raja et al. (2018) developed a linear regression model to estimate AADT on low-volume roads for 12 counties in Alabama. Their research concluded that the linear regression model can be used to estimate AADT on low-volume roads for future application. Several states in the United States have conducted studies on rural roads. A number of factors can affect traffic volumes. Demographic data, including population, household, and employment, are usually used in travel demand model. To improve the model prediction accuracy, some other factors were also included in the previously developed models. In addition to demographic data, Saha and Fricker (1986) used some economic factors, such as gasoline price, consumer price index (CPI), and gross national product (GNP) to develop models for rural traffic forecasting. Tourism trips occupy a major part of traffic volumes in Wyoming, especially near Yellowstone National Park. The use of tourism-related travel data in travel demand model is one of the ways for transportation planners to incorporate tourism issues into their forecasting, planning, and designing processes. More focus has recently been given to the transportation systems in and near national parks because of the levels of visitor demand exceeding the transportation infrastructure in many parks (National Park Service, 2016). Several studies have assessed the cost-effectiveness and practicality of alternative transportation solutions, including roads, parking, bus services, and other forms of transit facilities. Overall, 42% of the state DOTs and 54% of the other agencies reported that they regularly make use of tourism travel forecasts. Among the state DOTs that do make use of tourism forecasts, the dominant use is for transportation planning (National Cooperative Highway Research Program, 2012). In tourism planning, evaluation in new and expanded transportation facilities can serve to support the operation and development of attractions (such as national parks) and identify needs for future maintenance.

2.5 Four-Step Travel Demand Models

Although the impact of tourism on transportation has been widely discussed in literature, quantitative analysis that measures the impact using numerical models is scarce. Some studies applied computable general equilibrium (CGE) models (Van Truong and Shimizu, 2017). A variety of methodologies have been used to estimate traffic volumes. Of all the methodologies, a four-step travel demand modeling, including trip generation, trip distribution, mode choice, and trip assignment, has been widely used for transportation planning. A travel demand model is a computer-based model used to estimate travel demand and pattern in the future based on a number of factors (McNally, 2007). Travel demand models are useful tools for transportation planning purposes. The outputs of travel demand models can help decision makers make appropriate transportation planning decisions. Developing transportation analysis zones (TAZs) is the first step of TDM. TAZs serve as the primary unit of analysis in a travel demand forecasting model. They contain socioeconomic data related to land use. TAZs are where trips begin and end. The first step could be to calculate the area of TAZs using a geographic information system (GIS) to determine if they are too large for the density of that area. Additionally, one can overlay the current TAZ structure with census and political boundaries to determine their current compatibility. A number of studies have integrated GIS for defining TAZs (shown in Figure 2.4). The integrated method takes advantages of topological functionality of GIS technology to support TAZ design.

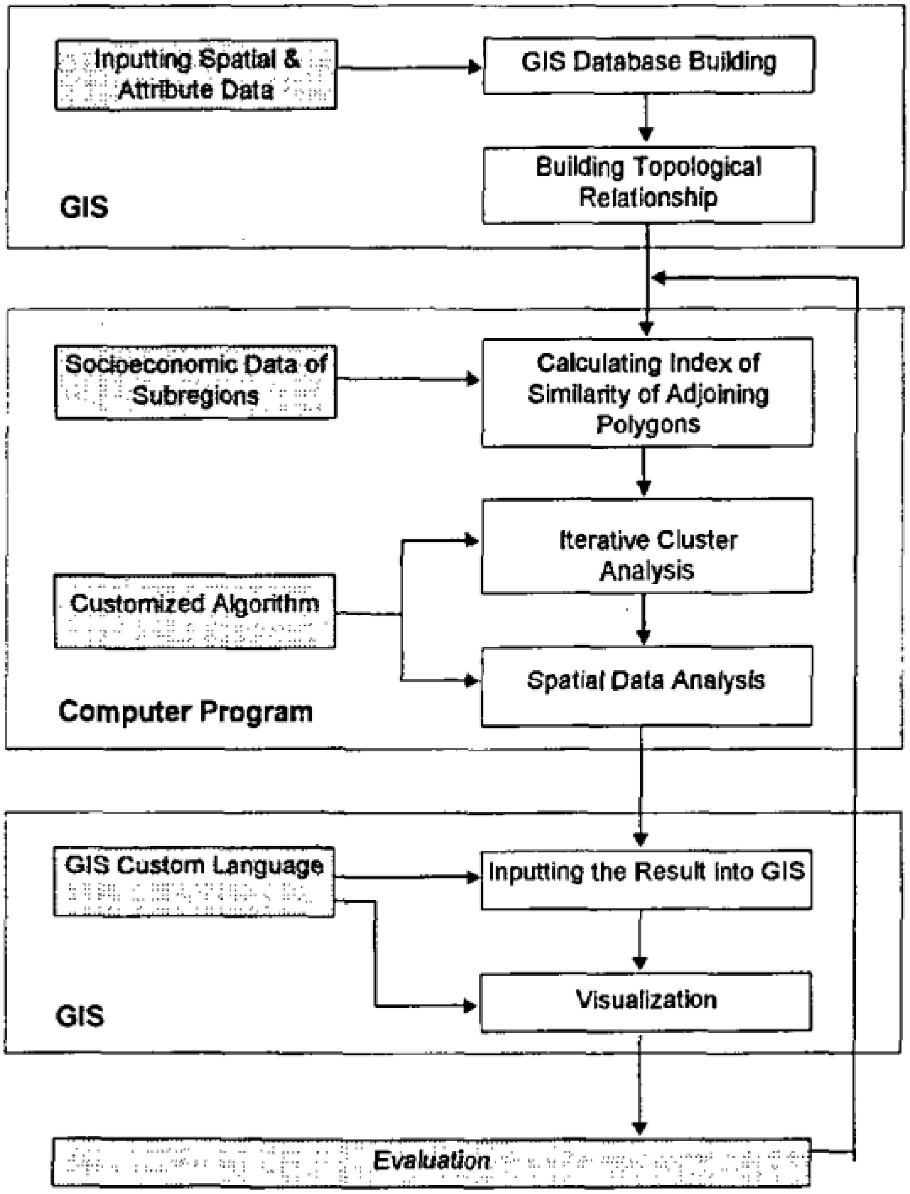

Figure 2.4 Procedures of Developing TAZs with GIS (You et al., 2007)

The applications of travel demand models began in the United States in the 1950s. The models consist of surveys and the development of a computer package for travel forecasting by 1969 (Weiner, 1992). They provide estimates of a number of parameters that can be used in transportation forecasting and planning. With the introduction of desktop computers, transportation agencies had access to computing power for developing more sophisticated models. Travel demand models have been largely used in statewide models for estimating traffic demand along regional corridors and for intercity corridor studies, bypass studies, and statewide system planning applications such as air quality conformity analysis, traffic impact studies, freight planning, and economic development studies (Horowitz, 2006). Most state DOTs have developed and implemented four-step TDMs for large metropolitan areas. However, some of those advanced models are not applicable for most county or rural roads that carry a low ADT. Therefore, a travel demand model that is designed for low-volume roads is needed for local agencies (Mohamad et al., 1998). A four-step TDM begins with trip generation procedure. Table 2.1 lists trip generation equations for tourism-related trip generators.

Table 2.1 Trip Generation Equations for Tourism-Related Trip Generators (Mamun et al. 2010)

Special Generators	**Trip Rate Equations**
Airports	exp(1.368×ln(registered aircrafts)-0.347) 104.73×(operations)/365
Bus Terminals	0.631× boarding passengers
Secretary of State	44.54×employees
Tourist Attractions	2×attendances
Campgrounds	0.27×camp sites
Parks	0.2 ×acres
Golf Courses	37.59×holes
Marinas	1.891×berths+410.795
Hospitals	exp(0.634×ln(beds+4.628)
Shopping Centers	exp(0.756×ln(TSF)+5.154) if TSF>570 exp(0.625×ln(TSF)+5.985) if TSF<570 TSF: Total Square Footage
Colleges and Universities	2.37× students for University 1.55× students for Community College

The Virginia Department of Transportation (VDOT) used a trip generation method to estimate traffic volumes on secondary local roadways. This method allowed the VDOT's staff to identify eligible traffic links and estimate traffic volumes, and several benefits were realized such as time and cost savings. The VDOT will continue to implement the trip generation method for estimating traffic volumes on local roads. Figure 2.5 presents a four-step modeling process used by the VDOT, highlighting the typical major input data elements, model components, and model outputs. The Arizona Department of Transportation (ADOT) developed a Low-Volume State Routes Study on 22 low-volume state routes to identify opportunities and limitations for each route. The ultimate goal of this study was to determine the potential for reducing costs for maintain these routes. This study proposed a guideline for state route management that can be used by state agencies (Arizona Department of Transportation, 2017).

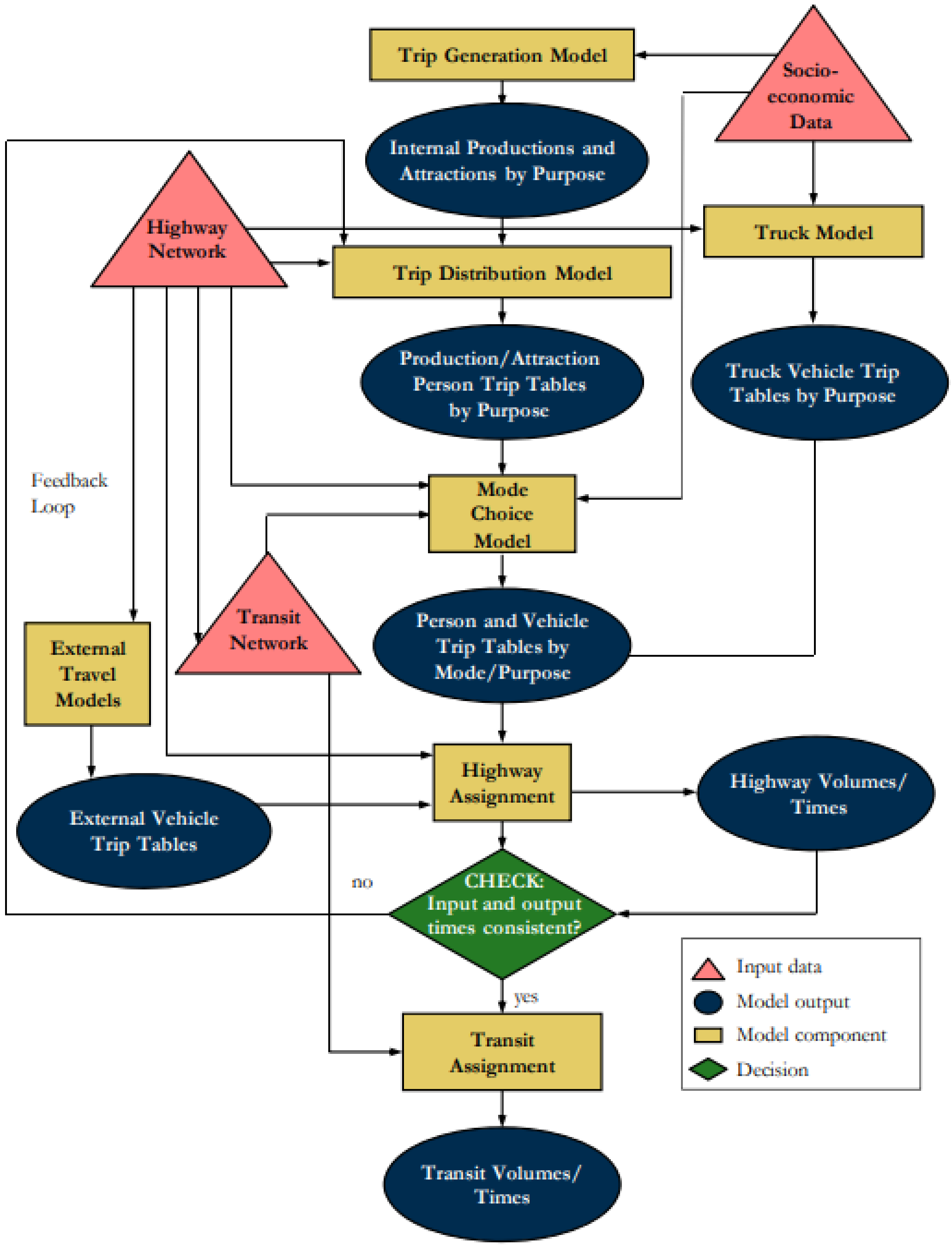

Figure 2.5 TDM Developed by the VDOT (Virginia Department of Transportation, 2014)

As a part of the Wyoming Multimodal Statewide Transportation Planning model, a method was developed that allowed for the generation of trip tables — those tables used to predict origin-destination values — using traffic counts and basic assumptions about traffic flows in the state. Once such assumption is that city-to-city work commutes are negligible since most Wyoming cities are so far apart (Wilson and Wang, 1995).

The model stratified total traffic volumes into several major groups by travel characteristics, such as the reason for the trip and trip end points based on the judgment of planners and categorized traffic counts. Trips were assigned to one of three types: goods movement, work (commuter), and tourist (non-commuter). Work trips were defined as regularly scheduled trips, while tourist trips comprise irregular business trips, social and recreational trips, and shopping trips. These three categories were tailored to Wyoming's rural travel characteristics (Wilson and Wang, 1995). The overall modeling process is summarized in Figure 2.6. Links and nodes were established at intersections and points of trip generation. When developing the planning network, the state was viewed as a big city. However, travel and land use characteristics are very different.

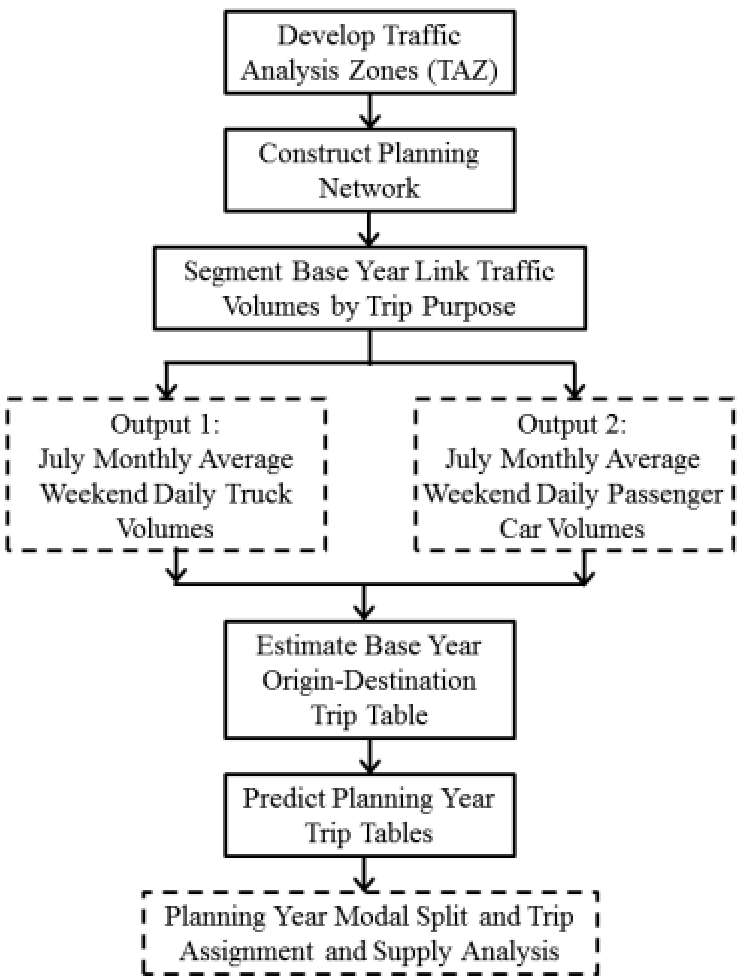

Figure 2.6 Previous TDM Developed for Wyoming (Wilson and Wang, 1995)

The use of tourism-related travel data in the travel demand model is one way for policy-makers to incorporate tourism issues into their forecasting, planning, and designing processes. Rosselló et al. (2005) applied a diffusion model and a traditional travel demand model to analyze the performance of British and German tourists to the Balearic Islands between 1960 and 2001. Divisekera (2003) developed a demand model for international tourism in Australia. This research evaluated the sensitivity of economic parameters, which can be used in international tourism policy making. More research has recently focused on the transportation systems in and near national parks because of the increasing visitors to the parks in recent years (National Cooperative Highway Research Program, 2004). A variety of government agencies and private organizations have become involved in issues regarding tourism and recreation travel (Florida

Department of Transportation-District Five, 2007). Transportation planning agencies typically lead the research in identifying travel issues and needs and provide guidance to travel segments for tourism and recreational development.

Before the 2002 Winter Olympic Games, the Utah DOT used the CORSIM travel forecasting simulation model and applied that model to determine Olympics-related peak-period traffic volumes. The model focused on three planning levels: (1) the Olympic global level, (2) the corridor level, and (3) the interchange/intersection level. Analysis at each level addressed different issues. From the Olympic global level, the Salt Lake City Olympic Committee published a transportation guidebook for all Olympic-related travelers, listing travel time tables for different trip segments. The corridor-level analysis tested ways to reduce congestion and improve travel time through a critical 20-mile stretch of the corridor. The decision was to campaign for a reduction in truck volumes in the peak direction during peak travel periods to and from Olympic venues. The analysis at the interchange/intersection level pointed toward numerous infrastructure and traffic control improvements. Overall, the transportation modeling helped inform and define strategies to manage travel demand, and the result was a well-functioning transportation system during the Olympic Games (National Cooperative Highway Research Program, 2004).

The Florida DOT District Five office (covering the Orlando region) developed a model to provide more accurate forecasts of tourism travel to central Florida. The goal was to produce more policy-sensitive forecasts to inform ongoing transportation planning efforts. The model covered more detailed dynamics of trip generation and allocation by visitors to a destination. The model included three tourist trip purposes: Disney tourist (Disney to and from hotel), Disney resident (Disney to and from homes in the Orlando area), and Disney external/internal (Disney to and from external stations). Additional attraction-oriented trip generation was also considered for Universal Studios and Orlando International Airport. The study was successfully completed by focusing on improving the highway network and forecasting traffic flow (Florida Department of Transportation-District Five, 2007). Figure 2.7 shows the tourism TDM developed for Florida.

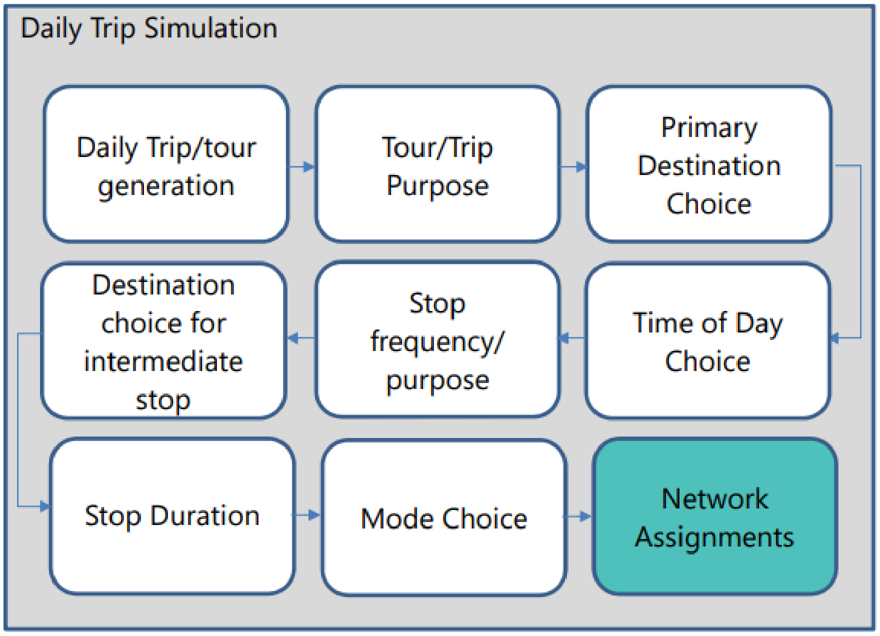

Figure 2.7 Tourism TDM Developed for Florida (Florida Department of Transportation-District Five, 2007)

The Louisiana DOT developed a statewide travel demand model to support planning and programming activities. This model was used to forecast traffic volume on rural portions of the state highway system. A number of modeling parameters were applied for the model, such as person trips, business, and others, on highways and local roads. Although the absolute number of tourism-related trips was relatively small, the impact of vehicle miles traveled **(**VMT) on the rural roadway system was significant (Giaimo and Schiffer, 2005).

2.6 Tourism Seasonality

Seasonality is one of the significant characteristics in tourism and has been viewed as a problem, especially for economy and transportation (Butler, 1998). Seasonal adjustment is used to estimate and remove variations in a time-series caused by seasonal activities, such as an increase in travelers during summer months (Bureau of Transportation Statistics, 2017). Researchers have analyzed tourism seasonality in different parts of the world due to increased tourists. Þórhallsdóttir and Ólafsson (2017) developed a method to analyze tourism seasonality in Iceland at three levels: national, regional and destination. Their analysis provided a useful tool for finding the tourist flows on Iceland. Fernández-Morales et al. (2016) applied a decomposition analysis on seasonality of tourism demand in the United Kingdom. They found that tourism seasonality was due to a combination of demand and supply factors. The methodology they developed can be used to identify areas where tourism agencies need to make efforts reducing seasonality. Lim and MaAleer (2001) used a statistical technique to estimate monthly seasonal variations of Asian tourists to Australia. The results showed that there are differences in the monthly patterns of the inbound tourists from Hong Kong, Malaysia, and Singapore to Australia. Their analysis can be used for forecasting and planning the supply of transportation, hospitality, and other services. Tourism highly depends on transportation. The development of transportation infrastructures and technologies speed up the development of tourism (Mammadov, 2012). The road networks that are used for tourism differ significantly from road networks that are used for commuting or industry. Roadways that support tourism, such as recreational and rural travel, are generally of lower functional class and have lower traffic volumes (Federal Highway Administration, 2016). Measuring tourism-related seasonal traffic volumes in regions with low population can be a low priority. However, traffic volume estimation on low-volume roads in local and rural areas are important for transportation infrastructure management, safety, and environmental analysis (Apronti et al., 2016). Kastenholz and Lopes de Almeida (2008) analyzed seasonality and travel demand of rural tourism in North Portugal. The results indicated significant differences between the high versus low season, in terms of number of tourists and travel behavior.

Monthly seasonal adjustment factors are widely used by both transportation agencies and researchers for analyzing seasonal traffic patterns. Monthly factors are defined as the ratios of monthly ADT to AADT. Illinois Department of Transportation used seasonal adjustment factors for each month and each Automatic Traffic Recorder (ATR) site. The adjustment factors were also used to generate AADT for each road segment (Illinois Department of Transportation, 2004). Similarly, Georgia Department of Transportation developed different types of traffic adjustment factors, including monthly factors, day-of-the-week factors, and axel correction factors to estimate average conditions of traffic variability (Wiegand, 2018). In the State of Kentucky, Stamatiadis and Allen (1997) calculated seasonal adjustment factors for the number of different vehicle types. Their research used two years of vehicle type data to develop vehicle type groups. The conclusions indicated the importance of seasonal adjustment factors for traffic volume estimations. Ha and Oh (2014) used adjustment factors of permanent traffic count (PTC) locations to estimate AADT. Their research showed that the accuracy of AADT estimation was improved by using adjustment factors since they represented time-series patterns. Li et al. (2006) developed a methodology to assign seasonal factor groups short-term traffic count locations. The methodology succeeded in establishing seasonal factor groups and assigning a group to a given portable traffic count site.

Cluster analysis is a statistical technique that is used by researchers in different fields. It is a methodology that recommended by the Federal Highway Administration (FHWA) to define road groups with similar traffic patterns based on seasonal adjustment factors (Federal Highway Administration, 2016). The literature review indicates that most transportation agencies followed the FHWA clustering methodology to identify road groups. The purpose of cluster analysis is to place road segments into groups so that road segments in the same group have similar seasonal traffic patterns. Some research on road cluster analysis have been developed based the FHWA procedure. Gastaldi et al. (2013) presented an approach, using a fuzzy set theory and neural networks, to estimate AADT and assign road segments to road groups based on one-week seasonal traffic volumes. Their methodology maintained the FHWA structure and was able to estimate AADT and identify road groups accurately. Zhao et al. (2004) evaluated various clustering methods to seek reasons of seasonal traffic fluctuation patterns in Florida. Their research confirmed that geographic locations play an important role in road segment seasonal grouping and provided a theoretical basis for assigning short-term traffic counts to seasonal groups. In addition to cluster analysis, some mapping techniques are also used in determination of seasonal factor groups. Aunet (2000) recommended a combination of methods, including cluster analysis, plots of monthly traffic, and geographic mapping, to develop seasonal factor groups.

2.7 Summary

This literature review indicated that previous research mainly applied models to estimate traffic volumes on high-class roads, since traffic data is usually ignored for low-volume roads. Although statewide TDMs have been developed and implemented in several states, they are not applicable on low-volume roads as the local roads are generally excluded in these models. There is a growing need for incorporating tourism/recreation travel into travel demand modeling and transportation planning (National Cooperative Highway Research Program, 2004). One element making this the time to consider tourism in transportation planning is the growing number of visitors to the U.S. national parks. A wide range of issues need to be addressed at the intersection of tourism travel and the transportation facilities currently available to carry tourists (Litman, 2017). Another element is the development of transportation and travel modeling software. As GIS and related software has been widely used in research and practice, more comprehensive travel models have been developed (Goodchild, 2000). A final element is the rapid growth of many urban and suburban communities extending to the areas once known as rural, which has changed traffic patterns and local economies (Goodwin et al., 2004). Therefore, an inexpensive and effective means of estimating traffic on the state's lower volume roads is highly desirable (Apronti et al., 2016). It will assist government and travel agencies in transportation decision making.

3. DATA COLLECTION

3.1 Introduction

This section summarizes the procedures of data collection for TDM development. Three types of data were required as model inputs: road network data, socioeconomic data for developing TAZs, and tourism data. This section describes data sources for each type of data and how they can be input into the model.

3.2 Road Network Data

The estimation of traffic volumes requires an accurate representation of the road network serving the region. All models that include highways/local roads, transit elements, and/or mode choice must include road networks. Accurate transportation model calibration and validation also require that the transportation networks represent the same year as the input data used to estimate travel demand. The road network data used in this study was obtained from the WYDOT. The WYDOT maintains a transportation network database that lists the physical characteristics of each road segment, including number of lanes, posted speed limit, road capacity, and direction (one-way or two-way facility). The road network GIS shapefiles were downloaded from the WYDOT website. Figure 3.1 shows the road network used in the model. Table 3.1 lists the number of road segments and total length of roads in each region. Figure 3.2 presents the detailed procedures of preparing road network data.

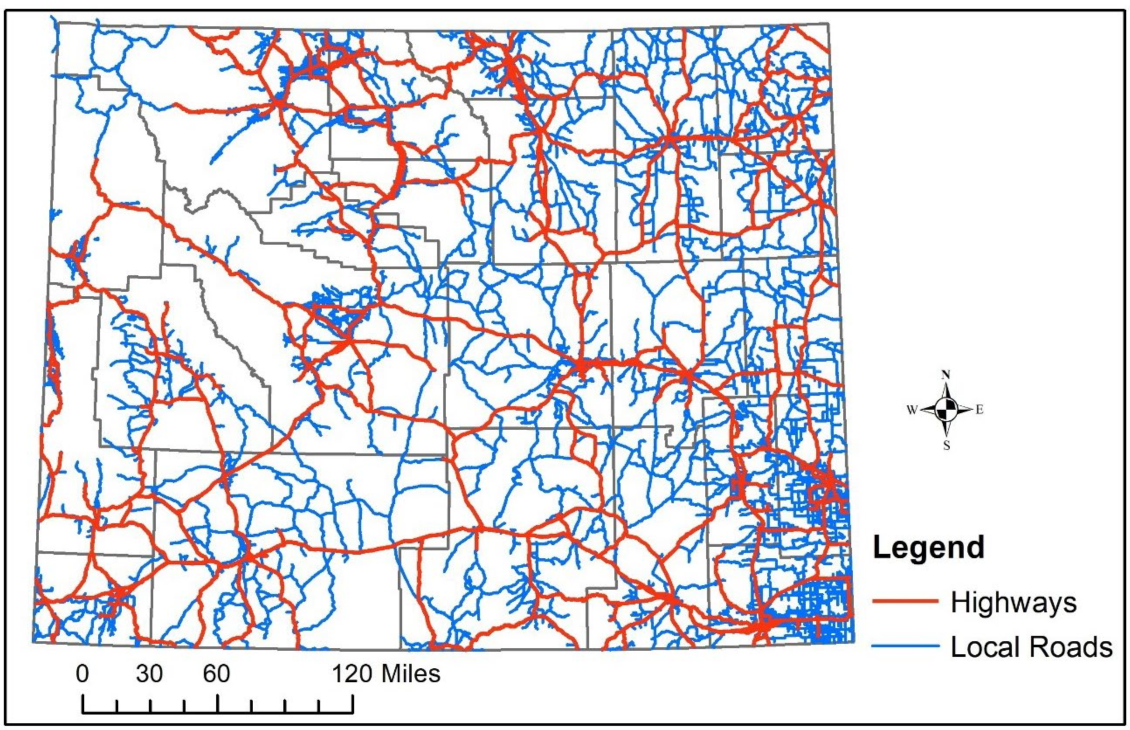

Figure 3.1 Wyoming Road Network

Table 3.1 Road Network Data for Each Region

Region	Number of Segments	Length (Miles)
1	4,273	5,476
2	3,273	4,697
3	2,424	3,682
4	3,639	5,559

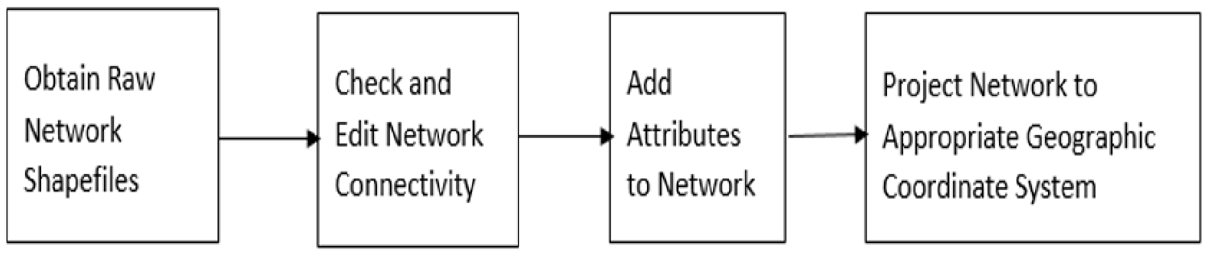

Figure 3.2 Road Network Data Preparation Procedure

3.3 Input Data for TAZs

Socioeconomic data, including household and employment data for the modeled area, are usually organized into geographic units called transportation analysis zones (TAZs, sometimes called traffic analysis zones or simply zones). Note that some activity-based travel forecasting models operate at a more disaggregate level than the TAZ (for example, the parcel level); however, the vast majority of models still use TAZs. The following discussion of data sources is applicable to any level of model geography

The Decennial U.S. Census offers the best source for basic population and household data, including age, sex, race, and relationship to head of household for each individual. The census also provides data for housing units (owned or rented). These data are available at the census block level and can be aggregated to traffic zones. The decennial census survey is the only questionnaire sent to every American household with an identifiable address. The TAZ shapefile dataset is developed from 2010 census block data downloaded from: https://www.census.gov/cgi-bin/geo/shapefiles/index.php?year=2010&layergroup=Blocks. Figure 3.3 shows the census block for Laramie County in Wyoming.

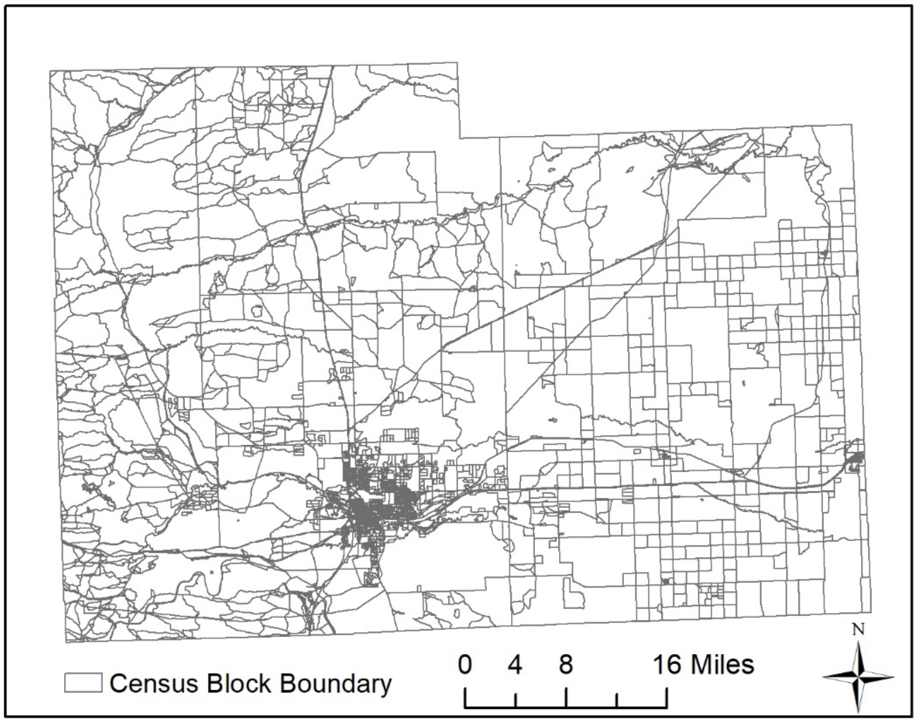

Figure 3.3 Census Block for Laramie County

Input parameters for tourism trips were based on the suggestions of Trip Generation Manual (Institute of Transportation Engineers, 2017). Three parameters were included in the model: ADT at park entrance, park area, and number of campsites. Appendix 1 listed these parameters for each park. These input parameters were incorporated into TAZs and were used in the model for computing the tourism trips generated in each TAZ. The next section will discuss the detailed procedures of tourism data collection.

3.4 Tourism Data

This study incorporated park visitation data, park areas, and number of campsites as model input parameters into the previously developed TDM for Wyoming low-volume roads. Figure 3.4 shows the spatial distribution of national and state parks in the study area. Yellowstone and Grand Teton National Parks have multiple entrances. The entrances connected to the roads in Wyoming were selected for this study. The selected entrances are displayed in Figure 3.5. The year of 2014 park visitation data was used in this study since the actual traffic count data used for model validation was mainly obtained in the summer of 2014.

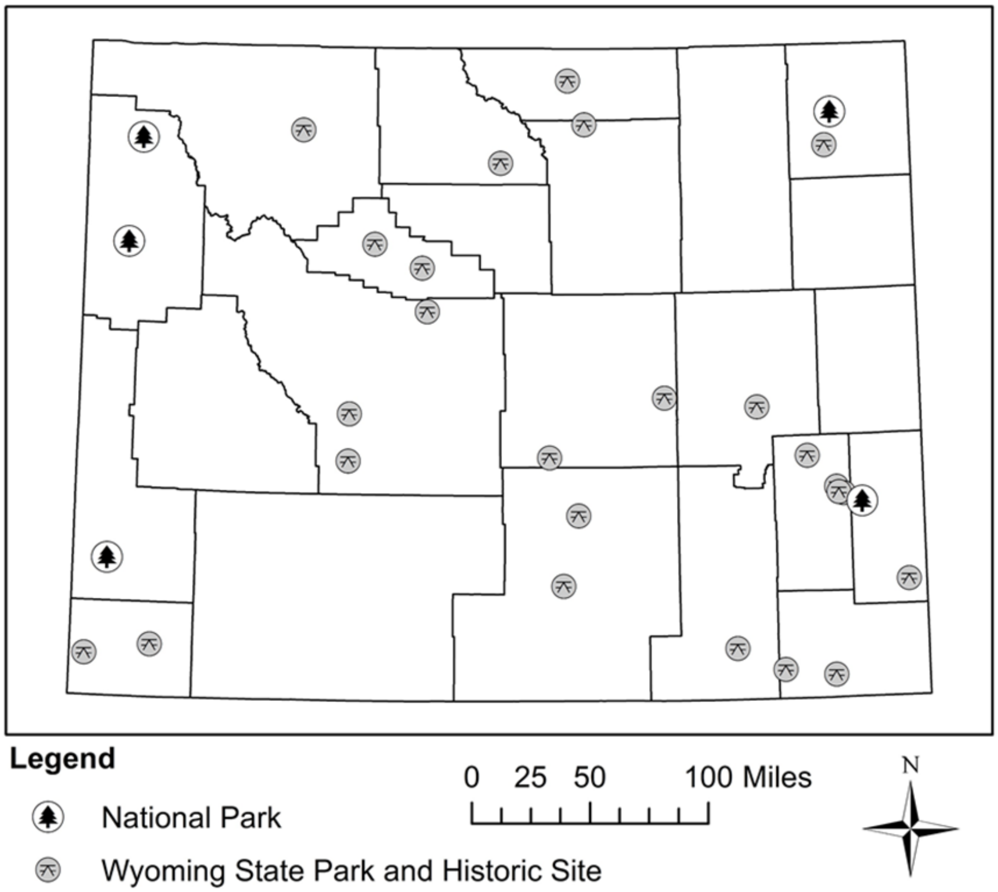

Figure 3.4 Parks Included in This Study

The NPS collects visitation data for all national parks, and the WSPHST collects visitation data for 25 state parks and historic sites. Parks without visitation data are either due to no public access or limited management by the WSPHST. Visitation data obtained from the parks was converted to ADT values as model inputs.

The NPS conducts visitor use and recreation research to examine how people physically move throughout a park, what they do while there, and how they perceive their experiences. The NPS Social Science Program is responsible for coordinating visitation statistics reports to develop appropriate data collection procedures and provide quality control for public use data collection and reporting (National Park Service, 2016). The NPS publishes several visitor use statistics reports each year. This study used monthly traffic count at park entrances and converted monthly traffic count to ADT to generate tourism-based trips in the model. The numbers of traffic count have been adjusted to only report the number of vehicles entering the park, including employee, non-recreation and recreation vehicles.

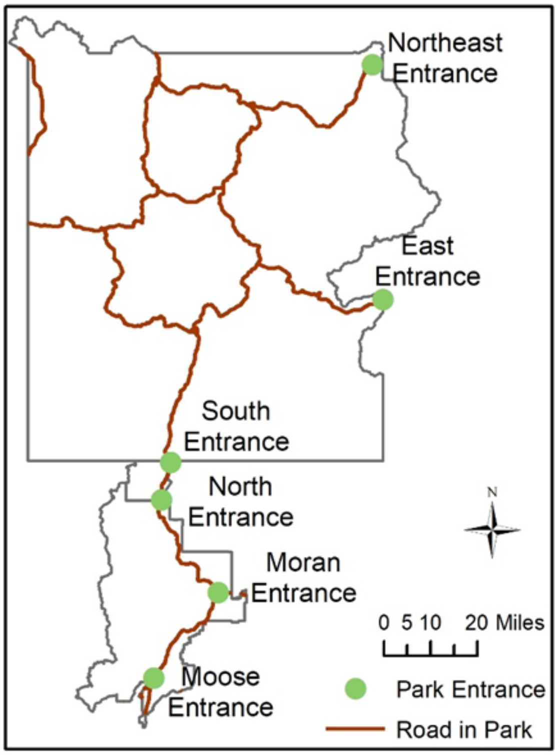

Figure 3.5 Park Entrances of Yellowstone and Grand Teton National Parks

The WSPHST collects visitor use data by traffic counters (in Figure 3.6) or manual hand counts. The traffic counters monitor lanes of traffic by counting vehicle traffic and could be used to document traffic volumes at each WSPHST. Some parks have multiple traffic counters while others have one counter, depending on the number of entrances into the park. Raw data is retrieved at the end of each collection month and then, the raw counts are analyzed using internal software (Wyoming State Parks and Historic Sites, 2014). Although the WSPHST collects traffic counts, data published in the report is the total number of visitors. To obtain traffic counts for this study, the total number of visitors was divided by the average number of people per vehicle, which is available from the Visitor Use Survey conducted by the WSPHST. This Visitor Use Survey is the WSPHST's formal monitoring tool to collect information on several issues affecting WSPHST system wide, including questions to give management insight on visitor behaviors, such as activities participated in, how visitors find out about sites, equipment visitors travel with, and length of stay (Wyoming State Parks and Historic Sites, 2014).

Figure 3.6 Pegasus Traffic Counter Used by WSPHST

3.5 Tourism Seasonality in Wyoming

Seasonality is a key element in tourism industry. Seasonal patterns of tourism travel demand create overcrowding traffic at certain times. The analysis of seasonality in tourism demand helps to improve the accuracy of modeling results (Cannas, 2012). Modelling seasonal variation in tourism demand has become an important issue in tourism forecasting in recent years. However, most previous studies focused only on the time-series methods, such as the traditional autoregressive integrated moving average (ARIMA) model, the seasonal ARIMA model, and the basic structural time-series model (BSM) (Shen and Song, 2009). This study added a seasonal adjustment factor into the model and treated different tourism seasonality separately to evaluate traffic volumes resulting from tourism activities.

Based on the monthly visitation of national and state parks in Wyoming, the year was divided into peak season and off-peak season. Visitation data from the NPS and WSPHST indicated approximately one quarter of the visitors come to the parks from November to April and three quarters during the summer season (Wyoming State Parks and Historic Sites, 2014). Figure 3.7 shows average monthly traffic count at park entrances in 2014 for all five national parks and 25 state parks in Wyoming. Based on the monthly traffic count, peak season is defined as May through October and off-peak season is November through April.

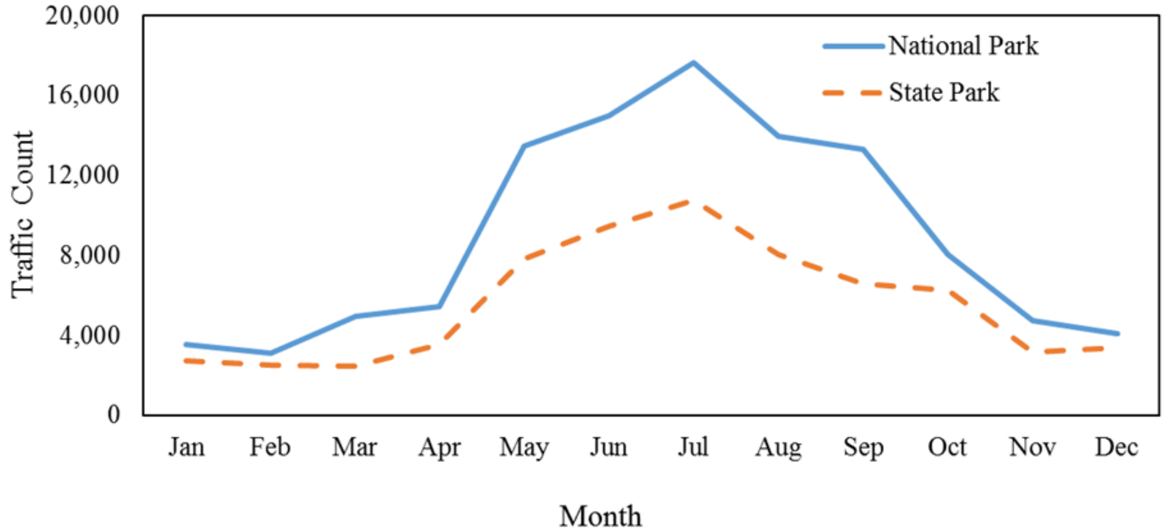

Figure 3.7 Monthly Traffic Count for National and State Parks

3.6 Summary

This chapter presents the procedures of data collection. Road network was obtained from the WYDOT. Socioeconomic data was obtained from the 2010 U.S. Census. Tourism data was collected from the NPS and WSPHST. These data were then used for model development. Based on the collected tourism data, it was found that tourism traffic has a strong seasonal pattern in Wyoming. May to October is the peak season and October to April is the off-peak season.

4. MODEL DEVELOPMENT

4.1 Introduction

The model development procedure in this study followed the sequential process for estimating travel demand that is often called the "four-step" TDM, including trip generation, trip distribution, mode choice, and trip assignment. In four-step TDMs, the unit of travel is the "trip," defined as a person or vehicle traveling from an origin to a destination. Since people traveling for different reasons behave differently, four-step models classify trips by trip purpose. The number and definition of trip purposes in a model depend on types of information the model needs to provide for planning analyses, characteristics of the region being modeled, and availability of data to obtain model parameters and the inputs to the model.

The minimum number of trip purposes in most models is three: home-based work, home-based-non-work, and non-home based. The four-step modeling process has seen a number of enhancements. These include the more widespread incorporation of time-of-day modeling into what had been a process for modeling entire average weekdays; common use of supplementary model steps, such as vehicle availability models; the inclusion of nonmotorized travel in models; and enhancements to procedures for the four main model components (e.g., the use of logit destination choice models for trip distribution). A new generation of travel demand modeling software has been developed, which not only takes advantage of modern computing environments but also includes, to various degrees, integration with ArcGIS software. Citilabs CUBE software was used for developing and running TDM in this study. The software is compatible with ArcGIS shapefiles and can import the TAZ and network dataset for running the model. The TDM development used a modified four-step travel demand modeling process. The processes in the model are trip generation, trip distribution, mode choice, trip assignment. Each of the processes used in developing the model are explained below. Figure 4.1 provides an overview of the model and how the data elements are interrelated. Data elements are categorized into (1) data inputs, (2) data vessels, (3) models, and (4) outputs. Details of each element are discussed in this document. Figure 4.2 shows the model development procedures in CUBE software. Figure 4.3 shows the model development procedures, especially for tourism.

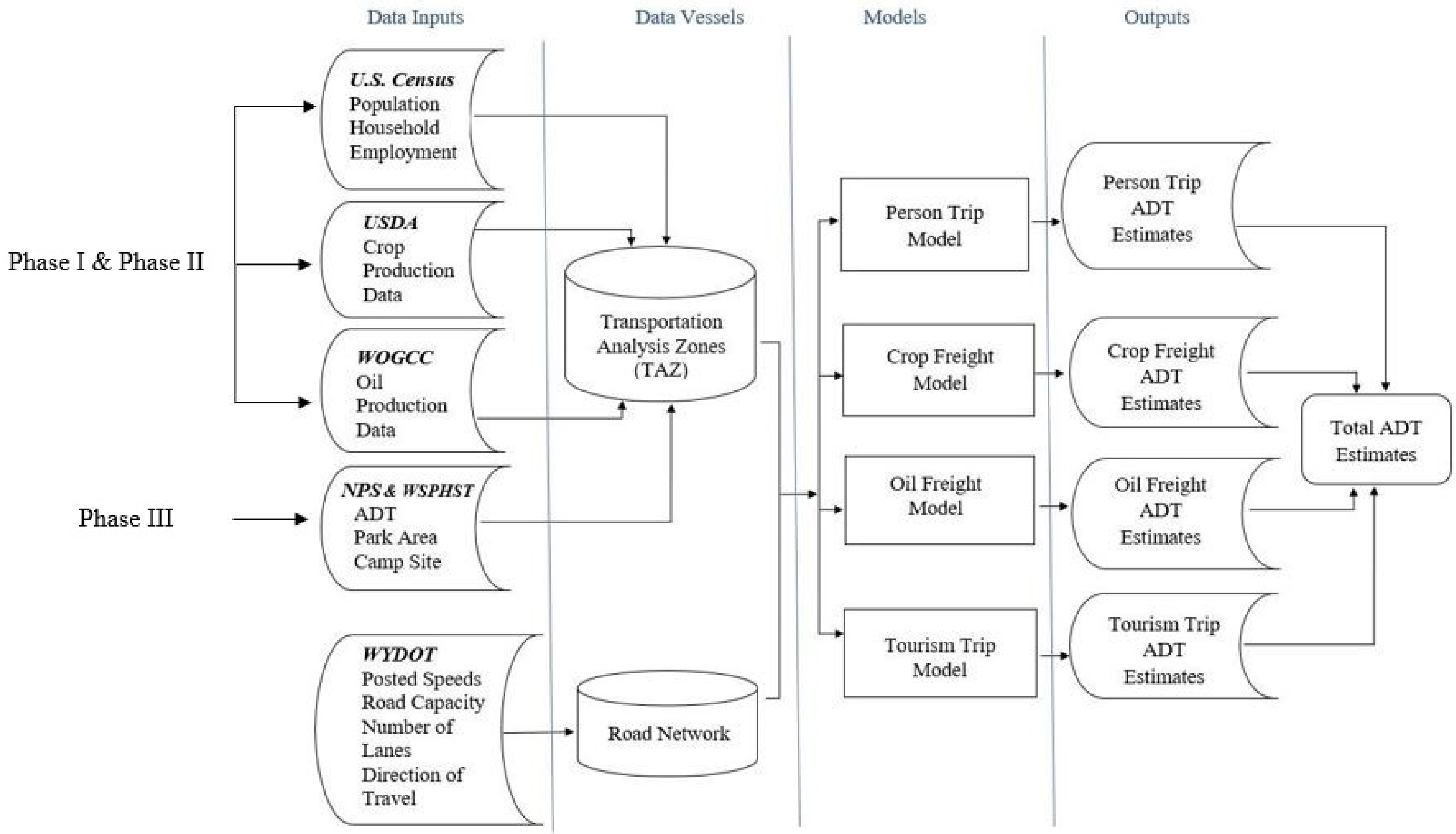

Figure 4.1 Overview of Phase I, II, and III of the Study

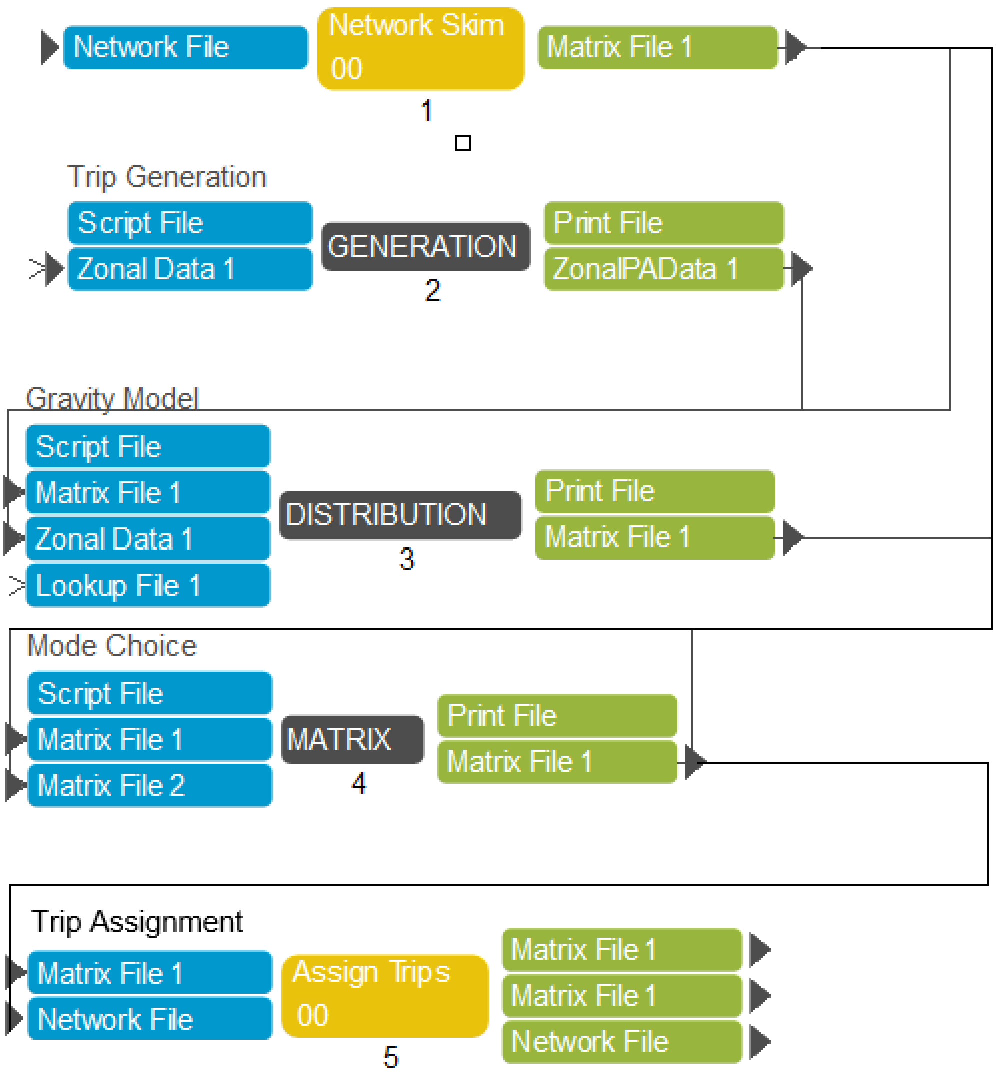

Figure 4.2 Model Development in CUBE

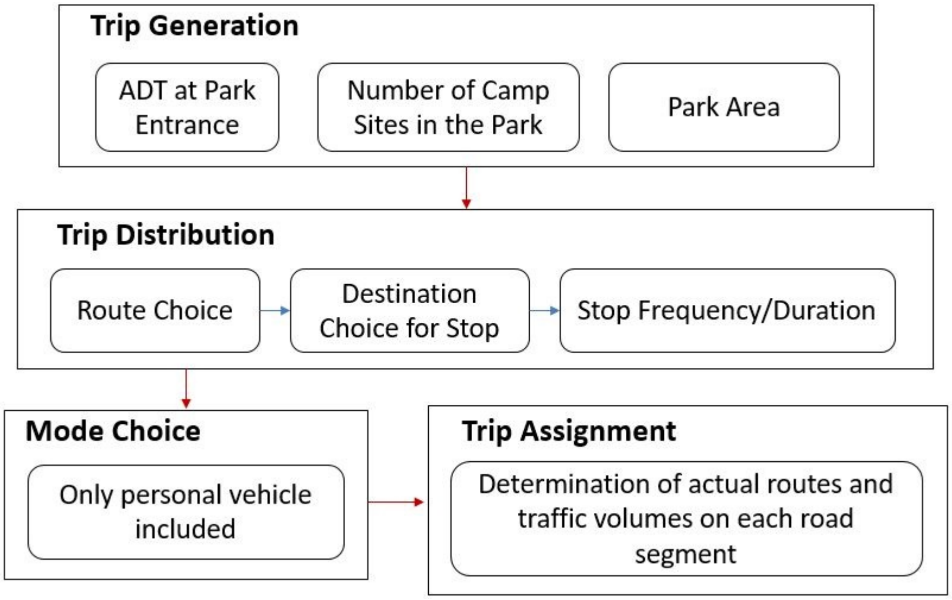

Figure 4.3 Model Development Procedure for Tourism

4.2 Defining TAZs

A fine TAZ structure, with reliable socioeconomic data, helps to produce more accurate traffic volume estimates at smaller geographic levels. However, the ability to accurately allocate socioeconomic data to zones diminishes as zone size decreases (particularly for future forecasts). Refinement of TAZs is an important model component. Figure 4.4 shows the TAZ delineation procedure in this study.

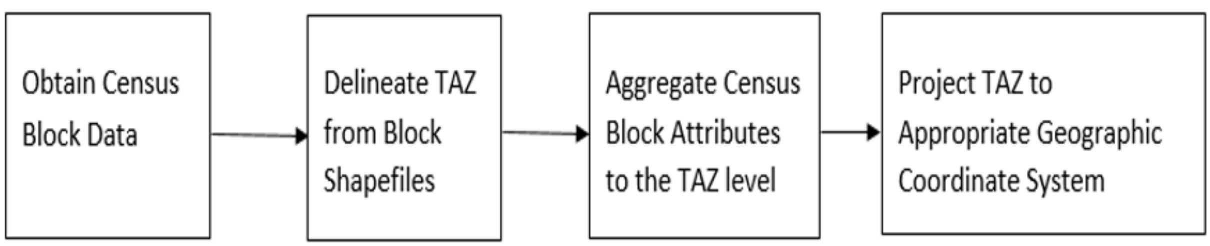

Figure 4.4 TAZ Delineation Procedure

Figure 4.5 shows the TAZs for the entire State of Wyoming. Figure 4.6 shows the TAZs and road network for Laramie County. Table 4.1 listed number of TAZs in each region. The rules used to delineate the zones are as follows:

1. All TAZs were developed from census blocks; therefore, each TAZ has census block boundaries.
2. Physical barriers such as lakes, rivers, streams, and railroad tracks served as boundaries to TAZs where feasible.
3. Beyond physical barriers, each TAZ was delineated to ensure that at least a part of its borders coincides with the road network.
4. Each TAZ must have some population. Census blocks with zero population counts must be combined with neighboring census blocks until there is at least a population size of one in the TAZ.
5. Populations exceeding 200 for a rural location and covering an area of at least 15,000 acres must be split where feasible.

6. Aerial photographs were reviewed to ensure that each TAZ covers an area of similar land use to improve homogeneity.
7. Urban TAZs were created by only considering major road and physical boundaries. Urban TAZs were also restricted to a maximum population size of 6,000.
8. TAZs were created such that a TAZ was not wholly in another TAZ.

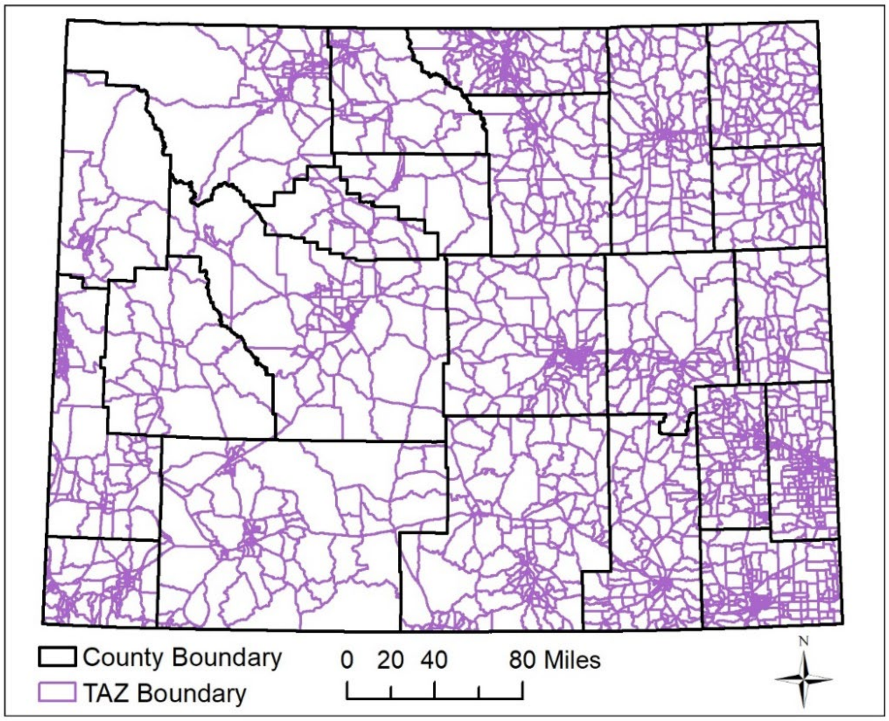

Figure 4.5 TAZs for Wyoming

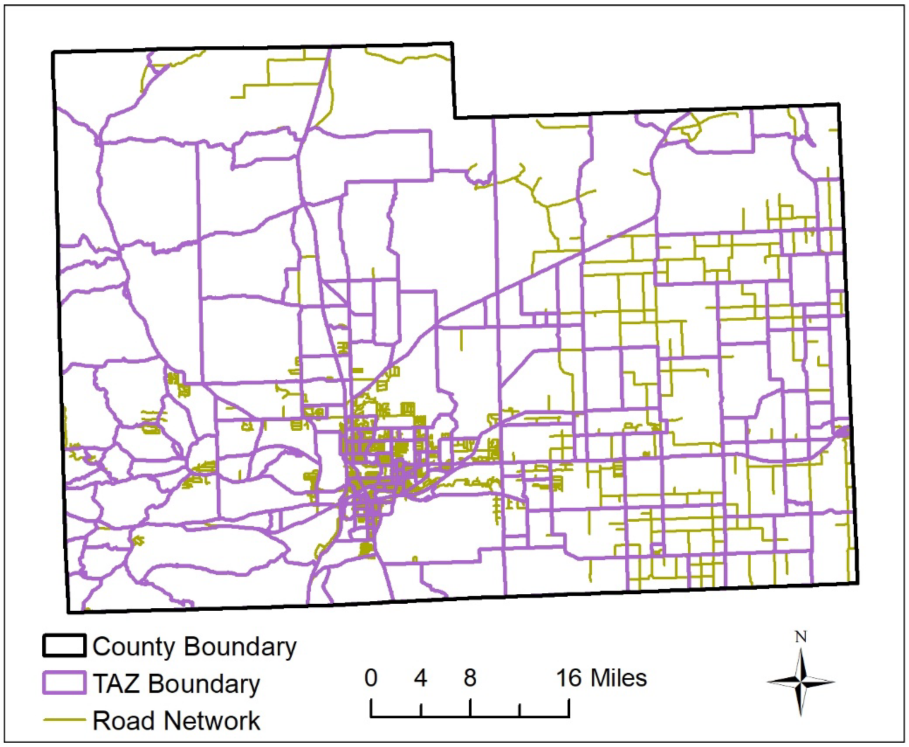

Figure 4.6 TAZs and Road Network for Laramie County

Table 4.1 Number of TAZs in each region

Region	Number
1	888
2	573
3	513
4	748

4.3 Trip Generation

In the first step of the four-step modeling process, trips generated were computed for each TAZ. The TAZ database contained tourism attribute data. The network dataset was connected to the TAZ dataset in the CUBE environment using two tools — Automatic Add Centroid and Automatic Add Centroid Connectors.

The Automatic Add Centroid feature automatically generated centroids at the center of each zone, and the Automatic Add Centroid Connectors created links from the nearest network segments to the centroid of the zone. The centroid connectors are imaginary access roads that connect traffic generated in a zone to the network. In this model, centroids could connect to all road types except interstates. This is because interstates are not typically connected to driveways (centroid connectors). All the centroid connectors were assigned the program's default travel time of 0.5 minutes, which represents an approximate time it would take for a car to traverse a driveway and leave a block.

In the trip generation stage, trip generation equations were derived from recommendations by the Trip Generation Manual (Institute of Transportation Engineers, 2017). Two trip types were included: home based and non-home based. The ratio of home based and non-home based tourism trips was based on data from visitor survey conducted by the NPS and WSPHST. The ratios of 0.22 and 0.78 indicate that 22% of total tourism trips were generated by tourists from Wyoming and 78% of total tourism trips were generated by tourists from other states or countries. Table 4.2 listed trip generation equations for tourism. Figure 4.7 shows how TAZs and trip generation equations were input into CUBE software. Figure 4.8 shows the trip attractions in each zone based on the input parameters.

Table 4.2 Trip Generation Equations

Activity	**Trip Type**	**Equation**
Tourism trips	Home based	0.22*(2*ADT at park entrance +0.2*Park area+0.27*Number of campsites)
	Non-home based	0.78*(2*ADT at park entrance +0.2*Park area+0.27*Number of campsites)

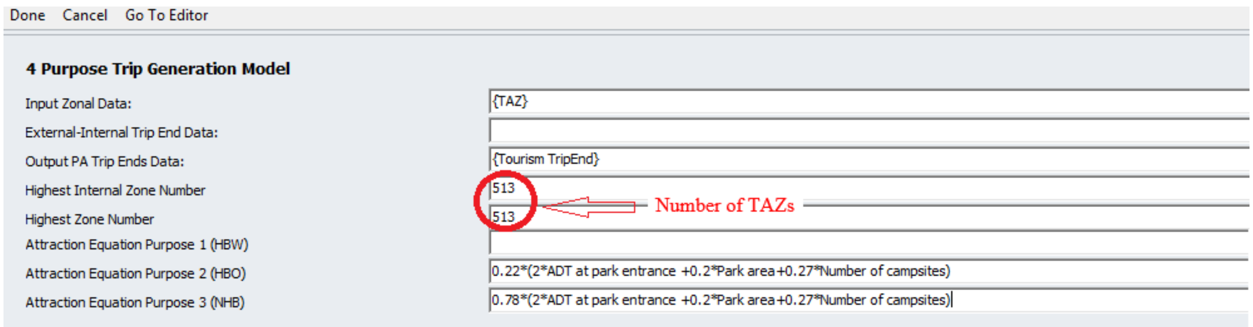

Figure 4.7 Trip Generation in CUBE

Z	A1	A2	A3	A4
1	140	426	193	0
2	1196	4288	1772	0
3	27	86	45	0
4	22	61	34	0
5	5	19	9	0
6	8	27	16	0
7	90	279	152	0
8	12	37	23	0
9	16	53	27	0
10	11	32	17	0
11	37	114	45	0
12	25	72	37	0
13	25	80	43	0
14	20	66	35	0
15	11	32	17	0
16	20	66	31	0
17	11	38	19	0
18	20	69	35	0
19	29	104	57	0
20	12	39	23	0
21	12	41	24	0
22	12	37	23	0
23	5	19	9	0
24	15	48	26	0
25	35	110	60	0

Figure 4.8 Trip Attractions by Tourism per TAZ

4.4 Trip Distribution

In this step, the trips estimated from trip generation stage were paired based on relative attractiveness of traveling between two zones compared to others. The relative attractiveness of moving between zones was determined by the travel impedance/cost using travel time or distance between the zones. This method of pairing productions and attractions is called the gravity model. The gravity model estimates the relative number of trips made between two TAZs using the number of productions and attractions in each TAZ and the spatial separation or travel time between the two zones. The gravity model formula is shown in Equation 4.1:

$$T_{ij} = P_i \left[\frac{A_j F_{ij} K_{ij}}{\sum_{k=1}^{zones} A_k F_{ik} K_{ik}} \right]$$ **Equation 4.1**

Where:

T_{ij} = number of trips from zone i to zone j,

P_i = number of trips productions in zone i,

A_j = number of trip attractions in zone j,

F_{ij} = friction factor relating the spatial separation between zone i and zone j, and

K_{ij} = optional trip distribution adjustment factor for interchanges between zones i and j.

The K factor in the trip distribution model is used to modify the results of the gravity model to match travel characteristics in the study area. The friction factor in Equation 4.1 is the gamma function presented in Equation 4.2:

$$F_{ij} = a \times t_{ij}^{b} \times e^{c \times t_{ij}} \qquad \textbf{Equation 4.2}$$

Where:

F_{ij} = friction factors representing the cost of travel,

t_{ij} = travel time between zones i and j, and

a, b, c = constants determined by the trip type as shown in Table 4.3.

The friction factor depends on travel time between the two zones and three constants given in Table 4.3. These coefficients were obtained from the Trip Generation Manual (Institute of Transportation Engineers, 2017). In this study, a modification was required to account for the barrier introduced by zones connected by unpaved roads. Unpaved roads were assigned artificial 10 mph speed reductions to represent the cost associated with driving unpaved roads compared to paved roads. Figure 4.9 shows trip distribution inputs.

Table 4.3 Gamma function coefficients used in Equation 4.2

Trip Purpose	a	b	c
Tourism	24,108	0.032	0.158

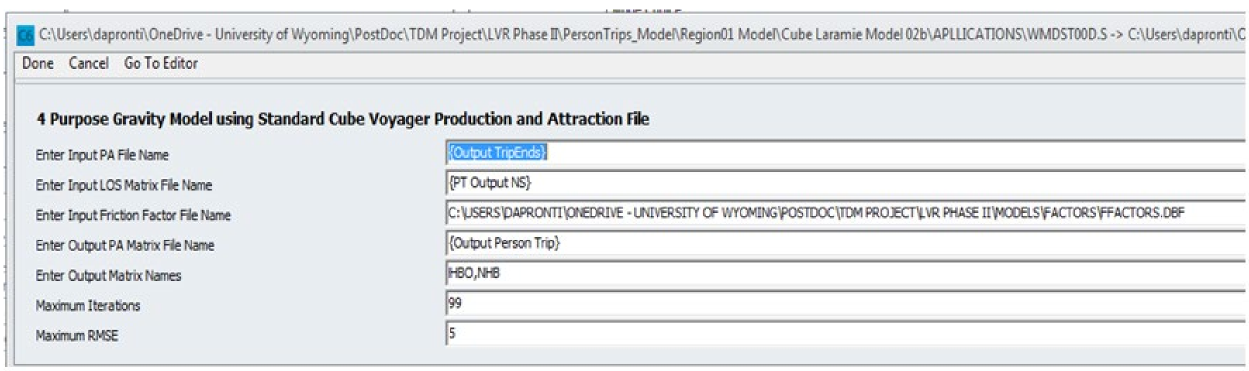

Figure 4.9 Trip Distribution Inputs

Outputs from the trip distribution step is a matrix table with assigned trips between all pairs of zones in the study area (shown in Figure 4.10). The next step in the four-step process (mode choice step) converted output of the trip distribution step to an origin-destination format.

2 HBO | 3 NHB | 4 M4

	Sum	1	2	3	4	5	6	7	8	9	10	11
	135617.79	139.85	1196.42	26.43	21.43	4.41	7.39	89.87	11.31	15.45	10.50	36.44
1	87.37	67.17	0.16	6.34	0.62	0.01	0.01	2.98	0.05	0.01	0.00	0.03
2	1185.07	0.44	848.98	0.11	0.12	0.02	0.04	0.41	0.08	0.06	0.04	0.13
3	16.11	7.98	0.05	5.12	0.16	0.00	0.00	0.15	0.01	0.00	0.00	0.01
4	5.25	0.27	0.02	0.05	2.23	0.01	0.00	0.06	0.00	0.00	0.00	0.00
5	5.24	0.02	0.04	0.01	0.13	0.68	0.30	0.77	0.00	0.00	0.00	0.01
6	3.28	0.01	0.02	0.00	0.01	0.10	0.63	0.25	0.00	0.00	0.00	0.00
7	47.54	4.12	0.21	0.16	0.20	0.25	0.24	28.30	0.24	0.02	0.01	0.04
8	1.26	0.03	0.02	0.00	0.00	0.00	0.00	0.11	0.48	0.00	0.00	0.01
9	9.31	0.02	0.04	0.01	0.01	0.00	0.00	0.02	0.01	2.92	0.15	0.15
10	5.48	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.12	0.28	0.01
11	28.51	0.06	0.10	0.02	0.02	0.00	0.01	0.06	0.02	0.17	0.01	11.11
12	9.25	0.03	0.04	0.01	0.01	0.00	0.00	0.02	0.06	0.59	0.02	1.47
13	16.23	0.03	0.05	0.01	0.01	0.00	0.00	0.03	0.01	0.09	0.02	1.35
14	14.29	0.02	0.03	0.00	0.01	0.00	0.00	0.02	0.00	0.05	0.01	0.45
15	5.38	0.01	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.19

Figure 4.10 Trip Distribution Outputs

4.5 Mode Choice

The mode choice process determines the share of trips by travel mode between zones. The personal vehicle is the only mode of travel considered in person trip estimates for this study since other travel alternatives such as transit are not represented in the study area. Average auto-occupancy rate was applied to the tourism trips output from the trip distribution step to obtain estimates of total daily travel in hourly origin-destination format. This is done by dividing total person trips by the average auto occupancy rate (shown in Table 4.4) to obtain vehicle trips for tourism trips. The average auto-occupancy rate was obtained from the WSPHS visitor survey. Diurnal or time-of-day factors enabled total vehicle trips to be spread over a 24-hour period.

Table 4.4 Auto-Occupancy Rates

Trip Purpose	Average Auto-Occupancy Rate (Persons/Vehicle)
Tourism	3.04

4.6 Trip Assignment

The traffic assignment step in this study utilized the user equilibrium method in assigning traffic to the network. The user equilibrium method of network assignment is based on the principle that as congestion delay arises, road users seek alternative routes until all vehicles traveling between two zones are using the shortest routes available. This method increases the travel time on a link when traffic volumes approach or exceed the link capacity and diverts traffic to other routes. Travel time associated with a highway is determined by applying the Bureau of Public Roads (BPR) volume-day relationship equation presented in Equation 4.3 to the trip tables produced from the mode choice step:

$$T_c = T_f \times \left(1 + \alpha \times \left[\frac{v}{c}\right]^{\beta}\right) \qquad \textbf{Equation 4.3}$$

Where:

T_c = congested link travel time,

T_f = link free − flow travel time,

v = assigned link traffic volume (vehicles),

c = link capacity, and

α, β = volume − delay coefficient ($\alpha = 0.15$, and $\beta = 4.0$).

Application of time-of-day factors to the vehicle trips converts the daily trip tables to peak period, peak direction tables that enable determination of assigned link traffic volumes. Figures 4.11 and 4.12 show the trip assignment inputs and outputs.

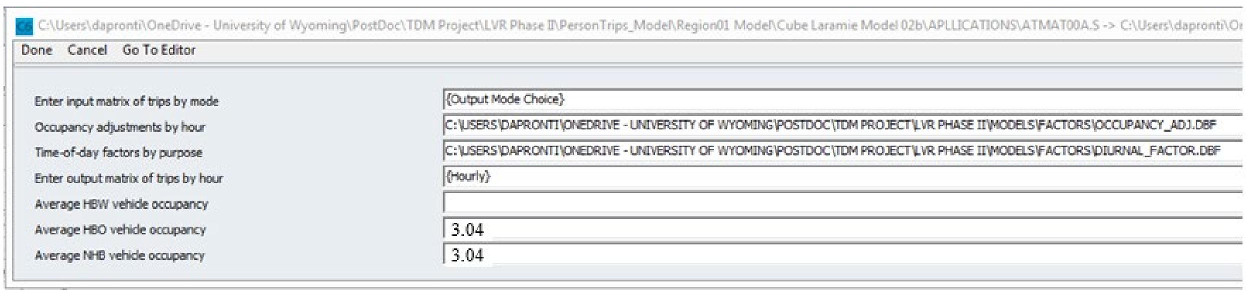

Figure 4.11 Trip Assignment Inputs

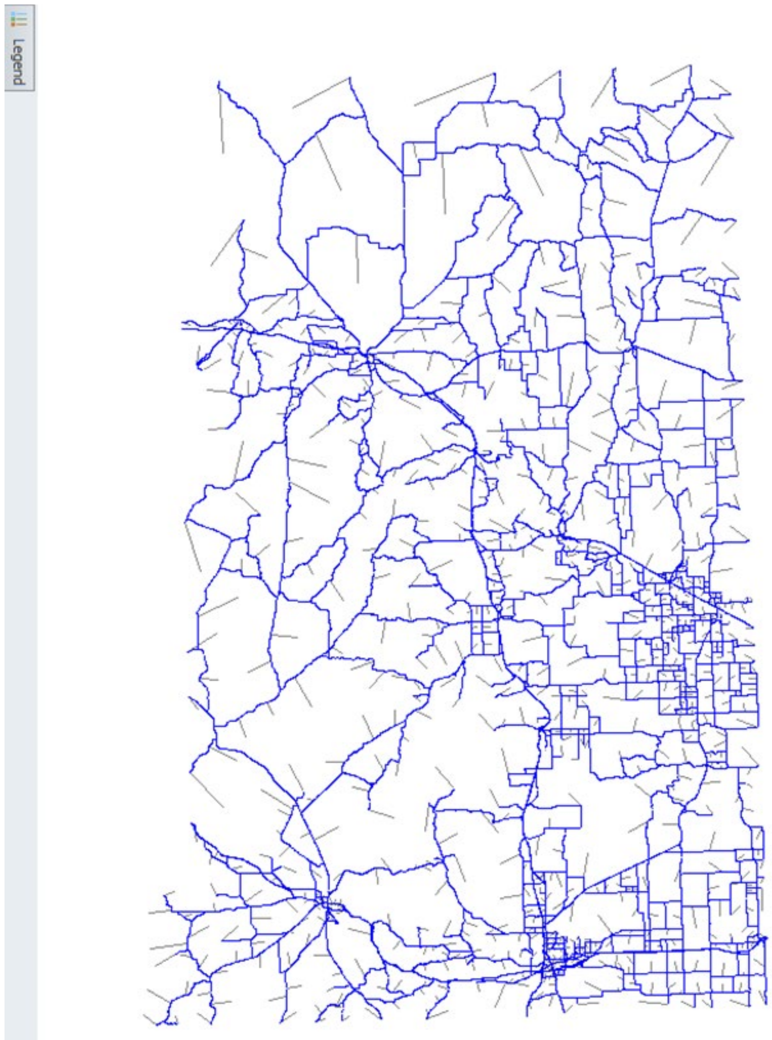

Figure 4.12 Trip Assignment Outputs

4.7 Summary

This section details the four-step TDM development. Trip generation equations were created based on recommendations of the ITE Trip Generation Manual. ADT at park entrances, park areas, and number of campsites in each park were included in trip generation equations. The model is designed to capture interactions between tourism activities and traffic volumes.

5. MODEL OUTPUT DATA

5.1 Introduction

This section presents the outputs from CUBE software and how the outputs were converted to traffic volumes. This section also discusses the model validation procedures. Model outputs can assist planners to make informed transportation planning decisions. The outputs vary depending on the ideas and information used and sophistication of the particular model. The outputs from this model provide users with estimated traffic volumes on low-volume roads.

5.2 Model Outputs

Figure 5.1 shows the model outputs from CUBE for each road segment. The outputs were in the format of GIS shapefiles so they can be further interpreted in ArcGIS software.

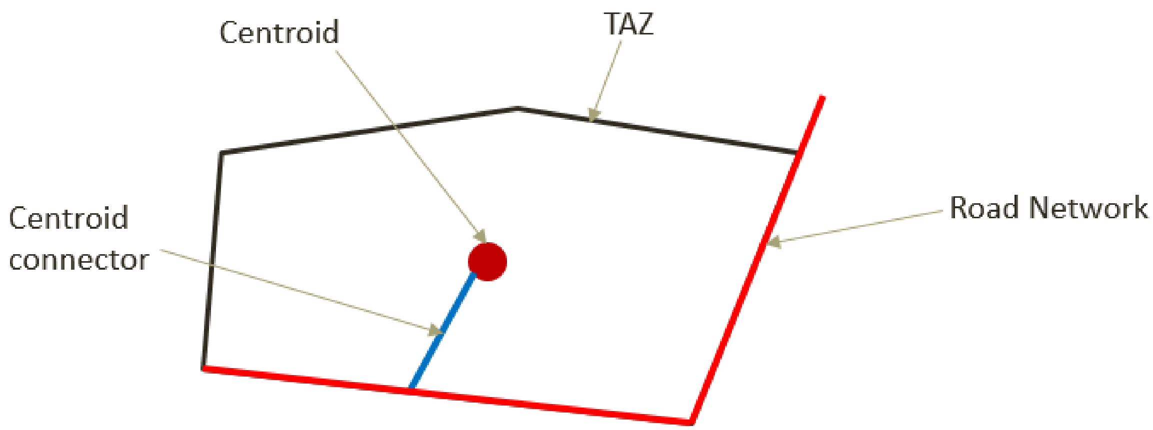

Figure 5.1 Output for Each Road Segment

The outputs were rounded up to whole numbers and combined to obtain the estimated ADT for each road. Appendices 2 to 5 show the results from comparing ADT estimates to actual ADT. The output includes all the major road networks and the local roads. Some collectors in TAZs are not indicated in the output. However, these collectors are represented by the centroid connector within the TAZ for estimating their volumes. Figure 5.2 shows part of the model output map. The roads of interest are the access roads in TAZ number 353.

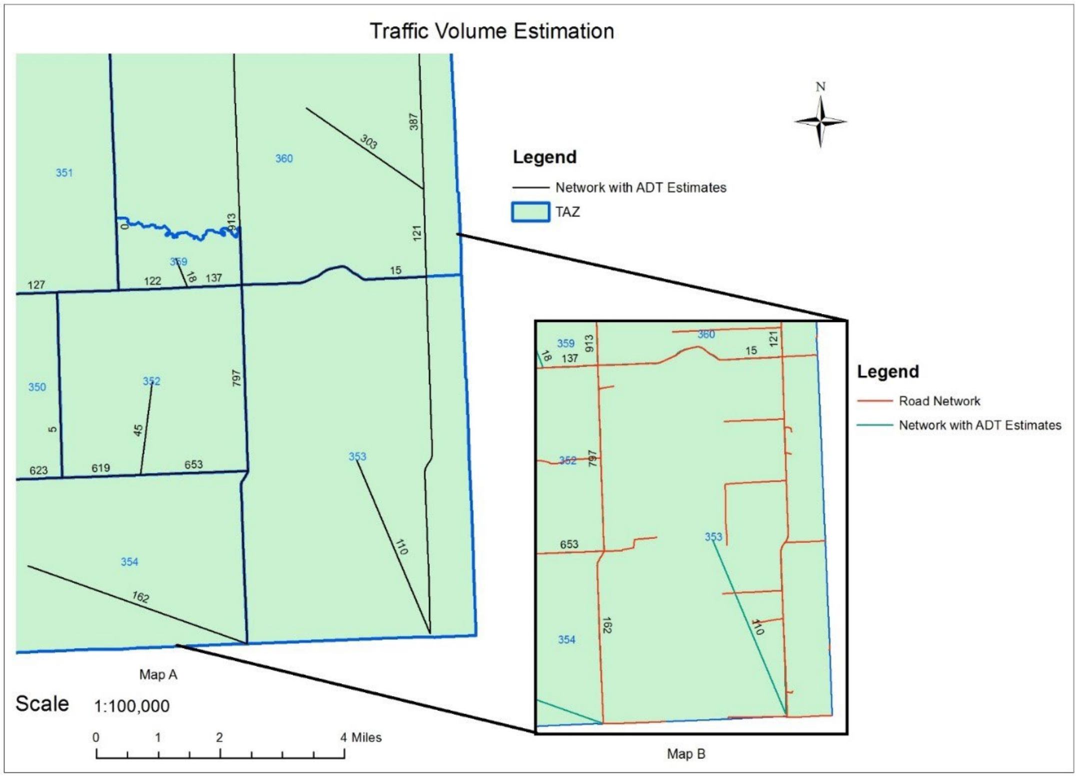

Figure 5.2 Interpreting Model Outputs in ArcGIS

Map A in Figure 5.2 shows the black lines, which represent roads for which traffic volumes have been estimated. The traffic volume estimates are shown by the links in black text. For TAZ 353, there is a single centroid connector with a traffic volume of 110. However, in Map B, there are six access roads to the zone. In such a scenario, the estimate on the centroid connector is used for estimating traffic on the access roads. Thus, the traffic volume on each access link can be described as being less than 110 vehicles, or the combined traffic volume for all the access roads of the zone is equal to 110 vehicles. In the case of a link between two junctions that is joined midway by a centroid connector (e.g. the south link of TAZ 352), the estimated volume on either side of the connector with the highest volume should be used for the entire link. For instance, the road bordering the south of TAZ 352 will have an estimated traffic volume of 653. The link can be clicked for more detailed information such as the freight traffic volume and the road number of the link.

Figure 5.3 shows outputs in terms of attribute table in ArcGIS. The attribute table contains ADT values from different trip types for each road segment. Figure 5.4 shows the results of low-volume roads (ADT < 400) and non-low-volume roads based on the model outputs. Figure 5.5 shows the detailed road distribution in each range.

FID	Shape *	Person	Crop	Oil	Tourism	Total_ADT
0	Polyline	38	0	4	3	45
1	Polyline	272	0	0	26	298
2	Polyline	13	0	0	1	14
3	Polyline	9	0	0	10	19
4	Polyline	3	0	0	0	3
5	Polyline	3	0	0	0	3
6	Polyline	34	0	2	2	38
7	Polyline	4	1	1	7	13
8	Polyline	7	2	1	21	31
9	Polyline	6	0	1	3	10
10	Polyline	17	4	1	5	27
11	Polyline	10	0	1	0	11
12	Polyline	13	2	0	1	16
13	Polyline	11	3	0	9	23
14	Polyline	5	7	0	5	17
15	Polyline	12	2	0	0	14
16	Polyline	6	0	0	0	6

Figure 5.3 Attribute Table in ArcGIS

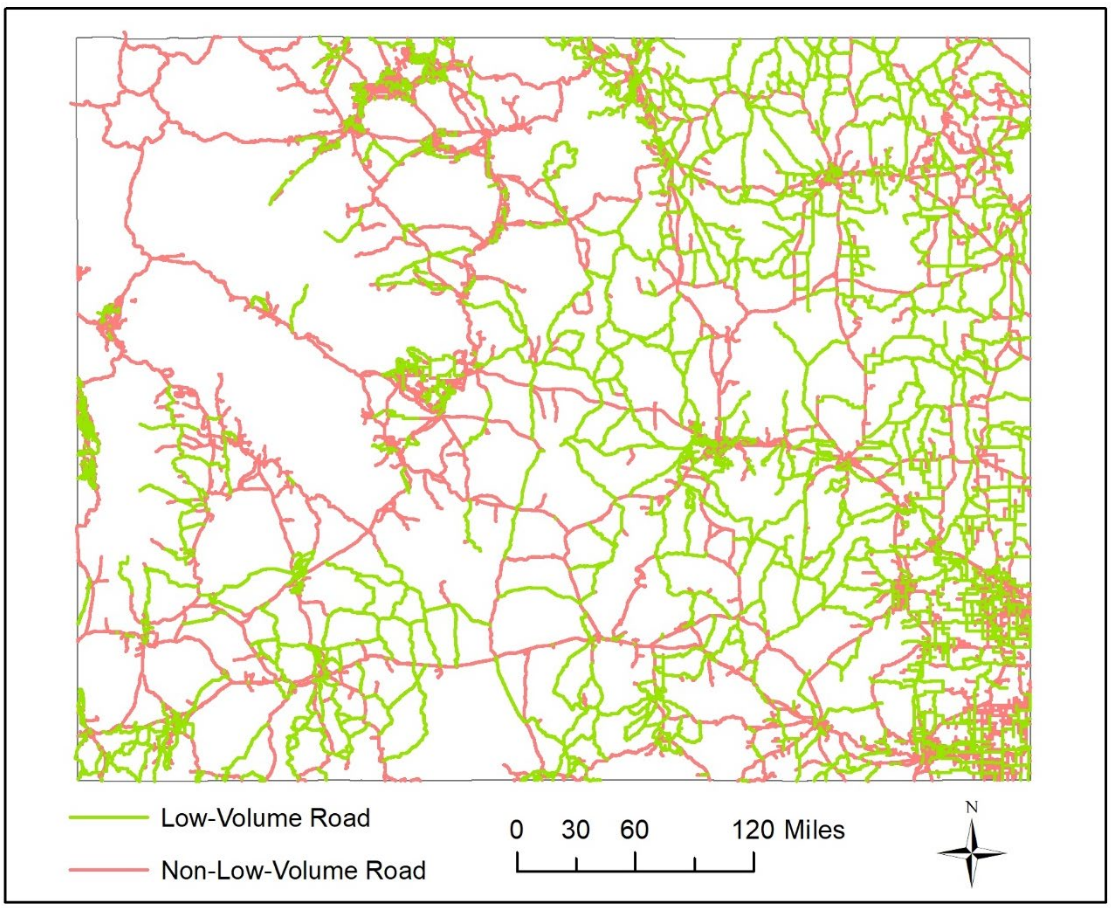

Figure 5.4 Low-Volume Roads and Non-Low-Volume Roads

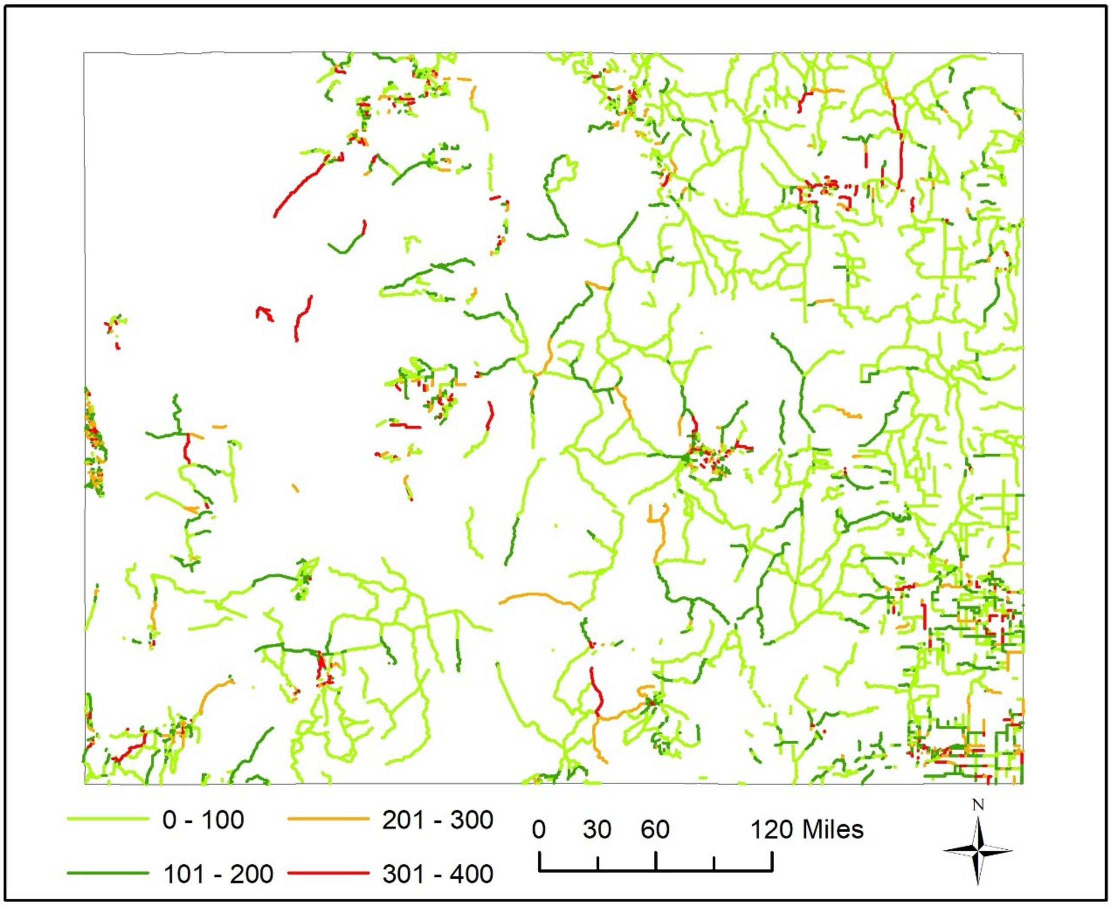

Figure 5.5 ADT on Low-Volume Roads

5.3 Model Validation

Model developers should focus model calibration efforts on using accurate data inputs (network coding, socio-economic data, etc.), reasonable model parameters and appropriate modeling procedures. If isolated traffic counts are poorly modeled, then model developers should ask why the model is not representing the situation well. Often such problems are a result of the size of zones, isolated high trip generators, the location of centroid connector's incorrect socio-economic data, or any number of factors that should be investigated. Sometimes it is better to accept that the model cannot represent particular situations well rather than inserting ill-advised model adjustments just to make the assignment appear to be better.

Validation of the model results to locations that have actual traffic counts is necessary so that it can be shown that the model is within expected ranges. In validating the model for calibration, traffic volume data generated by the model were compiled and compared to actual traffic volume of selected low-volume roads in the study area. Figure 5.6 shows the distribution of actual traffic counters for model validation. Table 5.1 lists the number of paved and unpaved roads where actual data were collected. Table 5.2 lists the R-square improvement after incorporating tourism into TDM. Results indicate that model accuracy for Region 3 (where Yellowstone and Grand Teton National Parks are located) has been improved dramatically after considering tourism (see Figure 5.7). However, the model accuracy for Region 1 and 4 are not much improved. As a result, additional model validation was done to improve the model accuracy.

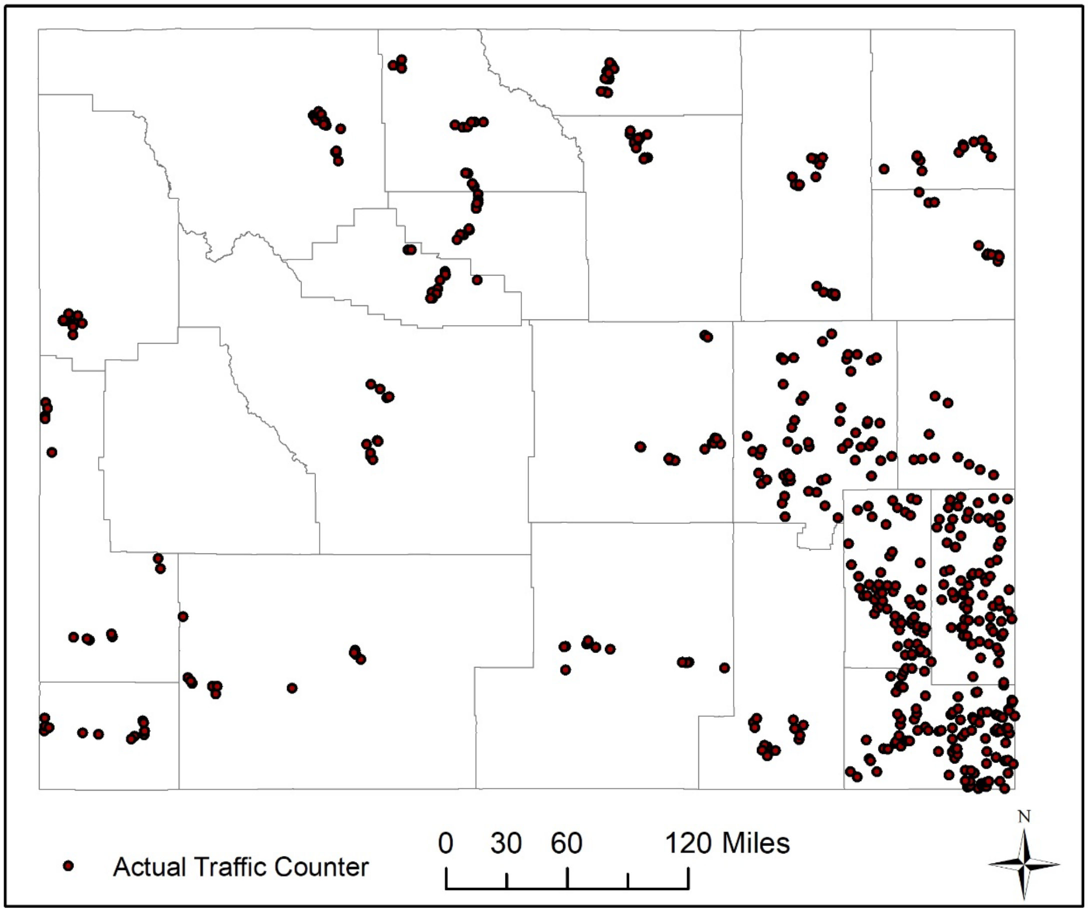

Figure 5.6 Locations of Actual Traffic Counters for Model Validation

Table 5.1 Actual Traffic Count Data Collected in Each Region

Region	Paved	Unpaved
1	57	270
2	36	35
3	43	33
4	42	26

Table 5.2 R-Square Improvement

	Without Tourism	With Tourism
Region 1 (Southeast)	0.70	0.81
Region 2 (Northeast)	0.91	0.93
Region 3 (Northwest)	0.60	0.88
Region 4 (Southwest)	0.73	0.84

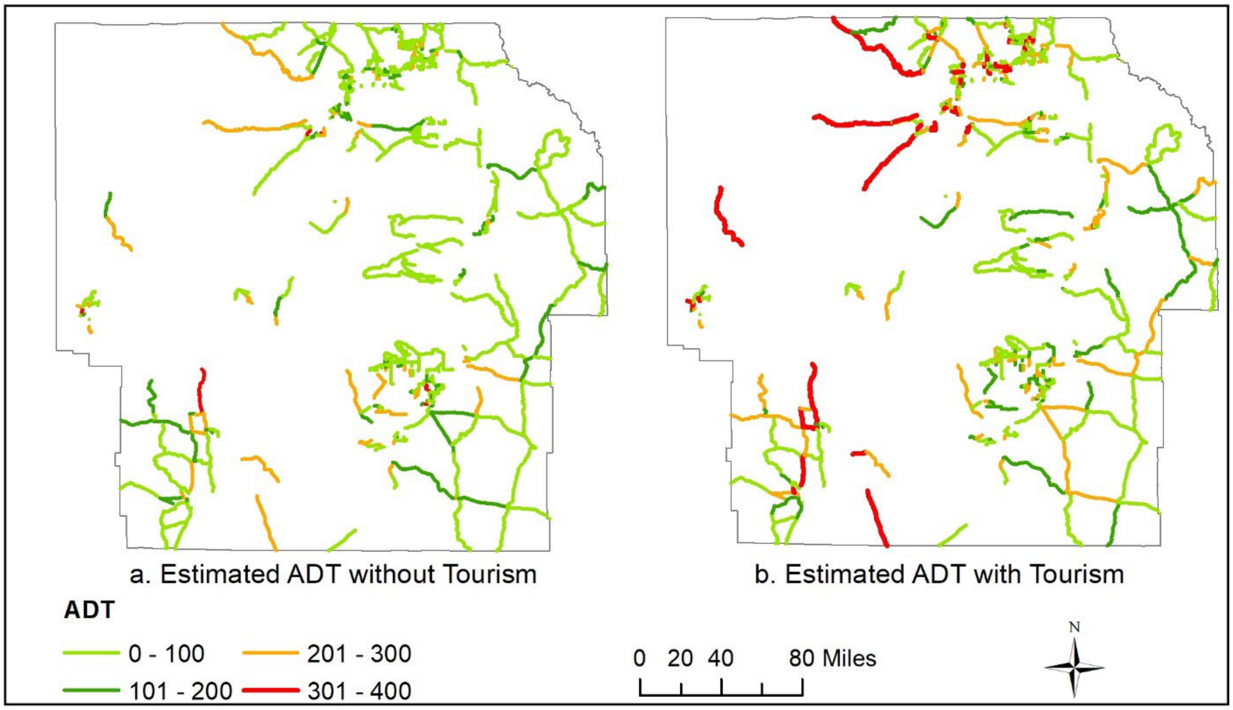

Figure 5.7 Estimated ADT Without and With Tourism in Region 3

The additional model validation involved adding more tourism destinations as model inputs. Modification was attempted by adding one tourism destination in Region 1 near Casper and one tourism destination in Region 4 near Rock Springs. However, there is no official ADT values available for these two places. As a result, the ADT values near these two places recorded by the WYDOT were used as model inputs. Figure 5.8 shows the locations of the tourism destinations and WYDOT traffic recorders.

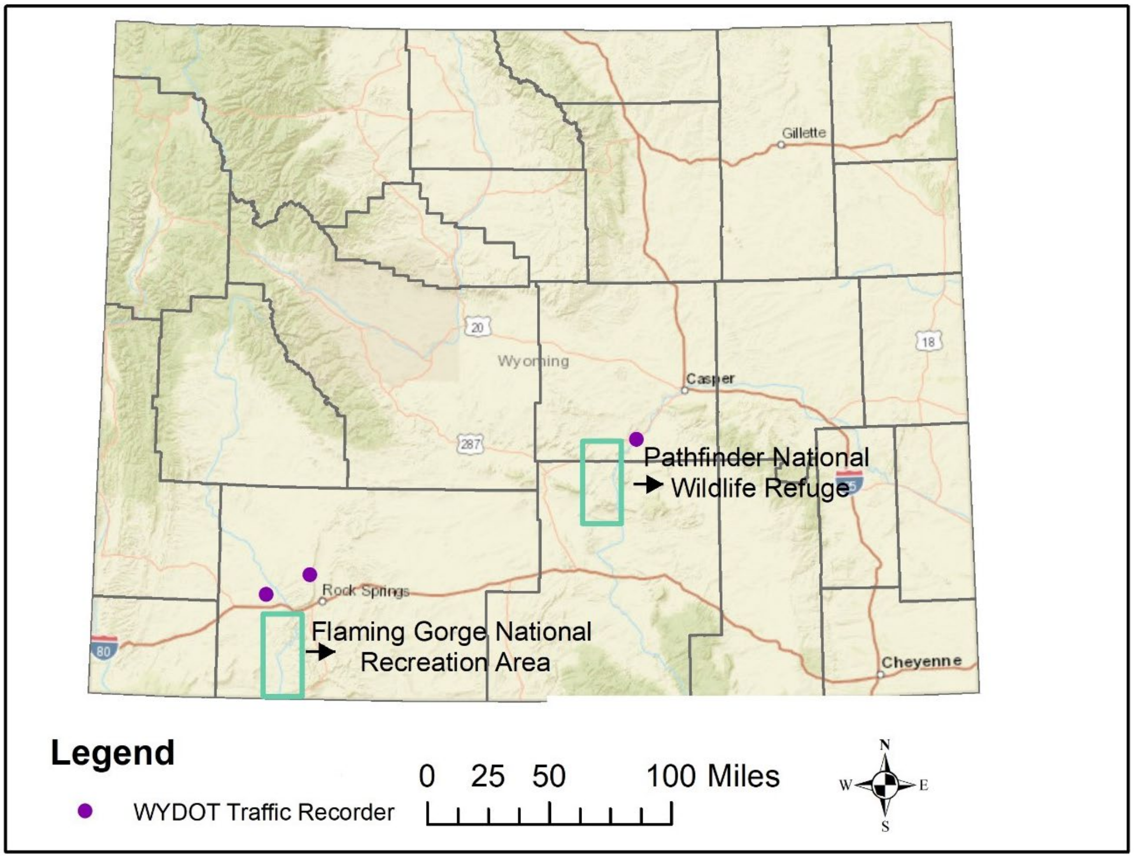

Figure 5.8 Locations of WYDOT Traffic Recorders for Model Validation

Figures 5.9-5.12 show ADT frequencies in different regions. Most of the low-volume roads in Wyoming have ADT values smaller than 100. In Region 3, road segments with ADT between 200 to 400 are more than the other three regions due to tourism activities. The improvement in prediction accuracy for the model after the model validation was satisfactory. Table 5.3 shows the R-square improvement after adding two more tourism destinations into the model.

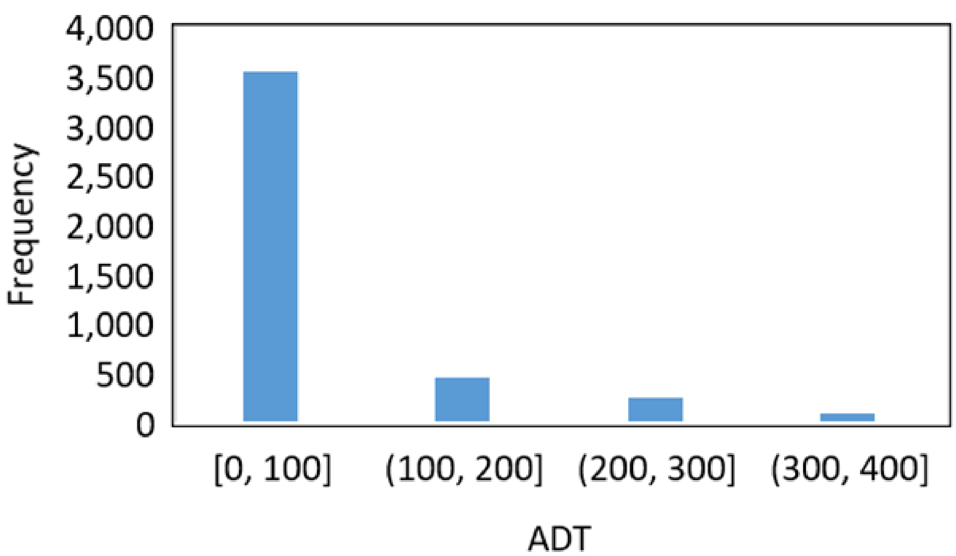

Figure 5.9 ADT Frequency in Region 1

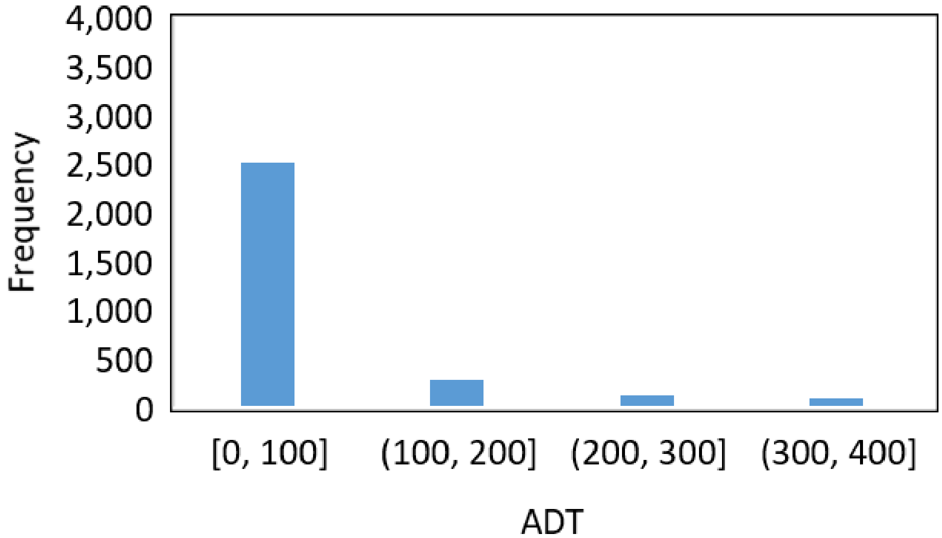

Figure 5.10 ADT Frequency in Region 2

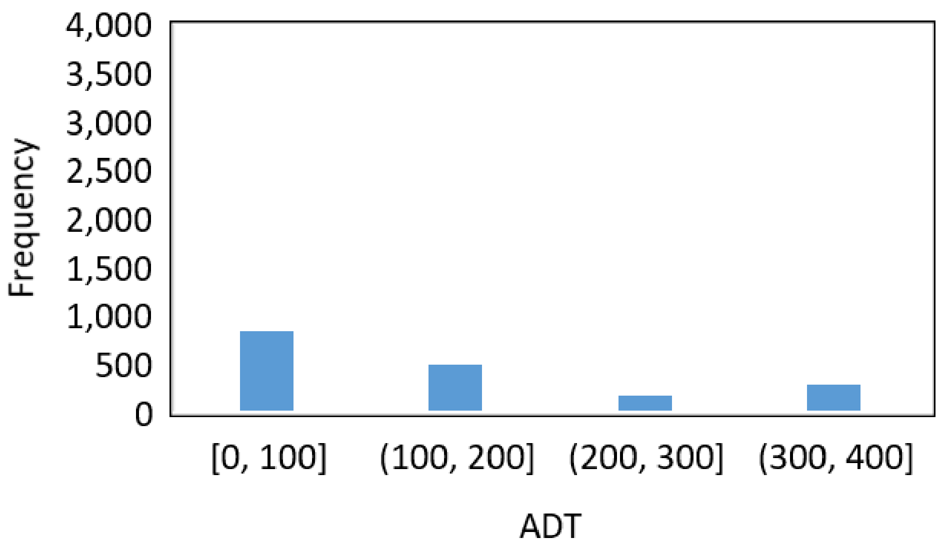

Figure 5.11 ADT Frequency in Region 3

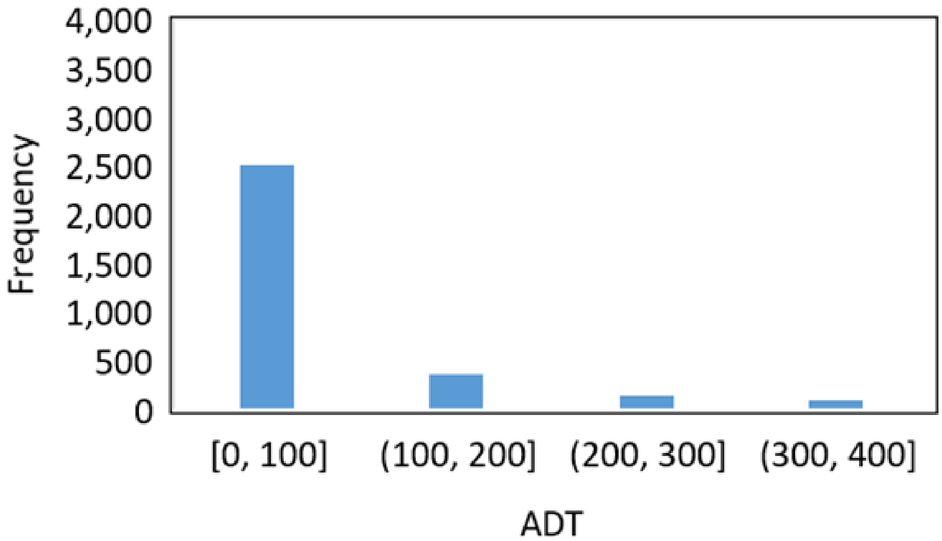

Figure 5.12 ADT Frequency in Region 4

Table 5.3 R-square Improvement after Model Validation

	Without Tourism	**With Tourism**	**After Model Validation**
Region 1 (Southeast)	0.70	0.81	0.86
Region 2 (Northeast)	0.91	0.93	0.93
Region 3 (Northwest)	0.60	0.88	0.88
Region 4 (Southwest)	0.73	0.84	0.87

5.4 Summary

This section presented the model outputs, which contain estimated traffic volumes on low-volume roads. It is also necessary to mention some drawbacks of TDMs. The main deficiency of TDMs was that the large sized transportation analysis zones took away the ability to estimate traffic volumes for some links that were completely within a zone. Such roads were not included in the trip distribution process because they did not provide a link between at least two zones necessary for the trips from one zone to be distributed to the other. This problem affected estimation accuracy of the model since trips generated in a zone were assigned to fewer links than what is the case for certain areas. An additional limitation is the lack of travel behaviour surveys for all the parks included in this study to enable local friction factor, time of day, and vehicle occupancy calibrations. Such surveys are resource-intensive, so the model calibration was limited to only the trip rate generation step in this study. Inclusion of the other calibration factors would improve the estimation accuracy of the model, but the additional expense may be prohibitive for local transportation agencies to implement.

6. SEASONALITY ANALYSIS

6.1 Introduction

The first objective of this analysis is to provide a cost-effective approach for development of statewide tourism traffic seasonal factors. The second objective of this analysis is to perform a cluster analysis to identify spatial variation patterns in tourism seasonal traffic to allow the analysts to develop grouping criteria for transportation planning. The determination of seasonal factors, followed by a review of how roads are grouped into common patterns of variation, may help transportation planners successfully group roads with similar seasonal patterns, and whether individual road segments can be correctly assigned to those groups. The methodologies developed in this study for seasonal factor grouping were implemented in a GIS program, which supports visualization of data on transportation system, traffic data, and statistics about seasonal factors and groups. This research recommended a strategic approach to determine the routes or general areas where the seasonal pattern is clearly identifiable. The results of this analysis are expected to provide important quantitative information about tourism seasonality which could be useful for both tourism and transportation management. Figure 6.1 shows the parks and historic sites included in the seasonal analysis. Monthly total traffic volumes at each park entrance were used in seasonality analysis.

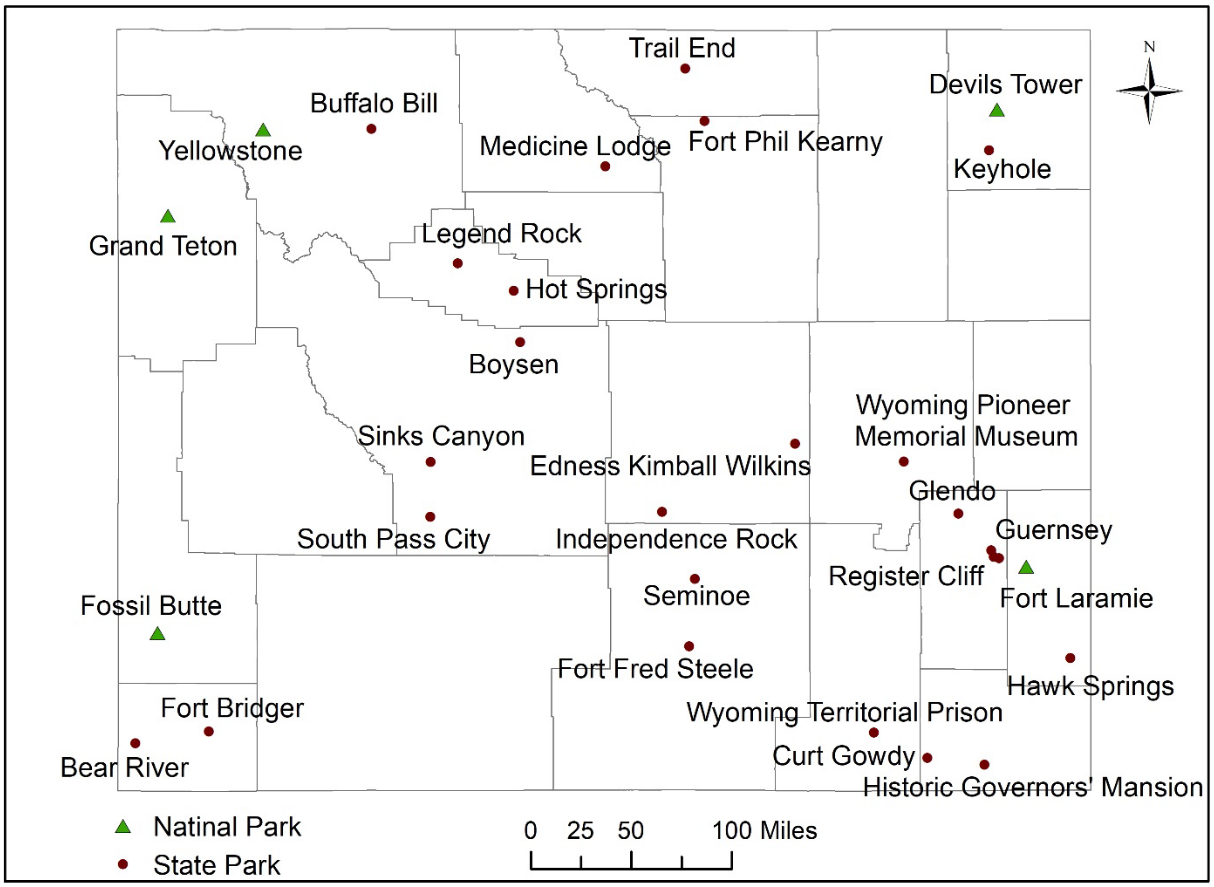

Figure 6.1 Parks Included in Seasonal Analysis

6.2 Methodology

A monthly pattern of higher and lower traffic counts compared to overall roadway AADT is called seasonality (Federal Highway Administration, 2016). Seasonal factors have been recognized as an important method in analyzing traffic data. Seasonal variations in traffic demand must be taken into consideration before estimating the capacity of a transportation facility. This ensures year-round accommodation of traffic demand. The seasonality pattern often repeats similarly from year to year for a roadway. The seasonal factors are usually estimated based on small samples of continuous actual traffic. After obtaining the monthly factors, they can be used as input to a computerized cluster analysis procedure to identify roadway sections with similar traffic patterns. Overall, this study evaluated the seasonality pattern based on the following steps:

1. Calculate seasonal factors for each park.
2. Perform cluster analysis and evaluate the factor groups.
3. Select the optimal clustering method to verify if seasonal groups are temporally stable.

The analysis began by determining the monthly average seasonal factors. To develop those factors, an agency should have a modest number of permanently operating traffic monitoring sites. Permanent data collection sites provide data on seasonal and day-of-week trends. Continuous count summaries also provide precise measurements of changes in travel volumes and characteristics at a limited number of locations. The seasonal analysis in this study was carried out on a monthly basis because other studies have shown that patterns based on weekly or daily variation reduce the veracity of the resulting seasonal factors (Federal Highway Administration 2018). The traffic count data used in this study was obtained from the NPS and WSPHST. For national parks, the NPS publishes a variety of visitor use statistics reports each year. The numbers of traffic count published by the NPS have been adjusted to only report the number of vehicles entering the park, including employee, nonrecreation and recreation vehicles. For state parks, the WSPHST collects visitor use data by traffic counters or by manual hand counts. The traffic counters monitor lanes of traffic by counting vehicle traffic and they could be used to document traffic volumes at each WSPHST.

Monthly seasonal factors are commonly used and are computed as follows:

$$M_j = \frac{AADT}{MADT_j}$$ **Equation 6.1**

Where:

M_j is the monthly factor for month j of the year,

AADT is the annual average daily traffic, and

$MADT_j$ is the monthly average daily traffic.

Monthly seasonal factors provide an insight into how travel changes month by month.

Cluster analysis is a methodology recommended by the FHWA to define road groups with similar traffic patterns based on seasonal adjustment factors. Cluster analysis places road segments into groups so road segments in the same group have similar seasonal traffic patterns. Two advantages of cluster analysis are that it allows for independent determination of similarity between groups, therefore making the groups less subject to bias, and it can identify travel patterns that may not be intuitively obvious to the analyst. Accordingly, it helps agency staff investigate road groupings that might not otherwise be examined, which can lead to more efficient and accurate factor groups and provide new insights into the state's travel patterns.

Several types of statistical cluster methods exist for grouping objects. Among these methods, nonparametric methods, including hierarchical clustering and nonhierarchical clustering, have been widely used to determine seasonal factor groups in transportation research and practice (Zhao et al., 2004). The hierarchical cluster analysis begins by treating each observation as a cluster by itself. The two closest clusters determined by a specific similarity measure are merged to form a new cluster to replace the two old ones. Merging of the two closest clusters is repeated until only one single cluster remains. The nonhierarchical analysis, such as K-means clustering algorithm, is also the most widely used. K-means method must specify the number of k clusters first. Given a certain threshold, all observations are assigned to the nearest cluster until no reclassification is necessary. K-means method has been greatly applied in transportation problems and proven its high accuracy (Al-Wakeel and Wu, 2016).

This study applied SPSS software to conduct the cluster analysis. The first step is to define the distance between variables. There are several types of distance measures and the most common used method is Euclidean distance. It is defined by using the following equation:

$$D_{ij} = \sqrt{\sum_{k=1}^{n}(x_{ki} - x_{kj})^2}$$ **Equation 6.2**

Where:

D_{ij} is the distance between cases i and j, and

x_{ki} is the value of variable X_k for case j.

The second step is to choose cluster method: hierarchical or nonhierarchical. Both methods have advantages and disadvantages. This study used a combination approach: first conducted a hierarchical method to define the number of clusters, and then used the nonhierarchical method (K-means method) to actually form the clusters. The combination approach will provide results that are more reliable. The third step is to validate the analysis. The clusters will be indicated on a map and evaluated for the relevance of variables in one cluster.

6.3 Results

Monthly seasonal factors for each park were calculated using Equation 6.1. AADT is the total traffic volumes on a road for one year divided by 365 days. MADT estimates the average daily traffic volume over one month. It can be computed by summing the daily volumes during a given month and then, dividing the sum by the number of days in the month (Federal Highway Administration, 2016). In this research, both national and state parks provided monthly total traffic volumes at park entrances, and these traffic volumes were converted to AADT and MADT to calculate monthly seasonal factors for each park. These monthly seasonal factors are presented in Appendix 6. In addition to monthly seasonal factors, some summary statistics can provide useful information in analyzing seasonal traffic flow patterns. Appendix 7 shows descriptive statistics of monthly seasonal factors, including range, minimum and maximum values, mean values, standard deviation, and coefficient of variance (CV). Usually urban areas have a percent coefficient of variation under 10%, while those of rural areas range between 10 and 25%. Coefficients of variation higher than 25% indicate highly variable travel patterns, which may be caused by tourism activities (Federal Highway Administration, 2016). By comparing these values, it was found that the parks with high range and CV values have a large variation in monthly seasonal factors. For all parks, peak season (May-October) has low values of monthly factors and the off-peak season (November-April) has high values of monthly factors.

SPSS software was applied to perform the cluster analysis, which was carried out to assess the degree of monthly seasonal variation existing in each park as detected from the traffic volumes at park entrances.

The major weakness of cluster analysis is the lack of theoretical guidelines for establishing the optimal number of groups. Therefore, a subjective assessment is needed to establish what is appropriate. However, the objective of this analysis is to identify patterns based on available actual traffic data rather than to provide an optimal solution. In general, three to six groups are usually sufficient to address traffic patterns in a state based on recommendations from Traffic Monitoring Guide (Federal Highway Administration, 2016). Establishment of the groups requires determination of relevant criteria (functional class, geography, topography, etc.) and use of analytical judgment.

In this research, the optimal number of clusters is determined by means of a dendrogram provided by SPSS. To determine the optimal number of clusters, the number of clusters is plotted against the rescaled distance cluster combine (see Figure 6.2). The optimal number of clusters is that number for which an extra step in the clustering procedure would lead to a more than proportional increase in the distance (Nowotny et al., 2003). In this case, the optimal number of clusters is four. Table 6.1 shows the cluster assignment for each park.

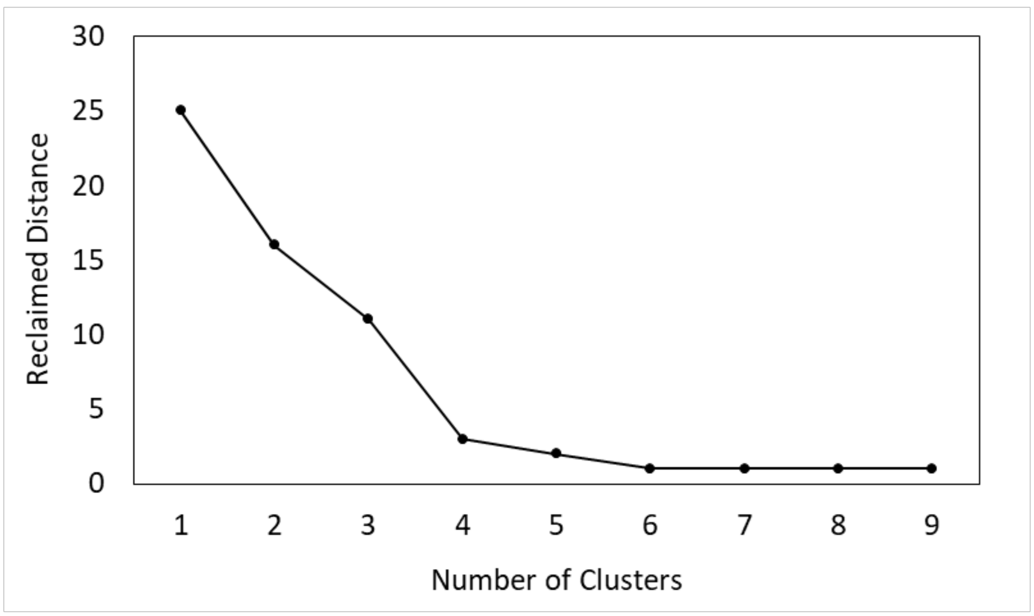

Figure 6.2 Number of Clusters vs. Reclaimed Distance

Table 6.1 Cluster Assignment for Each Park

Park Name	4 Clusters	Park Name	4 Clusters
Yellowstone (Northeast Entrance)	1	Glendo	4
Yellowstone (East Entrance)	1	Guernsey	3
Yellowstone (South Entrance)	1	Hawk Springs	3
Grand Teton (North Entrance)	1	Historic Governors' Mansion	4
Grand Teton (East Entrance)	1	Hot Springs	2
Grand Teton (South Entrance)	1	Independence Rock	4
Devils Tower	2	Keyhole	2
Fort Laramie	4	Legend Rock	2
Fossil Butte	2	Medicine Lodge	2
Bear River	4	Oregon Trail Ruts	4
Boysen	3	Register Cliff	3
Buffalo Bill	2	Seminoe	3
Curt Gowdy	4	Sinks Canyon	2
Edness Kimball Wilkins	4	South Pass City	3
Fort Bridger	4	Trail End	3
Fort Phil Kearny	2	Wyoming Pioneer Memorial Museum	3
Fort Steele	4	Wyoming Territorial Prison	4

Plotting locations of the parks and groups on a map is helpful for identifying clustering patterns. ArcGIS software was used to examine the location of groups on a map and identify characteristics of the spatial patterns. Figure 6.3 shows the cluster assignment and the road network in Wyoming. Parks showing similar seasonal traffic patterns were grouped into a cluster. Cluster 1 contains all entrances of Yellowstone and Grand Teton National Parks. These two parks are close to each other and they have similar patterns in terms of traffic volumes in each month. Cluster 2 contains nine parks, including two national parks and seven state parks, most of which are located in North Wyoming. Cluster 3 contains eight state parks, most of which are located in Central and Southeast Wyoming. Cluster 4 contains 10 parks, including one national park and nine state parks, most of which are located in Southeast Wyoming. The results show that parks in Northwest Wyoming fall into Cluster 1 and most of the other parks in North Wyoming falls into Cluster 2, although there is no obvious boundary for Cluster 3 and 4. Roads near parks that are in the same cluster can also be considered into one group for developing tourism travel demand and managing policy.

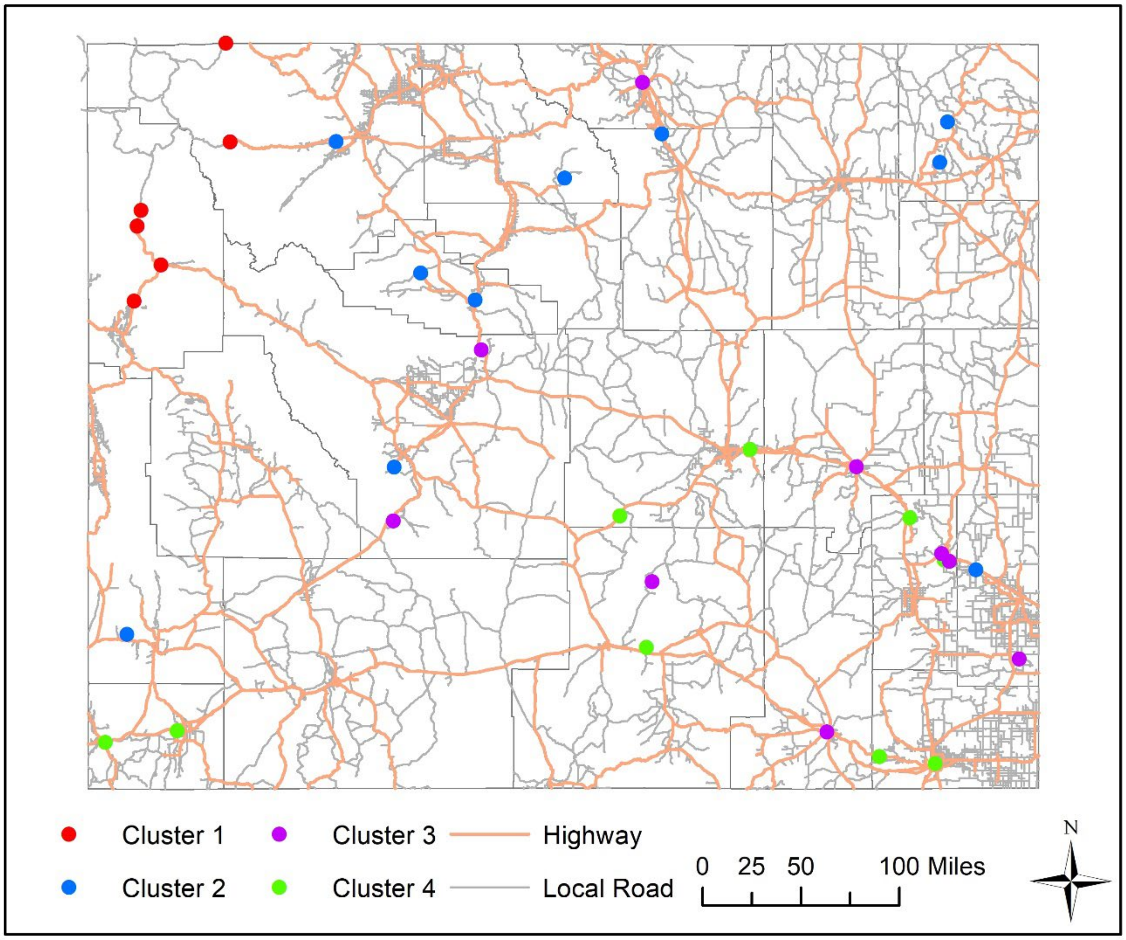

Figure 6.3 Cluster Analysis Results

6.4 Summary

This study first determined tourism-related traffic seasonal factors by using traffic count data at national and state park entrances. It was found that tourism traffic has a strong seasonal pattern in Wyoming. May to October is the peak season and October to April is the off-peak season. Then, this study applied hierarchical cluster analysis to evaluate spatial patterns in tourism seasonal traffic. Parks were grouped based on monthly seasonal factors and classified into four groups based on a statistical analysis. Parks in the same group have similar seasonal variations in traffic volumes.

The methodology developed in this research is easily applicable to other regions. Results of this research can be applied to monitor regular and irregular variations in traffic volumes near tourism destinations and provide a better estimation of the actual traffic volumes in a certain month at a certain location. The results of this research can be also used for tourism traffic forecasting and land use planning.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

This report provides sources for all data used to develop and implement the tourism-based statewide TDM. A description of the data and theory behind the parameters developed for the four-step TDM was presented. Procedures for model development were also presented. Generated model outputs from person trips, crop production related freight trips, oil production related freight trips, and tourism trips were combined to obtain the total vehicle trips. A description of how to read the estimated traffic volumes from the output map was also presented. In conclusion, the model outputs are adequate for estimating tourism-related traffic volumes on low-volume rural roads in Wyoming.

7.2 Conclusions

Tourism travel is a significant portion of the total travels in Northwest Wyoming and low-volume roads provide links to some popular recreational facilities. This study presented a method for estimating traffic volumes on low-volume roads due to tourism activities. In this study, a tourism-based travel demand model was developed to estimate ADT in Northwest Wyoming. Actual traffic counts were used for calibration purposes. It has been shown that tourism can be incorporated into a traditional four-step travel demand model to predict tourism-related ADT on the local road network. This data can then be compared to actual traffic data to locate sites that may have underrepresented traffic flows. Results from the model proved the existence of high traffic volumes in rural areas. It can be concluded from this study that the low-volume roads near Yellowstone National Park will experience traffic volume increase due to an increase in tourism trips. While this work looked specifically at tourism trips near Yellowstone National Park, the method could be applied to any trip type that has known origin and destination information. The model results can be applied in a variety of transportation designs and planning. The conclusions of this study are as follows:

1. A travel demand model is useful and practical for estimating traffic volumes on low-volume roads. A variety of tourism-related parameters, including ADT at park entrances, park area, and number of campsites in park were considered in trip generation to estimate the number of trips.
2. Compared to actual traffic counts, the travel demand model has an 88% prediction accuracy after incorporating tourism into the model, which captures traffic flows on low-volume roads near tourism destinations. Local roads with high traffic volumes should be given priority in transportation planning and maintenance.
3. Results of this study indicated that TDM is capable to work well with a variety of tourism data sets and can be used to predict traffic volumes in future. Traffic volume data does not exist for the majority of low-volume roads. A TDM is a cost-effective method to obtain traffic volumes.
4. Tourism-related traffic seasonal factors were calculated by using traffic count data at national and state park entrances. It was found that tourism traffic has a strong seasonal pattern in Wyoming. May to October is the peak season and October to April is the off-peak season.
5. Cluster analysis was used to evaluate spatial patterns in tourism seasonal traffic. Parks were grouped based on the monthly seasonal factors. Based on a statistical analysis, the parks were classified into four groups. Parks in the same group have similar seasonal variations in traffic volumes. The results from cluster analysis provided a good starting point for transportation agencies to group roads with similar seasonal traffic patterns.
6. Existence of the tourism seasonal pattern can also represent traffic patterns on road networks. The roads near the parks that are in the same cluster can also be considered into one group for developing tourism travel demand and managing policy.

This study shows the significance of capturing the tourism-related traffic volumes for transportation planning and maintenance. The tourism-based model can be easily incorporated into the existing statewide travel demand model and used for future tourism travel demand prediction. This study also adds to existing knowledge on the estimation of traffic volumes by travel demand model in rural areas. Previous studies mainly focused on estimating traffic volumes in urban areas and Interstate highways. The model developed in this study can be used to estimate ADT in rural areas where not enough traffic counters are installed. The model is recommended for an update based on the updated census data from the U.S. Census Bureau and the visitation data from the NPS. It is recommended that the model developed in this study be applied by government and tourism agencies in other states or regions where tourism is a major generator of traffic flow on low-volume roads.

7.3 Recommendations

This study shows the significance of capturing tourism-related traffic volumes for transportation planning and maintenance. The tourism-based model can be easily incorporated into the existing statewide travel demand model and used for future tourism travel demand prediction. This study also adds to the existing knowledge on the estimation of traffic volumes by travel demand model in rural areas. Previous studies mainly focused on estimating traffic volumes in urban areas and Interstate highways. The model developed in this study can be used to estimate ADT in rural areas where not enough traffic counters are installed. The model is recommended for an update based on the updated census data from the U.S. Census Bureau and the visitation data from the NPS. The model developed in this study is recommended to be applied by government and tourism agencies in other states or regions where tourism is a major generator of traffic flow on low-volume roads. The model is recommended for upgrade after new ADT values at park entrances are available. Updating the model will ensure that the model is not using outdated data and its predictions match closely with the actual traffic volumes on the low-volume roads in Wyoming.

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APPENDICES

Appendix 1 Input Data for TAZ

Park Name	ADT in Off-Peak Season	ADT in Peak Season	Area (Acres)	Number of Campsites
Yellowstone National Park (Northeast Entrance)	0	521	1,109,895	260
Yellowstone National Park (East Entrance)	2	937	554,947	1,434
Yellowstone National Park (South Entrance)	2	1,444	554,947	535
Grand Teton National Park (North Entrance)	43	1,641	155,000	235
Grand Teton National Park (East Entrance)	173	1,669	77,500	416
Grand Teton National Park (South Entrance)	146	1,673	77,500	349
Devils Tower National Monument	58	728	1,346	89
Fort Laramie National Historic Site	28	100	833	0
Fossil Butte National Monument	0	20	8,198	0
Bear River State Park	131	407	324	0
Boysen State Park	57	179	35,952	65
Buffalo Bill State Park	24	109	11,276	99
Curt Gowdy State Park	50	258	3,395	159
Edness Kimball Wilkins State Park	45	127	361	0
Fort Bridger State Historic Site	12	126	40	0
Fort Phil Kearny State Historic Site	3	40	713	0
Fort Steele State Historic Site	0	12	139	0
Glendo State Park	105	514	18,382	568
Guernsey State Park	22	137	8,631	245
Hawk Springs State Recreation Area	10	32	996	24
Historic Governors' Mansion State Historic Site	8	14	1	0
Hot Springs State Park	269	678	1,109	0
Independence Rock State Historic Site	26	92	203	0
Keyhole State Park	42	343	15,890	286
Legend Rock State Petroglyph Site	2	23	31	0
Medicine Lodge Archaeological Site	6	60	200	28
Oregon Trail Ruts State Historic Site	8	52	34	0
Register Cliff State Historic Site	6	51	1	0
Seminoe State Park	3	48	20,848	88
Sinks Canyon State Park	78	357	600	30
South Pass City State Historic Site	0	28	346	0

Trail End State Historic Site	11	23	4	0
Wyoming Pioneer Memorial Museum State Historic Site	5	14	2	0
Wyoming Territorial Prison State Historic Site	2	56	197	0

Appendix 2 Region 1 Validation Data

Road ID	Actual ADT	Estimated ADT (Without Tourism)	Estimated Tourism ADT	Estimated Total ADT
RIN 5	350	341	66	407
RIN 26	198	16	89	105
RIN 992	173	141	25	166
RIN 169	168	106	54	160
RIN 118	142	149	8	157
RIN 920	136	21	86	107
RIN 55	115	75	35	110
RIN 260	115	75	37	112
RIN 120	111	118	56	174
RIN 212	110	173	3	176
RIN 159	108	100	35	135
RIN 178	102	56	42	98
RIN 42	95	16	38	54
RIN 208	91	48	15	63
RIN 102	88	106	15	121
RIN 168	85	106	9	115
RIN 702	81	30	33	63
RIN 121	81	17	11	28
RIN 6012	77	74	32	106
RIN 23	73	68	3	71
RIN 136	73	73	29	102
RIN 710	70	38	31	69
RIN 138	69	83	1	84
RIN 170	68	69	28	97
RIN170	68	68	2	70
RIN 131	65	21	35	56
RIN 152	64	16	28	44
RIN 124	62	35	24	59
RIN 144	62	62	4	66
RIN 256	62	28	15	43
RIN 128	61	59	12	71
RIN 74	60	13	24	37
RIN 175	60	83	11	94
RIN 41	59	29	17	46
RIN 52	59	46	9	55
RIN 106	59	32	4	36
RIN 1088	57	40	2	42

RIN 148	57	74	2	76
RIN 49	50	8	2	10
RIN 13	49	21	11	32
RIN 2102	45	27	10	37
RIN 2028	45	15	12	27
RIN 25	43	21	20	41
RIN 104	43	80	8	88
RIN 142	43	27	15	42
RIN 991	42	14	4	18
RIN 165	42	33	4	37
RIN 112	40	6	2	8
RIN 1090	40	41	4	45
RIN 105	39	13	3	16
RIN 1125	39	18	3	21
RIN 70	38	13	11	24
RIN 980	37	28	5	33
RIN 3033	35	3	1	4
RIN 3045	35	3	1	4
RIN 707	33	19	5	24
RIN 3030	33	4	13	17
RIN 176	33	30	2	32
RIN 2029	33	15	16	31
RIN 6014	32	25	2	27
RIN 216	32	31	10	41
RIN 111	31	5	2	7
RIN 1193	31	28	2	30
RIN 2086	30	12	4	16
3032	29	4	1	5
RIN 2090	29	7	4	11
RIN 161	28	28	5	33
RIN 224	26	3	1	4
RIN 261	26	5	2	7
RIN 1132	26	24	1	25
RIN 150	26	9	2	11
RIN 857	25	29	0	29
RIN 258	25	23	11	34
RIN 214	25	63	0	63
RIN 219	25	14	11	25
RIN 45	24	4	13	17
RIN 252	24	3	6	9
RIN 146	24	5	1	6

RIN 215	24	11	1	12
RIN 2105	23	29	2	31
RIN 139	23	8	2	10
RIN 2036	23	23	1	24
RIN 1153	22	18	3	21
RIN 2056	21	10	14	24
RIN 1150	21	5	5	10
RIN1068	21	14	1	15
RIN 3028	21	4	1	5
RIN 3010	21	4	2	6
RIN 3005	21	12	2	14
RIN 160	21	14	2	16
RIN 1137	21	7	2	9
RIN 207	21	5	3	8
RIN 1107	21	3	3	6
RIN 126	20	8	0	8
RIN 2118	20	4	2	6
RIN 1257	20	3	9	12
RIN 1029	20	15	1	16
RIN 229	20	5	2	7
RIN 3020	20	7	2	9
RIN 47	19	3	1	4
RIN 113	19	19	0	19
RIN 201	19	4	7	11
RIN 3026	19	3	1	4
RIN 2083	19	4	2	6
RIN 10	18	16	2	18
RIN 73	18	14	0	14
RIN 888	17	11	1	12
RIN 123	17	9	5	14
RIN 728	17	8	3	11
RIN 1043	17	6	6	12
RIN 158	16	9	6	15
RIN 2045	16	6	8	14
RIN 18	16	11	0	11
RIN 43	16	4	3	7
RIN 227	16	3	7	10
RIN 1126	16	6	4	10
RIN 1100	16	3	6	9
RIN 2116	15	12	0	12
RIN 1064	15	8	2	10

RIN 2078	15	3	2	5
RIN 1099	15	3	1	4
RIN 3087	14	13	0	13
RIN 1139	14	11	9	20
RIN 1095	14	14	1	15
RIN 68	13	4	1	5
RIN 1071	13	17	1	18
RIN 2077	13	3	2	5
RIN 65	12	5	1	6
RIN 2119	12	5	1	6
RIN 1034	12	4	1	5
RIN 147	12	10	4	14
RIN 3113	12	5	1	6
RIN 1114	12	4	1	5
RIN 16	11	17	2	19
RIN 2127	11	3	1	4
RIN 771	11	13	0	13
RIN 1133	11	3	8	11
RIN 1113	11	3	1	4
RIN 2038	10	4	2	6
RIN 179	10	14	6	20
RIN 1062	10	26	13	39
RIN 1057	10	8	4	12
RIN 3025	10	14	2	16
RIN 107	9	13	12	25
RIN 51	9	5	7	12
RIN 1152	9	4	2	6
RIN 3076	9	7	1	8
RIN 1136	9	4	5	9
RIN 2125	8	3	0	3
RIN 2123	8	3	2	5
RIN 1266	8	5	2	7
RIN 3099	8	3	0	3
RIN 1135	8	4	1	5
RIN 203	7	4	0	4
RIN 3029	7	4	0	4
RIN 1124	7	5	1	6
RIN 1117	7	4	1	5
RIN 21	6	5	1	6
RIN 2130	6	3	2	5
RIN 2091	6	4	0	4

RIN 3070	6	6	0	6
RIN 3090	6	10	1	11
RIN 889	5	13	5	18
RIN 200	5	7	0	7
RIN 3057	5	3	4	7
RIN 1101	5	3	1	4
RIN 31	4	3	10	13
RIN 3022	4	9	7	16
RIN 210	4	9	4	13
RIN 726	2	3	0	3
RIN 1039	2	3	1	4
RIN 125	1	6	3	9

Appendix 3 Region 2 Validation Data

Road ID	Actual ADT	Estimated ADT (Without Tourism)	Estimated Tourism ADT	Estimated Total ADT
ML5377B	936	826	235	1061
ML6704B	507	410	118	528
ML6275B	479	470	13	483
ML5625B	302	342	49	391
ML8202B	260	172	22	194
ML8977B	210	138	56	194
ML8910B	189	226	7	233
ML5681B	189	83	46	129
ML8233B	186	190	22	212
ML9614B	177	113	0	113
ML8231B	164	186	12	198
ML8918B	157	159	53	212
ML5629B	157	52	12	64
ML5318B	126	122	32	154
ML8276B	120	155	18	173
ML8196B	118	187	22	209
ML6711B	113	156	16	172
ML6273B	108	3	10	13
ML9396B	105	55	25	80
ML5645B	92	93	18	111
ML5328B	88	67	25	92
ML6272B	88	3	7	10
ML8187B	86	145	18	163
ML6261B	81	11	17	28
ML5632B	75	52	0	52
ML6256B	75	14	0	14
ML5421B	62	3	0	3
ML5384B	59	13	2	15
ML8219B	48	58	15	73
ML8906B	47	15	18	33
ML8208B	47	138	3	141
ML8939B	46	28	14	42
ML6283B	32	7	3	10
ML5669B	30	3	0	3
ML8927B	27	11	2	13
ML9224B	26	26	0	26
ML5630B	19	23	1	24

ML5661B	19	13	0	13
ML6262B	17	46	0	46
ML5636B	12	24	5	29

Appendix 4 Region 3 Validation Data

Road ID	Actual ADT	Estimated ADT (Without Tourism)	Estimated Tourism ADT	Estimated Total ADT
ML78705B	1841	1670	264	1934
ML8656B	750	7	635	642
ML5867B	670	69	540	609
ML7807B	654	355	401	756
ML8654B	576	837	144	981
ML5249	527	315	231	546
ML8653B	394	608	44	652
ML5867B	385	69	196	265
ML1136B	363	122	121	243
ML7791B	352	124	270	394
ML5823B	326	203	52	255
ML5713B	320	156	163	319
ML5298B	301	113	217	330
ML7811B	285	122	11	133
ML5702B	282	229	28	257
ML7811B	258	46	11	57
ML5289B	182	135	85	220
ML8670B	182	107	45	152
ML5271B	151	354	10	364
ML8668B	151	170	12	182
ML5835B	148	147	21	168
ML5262B	137	354	10	364
ML7811B	131	124	28	152
ML5104B	126	354	10	364
ML8889B	124	64	38	102
ML7792B	114	11	13	24
ML5899B	103	203	35	238
ML5256B	91	63	45	108
ML7881B	83	155	25	180
ML5817B	78	111	2	113
ML5764B	74	53	2	55
ML5261B	73	114	54	168
ML5777B	73	147	10	157
ML7797B	69	11	15	26
ML7801B	57	155	24	179
ML7799B	49	191	10	201
ML5302B	38	76	4	80

ML8873B	35	4	0	4
ML7791B	21	3	0	3
ML7794B	13	16	32	48
ML5264B	11	14	10	24
ML5266B	11	21	4	25

Appendix 5 Region 4 Validation Data

Road ID	Actual ADT	Estimated ADT (Without Tourism)	Estimated Tourism ADT	Estimated Total ADT
ML7700B	389	330	64	394
ML8399B	360	151	227	378
ML7623B	358	61	103	164
ML8688B	357	148	181	329
ML8476B	306	312	61	373
ML8722B	298	167	117	284
ML8744B	283	219	56	275
ML5465B	262	112	137	249
ML8386B	260	169	129	298
ML7442B	241	129	84	213
ML7635B	213	96	177	273
ML7566B	199	67	79	146
ML8689B	193	161	35	196
ML7699B	191	152	36	188
ML7635B	183	35	159	194
ML7451B	158	165	25	190
ML5476B	149	81	27	108
ML8737B	144	74	55	129
ML5471B	136	50	37	87
ML8721B	136	145	34	179
ML8399B	135	51	98	149
ML7655B	132	14	148	162
ML5480B	117	43	87	130
ML7656B	109	96	33	129
ML8441B	104	20	76	96
ML7621B	104	15	103	118
ML7654B	102	85	33	118
ML7569B	97	19	85	104
ML5478B	90	25	31	56
ML5428B	86	35	23	58
ML8691B	85	28	20	48
ML7577B	84	28	25	53
ML5425B	78	39	34	73
ML7466	78	52	16	68
ML8401B	72	32	61	93
ML7568B	71	58	27	85
ML5436B	71	39	6	45
ML8400B	69	32	62	94

ML5469B	66	50	2	52
ML7653B	48	72	2	74
ML5503B	40	12	21	33
ML7586B	36	7	25	32
ML8399B	24	51	4	55
ML7645B	24	14	38	52
ML7513B	22	34	0	34
ML7576B	16	11	12	23
ML7557B	13	6	4	10
ML7694B	10	10	0	10
ML8714B	10	8	5	13

Appendix 6 Monthly Seasonal Factors for Each Park

Park Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Yellowstone (Northeast Entrance)					1.89	0.89	0.64	0.70	0.93	3.48		
Yellowstone (East Entrance)					1.50	0.70	0.55	0.62	0.94	2.53		
Yellowstone (South Entrance)					1.70	0.69	0.54	0.61	0.94	2.64		
Grand Teton (North Entrance)	16.07	19.13	18.82	20.17	1.06	0.42	0.31	0.36	0.53	1.55	22.68	21.60
Grand Teton (East Entrance)	5.21	6.62	5.25	3.95	0.93	0.44	0.35	0.42	0.58	1.36	5.29	5.96
Grand Teton (South Entrance)	6.54	6.89	5.71	4.99	1.22	0.50	0.35	0.35	0.50	1.43	6.58	6.54
Devils Tower	13.32	13.32	5.69	3.42	1.03	0.45	0.34	0.35	0.60	1.62	5.43	10.73
Fort Laramie	2.54	2.99	2.12	1.62	0.82	0.53	0.44	0.53	0.64	1.53	2.39	2.29
Fossil Butte					2.82	0.81	0.55	0.77	0.87	0.96	11.47	
Bear River	2.48	2.43	1.46	1.49	0.56	0.60	0.56	0.62	0.81	0.92	2.45	2.66
Boysen	2.15	3.14	1.91	1.44	0.73	0.52	0.40	0.56	1.06	1.43	1.96	2.36
Buffalo Bill	4.10	3.56	2.04	1.57	0.83	0.53	0.44	0.44	0.62	1.28	4.33	3.47
Curt Gowdy	10.49	10.49	2.42	1.27	0.61	0.43	0.46	0.52	0.62	1.75	4.52	2.86
Edness Kimball Wilkins	2.19	2.71	1.63	1.35	0.63	0.64	0.49	0.51	0.91	1.31	2.01	2.09
Fort Bridger	7.37	12.56	6.42	4.09	0.95	0.86	0.60	0.78	0.22	3.17	3.16	
Fort Phil Kearny					1.29	0.70	0.72	0.51	0.88	1.23	2.84	
Fort Steele					1.42	0.80	0.72	0.90	1.84			
Glendo	3.41	4.76	2.69	6.09	0.71	0.42	0.32	0.69	1.05	1.24	1.77	2.18
Guernsey		4.07	2.11	2.32	0.80	0.51	0.43	0.35	1.17	0.80	1.88	
Hawk Springs	5.14	12.24	1.10	0.68	0.47	0.43	0.45	0.61	1.60	3.02	7.27	7.70
Historic Governors' Mansion	4.97	3.08	2.91	1.28	0.99	0.50	0.49	0.65	1.15	4.68	1.08	0.53
Hot Springs	5.92	7.03	4.88	4.91	4.26	4.56	0.42	0.35	0.42	0.91	1.04	0.75
Independence Rock	9.43	11.62	0.85	1.47	0.75	0.41	0.35	0.64	1.15	2.12	2.19	6.14
Keyhole	6.41	5.73	9.42	2.52	0.66	0.39	0.27	0.51	1.51	2.56	5.46	3.24
Legend Rock	15.00	13.36	3.57	3.95	0.72	0.43	0.42	0.42	0.46	1.67	5.36	28.68
Medicine Lodge	10.54	8.59	9.18	3.23	0.62	0.57	0.45	0.40	0.62	0.71	3.75	7.18
Oregon Trail Ruts	4.40	7.91	2.57	1.91	0.80	0.39	0.57	0.40	0.61	1.15	4.43	6.53
Register Cliff	5.26	10.11	5.05	2.27	0.65	0.44	0.38	0.49	0.66	1.16	4.22	6.21
Seminoe			13.32	2.81	0.73	0.48	0.30	0.48	0.82	3.75	7.32	
Sinks Canyon	5.49	2.97	3.82	1.70	0.72	0.51	0.37	0.61	0.87	0.89	2.18	2.80
South Pass City					1.89	1.60	0.45	1.12	1.39			
Trail End	2.04	2.86	2.61	1.75	0.82	0.62	0.54	0.50	1.31	1.34	1.20	0.74

Wyoming Pioneer Memorial Museum	1.31	1.77	2.11	1.29	1.77	0.86	0.67	0.21	1.87	1.76	3.14	5.14
Wyoming Territorial Prison	14.39	17.14	17.64	6.13	0.85	0.48	0.32	0.59	0.93	0.40	47.57	5.81

**Months without seasonal factors indicate park closures in these months.

Appendix 7 Descriptive Statistics for Monthly Seasonal Factors

Park Name	Range	Min.	Max.	Mean	Std. Deviation	CV
Yellowstone (Northeast Entrance)	2.84	0.64	3.48	1.42	1.11	1.22
Yellowstone (East Entrance)	1.98	0.55	2.53	1.14	0.76	0.58
Yellowstone (South Entrance)	2.10	0.54	2.64	1.19	0.83	0.69
Grand Teton (North Entrance)	22.37	0.31	22.68	10.23	10.07	101.43
Grand Teton (East Entrance)	6.27	0.35	6.62	3.03	2.54	6.46
Grand Teton (South Entrance)	6.54	0.35	6.89	3.47	2.92	8.54
Devils Tower	12.98	0.34	13.32	4.69	5.08	25.81
Fort Laramie	2.55	0.44	2.99	1.54	0.92	0.85
Fossil Butte	10.92	0.55	11.47	2.61	3.98	15.86
Bear River	2.10	0.56	2.66	1.42	0.86	0.74
Boysen	2.74	0.40	3.14	1.47	0.86	0.73
Buffalo Bill	3.89	0.44	4.33	1.93	1.52	2.31
Curt Gowdy	10.06	0.43	10.49	3.04	3.69	13.64
Edness Kimball Wilkins	2.22	0.49	2.71	1.37	0.76	0.57
Fort Bridger	12.34	0.22	12.56	3.65	3.82	14.59
Fort Phil Kearny	2.33	0.51	2.84	1.17	0.79	0.63
Fort Steele	1.12	0.72	1.84	1.14	0.48	0.23
Glendo	5.77	0.32	6.09	2.11	1.83	3.36
Guernsey	3.72	0.35	4.07	1.44	1.17	1.37
Hawk Springs	11.81	0.43	12.24	3.39	3.87	14.96
Historic Governors' Mansion	4.48	0.49	4.97	1.86	1.63	2.67
Hot Springs	6.68	0.35	7.03	2.95	2.51	6.32
Independence Rock	11.27	0.35	11.62	3.09	3.83	14.69
Keyhole	9.15	0.27	9.42	3.22	2.93	8.58
Legend Rock	28.26	0.42	28.68	6.17	8.69	75.49
Medicine Lodge	10.14	0.40	10.54	3.82	3.95	15.64
Oregon Trail Ruts	7.52	0.39	7.91	2.64	2.59	6.71
Register Cliff	9.73	0.38	10.11	3.08	3.11	9.66
Seminoe	13.02	0.30	13.32	3.33	4.40	19.33
Sinks Canyon	5.12	0.37	5.49	1.91	1.60	2.55
South Pass City	1.44	0.45	1.89	1.29	0.55	0.30
Trail End	2.36	0.50	2.86	1.36	0.80	0.65
Wyoming Pioneer Memorial Museum	4.93	0.21	5.14	1.83	1.29	1.66
Wyoming Territorial Prison	17.32	0.32	17.64	6.77	9.47	31.72