TRUCKLOAD FREIGHT TRANSPORTATION UTILIZING RELAY POINTS TO IMPROVE THE DRIVING JOB

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CHAPTER 1

INTRODUCTION

Freight transportation has increased dramatically over the last thirty years as freight and shipment demand has expanded resulting in driver and equipment capacity issues and infrastructure problems. Freight transport tonnage in the domestic U.S. is predominately truck transportation and is reported by the American Trucking Association (ATA) to consist of 69% of all freight distribution with a growth expectation of 27% between the years 2006 and 2018 [1]. Truck transportation currently represents about 5% of the U.S. Gross Domestic Product (GDP) [1]. Rail freight ranks second in tonnage distributed at 13% [1]. Within the trucking industry, truckload transportation makes up about 50% of all truck tonnage shipped [1]. Truckload transportation involves transporting full trailers or containers over long distances (i.e. typically greater than 500 miles over a one-way transit) from a shipper to a receiver where drivers may also be required to physically load and unload trailers depending on customer requirements and freight characteristics. As a result of the large amount of truckload transportation, truckload driver capacity concerns, driver problems, and work conditions have become critical issues over the years. Truckload driver retention and turnover have had significant negative impacts on the truckload transportation industry over the years primarily because of poor working conditions and strenuous job requirements.

Truckload drivers are away from home quite often and spend a significant amount of time either driving or sleeping in a truck during off-duty time. Some truckload drivers are required to load freight at a shipper, unload freight at a customer, strap and secure flatbed freight, monitor refrigerated freight, manually lift product, wash the inside of a trailer after delivering to the final customer, bracing product, and other responsibilities in addition to driving a truck. The truckload driving job is an unattractive job because it requires a large amount of miles and time driving alone each week, long hour work weeks (i.e. typically 70 hours over an eight day time span or 60 hours over a seven day time span), being away from family and friends anywhere from two to four weeks at a time, low hourly pay wages compared to other professions, a distant or impersonal relationship between direct supervision and management, route irregularities, and other factors. Due to the current unattractive nature of the truckload driving job, many drivers quit driving and find employment closer to home while many people refuse to consider entrance into the driving market because of poor work conditions, the poor image of the driving profession, and unpleasant job requirements. Since the truckload driving job is unattractive, driver shortages and retention problems persist and have shown to result in: higher truckload transportation price rates due to capacity limitations, significant costs associated with driver turnover and recruitment, high driver training costs, safety and accident related issues, and idle truck and trailer equipment due to a lack of truck drivers. Also, customer related issues exist involving a lack of equipment to ship products, poor delivery service, and missed pick-ups at the shipper.

Reports on the state of the trucking industry show that truckload transportation continues to suffer major driver shortages and very high driver turnover rates which will continue to worsen as the U.S. economy grows. It has been reported that truckload driver turnover is consistently above 100% and has reached 300% in some extreme cases while the overall U.S. unemployment rate averages around 9%. According to the ATA, the driver shortage is expected to be over 110,000 drivers by the year 2014 unless measures are taken to improve the truckload driving job and working conditions. Truckload driver turnover and shortage issues cause truckload transportation capacity shortages resulting in numerous economic problems and customer service related issues. A national shortage of truckload drivers causes economic implications beyond trucking's own boundaries, and the U.S.

economy ultimately feels the pinch of the driver shortage and turnover problem. Although the truckload driving job has been a major concern for many years, there have been limited research efforts made to explore methods for making the truckload driving job more attractive, and there have been minimal proactive techniques applied to curb driver turnover. Most transportation carriers have provided driver wage increases and more fringe benefits as strategies for retaining drivers with little efforts made to improve driving jobs and working conditions. Min and Emam [2] explain that 80% of the top 100 transportation carriers used driver wage increases in the 1990s as a means to reduce the driver turnover rate, which had minimal long term impact on driver turnover rates.

The truckload driving job is a relatively unexplored area of research but a significant part of the U.S. economy. Some research has been done in recent years to analyze driver turnover but with very few practical methods and applications for improving the driving job and working conditions long term, and most studies have been limited in scope failing to look at the truck driver, transportation carrier, and customer together holistically. Efforts have attempted to improve the driving job long term but with mainly short term prescriptions in the form of driver wage increases and fringe benefit improvements. Additionally, most research endeavors have minimal to no implementation efforts using a holistic approach, which has limited the significance of the studies and thwarted practical application. The purposes of this research are to better understand why driver turnover and shortage problems exist and to conduct more needed research on the work related factors and driving conditions associated with the truckload driving job and the implications for not improving the driving job. A progressive study needs to determine what critical factors cause the truckload driving job to be unattractive causing high driver turnover and driver shortages, which will be done in this study. Also, an approach that considers the truck driver, transportation carrier, and customer holistically needs to be taken to improve the truckload driving job while considering industry specific performance metrics. A holistic approach must be taken to make sure benefits are not reaped only by the driver at the expense of either the transportation carrier or customer. This study will consider a holistic approach to improving the truckload driving job.

To retain and satisfy truckload drivers and achieve long term market success, an engineered truckload transportation network must be designed to simultaneously match driver needs with the needs of the transportation carrier and customer. It is asserted here that successful transportation endeavors have followed specific implicit rules that represent necessary, but not sufficient, criteria for market success. An in-depth study of truckload transportation concentrating on the driving job and work conditions by analyzing, studying, and proposing a way to improve the driving job as it relates to the supply chain and transportation network will be conducted. Industry specific performance measures will be used to evaluate the proposed method while focusing simultaneously on the truck driver, transportation carrier, and customer. Since trucking accounts for a significant amount of the U.S. GDP and minimal proactive efforts have been made to improve the truckload driving job, the motivation of this research is to present a better method for reducing driver turnover and consistently retaining drivers long term by improving the truckload driving job and working conditions. Therefore, the focus of this research will be to produce long term results instead of on short term results that merely rely on driver wage increases or expanded fringe benefits. This research is truck driver oriented, but will also realize important performance factors as related to the transportation carrier and customer. The intention is not to improve the driving job at the expense of the transportation carrier or customer but to make sure all three entities benefit together.

This paper will present a method for enhancing the truckload driving job and reducing driver turnover, while considering key performance measures as related to the truck driver, transportation carrier, and customer. Eight sections are included in the paper. Section 1 includes an introduction to the topic. Section 2 concentrates on previous research endeavors and the literature review. Section 3 presents the research statement. Section 4 covers the methodology of the research. Section 5 concentrates on the data and model. Section 6 includes the implementation of the model and an analysis of the initial results. Section 7 focuses on a more detailed analysis of the findings and results by comparing a relay point scenario to a non-relay point scenario. Section 8 closes with some concluding remarks and future research endeavors.

CHAPTER 2

REVIEW OF LITERATURE

2.1 General Transportation Information

There are several transportation modes used in the U.S. to transport products, materials, and other goods from a shipment origin to a receiver destination. The predominant transportation modes are truck, rail, water, and air with different mode combinations serving as intermodal movements. An intermodal movement may involve a freight train moving goods over long distances on the railroad while local trucks transport goods to-and-from rail operation facilities over short distances to position loads on or off the railroad. It is estimated that the mode of distribution consists of 69% truck, 13% rail, 10% pipeline, 7% water, and 1% other transportation [3]. Typically, rail operations are used to move freight less expensive over long distances (e.g. coast-to-coast distances) while truck operations move freight cheaper over shorter distances. On-time service levels tend to be better in truck operations compared to rail operations due to the anomalies of scheduling trains and positioning rail cars on the train, the timely positioning of loads by truck to-and-from rail facilities, operational constraints and issues at rail terminal facilities, and switching rail cars between railroads. Transporting freight involves many operations and logistical services that involve ensuring goods are transported in a timely fashion and in the proper condition and correct quantity. Truck distributed 69% of the total freight tonnage in 2006 and accounted for 84% of the total freight revenue in 2006 while rail accounted for 13% of the total freight tonnage and 6% of the total freight revenue in 2006 according to statistics from the ATA [1]. The trucking industry generated about $650 billion in revenue in 2006 [1]. According to truckinfo.net, the trucking industry hauls about $670 billion worth of manufactured and retail goods annually and accounts for over 430 billion annual miles [4]. The trucking industry employs about 3.5 million truck drivers according to the U.S. Department of Labor [5]**.** Based on statistics, truck transportation is a dominant transportation mode with respect to freight tonnage hauled, miles traveled, and revenue generated, and is utilized to transport goods in many different environments involving inbound shipments, store deliveries, inter-facility moves, intermodal moves, and other move types utilizing less-than-truckload (LTL), parcel, and truckload transporting services.

2.2 Less-Than-Truckload and Truckload Trucking

The two main segments of freight transportation in the trucking industry are the truckload and LTL trucking segments. The LTL segment involves transporting small amounts of freight with shipments averaging between 150 pounds and 20,000 pounds. In the LTL industry, carriers collect freight from various shippers and consolidate the freight into trailers for line-haul delivery to a terminal where the freight may be sorted and consolidated for additional line-haul moves. In the truckload industry, freight is moved from a shipment point to a receiver point with virtually no freight consolidation occurring between the origin and the final destination. Truckload moves are termed point-to-point with freight consolidation done at the shipper. Occasionally, truckload shipments involve multiple stops between the origin and final destination, but intermediate stops are usually minimal- at most one or two stops prior to the final destination. Truck fleets are further classified as private and non-private fleets where non-private fleets are equivalent to for-hire or third party transportation. In 2006, the non-private and private fleet truckload sector together accounted for 10.5 billion tons of hauled freight and $600 billion in generated revenue compared to 155 million tons and $50 billion in generated revenue for LTL operations, which are further illustrated in Figure 1 and Figure 2 [1].

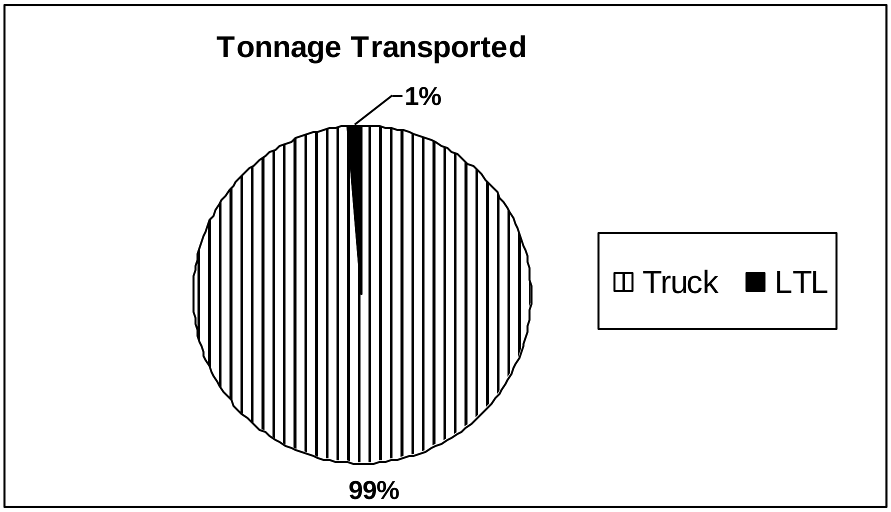

Figure 1. Truck and LTL tonnage transported in 2006 [1]

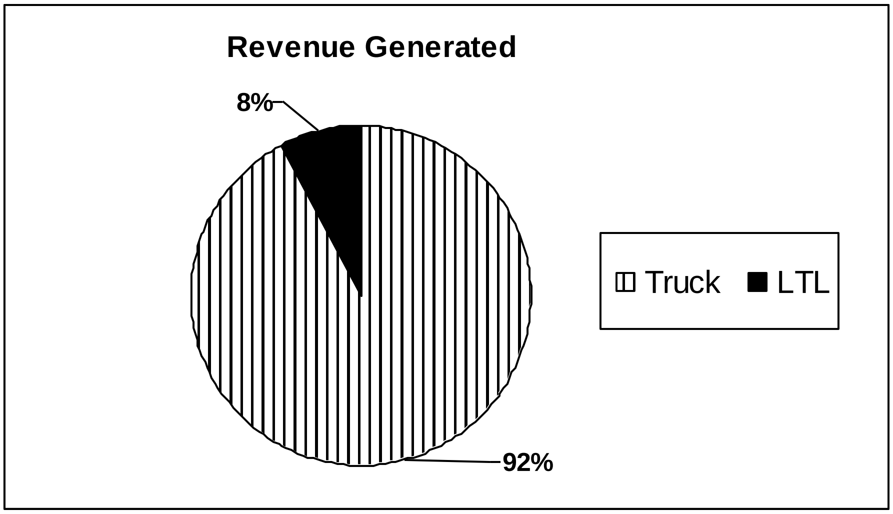

Figure 2. Truck and LTL revenue generated in 2006 [1]

Trucking is a low margin industry compared to its rail counterpart, which has profits as high as 20% or more in some cases. Truckinfo.net [4] reported that trucking companies average an operating ratio of 95.2, which leaves only 4.8 cents of profit for every dollar made. With such a large amount of economic impact and importance, operational significance, and very low profit margins, the trucking industry offers a wide variety of opportunities that can result in significant company gains from a financial, operational, and competitive standpoint.

Two areas that continue to plague the trucking industry, especially the truckload sector, is the driver shortage and driver turnover epidemic. The LTL sector traditionally experiences annual driver turnover rates around 10% while the truckload sector experiences driver turnover rates in excess of 100%. The driver turnover rate for LTL carriers was reported to be 4.5% for city drivers and 10% for line-haul drivers in the late 1980s [6, 7] and has been consistently low over recent years. The truckload sector consisting of dry van, tankers, refrigerated truckload, and flatbed modes typically move long distances compared to the LTL sector which moves shorter distances (i.e. typically greater than 200 miles up to 600 miles one-way). In 1992, the truckload trucking industry experienced an employment growth of 31% [2], but at the same time, experienced a driver turnover rate between 100% and 200% [2], which compared to a median overall U.S. unemployment rate of 8.4%. Min and Emam [2] stated that some truckload carriers had driver turnover rates as high as 300%. According to Rodriguez [8], the truckload industry has a driver turnover rate of 100% each year, and Bush [9] stated that the driver turnover was between 80% and 100% each year. At the end of 2007, the LTL driver turnover rate was 15% compared to 112% for the truckload trucking industry [10]. The truckload driver turnover rate has also been reported to be in the range of 85% to 110% by Mele [6, 7], 110% to 120% by Richardson [11], and as high as 200% by Stephenson and Fox [12]. Also, the Bureau of Labor and Statistics [13] reports that some of the highest turnover rates are in the transportation and logistics industries. In January 2010, the driver turnover rate was reported to be 43% [14] in the third quarter of 2009, which was the lowest driver turnover rate since turnover statistics have been reported by the ATA. The main reasons for the low driver turnover rate were due to an overall high U.S. unemployment rate of 10%, a poor economy resulting in a low number of shipments, and a lack of jobs and company hires, which prevents drivers from voluntarily terminating to find other employment or the same employment with another transportation carrier. According to transportation industry experts, the low truckload driver turnover rate in 2009 is an anomaly and will reach triple digits once again as the economy comes out of the recessionary period. The driver shortage and high driver turnover rate have a significant negative impact on the economy. The disparity in driver turnover between the LTL and truckload trucking sectors is due in part to the differences in the LTL driving job and work requirements compared to the truckload driving job.

The LTL driving job involves moving small shipment amounts from a shipper(s) to a terminal facility and then to a break-bulk facility or a network of break-bulk facilities where the shipments may be possibly reloaded on several trucks and then routed to an end terminal and then routed to a final destination [15]. In the LTL environment, cross-docks are utilized to better optimize vehicle and labor capacity by consolidating multiple shipments, and driving routes tend to be more regularized with shorter transit distances. The cross-docks serve to consolidate freight into truckload shipments to better utilize truck and trailer equipment. Customer service tends to be quite good in an LTL environment, but LTL operations require more logistics and planning in order to coordinate and match loads, consolidate shipments, schedule driver pick-ups and deliveries, and regularize routes. Since the LTL driving job is more regularized and driving distances are shorter with driving routes that support end-of-line break-bulk facilities [16], LTL driving jobs are more attractive and offer more home time compared to truckload driving jobs, which leads to lower driver turnover levels. The more regularized driving job allows drivers to be home on a frequent basis, experience the same driving routes consistently, be in direct contact with supervision more frequently, and become more acquainted to frequented customers. Additionally, there are some large LTL driver unions that have work rules that keep drivers from switching employment to other carriers, which also keeps driver turnover down [17].

As previously mentioned, the truckload industry has experienced high levels of driver turnover dating back to the early 1990s and beyond with driver turnover in excess of 100%. The truckload driving job is considerably different than the LTL driving job. The truckload driving job typically moves freight from point-to-point locations over long distance routes compared to the LTL driving job. Truckload drivers spend a lot of hours driving and sleeping in their truck during off-duty time, and are away from family, friends, and supervision for a significant amount of time. Truckload drivers are typically on the road away from home two to four weeks at a time before returning home for a short break (i.e. typically 1 to 3 days). Truckload drivers usually work sixty to seventy hours over a seven to eight day time span compared to LTL drivers who work closer to forty hours per week over a five day work week. Also, truckload drivers experience many driving challenges as they spend countless hours on the road which leads to higher stress levels. Over the years, the truckload driving job has changed and has been segmented into several categories including dedicated contract, regional, local, and over-the-road (OTR) transportation operations. Each category is unique to a certain degree; therefore, a brief explanation of each is made.

Dedicated truckload driving jobs involve moving freight on more regularized routes dedicated to a specific contracted customer that may include inbound vendor deliveries, outbound store deliveries, or a combination of both, where headhaul freight is matched with backhaul freight in order to reduce empty miles and maximize revenue generating miles. Headhaul freight is outbound freight and backhaul freight is return freight. Empty miles are non-revenue generating miles that must be minimized. Dedicated truckload driving jobs are usually more driver friendly allowing drivers to be home daily or every other day with consistent routes, but jobs tend to be more specialized and may require more driver work in the form of driver loading and unloading freight, load strapping, and freight monitoring. Dedicated driving jobs in the past considered shipment routes with less daily and weekly demand variability, but more recently, dedicated driving environments have considered demand more stochastically. Harding [18] considers demand variability on truck lanes in regard to weekly freight volumes and the associated cost as it relates to the shipper while Mulqueen [19] developed a policy of transportation resource utilization for shippers, which is based on both optimization and simulation methods using probabilistic demand functions. Traditionally, dedicated environments have only considered more deterministic demand situations that promote driver home time and route consistency.

Regionalized truckload driving jobs involve longer length-of-hauls (i.e. 300 mile radius) over a defined region where miles are usually less than OTR driving jobs. Regionalized drivers are home more frequently than OTR drivers but less often than dedicated drivers. Regionalized routes are less regularized than dedicated routes and tend to resemble OTR freight patterns but with the privilege of shorter traveling distances within a defined region. Similar to the dedicated environment, headhaul and backhaul matches are sought in a regionalized environment in order to minimize empty miles and maximize revenue generating miles.

Local driving jobs involve moving freight over very short distances allowing drivers to be home daily, and the drivers operate day cab trucks (i.e. non-sleeper berth trucks). Local driving routes are often too short to procure backhaul freight matches, so round-trip routes are usually 50% loaded and 50% empty. Local drivers typically replenish warehouses from a local manufacturing plant and are also responsible for moving freight to-and-from rail facilities (i.e. dray moves). Local drivers tend to travel in a small radius ranging from less than 50 miles up to 200 miles.

OTR driving jobs involve long distance freight movements where drivers are away from home up to four weeks at a time [12]. The OTR driving job consists of matching headhaul freight with backhaul freight in order to route drivers back to a home domicile or home base in such a way to minimize empty miles. OTR driving jobs are more dynamic irregular driving jobs subject to a high degree of demand variability involving many driving challenges including: road hazards, safety concerns, weather related factors, equipment issues, shipper and receiver related problems, away from home family issues, supervisory problems, etc. These concerns are also present with other driving jobs, but with a more heightened probability of occurrence in an OTR environment because OTR drivers spend more time driving over a wide range of climate possibilities and challenging situations. OTR driving jobs are similar to regional driving jobs except OTR driving jobs can span across many regions leaving the driver thousands of miles away from home. Spending a significant amount of time away from home and living and sleeping predominately in a truck presents challenges to job satisfaction, job retention, and driver turnover. Irregular driving routes, high freight demand variability, and job requirement inconsistencies also result in inflated job discontentment and stress. The current nature of the OTR driving job makes for an unattractive driving job, causing a shortage of people entering the driving market and can result in high driver turnover causing drivers to switch employment between transportation carriers or to opt out of the trucking industry altogether. It was reported in a study conducted by the Gallup Organization [20] that about 80% of the drivers who turnover move from one transportation carrier to another with no pay differences in order to seek better job satisfaction. Various research endeavors have considered the truckload driving job by trying to understand and combat the driver turnover and shortage issue.

2.3 Understanding Truck Driver Turnover

LeMay et al. [17] did a study on driver turnover by issuing surveys to the CEOs of 650 member firms of the Interstate Truckload Carriers Conference of the American Trucking Associations, and 190 responses were returned, but only 175 responses were used since 15 responses were from exclusive owner operators. Firms involved in the study were company drivers only and a mix of company and owner operator drivers. The study used the Spearman's correlation coefficient between driver turnover and selected variables to determine the statistical significance of certain factors. The study results showed there was a statistically significant positive correlation between driver turnover and the number of drivers, operating revenue, and the number of power units. It was found that there was no statistical significant correlation between driver turnover and team-single mix drivers, experience required, and training offered. It was determined that there was a statistically significant negative correlation between driver turnover and mileage pay, a statistically significant positive correlation between driver turnover and average miles per week, and no statistical significance between driver turnover and benefits paid. The results also showed there was a statistically significant positive correlation between driver turnover and average length of haul and average fleet age. The study concluded that multiple factors impact driver turnover.

DeWeese [21] reinforced the fact that there are major driver turnover and retention issues due to poor management communication, poor training, and lackluster wages. He noted that safety is an important concern since driver turnover results in a lack of experienced and knowledgeable drivers. This research points out that the potential cost to replace a truck driver is between $10,000 and $30,000, which includes recruiting, advertising, training, exit interviews, and other miscellaneous costs. In other related studies, researchers have made attempts to measure costs associated with driver turnover, among them Sagie et al. [22] and Pinkovitz et al. [23]. In a particular study, Pinkovitz et al. [23] classified turnover related factors that likely impact a company's finances which include: separation costs, vacancy costs, replacement costs, and training costs. Karsan [24] also stated that intangible costs are more difficult to measure but contribute to a company's turnover costs. Such costs include reduced employee morale when a senior level driver leaves, lost productivity, knowledge and experience loss when a person leaves a company, and lost opportunities that an experienced worker might have gained. DeWeese [21] pointed out that Browning-Ferris Industries has been successful in retaining drivers because of an aggressive communication and training program established between management and employees and as a result, the company has many long tenured drivers and has maintained relatively low turnover rates. The research concludes that a significant amount of costs are involved in replacing drivers- who voluntarily turnover- causing deterioration in company profit margins.

In a similar study, Rodriguez et al. [8] report that the average cost of turnover per driver for all companies was $8,234 and ranged from $2,243 to $20,729. The following average costs of turnover per driver were noted: company driver fleets, the average was $7,923; dry van company driver fleets, the average was $8,612; and refrigerated company driver fleets, the average was $6,420. Individual companies differed broadly from these averages, mainly due to the quality of data records kept. The carrier size in the study ranged from 32 to 9,463 trucks. Rodriguez et al.

[8] made a thorough investigation of costs as related to driver entry and exit costs, fixed asset costs, profit loss, and miscellaneous costs. The driver turnover entry and exit costs included: advertising costs, staff labor costs, testing fees, recruitment costs, orientation costs, training costs, and referral/sign-on bonuses. The fixed asset costs due to idle equipment included: monthly cost of interest on trucks and trailers, monthly cost of depreciation on trucks and trailers, and monthly cost of insurance on trucks and trailers. The profit loss due to idle equipment involved: percent of fleet idle, revenue per truck, and gross profit percentage. Miscellaneous costs considered included: safety/insurance/legal costs, equipment maintenance costs, and production loss due to new drivers. The study provided a thorough categorization of costs and their significance in relation to driver turnover.

McElroy et al. [25] conducted a survey of 13 truckload motor carriers in the U.S. where 11,390 surveys were distributed and 3,379 returned usable. Short road time and long road time drivers were critical in this research and were defined in the following way. Drivers who reported being away from home one weekend or less were considered short road time drivers while drivers being gone more than one weekend were considered long road time drivers. In the study, there were two independent variables associated with the driver's career stage and the amount of time a driver spent on the road. There were fourteen dependent variables associated with driver attitudes which included: overall job satisfaction, interest in job enlargement, importance of equipment to satisfaction, importance of influencing management, interest in training, benefit adequacy, importance of recognition, supervisor description, perceived attitude of a company toward employees, standard of living, income compared to other trucking companies, income compared to other industries, advancement opportunity within a company, and advancement opportunity within an industry. The time spent on the road independent variable was considered important as it impacted nearly all fourteen dependent driver attitude variables. The results show that a short amount of time that a driver spends on the road does not significantly impact driver attitudes while a long amount of time that a driver spends on the road significantly impacts all driver attitudes excluding interest in job enlargement, job satisfaction, and perceived advancement opportunities within the industry. Trucking equipment was found to be important to long road time driver satisfaction, as well as the importance of influencing management and recognition, compared to short road time drivers. Also, long road time drivers had more negative attitudes in regard to issues like income, benefits, and advancement opportunities compared to the short road time drivers. In the study, the road time appears to have less of an impact than does the career stage amount when explaining the amount of variance in driver attitudes. Career stage and road time interact to significantly affect five of the fourteen driver attitudes: importance of equipment to satisfaction, importance of recognition, how favorably drivers describe their supervisors, driver perceptions of their companies' attitudes toward employees, and perceived advancement opportunities within the company. Based on the study, time spent on the road appears to have less utility as a means of classifying drivers than career stage while time spent on the road did significantly affect driver attitudes while the amount of variance explained was low [25]. This study concludes that several factors influence drivers' attitudes toward their job which impacts driver turnover.

Stephenson et al. [12] studied drivers associated with different truckload carrier types involving dry van, flatbed, tankers, and refrigerated to gain an understanding of driver retention and driver turnover. A driver survey was conducted across the different carriers and carrier types. In the research, 2,256 surveys were sent to different carriers and 1,791 usable surveys were returned completed. The results showed that driver home time was one of the key factors that played a role in driver retention and driver job satisfaction along with training, driver attitudes toward direct supervisors, career path advancement, company pride, compensation and benefits, and working conditions. It was stated numerous times in this study that drivers spend much time away from home and about 67% of the truck drivers average 60 or more hours of work per week and 22% average more than 70 hours of work per week. It was also noted that 70% of the drivers drive 2,200 miles or more per week and about 39% drive more than 2,600 miles per week. The results showed that 29% of the drivers get home less often than once every two weeks, 15% once every two weeks, and 21% once a week. It was noted that drivers make better pay compared to other professions but at the expense of longer hour work weeks (i.e. up to 20 additional work hours or more per week compared to other professions) and reduced home time. Longer work weeks and reduced home time are shown to be contributors to driver turnover. Similar results in a study done by Arnold et al. [26] showed that a large number of unregulated truck drivers in Australia worked in excess of fourteen hours per day and numerous drivers obtained less than ten hours of downtime between work shifts. This lack of downtime was reinforced by the finding that 12.5% of the drivers obtain less than four hours of sleep on a given night prior to driving [26]. Arnold et al. [26] also stated that the number of hours driving played a critical role in driver fatigue. The studies conclude that long working hours play a key role in driver fatigue and job satisfaction, and the downtime between work shifts in the trucking industry is substantially low.

The driver shortage issue became more pronounced in the 1990s as the economy grew and as driver retention slumped and driver turnover increased. High consumer demand in combination with a lack of driver supply and Union Pacific rail issues forced many carriers to turn down shipments and increase truck price rates in order to combat the driver supply problem. In Gooley's [27] article, Gooley took a different approach and focused on the driver shortage issue in the late 1990s as related to critical items that keep drivers satisfied rather than concentrating on the negative aspects of why drivers leave their job. The study noted several things that keep drivers more satisfied including: career advancement opportunities, good training programs, pay, benefits, and home time. This research emphasized the important factors that keep drivers more satisfied, so that driver retention can be enhanced.

In relation to driver turnover, Shaw et al. [28] explored voluntary and involuntary turnover rates separately or as different entities. Most traditional driver turnover studies combine voluntary and involuntary turnover, which can lead to erroneous conclusions. This study was conducted utilizing a questionnaire mailed to human resource managers of 1,072 different companies and 379 questionnaires were completed and returned. The questions focused on the effects and characteristics of the human resource management systems within the companies questioned. From the results, it was determined that the average pay and time on the road had a strong relationship with voluntary turnover rates. The results also showed that benefits and electronic driver monitoring had moderate relationships with voluntary turnover rates. The paper stated that voluntary driver turnover is more of a problem than involuntary driver turnover, which can result in significant driver shortages. The research shows that inducements and investments (i.e. pay and benefits) and employer expectations (i.e. home time, road time, monitoring) are good predictors of voluntary turnover. The study claims that the separation of voluntary and involuntary turnover is necessary since voluntary driver turnover is the predominant driving force behind the driver shortage and driver turnover issue.

Min and Lambert [29] conducted a survey on driver turnover and a statistical analysis to investigate the driver shortage issue. The survey included 3,000 mailed questionnaires to randomly selected trucking companies and 422 valid questionnaires were returned. The questionnaires were mailed to various trucking companies with the response rate from the following trucking company types: 33.5% regional truckload carriers, 21.8% national truckload carriers, 11.4% both national LTL and truckload carriers, 8.7% both regional LTL and truckload carriers, 6.1% regional LTL carriers, 1.9% national LTL carriers, and 16.5% others (e.g. tankers, dump trucks, towing trucks, and mobile home transporters). The study concluded that the continuing driver shortage is mainly due to poor driver management and is not a byproduct of the economy. Studies over the last two decades have shown persistent driver shortages in both upswings and downswings in the economy, which illustrates that driver shortages are not a byproduct of the economy. This research emphasizes that driver pay is critical in recruiting and retaining drivers, but driver pay is not the sole component in retaining drivers over the long run. Based on the survey results, poor supervisory skills were shown to significantly contribute to driver turnover with a dispatcher's behavior and attitude playing a key role in retaining drivers and reducing turnover. The results showed that drivers who tend to stay with a company for a long length of time are those in the age group between twenty-one to twenty-five years old and forty-six years old and older. Drivers with an age in the late twenties or thirties tend to turnover more frequently than any other age group. Min and Lambert [29] pointed out that a lack of home time played a role in driver turnover, but it is not deemed as the most significant factor. Drivers deemed pay, truck equipment, company reputation, and time on the road as important factors, and it was concluded that many of these factors interact to impact a driver's attitude. Many factors interact to cause a driver to quit a job or opt out of the trucking industry.

In Min and Emam’s [2] paper, it was noted that substantial productivity gains in the trucking industry come by reducing driver turnover and improving driver retention. High turnover rates significantly impact competitiveness, productivity, and safety. Min and Emam [2] state that an uneducated driver is more likely to stay with a company longer due to the training and investment the company places in the driver. Other research has also reported that age, educational levels, gender, job scope, and tenure may also impact driver turnover behaviors. The findings in this research show that a firm's organizational characteristics impact driver turnover, and a person's work environment determines one’s job satisfaction level. The study states that small trucking firms tend to have lower turnover rates than large trucking firms, which may be attributed to smaller firms having more direct contact time with their drivers. The paper states that drastic measures such as pay increases, advancement opportunities, and equipment upgrades do little to reduce driver turnover in large companies, but these advances should be targeted to specific drivers who meet a certain profile such as a certain seniority level or age group.
Min and Emam [2] illustrated that a driver's longevity with the same trucking company is a predictor of turnover and state that short tenured drivers of less than six years are more likely to turnover compared to drivers with tenure of six years or more. Special care needs to be taken with short tenured drivers to improve job satisfaction. It was also reported that 50% of drivers leave their jobs within the first three months of employment. It can be concluded that a strategic

approach should target drivers with certain characteristics in an effort to minimize driver turnover.

A two year longitudinal study examining antecedents and consequences of driver turnover among Dutch truck drivers was conducted by Croon et al. [30]. The study combined existing organizational stress theory and job transition theory. Self-reported data on stressful work including job demands and control, psychological strain, and turnover were obtained from 820 drivers in the years 1998 and 2000 [30]. Strain is defined as the need for recovery after work and fatigue. According to Croon et al. [30], the results indicate that strain mediates the influence of stressful work on voluntary turnover. Additionally, results show that job movement to any job external to trucking (i.e. inter-occupational) produces a larger strain reduction in comparison to job movement within trucking (i.e. intra-occupational). Strain was also found to provoke inter-occupational turnover stronger than intra-occupational turnover. The findings show that inter-occupational turnover in relation to truck drivers may be due to strain resulting in voluntary job turnover.

The truckload industry consists of many carriers having the same characteristics, but operational characteristics, management policies, and carrier size are the main differentiating factors in truckload transportation companies as expressed by Taha and Taylor [31]. Most truckload trucking companies experience the same daily challenges under tight profit margins and attempt to combat high driver turnover from several different angles including: driver pay increases, better fringe benefit packages, new equipment, driver route regularization, reward programs, and other perk programs. These perk programs have been of limited success- mainly short term success. Over the years, several research endeavors have been considered in an attempt to make the truckload driving job more attractive by creating regularized routes, utilizing driver/equipment relay points on a small scale where drivers exchange trailer equipment, utilizing freight zones, and using driver domicile and hub techniques. These efforts have been mainly considered and implemented on small, regional networks to seek improvements in truckload driver turnover with the hope of enhancing the driving job. Even though some of these strategies have been developed and executed on a small scale, there is still a need to improve truckload driving jobs and continually develop strategic methods to create a better long term working environment, as evidenced by consistent high truckload driver turnover rates. Most strategic approaches have failed to consider the costs associated with improving the driving job and have not considered the impact on the transportation carrier and customer. In the following, several key methodologies and studies will be presented concerning important techniques and concepts that researchers have considered and implemented to some degree in an effort to improve the truck driving job.

2.4 Methodologies to Improve Truck Driver Turnover

Tsu and Agarwal [32] considered creating consistent and regularized transportation tours for a retail transportation network utilizing equipment relay points where trailers were switched between trucks to prevent drivers from traveling long distances with the aim of getting drivers home more often, making the driving job more driver friendly with frequented routes, and utilizing more private fleet drivers instead of third party drivers. The retail business in this study utilized a private fleet but also outsourced transportation to third party carriers for freight beyond the private fleet's capacity. A transportation relay point is a physical location where a shipment is divided into two transportation legs and involves switching trailer equipment. At the relay point, there are multiple ways to route freight with a truck fleet. Figure 3 shows an example of transportation movements with and without relay points. The route without the relay point includes a loaded outbound leg and an empty return leg. Key operational parameters were considered in the study incorporating circuitous and empty miles to make sure operational

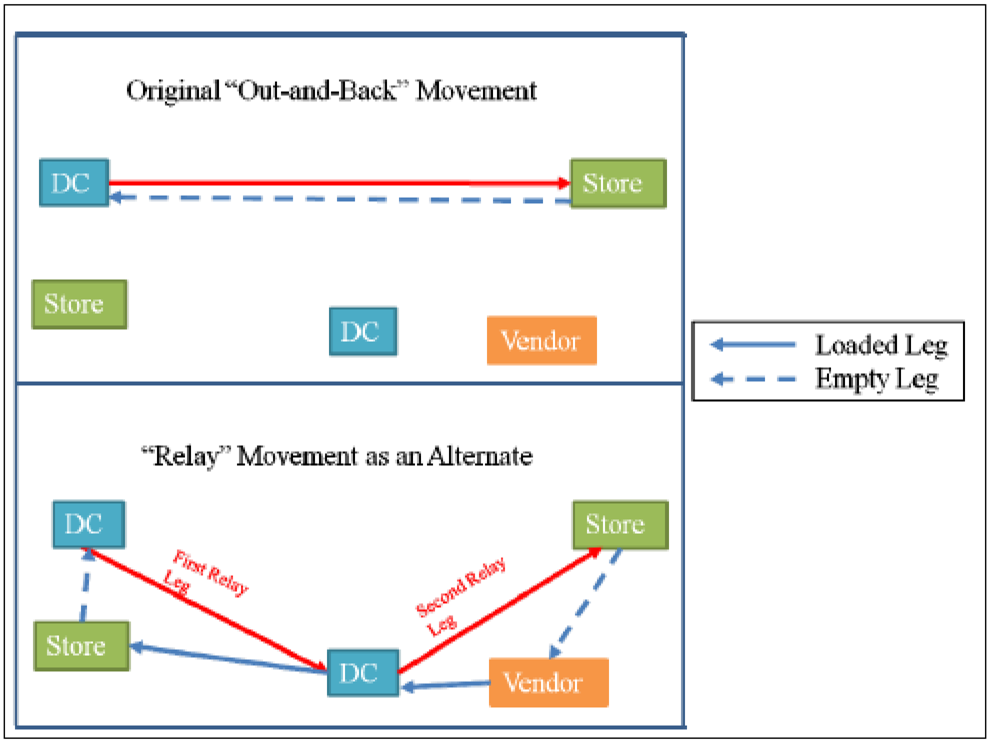

Figure 3. Freight movement example with and without relay points [32]

parameters were at acceptable levels. For example, circuitous and empty miles were kept at reasonably low levels when developing driving tours in order to minimize non-revenue generating empty miles. Circuitous miles are excess miles per trip for shipments in comparison to point-to-point distances and should be minimized. A baseline model consisting of an optimized solution without relay points was compared to a solution with relay points. The results showed that relay points increased private fleet usage by 17% and reduced the total transportation cost by 6%. The relay points increased private fleet utilization on the inbound lanes while shifting the private fleet capacity between neighboring distribution centers on outbound moves. Tours consisted of headhaul and backhaul matched tours, inter-facility moves, and out loaded/back empty tours with variations of each type of tour. The study concluded that relay points better utilized the private fleet and justified the purchase of additional private fleet truck and trailer capacity to displace some third party carriers.

Taylor [16] conducted a study with J.B. Hunt Transport, Inc. utilizing delivery lanes, zones, and transshipment hubs to simulate driving activity in two regions of the United States-

Southeast and Northeast regions. In the study, Taylor [16] used zone, key lane, hub, and hybrid models, and the different models were compared to a defined baseline model. The study realized key performance measures as related to the carrier, customer, and driver with emphasis on specific performance measures such as: miles per driver per day, customer lateness, circuitous miles, and first dispatch empty miles. Taylor et al. [33] and Taylor and Meinert [34] stated that factors in the truckload industry impacting service performance levels can be taken from the viewpoint of the trucking company, the customer, and the driver. From a driver's viewpoint, the important factors included daily miles, driver home time frequency, route regularity, and tour length. The critical factors for a company included service and cost. On-time pick-up and delivery are key performance customer measures with regard to service quality, while first dispatch empty miles and circuitous miles are critical cost measures the customer deems as highly important. In this study, the circuitous mileage percentage is the percentage of out-of-route miles added when point-to-point dispatching is not utilized, while first dispatch empty miles are the empty miles from a given location point to another location point to pick-up freight. In this research, Taylor [16] used a simulation approach to evaluate alternative driver dispatching methodologies as compared to current OTR practices. Several scenarios were utilized in the study with different combinations of hubs, key lanes, and zone definitions to route drivers. It was shown that the zone model performs well among these scenarios when considering, simultaneously, performance metrics from the perspective of the driver, customer, and company. The zone model provides good results in relation to percent delivery lateness, first dispatch empty miles, miles driven per driver per day, and utilizes fewer drivers, but the model creates more circuitous miles. It was determined that delivery zones with perimeter hubs provided the best results with regard to customer service and driver retention possibilities with the hybrid models performing well from the perspective of minimizing circuitous miles and lateness. It was concluded that lanes, zones, and transshipment hub strategies can enhance the truckload driving job within certain parameters while maintaining focus on key performance measures as related to the driver, customer, and company.

In a similar fashion, Taylor et al. [35] looked at multi-zone dispatching on a large scale in the truckload trucking industry by sectioning the U.S. into dispatch zones with the inclusion of zone interior hubs and zone edge hubs. Figure 4 shows an illustration of the zone and hub system used in the study including five zones with zone edge hubs and interior hubs.

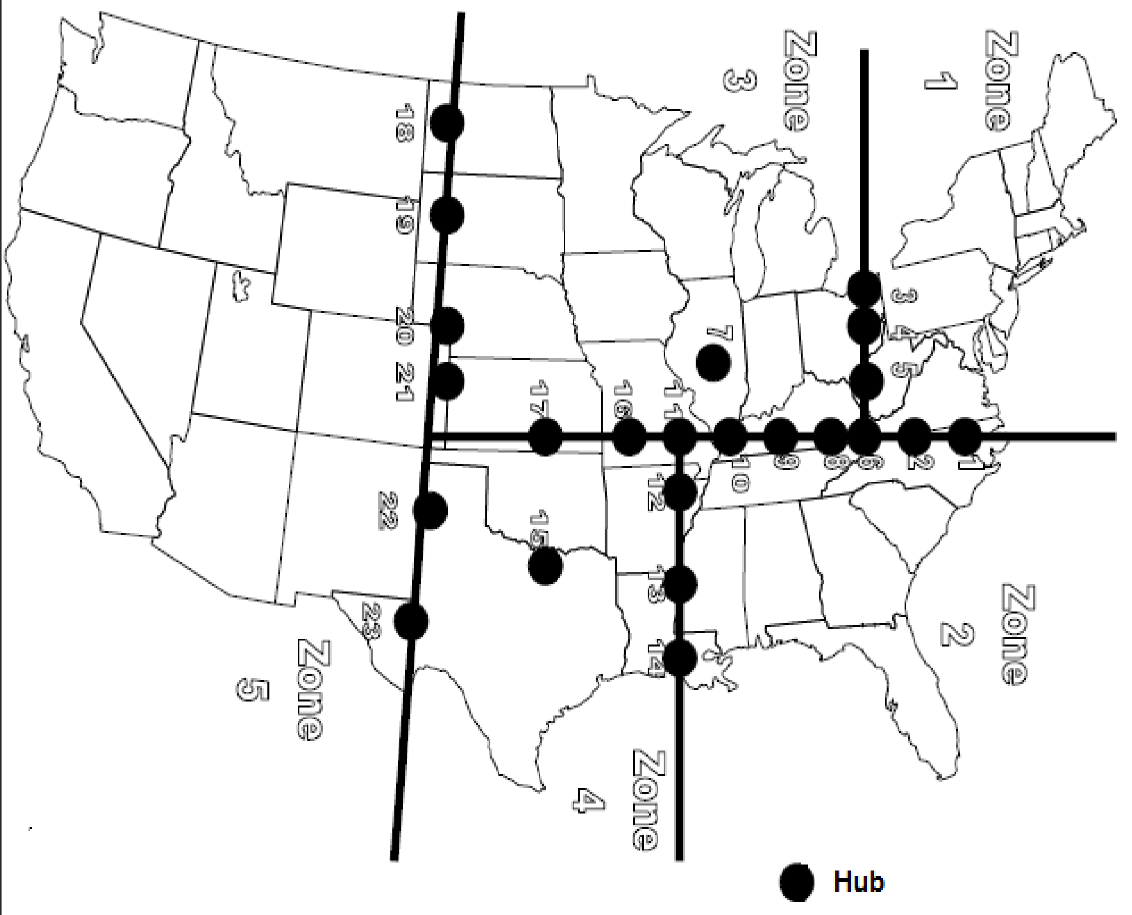

Figure 4. Zone and hub system used in the multi-zone dispatching [35]

This research involves describing a new dispatching methodology that also considers the needs of the customer, the driver, and the transportation carrier. Zone dispatching aids in maintaining high driver utilization and equipment utilization while meeting customer expectations. Simulation was utilized to evaluate the zone dispatching concept and research data was provided by J.B. Hunt Transport, Inc. Seven different scenarios were included: an OTR baseline scenario, a zone baseline scenario, a reduced hub scenario, a reduced zone scenario, a no interior point scenario, a minimum imbalance scenario, and a low circuitous miles scenario. Of the seven scenarios, the scenario with minimum imbalance was the most effective resulting in the smallest tour length and lowest freight imbalance. The minimum imbalance scenario included the configuration of zone boundaries in such a way to minimize freight imbalances between zones. Additionally, about 50% of all the loads were candidates for zone dispatching participation, which accounted for about 67% of the loaded miles. Since this study involved a more holistic approach, key performance indices as related to the driver, the transportation carrier, and the customer were simultaneously at the forefront of the study which is not the typical case in most transportation research efforts.

The LTL industry has been able to maintain reasonably low driver turnover levels due in part to the utilization of a hub-and-spoke network strategy that generates more regularized routes allowing drivers to be home frequently. LTL driver turnover consistently hovers around 10%, which is very low compared to the truckload transportation industry. Taha and Taylor [31] considered a hub-and-spoke network for the truckload trucking industry based on the location of freight volumes, existing terminals, and the space between equipment relay points. Likewise, Taylor et al. [36] considered a hub-and-spoke network system in truckload transportation and used a simulation software- HUBNET simulator- to produce different equipment relay point scenarios consisting of a varying number of relay points, network configurations, and driver tour length conditions. HUBNET simulator is a simulation program developed in SIMNET II simulation language with a C-shell user interface [36]. Different hub-and-spoke alternatives and point-to-point combinations were considered in an experimental study to deal with problems associated with allocating drivers among hubs and among different driver types including lane drivers, local drivers, and non-network drivers, based on a freight density and network analysis. Figure 5 shows an example illustration of a hub-and-spoke system.

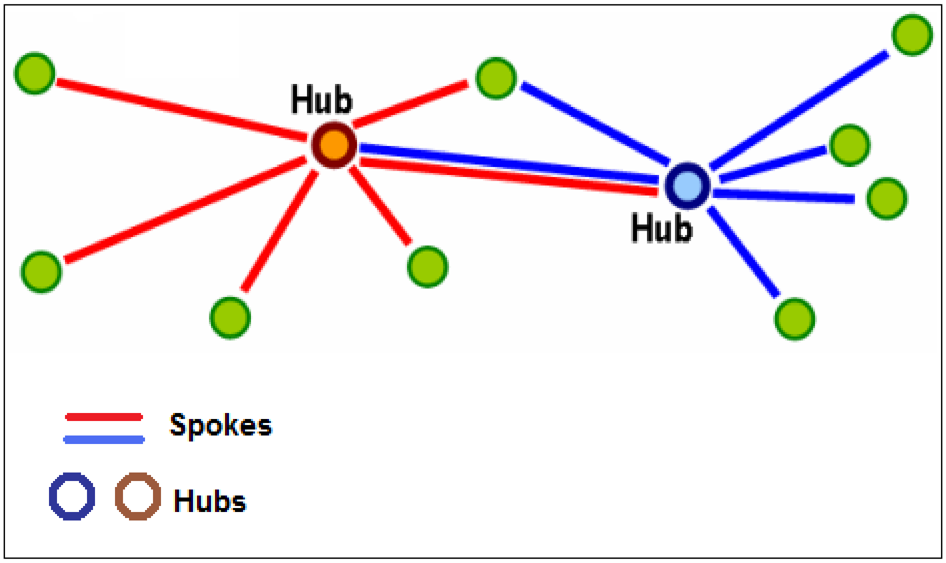

Figure 5. Hub-and-spoke system

A critical factor in the study included the layout of the hub-and-spoke system with regard to the number of hubs, hub locations, spoke and lane locations, and service area allocation. The experiments executed in the study were conducted as a three factor experimental design. The first factor considered the hub location incorporating three hub scenarios: distance based, flow based, and a hybrid approach. The second factor involved the number of hubs with two levels-24 hubs and 32 hubs. The third factor involved driver usage with two levels- 1-hub and 2-hub tours. Different combinations of the three factors were executed in a simulation experiment involving the measurement of five different performance measures: lane driver tour length, local tour driver length, miles per driver per day, first dispatch empty miles as a percent of trip miles, and circuitous miles as a percent of trip miles. After conducting the experiments, the alternative involving hybrid hub locations utilizing 32 hubs and a 1-hub tour level provided the best solution in regard to lane tour length and first dispatch empty miles and also performed well from a circuitous mileage standpoint. The only concern with this scenario included the lower average miles per driver per day statistic, which impacts driver pay for mileage pay based drivers. It was concluded that using this methodology may provide beneficial results in the form of better driver route regularization, enhanced customer service levels, less load imbalances, and decreased circuitous miles.

Taylor et al. [37] considered the usage of freight pipelines in truckload transportation as a means for more optimally dispatching drivers in an effort to improve driver life quality while keeping circuitous mileage to a minimum. This study was done in conjunction with J.B. Hunt Transport, Inc. Freight pipelines were established between two lane endpoints in such a way that three drivers and three dispatches would be required on a given load. One driver would be required on the origin end (origin dray) between the shipper and the pipeline begin point, one driver would be required on the destination end (destination dray) between the pipeline end point and destination receiver, and one driver would be required on the pipeline move between the pipeline end points. Figure 6 gives an illustration of a pipeline scenario including the pipeline and dray moves involving drop-and-swap points. A pipeline move is equivalent to a line-haul move and drop-and-swap points are similar to relay points where trailers are dropped by a dray driver and then picked up by a line-haul driver and vice versa.

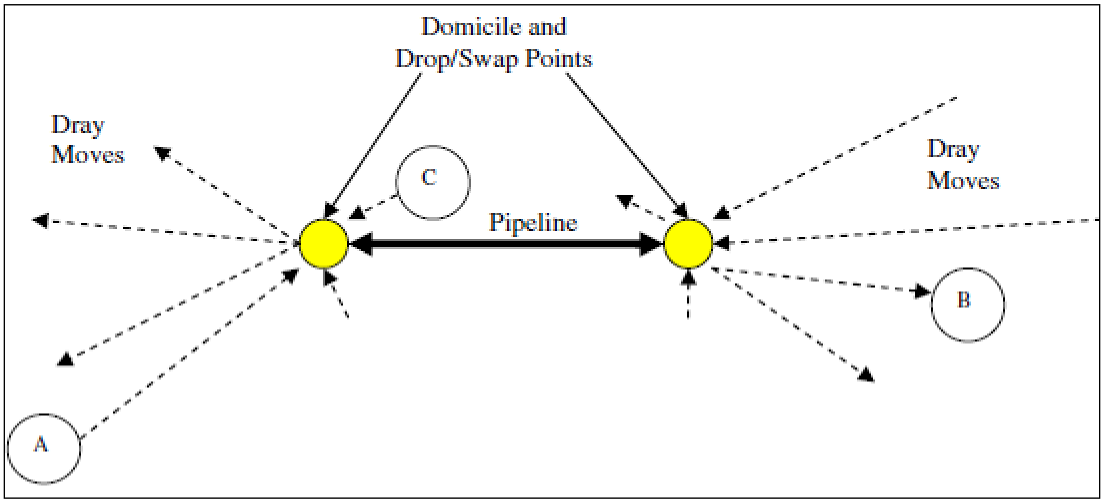

Figure 6. Pipeline illustration with pipeline and dray moves [37]

The goal of this study was to regularize driver moves where drivers could be regularized on the dray and pipeline moves in order to improve driver life quality through better dispatching practices and more frequent home time. The study revealed that 22% of all loads and 13% of all loaded miles at J.B. Hunt Transport, Inc. would be good candidates for pipeline moves where driver routes could be regularized and consistent driver tours could be developed. Pipeline candidate lanes were considered as high volume lanes with minimal freight imbalances and low demand variability.

In a similar fashion to Taylor's [16] zone methodology approach with critical performance measures, Üster and Maheshwari [38] provided an expansive network design consisting of multi-zone dispatching for the truckload industry using a multi-dimensional mathematical formulation. They developed a construction heuristic and a tabu search framework that considered driver tour length constraints to solve a mathematical model used for multi-zone dispatching [38]. In the network design formulation, hub location modeling and minimum cost multi-commodity flows were brought together, simultaneously, incorporating certain elements of the truckload trucking industry. Similar to Taylor's [16] critical performance factors, this model incorporates lane and local driver tour length constraints, load imbalance constraints, and circuitous percentage constraints. In the study, Üster and Maheshwari [38] examined the characteristics and dynamics of critical performance measures, accentuated the trade-offs, and observed that driver turnover rates and tour length constraints can be used to control load imbalance and circuitous miles. This model along with the solution procedure utilizing multi-zone dispatching provides an extensive design and decision tool that could potentially be used in the truckload trucking industry to enhance operational decision making and improve performance measures.

In light of equipment relay point facility research in the truckload trucking industry, Hunt [15] also considered truckload routing and the location of relay points. In this research, Hunt [15] focused on reducing driver tour length recognizing the significance of the driver turnover problem as related to driver home time. A three step method is used in the study to solve the routing and relay point location problem with the assumption that relay points can be located anywhere in the network without associating any fixed charges. First, a routing problem was solved on a network without considering relay points using a shortest path routing heuristic while considering backhaul. Second, relay point locations were determined using an iterative algorithm termed the spring algorithm, which considered proximity requirements and proximity levels at the beginning of algorithm. The user of this model is given the opportunity to express the minimum, maximum, and the desired distances between relay points, and then the spring algorithm is utilized to generate the relay points and to combine relay points that meet certain criteria. Figure 7 shows an illustration of two relay points between origin point one and destination point four spaced 200 miles apart. Figure 8 illustrates a small network configuration including nodes A, B, C, and D with relay points between nodes B and C and nodes B and D. In this example, the spring algorithm attempts to combine both relay points into one relay point located at node B.

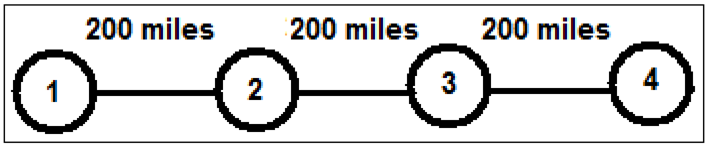

Figure 7. Relay point example with 200 mile spacing

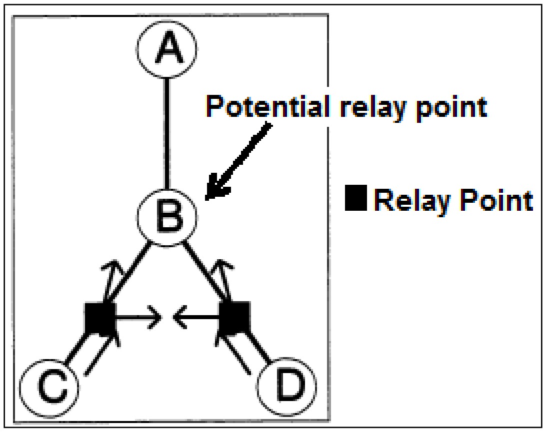

Figure 8. Relay point configuration [15]

Third, the routing problem was solved over the transportation network utilizing the created relay points, proximity requirements, and the shortest path heuristic. In every test case, the spring algorithm produced a solution with fewer relay points compared to the original network, and since drivers were domiciled at relay points, the drivers could deliver freight to nodes adjacent to the relay points [15]. The study produced results showing freight volumes being higher through the relay points when a fewer number of relay points existed. In a similar motivation to Tsu and Agarwal's [32] research, this study provided a unique approach for creating relay points in a transportation network in such a way to regularize driver freight tours and enhance driver home time. Costs to establish the relay points and holistic performance measures considering the driver, transportation carrier, and customer were not considered.

Another interesting and more modern approach was presented by Regan and Golob [39], which considered utilizing urban freight facilities in California as points where freight could be consolidated or de-consolidated or serve as relay points where equipment switching operations could be executed. The urban freight facilities could provide a place for truck drivers to wait during peak driving periods before transporting freight into urban areas in order to avoid traffic congestion issues, reduce environmental emissions, and decrease energy consumption of trucks. The facilities could additionally provide technology services including electronic data interchange (EDI) capabilities, internet capabilities, information services to aid carriers and drivers, or serve as a resting place for drivers. The urban freight facilities offer a means for streamlining operations and adding route flexibility, but would not serve as a location for storing inventory or equipment. In another related study, Golob and Regan [40] discuss the importance and utility of different sources of traffic information to aid in decision making and supporting decisions that could be used in conjunction with the usage of urban freight facilities. Based on a survey conducted in the study, the results indicate that a relatively large group of trucking companies would likely use the facilities especially, long distance carriers and carriers providing service to rail terminals. Survey results showed that the urban facility concept is viewed as a viable option to aid in minimizing traffic congestion and providing carriers with more routing flexibility. Funding requirements to build, maintain, and operate the facilities were a major concern in the study that would need to be appropriately addressed if the concept and operation were to be pursued.

Campbell [41] considered a facilities location and relocation problem as a means of minimizing transportation costs as demand levels change. Campbell developed an algorithm to approximate the location of new transportation facilities for transportation carriers that serve a fixed region with increasing levels of demand. In this model, facilities were added to a region when needed in order to decrease transportation costs as demand levels increased. Campbell considered all costs related to the terminal, transportation, and relocation costs. Although the optimal strategy for adding and locating facility terminals may require future demand knowledge, myopic strategic approaches may be close to optimal. Effective myopic approaches for providing location solutions that were near optimal were examined. Campbell developed a continuous distribution model that included economies of scale and line-haul transportation. In this model, trade-offs between location, transportation, and relocation costs were considered where the objective was to minimize total costs. Campbell used myopic strategies to develop lower and upper bounds on the objective value. The myopic strategy initially ignores relocation costs, which provides a lower bound on the objective value and then forbids relocation, which provides an upper bound on the objective value. It was shown that a myopic strategy with limited relocation capability was nearly optimal unless there were large terminal relocation costs, and the research states that extensive relocations to attain near optimal costs may not be needed. This approach provides a framework that could be incorporated in a transportation network to more optimally locate and relocate facilities and equipment relay points as customer demand levels change in different freight markets.

Campbell [42] also considered a multiple allocation of origin and destination nodes to more than one hub in a flow network contrary to the traditional method of allocating each node to a single hub. Most traditional approaches have considered single hub allocation methods. For example, Skorin-Kapov and Skorin-Kapov [43] considered an approach using tabu search for the location of interacting hub facilities allocating nodes to single hubs. Klincewicz [44] also considered assigning nodes to hubs where exchange heuristics were systematically applied to determine the most optimal hub location where nodes were assigned to single hubs. Campbell makes a claim that a multiple allocation is necessary to minimize total transportation costs. Similarly, Marianov et al. [45] considered a cost minimization approach where each origin and destination can go through either one or two hubs, and each demand point could be assigned to more than a single hub, depending on the different traffic destinations. Likewise, Ernst and Krishnamoorthy [46] considered an un-capacitated multiple allocation p-hub median problem. In Campbell's study, a p-hub median is defined and presented as an integer program for both single and multiple allocation p-hub median problems along with two heuristics designed to be evaluated on a single allocation p-hub median problem. The two heuristics were executed to obtain a solution to the single allocation p-hub median problem from the solution to the multiple allocation p-hub median problem [42]. The heuristics performed well and the approach provided a non-traditional method of allocating origin and destination nodes in a transportation network.

In regard to transportation relay points, Ali et al. [47] considered locating equipment relay points where freight is exchanged in order to better optimize driver and truck operations moving freight over long distances. This research provided location techniques along with heuristics and algorithms to determine the location of relay points on a highway network with the goal of minimizing the number of relay points while making considerations for improving the driving job and keeping empty and circuitous miles to a minimum. In the study, a driver distance constraint was established where a driver leaving a distribution facility cannot travel more than an established mileage amount before returning back to the origin point or rests before traveling further. Straight route and detour algorithms utilizing a shortest path transportation network were presented to model equipment relay points and transportation requirements pertaining to travel distances and circuitous miles. The straight route algorithm utilizes a user prescribed travel distance and a relay point is established at each increment of the prescribed travel distance on the shortest path network. The straight route algorithm requires adherence to the shortest path network and forbids any circuitous miles. Figure 9 illustrates a straight route example.

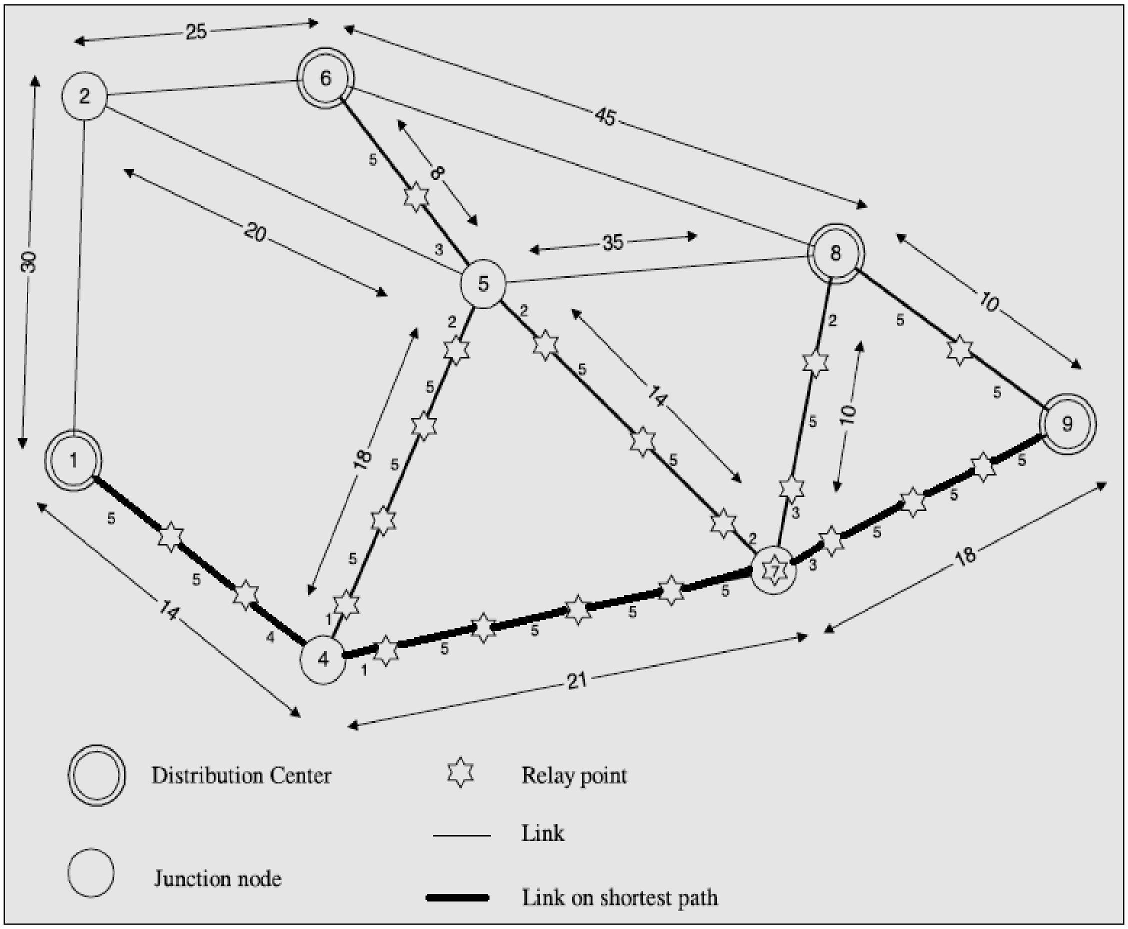

Figure 9. Straight route algorithm; 21 relay points, travel distance between relay points is 5; thick black line represents the route [47]

The two detour algorithms allow circuitous miles by permitting drivers to leave the shortest path network within certain mileage bounds or based on certain rules. Utilizing the detour algorithms, the user must prescribe a travel distance for relay point establishment and must also prescribe an additional distance (i.e. out-of-route or circuitous distance) that limits the amount of travel distance deviation from the shortest path network. If the additional distance prescribed is zero miles, then the detour algorithm reverts to the straight route algorithm since no deviation would be allowed from the shortest path network. The main goal of the detour algorithms is to allow deviation from the shortest path network to allow for the usage of previously established relay points in an effort to reduce the total number of relay points created, which would be cost effective if a fixed cost was associated with relay point establishment. There are two different detour algorithms (i.e. semi-Detour and d-Detour) considered in the study. The semi-Detour algorithm is similar to the straight route algorithm but allows different highway links to be traversed in order to use a previously established relay point, but the driver is only allowed to travel to a single previously established relay point before the driver must return to the shortest path network where the driver initially exited from. Figure 10 illustrates a semi-Detour example where a link of 1 distant unit at node 4 is traversed to utilize a single relay point previously established, which reduces the total relay point count from 21 (see Figure 9) to 20 (see Figure 10).

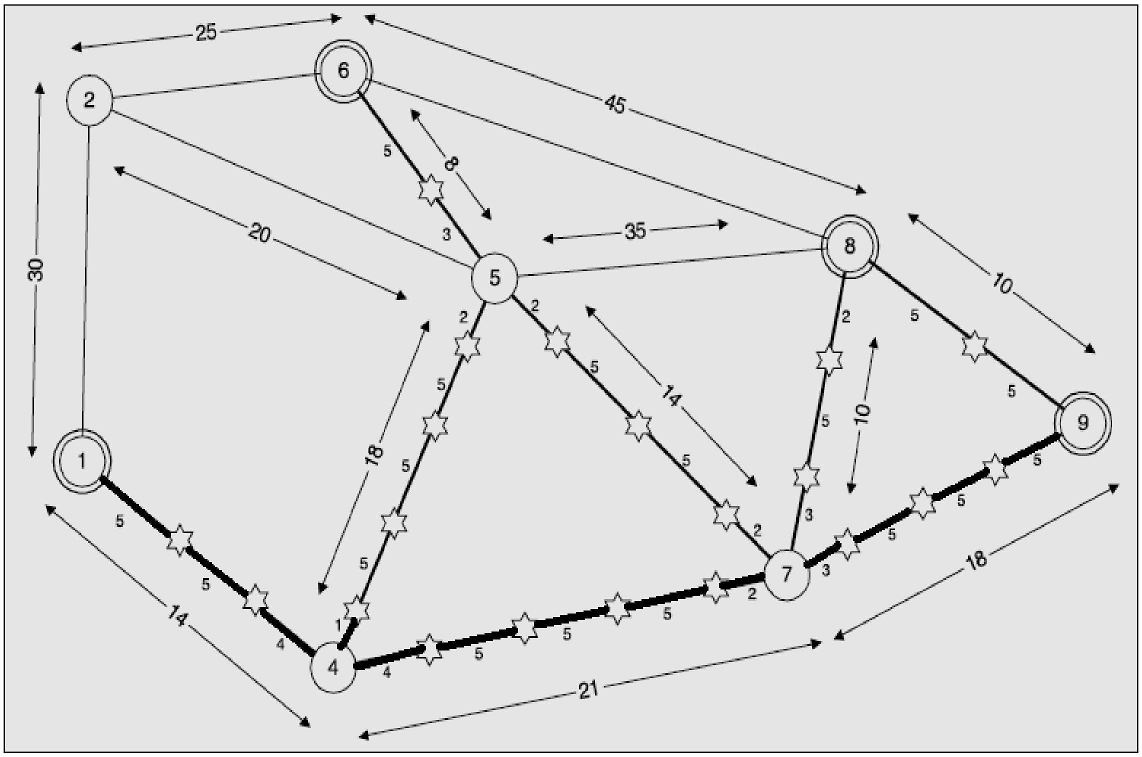

Figure 10. semi-Detour algorithm; 20 relay points, travel distance between relay points is 5; thick black line represents the route [47]

The d-Detour algorithm is similar to the semi-Detour algorithm but the driver is not required to return to the shortest path network but must adhere to the circuitous miles constraint. Figure 11 illustrates a d-Detour example where a deviation from the shortest path is executed in order to utilize previously established relay points, which further reduces the total relay point count to 17 (see Figure 11). Empirical evaluations were conducted on the algorithms.

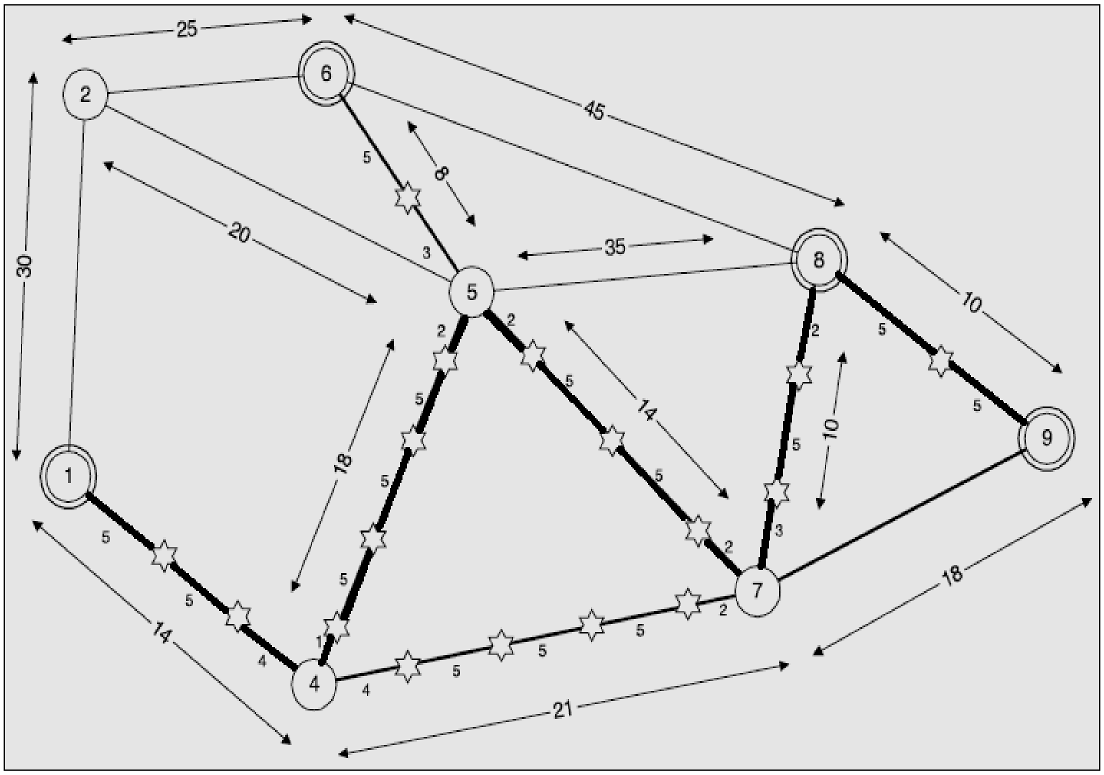

Figure 11. d-Detour algorithm; 17 relay points, travel distance between relay points is 5; thick black line represents the route [47]

The results show that the straight route algorithm locates a larger number of relay points compared to the detour algorithms because the straight route algorithm does not allow deviation from the shortest path. This research provided an alternative means of locating equipment relay points to potentially better optimize transportation networks by making driving routes conducive to more driver home time while keeping circuitous miles to a minimum. Extended research to consider fixed costs associated with relay points along with transportation costs would allow for cost comparisons to be made on different network design scenarios, which could potentially be implemented in an operational environment.

Taylor [48] developed a software program called Domicile_Finder that was created to locate regions with dense freight including outbound, inbound, or pass-thru activity to help determine the most optimal location of driver domiciles. These locations could also be used to locate terminal facilities, relay switch points, break-bulk facilities, and distribution centers.

Domicile_Finder uses seeded domicile locations, procedural parameters, freight data, and proximity definitions as inputs. The software program assigns freight to candidate domicile locations, and the domicile locations assigned the most freight are deemed the best locations to domicile drivers. Maximum allowable distances between domicile locations and freight endpoints were included in the proximity definitions along with maximum circuitous rules. Procedural parameters specified by the user were defined: load weighting, capacity limits, imbalance limits, and freight ownership specifications. The output included: percentage and number of loads assigned to each domicile, total miles and loads examined, a mileage and load breakdown assigned to each hub in the network, an estimate of the number of drivers required to cover the miles assigned to each domicile, the number of drivers required to cover the miles not assigned to a domicile, and load imbalance amounts at each domicile. The program and methodology could provide a means for allocating relay points in a transportation network utilizing lane data and parameter specifications while considering procedural parameters important to the transportation network.

Based on the above literature discussion, some approaches have been considered and tested to a certain degree to potentially create a better truckload driving environment, but a more optimal operational and implementable concept needs to be considered that would enhance the truckload driving job by improving job requirements and work conditions while, simultaneously, considering the transportation carrier and customer. Creating more optimal driving jobs in truckload transportation is a relatively unexplored area despite the triple digit turnover percentage rate. Most studies noted in the literature review focused on turnover statistics and some associated reasons for driver turnover but did not offer a clear picture on how to improve the driver turnover rate long term. On the other hand, other studies concentrated on locating relay points, freight terminals, and other infrastructure in a more optimal way to domicile drivers and switch equipment but without the holistic consideration of the overall operational and cost impact to the truck driver, transportation carrier, and customer. A few studies did consider the driver, transportation carrier, and customer together, but the research was limited on how the driver job and work conditions would be improved and how the transportation carrier and customer would be impacted. Most research failed to document or mention how the driver job would be changed once structural changes were made to the transportation network and did not consider what changes the transportation carrier and customer may need to make or what costs and benefits would be encountered while changing driving job requirements. An approach needs to be taken that considers necessary transportation network and structure changes, operational requirements, transportation and facility costs, and a holistic approach toward the driver, transportation carrier, and customer. Additionally, key performance measures need to be established and measured and a cost analysis needs to be conducted to determine the overall impact to the driver, transportation carrier, and customer. A cohesive approach needs to be taken.

CHAPTER 3

RESEARCH STATEMENT

3.1 Research Statement

Truckload transportation involves transporting full trailers over long distances from a shipper to a receiver where drivers may be required to physically load and unload product depending on customer requirements and freight characteristics. Truckload truck drivers spend a large amount of time away from home driving or sleeping in their truck during off-duty time. Some truckload drivers are required additional responsibilities of strapping flatbed freight, monitoring climate controlled freight, bracing product, and other duties. The truckload driving job is an unattractive job because it requires a large amount of miles and time driving alone each week, long hour work weeks, a significant amount of time away from family and friends, low hourly pay compared to other professions, a distant and impersonal relationship with direct supervision and management, route irregularities, and other factors. As a result of the unattractive nature of the truckload driving job, drivers quit driving and find employment- external to the driving market- closer to home, and most people refuse to consider entrance into the driving market because of poor work conditions, the profession's unglamorous image, and unpleasant job requirements. Also, a significant number of drivers shift employment between transportation companies in hope for a better truck driving situation. Since the truckload driving job is unattractive, driver turnover, driver shortages, and driver retention problems persist and have shown to result in a high price for transportation services, large driving recruiting costs, safety issues, etc. Also, as a result of a poor driving market, customer related issues exist including poor delivery service, missed pickups at the shipper, missed deliveries at the final receiver, etc.

In recent years, some research has been done to analyze driver turnover and the driving job but with few methods and practical applications for improving the driving job and work related conditions long term, and most studies have been limited in scope by failing to consider the truck driver, transportation carrier, and customer together. Also, key transportation costs have often been ignored. Most efforts have attempted to improve the driving job long term using short term prescriptions in the form of driver wage increases, fringe benefit improvements, new equipment provisions, etc. The short term prescriptions to combat driver turnover have shown to be beneficial over a narrow time period but with no significant long term positive impact; therefore, truckload driver turnover remains high. Additionally, most research endeavors have minimal to no implementation efforts using a more holistic approach that considers the driver, transportation carrier, and customer together, which limits the significance of the research and thwarts practical application.

Even though driver turnover and job related studies have been limited, some research efforts have helped pave the way to better understand the driver turnover issue while focusing on improving certain aspects of the driving job. Hunt [15] considered the location of relay point facilities and driver routing schemes with the goal of reducing a driver’s driving tour length. In this work, relay point costs were excluded but relay points could be located anywhere in the transportation network using an algorithmic approach. Similar to LTL transportation, Taha and Taylor [31] considered a hub-and-spoke design system for truckload trucking, and using a simulation rule-based model, determined the location of relay points, the assignment of nodes to relay points, and the service area associated with relay points with the goal of improving driving route distances. Tsu and Agarwal’s [32] work focused on developing consistent and regularized transportation tours for drivers utilizing existing facilities (i.e. distribution centers) to relay or switch trailer equipment in order to minimize driver tour lengths and enhance driver home time, while keeping empty miles to a minimum. Existing facilities were the main source for trailer exchange points in the study. Tsu and Agarwal's [32] work mainly concentrated on converting over for-hire transportation, for a retailer, to the retailer's private fleet in order to improve transportation costs while minimizing tour empty miles for the retailer. Taylor et al. [37] considered improving the driving job using consistent or more regularized driving routes. They developed local routes to transition freight to-and-from the freight pipeline, where the pipeline consisted of more regularized route and freight patterns along a longer length-of-haul path. Pipeline freight consisted of low demand variability and minimal imbalances between headhaul and backhaul freight; therefore, only a selective amount of freight qualified as a pipeline. Üster and Maheshwari's [38] multi-zone strategy addressed long driving tour lengths that keep drivers away from home for a significant amount of time. To some degree, Üster and Maheshwari [38] also considered the transportation carrier and customer in the scope of their research. Üster and Maheshwari's [38] work focused on creating freight zones with boundaries where nodes (e.g. shippers, receivers, etc.) were assigned to zones and included freight zone dispatching between and within zones. Circuitous miles and freight balance at the different zones were considered. Ali et al. [47] considered locating equipment relay points at a prescribed and static distance, so drivers could exchange freight to minimize driving distances or where drivers could rest. Ali et al. [47], using the detour algorithms, allowed drivers to deviate from the shortest path in order to re-use existing relay points. Specific fixed and variable transportation costs were not included in the study and key performance metrics were not considered. Table 1 summarizes some key characteristics for each research endeavor mentioned above.

Study	Focus	Model	Results
Hunt [15]	Create better and shorter driving tours using relay points; enhance driver home time	Spring algorithm (non-mathematical model)	Algorithmic approach created relay points and driver routes; does not include relay point costs or key transportation carrier and customer performance metrics or costs
Taha and Taylor [31]	Create hub-and-spoke type locations to shorten a driver's driving time; enhance driver home time	Simulation rule-based model	Relay point network created with assigned nodes to relay points and a defined service area for relay points; driver tours developed based on relay point locations
Tsu and Agarwal [32]	Create shorter driving tours using existing facilities to exchange trailers; convert for-hire transportation to the private fleet	Stochastic Flow Analyzer Optimization Model	Driver tours were developed based on exchange points utilizing distribution centers; result is a 6% weekly cost savings and 17% private fleet conversion; key performance measures were limited (cost and empty miles focused)
Taylor et al. [37]	Develop more consistent and regularized long-haul driving tours where drivers could be home more often	Factoral design used to identify pipelines; simulation experiments utilized	22% of all truckloads and 13% of all loaded miles were candidates for pipelines at J.B. Hunt Transport
Üster and Maheshwari [38]	Create shorter driving tours using a multi-zone dispatching technique and relay points in freight zones	Mathematical model; heuristic and Tabu search approach	Driver tours dictated by a prescribed tour length; lane tour length, local driver tour length, circuity, and load imbalance were key measures from the perspective of the customer, transportation carrier, and driver; out-of-route miles were allowed and freight balance was considered
Ali et al. [47]	Create shorter driving tours using a straight route algorithm and detour algorithms to create relay points	Straight route and detour algorithms	A routing scheme is developed using a static and preset relay point distance between locations; out-of-route miles are allowed using detour algorithms; key transportation costs and metrics and fixed relay point costs are not included

Table 1. Key transportation research endeavors to improve the truck driving job

The research endeavors outlined in Table 1 have helped lead the way to recognize a need for a better driver work environment to improve driver turnover and retention, and most of these efforts contain important components to develop a better driving job. Some shortcomings in the different approaches include: relay point cost considerations are often ignored; key transportation costs (e.g. line-haul market costs, relay point fixed costs, etc.) and metrics are not always considered; driver, transportation carrier, and customer are not considered or minimally considered in a more holistic fashion; most models are static by only incorporating preset and static distances to establish relay points; driver turnover measures are not included in the modeling efforts; etc. In some of the studies, driver turnover is mentioned as a byproduct of driver tour lengths but fail to include driver turnover as a component within the research model. Driver turnover may be a byproduct of the driving tour length and driver home time, but it is also a function of the miles driven per week per driver on a consistent basis. If drivers are not able to drive consistent and strong miles each week then drivers are more apt to turnover. A balance in weekly driving miles is needed to ensure drivers earn satisfactory pay and are home often. Too many miles results in driving fatigue and a significant reduction in driver home time while too few miles prevent drivers from earning satisfactory pay. Therefore, the miles per week per driver element must be incorporated into the modeling efforts. The research efforts noted in Table 1 have relevancy in improving the driving job, but some studies are limited in scope and some do not consider metrics to ensure the driver, transportation carrier, and customer will all benefit from an improved driving job.

The purpose of my research is to conduct a more in-depth analysis on the work related factors and job conditions that cause the truckload driving job to be unattractive while incorporating a relay point methodology to enhance the driving job by creating more attractive and shorter driving routes that enable drivers to be home frequently (i.e. 5 to 7 days per week) and to work less hours each week while maintaining strong driver pay. Additionally, industry specific performance metrics will be included to focus simultaneously on the truck driver, transportation carrier, and customer with the goal of ensuring that all three entities reap the benefits of an improved driving job. We do not want to improve the driving job at the expense of the transportation carrier or customer. Critical factors that cause the truckload driving job to be unattractive, such as, long driving distances, infrequent driver home time, inconsistent weekly driver routes and pay, idle equipment time due to federal hours-of-service rules compliance, etc., will be included in the model. Also, fixed costs will be included to establish “brick and mortar” facilities used as relay points. The goal of this study is to develop a method that will improve the driving job while minimizing key transportation costs.

3.2 Goals and Tasks

There are several goals to this research. The first is to develop a model that can better determine how truck drivers should be coordinated or routed differently using a relay point methodology that will shorten a driver’s driving distance and increase a driver’s home time while keeping driver pay at healthy levels. The second is to obtain and use pertinent transportation related data that will provide for the development of a national highway transportation network that can be used to model driver and transportation activity. The third is to incorporate and use industry specific performance and cost metrics from the perspective of the truck driver, transportation carrier, and customer, so that all three entities benefit from a better driving job. The fourth is to make meaningful performance and cost comparisons between the relay point and non-relay point results in order to state whether or not the relay point methodology is beneficial and worthwhile. The fifth is to ensure that the driving job is not enhanced at the expense of the transportation carrier and customer.

In order to achieve the goals of the study, several tasks must be completed. First, a national highway transportation network needs to be incorporated to model truck transportation, driver activity, and relay points. The highway network needs to include shipment or production locations (origins) and customer or consumption locations (destinations) and freight flows assigned on a shortest path network between the origin and final destination locations. The

Freight Movement Model (FMM) will be used as the data source for the origin and final destination locations and the assigned freight flows on a highway network. The FMM is discussed in more detail in Chapter 4. Second, a model must be developed to model transportation activity and determine where relay points should be located in order to enhance the driving job. In Chapter 5, a mathematical programming model will be explained in detail that shows how transportation and driver activity are modeled and how relay points are established. The mathematical program will be presented as a mixed integer quadratic program (MIQP). Additionally, the MIQP will need to be implemented and Chapter 6 outlines how the program is implemented using FICO Xpress Optimization Suite. Third, industry specific performance and cost metrics, from the perspective of the driver, transportation carrier, and customer, must be identified and incorporated into the modeling process to ensure that all three entities benefit from the relay point methodology. Chapters 4 and 5 outlines the performance and cost metrics. Fourth, a relay point benchmark scenario, using the MIQP, must be determined that can be compared to a non-relay point scenario. Chapter 6 shows how a relay point benchmark scenario is determined and used as a comparison to the non-relay point scenario. The cost metrics outlined in Chapter 4 are used to establish the relay point benchmark scenario. Fifth, after the relay point benchmark scenario is established in Chapter 6, more detailed performance and cost comparisons between the relay point and non-relay point scenarios must be executed, which is done in Chapter 7. Finally, it must be determined whether or not the relay point scenario is better than the non-relay scenario.

3.3 Research Limitations

There are some limitations to the modeling efforts. In the study, the model does not consider how drivers are scheduled or dispatched in order to exchange and relay truck and trailer equipment at relay points. The model assumes drivers will reach the relay points at the same time, but in actual practice, a scheduling and dispatching algorithm is needed to properly schedule and dispatch drivers so drivers can meet at relay points without a significant amount of wait or idle time. In addition, shipping and delivery time schedule windows are not included in the model. Also, drivers are assumed to be domiciled at all the relay points and at either the origin or final destination locations. From a cost and labor availability perspective, it may be better to domicile drivers differently and more strategically, so the model is limited in how drivers are domiciled. A driver domiciling algorithm would aid in better domiciling drivers based on labor costs, labor availability, market conditions, etc. From the perspective of potential relay point locations, the model considers 134,296 potential relay points. Some relay points are in close proximity to each other (e.g. within 0.1 miles), therefore, some relay points should be combined as clusters in order to better minimize the pre-processing time to define relay points. In conclusion, a scheduling algorithm to better schedule and dispatch drivers would benefit the study along with a better method for domiciling drivers. The driver scheduling and domiciling problem are outside the scope of this study, but provide an opportunity for future research.

CHAPTER 4

METHODOLOGY

4.1 Overview

The methodology focuses on developing a framework to model highway truck transportation while considering the production and consumption of goods, the distribution of goods, and a more optimal assignment of transportation routes on a highway network. The goal is to develop a more strategic technique for managing and routing truckload drivers utilizing relay equipment exchange points on a highway transportation network in order to improve driver turnover and enhance driver retention while considering key performance measures related to the customer and transportation carrier. A relay point is a physical location where a truck and trailer combination is exchanged between drivers in order to keep equipment and product continuously moving while shortening driving distances. A mixed integer quadratic programming model will be used to determine the location of relay points on a highway transportation network. The mathematical program will be developed to strategically tour and route drivers and locate relay points where drivers can rest or sleep, shower, use computing services, exchange truck and trailer equipment, have equipment maintenance performed, enjoy restaurant services, fuel trucks, or perform other transportation related duties. The key use of the relay point concept will involve exchanging truck and trailer equipment to reduce driving distances and enhancing driver home time while providing better customer service and lower transportation carrier costs. Exchanging equipment involves a driver with a truck and trailer exchanging the truck and trailer with another driver's truck and trailer. After exchanging equipment, the driver will deliver the loaded trailer to a final customer, reposition the trailer to a shipping location, or reposition the trailer to another location. Equipment will continuously move unless the equipment is being loaded or unloaded or briefly idle while being relayed.

An Oklahoma Department of Transportation sponsored project- the Freight Movement Model-will be used to provide the data and information to create a national U.S. highway transportation and freight network contiguous to North America. In conjunction with the FMM model, critical transportation data sources are used along with data collection methodologies to establish and develop the highway transportation network for the relay point concept. Prior to establishing relay points, a national highway transportation network must be defined and developed that encompasses freight movements across the U.S. The FMM framework provides a national highway transportation network that contains producer and consumer locations in all U.S. states excluding Hawaii. The FMM model distributes truckload freight between producers and consumers using the doubly constrained gravity model and assigns truckload freight using an in-house developed freight/route assignment model. In the following, a detailed methodology will be provided along with key data elements used to formalize the highway transportation network.

4.2 Methodology

An equipment relay point network is superimposed onto a highway transportation network. Equipment relay points are established to provide a means where truck and trailer equipment can be exchanged between drivers to minimize driving time and distances and reduce driver time away from home. A relay point network is created using a MIQP and is evaluated to determine the impact on the driver, customer, and transportation carrier in a more holistic fashion. Truck driver activity is analyzed on the transportation network to ensure drivers reap the benefits of more home time and shorter driving distances while maintaining healthy driver pay. Industry specific performance measures as related to the driver, transportation carrier, and customer are implemented and measured in the MIQP. An analysis will be conducted to determine the significant difference of key variables as related to industry established performance metrics. Data requirements and modeling concepts will be further discussed in detail in Chapter 5.

4.2.1 Equipment Relay Points

As mentioned, a MIQP is used to determine location points where truck and trailer equipment will be relayed or exchanged, where equipment maintenance can be performed, where information technology facilities can be accessed, where drivers can sleep or rest, where trucks can be fueled, etc. The objective of the mathematical program is to establish relay points on a highway transportation network in such a way to minimize key transportation costs while creating consistent driving tours/routes that have shorter length-of-hauls- compared to typical OTR freight- in order to enhance driver home time and improve long-term driver turnover while maintaining solid driver pay levels. It is crucial that drivers maintain a certain level of weekly driving miles in order to maintain healthy pay since driver pay is usually mileage based. The relay points are also established in such a way to enhance the performance metrics of the transportation carrier and customer while improving the driving job. From the perspective of the transportation carrier, key items such as line-haul transportation costs, equipment depreciation and maintenance costs, on-time customer service, driver pay, etc. are critical. The customer is also concerned about on-time service and costs. Therefore, the goal is not to improve the driving job at the expense of the transportation carrier and customer. Figure 12 illustrates a simple example of a driving route from Dallas, TX to Mason, TN without a relay point and with a single relay point. The relay point in this example is located in Arkadelphia, AR.

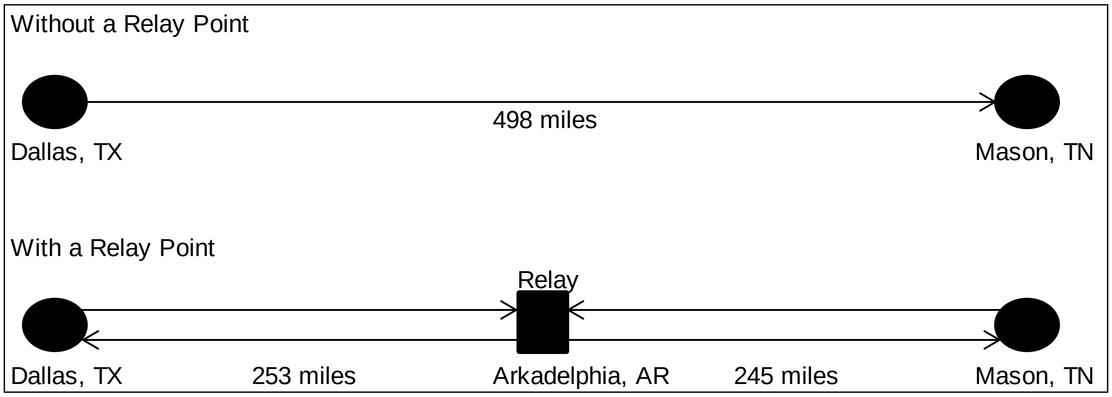

Figure 12. An example of a relay point on a driving route

In regard to the With a Relay Point scenario in Figure 12, Arkadelphia, AR serves as a location where truck and trailer equipment could be exchanged. In the Without a Relay Point scenario in Figure 12, the Dallas driver would drive to Mason, and then the driver would need to take a ten hour rest shortly after making the Mason delivery in order to comply with federal hours-of-service rules. The driver would either rest in the truck in the sleeper berth or in a hotel. If the driver rests in the truck, then a sleeper berth truck is required. In the With a Relay Point scenario in Figure 12, the Dallas driver would haul a truckload from Dallas to Arkadelphia and then exchange the truck and trailer with a Mason driver that travels from Mason to Arkadelphia. The drivers would exit Interstate 30 and relay equipment. The Mason driver would take the truckload to Mason for delivery and the Dallas driver would return back to Dallas with the Mason driver's truck and trailer. By exchanging the equipment at the relay point, the Dallas and Mason driver are back home daily and the drivers can rest at their home instead of sleeping in a truck. Since drivers can rest and sleep at home, day cab trucks are required instead of sleeper cab trucks. Day cab trucks are about $16,000 per unit cheaper than sleeper cab trucks. The Arkadelphia relay point is a physical location established along the highway transportation network off Interstate 30. If feasible, existing facilities can be used or new facilities must be established at the relay point location. Relay points are determined in-route from origins and final destinations, so costly out-of-route miles are not an issue. The relay point scenario allows the drivers to drive shorter length-of-hauls and to be home daily, whereas, the non-relay point drivers must drive the entire

498 mile length-of-haul and be away from home different days of the week. Similar to the Dallas to Mason path, the mathematical program determines where relay points should be located on a national highway transportation network throughout the U.S. Key costs are included in the mathematical program to appropriately model truck driver, transportation carrier, and customer attributes. Within the MIQP, driver quantity pools are determined and established on the transportation network for each origin-destination path at different relay points. Origins, destinations, and relay points serve as locations where drivers can be domiciled. A domicile is the home base where the drivers live or are stationed. Chapter 5 provides a detailed description of the MIQP and the data used in the program along with the key costs included in the mathematical program, which reflect the dominant costs for transportation carriers, drivers, and customers.

The relay point scenario generated from the MIQP will be compared to a non-relay point scenario without relay points. Comparisons will be made with regard to cost and performance metrics and driver and equipment quantity requirements. Key cost items focus on driver pay, truck and trailer depreciation, truck and trailer maintenance, and truck and trailer purchase costs. Performance metrics concentrate on order cycle time, driving length-of-haul, driver home time, driver work hours, driver and truck utilization, and equipment idle time. Purchase costs focus on truck and trailer equipment and the different types of truck equipment required (day cabs or sleeper cabs). Using relay points, drivers can drive day cabs, while most non-relay point drivers require sleeper cabs. A mixture of cost and performance metrics considers the driver, transportation carrier, and customer together. Derivatives of the total cost, such as, cost per mile, cost per hour, cost per truckload, etc. will be compared between the relay and non-relay point scenarios. Productivity measures will also be included.

In order to study truckload driver transportation and the simultaneous inter-relationships with the transportation carrier and customer, a truckload transportation network is created for modeling purposes. The transportation network is based on actual historical production and consumption data and information from the FMM model. Detailed information includes production and consumption truckload volumes throughout the U.S. along with freight distribution truckload volume flows between production and consumption locations, the appropriate transportation mode, and the freight assignment routes between production and consumption locations. Since this study is focused on truck drivers, truck transportation is the only transportation mode considered with specific focus on truckload transportation. To create the transportation network, three phases are executed in the FMM model. The first phase consists of freight generation by establishing the freight production and consumption location points. The second phase involves distributing freight flows between the production and consumption locations. The third phase consists of creating the appropriate freight route assignments between the freight production and consumption locations. Appendix A outlines, in more detail, the FMM steps involving freight generation, freight distribution, and freight assignment.

CHAPTER 5

DATA AND MODEL

5.1 Overview

It is important to understand the truckload transportation problem as it relates to the driver, customer, and transportation carrier in order to secure the proper transportation data and to develop an integrated mathematical model. The objective of the mathematical model is to minimize transportation costs as related to the following cost components: line-haul transportation costs, fixed costs associated with establishing relay points, driver turnover costs, truck and trailer depreciation costs, fuel costs, truck and trailer maintenance costs, and driver pay. The costs incorporated in the model reflect dominating transportation related costs and represent cost factors important to the driver, transportation carrier, and customer. Constraints in the mathematical model are used to limit a driver's length-of-haul, in accordance to federal hours-of-service rules, to a maximum threshold for each origin-destination path; to make sure inbound truckload volume flows to a relay point and outbound truckload volume flows from a relay point are coordinated and routed correctly through relay points or to a final destination location; to ensure all origin-destination truckload volume flows are fully used in the model; to create driver pool quantities associated with relay points, origins, and destinations for each origin-destination path; and to model driver turnover associated with average weekly miles per driver. To develop the mathematical model, the appropriate transportation data is required. Data is required with regard to transportation related costs, path distances, potential relay point locations, truckload flows, etc. The data requirements will be outlined.

5.2 Data

The data used in the mathematical model was obtained from the FMM model using the methodology and processes outlined in Chapter 4. The key input data includes: origin locations (shippers or producers), destination locations (consumers), origin-destination paths and path links, origin-destination path truckload volume flows, origin-destination path distances, link (arc) distances within each path, line-haul costs for each path, fuel costs for each path, truck miles per gallon (mpg), turnover cost per driver, fixed costs to establish relay points, truck and trailer depreciation costs, truck and trailer maintenance costs, and driver wages. A path is the shortest congested path assignment between each origin and final destination. Each data element is explained further.

5.2.1 Origin and Destination Locations

Origin locations are nodes where freight is produced or originates and final destination locations are nodes where freight is consumed. Non-final destination locations beyond the origin are represented as relay points where truck and trailer equipment are transitioned or exchanged with no actual consumption of goods. Origin locations are typically referred to as shippers where truckload freight (outbound freight) is produced and final destination locations are referred to as final customers where truckload freight (inbound freight) is consumed. There are 203 unique origins or shippers and 210 different final destinations or final customers used in the mathematical model based on MSA locations. Specific city/state locations for each MSA were determined based on the centroid city/state location for each MSA. Appendix C.1 lists the top 203city/state origins and associated outbound annual truckload flows based on outbound annual truckload flow. Appendix C.2 lists the top 193 city/state destinations and associated inbound annual truckload flows based on inbound annual truckload flow. Using TransCAD mapping software, all origin and destination locations were mapped and shown in Appendix D. For the remaining U.S. states, only MSA level data was considered. The MSA level city/state origin and destination centroid locations along with annual truckload volume flows provide a sufficiently dense freight network to model highway truck transportation on a national level within the U.S. A dense network of freight volume flows is necessary to determine if the relay point concept is a worthy endeavor on a national scale.

An origin-destination pair represents a path where freight is transported between the origin and final destination location. Each path represents a unique shipper and final destination combination. For example, referring back to Figure 12, Dallas, TX is the origin and Mason, TN is the final destination, and truckload freight is transported between the two locations via a truck and trailer combination. In the FMM model, there are 28,889 unique origin-destination paths with origins and destinations represented in each contiguous state (i.e. Hawaii is excluded). Appendix E shows the top 300 origin-destination paths based on annual truckload flow along with the percentage of truckload volume for each path compared to the overall annual truckload flow. As Appendix E illustrates, each origin-destination path makes up a small percentage of the overall annual truckload volume flow due to the numerous paths and significant truckload volumes associated with each path. In the study, origin-destination paths with a line-haul distance of less than 250 miles were excluded from the analysis because these lanes represent local driving paths where drivers are already home on a daily basis requiring no equipment relaying or special conditions to transition equipment or position drivers to improve driver home time. In other words, the less than 250 mile driving radius represents a local driving environment. This study is concerned with long-haul paths that require drivers to be away from home beyond one day or to shut-down to comply with federal hours-of-service rules.

Truckload volume flows between the origin and final destination are represented as truckloads. A truckload involves a single trailer, pulled by a truck, containing either a single commodity or multiple commodities unless the trailer is empty and being repositioned to a shipper, customer, or relay point. Truckloads usually weigh out due to the large amount of product weight on the trailer or cube out due to the large amount of space consumed by the products. Typically, in transportation, a truckload refers to freight hauled in either 48’ or 53’ trailers or containers, but in this study, a truckload refers additionally to refrigerated trailers, tanker trailers, flatbed trailers, etc. Less-than-truckload freight is excluded from the analysis. An origin-destination text file was created- ODDIST.txt- containing unique origin-destination paths along with the one-way distance between each origin and destination location. As an example of the data structure, Table 2 shows a small portion of the ODDIST.txt table. The ODDIST.txt file contains 28,889 origin-destination paths.

Origin	Destination	Miles
Wilmington, NC	Willow, OK	1,409
Wilmington, NC	White Plains, MD	381
Wilmington, NC	Westmoreland, NH	836
Wilmington, NC	Watson, OK	1,104

Table 2. Origin-destination paths and line-haul one-way miles example (ODDIST.txt)

Each origin-destination path contains truckload volume flow. An origin-destination truckload volume flow text file was created- FLOW.txt- containing unique origin-destination paths along with annual truckload flows between each origin and destination. As an example, Table 3 shows a small portion of the FLOW.txt table. The total annual truckloads included in this study are 205,119,400.

Origin	Destination	Annual Truckload Flow
Wilmington, NC	Willow, OK	7,366
Wilmington, NC	White Plains, MD	8,188
Wilmington, NC	Westmoreland, NH	14,284
Wilmington, NC	Watson, OK	7,889

Table 3. Origin-destination paths and annual truckload flow example (FLOW.txt)

Appendix F shows the inbound and outbound truckload flow density at different locations in the U.S. Also, Appendix G shows truckload flow between each origin and destination, which exhibits a high density of truckload flows covering the entire U.S. The high density of origin-destination paths and truckload flows provide sufficient volume flow data to effectively model truckload transportation on a highway network. As an example of a high density truckload flow path, the origin-destination path from Three Rivers, CA (Fresno, CA area) to Chandler, AZ

(Phoenix, AZ area) represents the largest number of annual truckload flows (20,046 truckloads) in the data set. The congested shortest path (i.e. based on the FMM freight assignment) from Three Rivers, CA to Chandler, AZ is shown in Figure 13.

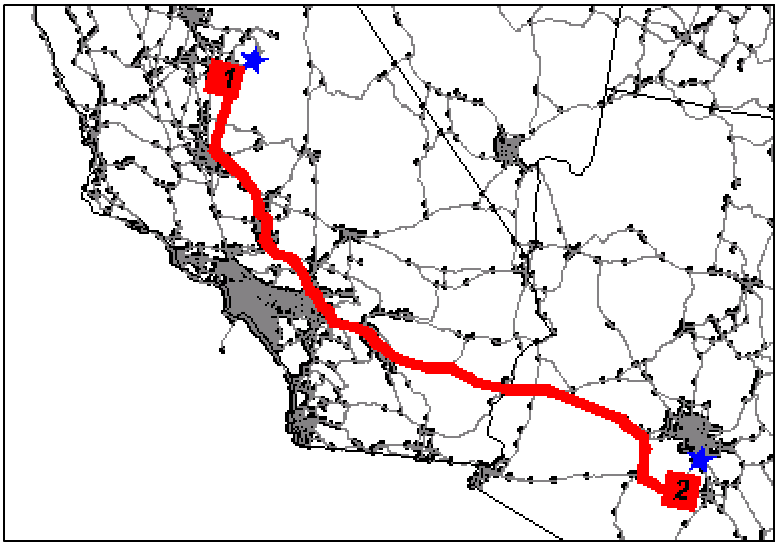

Figure 13. Three Rivers, CA (1) to Chandler, AZ (2) path

5.2.2 Transportation Links

An origin-destination path contains numerous transportation links or arcs. Transportation links are small segments of a highway path that contain freight flows between the origin and a relay point, between relay points, and between the final relay point and the final destination for a given origin-destination path. Along each origin-destination path, potential candidate relay points are located at link endpoints associated with the start and end nodes of each transportation link. As an illustration, Figure 14 shows transportation links between endpoints for section of highways around the Dallas, TX metropolitan area. In Figure 14, black dots represent endpoints and red lines represent transportation links. There are a total of 134,296 potential relay points at endpoints in the model.

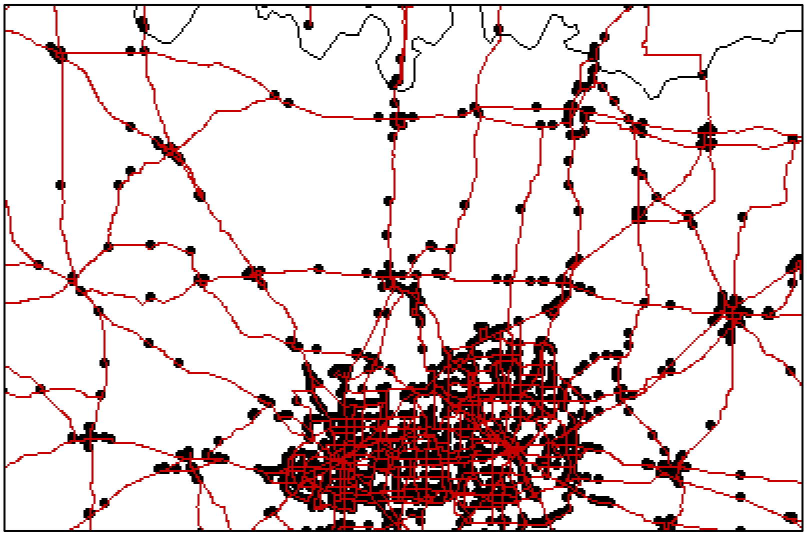

Figure 14. Transportation links and endpoints (Dallas, TX metropolitan area)

The mathematical model will determine where the relay points will be more optimally established based on the minimization of transportation costs, thus, some links will not contain relay points. Referring to Figure 12 for the Dallas, TX to Mason, TN path, a relay point is established in Arkadelphia, AR resulting in two driving routes for the path. A driving route exists between Dallas, TX and Arkadelphia, AR and between Arkadelphia, AR and Mason, TN; therefore, the path contains one relay point and two driving routes. Potential routes are defined for each origin-destination path and are dictated by the location of the relay points on the link endpoints. Potential routes are located in the ROUTES.txt file. As an example of the text file, Table 4 shows a small portion of the ROUTES.txt table. Routes are typically from one location to another location (e.g. relay point to relay point, origin to relay point, relay point to final destination) within an origin-destination path. A route and path are equivalent when a path does not contain a relay point. A route is a subset of a path.

Origin	Destination	From Relay	To Relay	Route
Wagoner, OK	Gage, OK	2	2	0
Wagoner, OK	Gage, OK	2	3	1
Wagoner, OK	Gage, OK	2	4	1
Wagoner, OK	Gage, OK	2	5	1
Wagoner, OK	Gage, OK	2	250	1
Wagoner, OK	Gage, OK	3	3	0
Wagoner, OK	Gage, OK	3	4	1
Wagoner, OK	Gage, OK	3	5	1
Wagoner, OK	Gage, OK	3	250	1
Wagoner, OK	Gage, OK	4	4	0
Wagoner, OK	Gage, OK	4	5	1
Wagoner, OK	Gage, OK	4	250	1
Wagoner, OK	Gage, OK	5	5	0
Wagoner, OK	Gage, OK	5	250	1
Wagoner, OK	Gage, OK	306	2	1
Wagoner, OK	Gage, OK	306	3	1
Wagoner, OK	Gage, OK	306	4	1
Wagoner, OK	Gage, OK	306	5	1
Wagoner, OK	Gage, OK	306	20	1

Table 4. Origin-destination path with From Relay and To Relay points (ROUTES.txt)

In Table 4 above, the path is from Wagoner, OK to Gage, OK. Link endpoints are termed From Relay and To Relay in Table 4. The From Relay column defines the begin point (node) for each link and the To Relay column defines the end point for each link for the given origin-destination path with the 1 in the Route column representing the presence of a route on a given link. A 0 route value represents the absence of a route for a given From Relay-To Relay link. The numerical values in the From Relay and To Relay columns represent city/state code numbers that cross reference to actual city/state names or locations. A single route on a given path from the origin to the final destination with no intermediate relay points would indicate that a relay point was not established on the path, and freight flows directly from the origin to the final destination without passing through a relay point. Considering the example in Table 4 above, if a relay point was established at point 2 and 4 only, then, there would be a route from point 306 to point 2, from point 2 to point 4, and from point 4 to point 250. Point 306 is a code value representing Wagoner, OK (the path origin point) and point 250 is a code value representing Gage, OK (the path final destination point). The relay points and routes must be sequenced correctly in order to properly define the path. There are 6,200,619 potential routes in the model data set. Each path consists of an average of 214.6 potential routes.

Each potential route contains a line-haul or one-way distance, which is defined in the DIST.txt text file. The DIST.txt table contains 6,200,619 rows of information (i.e. a row for each potential route) similar to the ROUTES.txt file. The distances are represented in miles, but the distances could be represented in other distance units such as kilometers, meters, etc. Table 5 shows a small portion of the DIST.txt table.

Origin	Destination	From Relay	To Relay	Miles
Wilmington, NC	Willow, OK	210	2	50
Wilmington, NC	Willow, OK	210	3	100
Wilmington, NC	Willow, OK	210	4	150
Wilmington, NC	Willow, OK	210	5	200
Wilmington, NC	Willow, OK	210	6	250

Table 5. Origin-destination path with From Relay and To Relay points and distance (DIST.txt)

From Table 5 above, for the given origin-destination path, the one-way distance between From Relay 210 and To Relay 2 is 50 miles.

Additionally, each route contains a line-haul cost per mile, which is defined in the COST.txt file. The cost per mile includes all variable costs outside the scope of the depreciation costs, fuel costs, maintenance costs, and driver pay. Depreciation costs, fuel costs, maintenance costs, and driver pay are significant individual costs and are captured individually in the mathematical model. In the transportation industry, variable costs are usually represented as a mileage rate, but other units can be used as well, such as, an hourly rate, a daily rate, a payload weight based rate, rate per hundred pound, etc. Similar to the ROUTE.txt and DIST.txt files, the

COST.txt file contains 6,200,619 rows of information. Table 6 shows a small portion of the COST.txt table.

Origin	Destination	From Relay	To Relay	Mileage Rate
Wilmington, NC	Willow, OK	210	2	$0.55
Wilmington, NC	Willow, OK	210	3	$0.59
Wilmington, NC	Willow, OK	210	4	$0.57
Wilmington, NC	Willow, OK	210	5	$0.46
Wilmington, NC	Willow, OK	210	6	$0.66

Table 6. Origin-destination path with From Relay and To Relay points and Mileage rates (COST.txt)

From Table 6 above, for the given origin-destination path, the line-haul cost per mile between From Relay 210 and To Relay 2 is $0.55. As exhibited in Table 6, mileage rates are different for each From Relay-To Relay combination because line-haul costs tend to be somewhat different between locations due to economic market conditions. For example, the overall line-haul truck rate inbound to the state of Florida compared to the line-haul rate outbound from the state of Florida can be as much as a $1.00 per mile more expensive since there is minimal truck freight coming out of the state of Florida. Since it is difficult to find freight outbound from Florida, the truck rate inbound to Florida is expensive while the outbound rate from Florida is very inexpensive. Economic market conditions dictate truck rates for all regions of the U.S. Line-haul costs make up approximately 25%-30% of the total transportation cost. To establish relay points on a given path, link line-haul costs are required for a given path in order to represent the appropriate market-to-market transportation costs. The cost per mile rates were obtained as confidential information from a large transportation company; therefore, the mileage rates shown in Table 6 have been modified and do not exhibit actual rates. The actual rates were used in the mathematical model.

5.2.3 Driver Turnover Percentage and Cost

As mentioned previously, it has been reported that the cost to replace a single truck driver due to driver turnover can range anywhere from $2,000 to $30,000 depending on the situation and the driving market and unemployment conditions. Since driver turnover is a significant and costly problem in the truckload transportation industry, a measure of driver turnover and cost must be incorporated into the mathematical model. Driver turnover can be a function of several variables such as driver home time, average driving length-of-haul, driver attitudes toward supervision, truck equipment age and condition, family conditions of a driver, driver career stage, etc. Also, weekly driver utilization (driving miles per week per driver) is considered to be a very important metric to gauge driver turnover since long-haul drivers are typically compensated based on mileage driven at a specific wage rate per mile. Drivers expect to drive a healthy number of miles each week to maintain a good annual salary with some level of home time. If a long-haul driver averages a small quantity of driven miles per week (i.e. 2,300 miles or less) over an extended time period, there is a high probability the driver may turnover because paid miles are not adequate enough to sustain a living or an expected standard of living. In other words, a driver's annual pay will be too low. Also, if a long-haul driver averages a large amount of miles per week (i.e. 3,200 miles or more) over an extended time period, there is a high probability the driver may turnover due to driving fatigue and a lack of rest and a lack of home time. Therefore, miles driven per week based on mileage bands with associated driver turnover percentages were used to establish driver turnover and the associated cost. Table 7 shows the driver turnover percentage based on miles driven per week per driver mileage bands based on work done with a large transportation company [52]. Mileage band driver turnover information can be modified to reflect changes in economic conditions with regard to unemployment. Driving mileage needs to be consistent on a weekly basis, so drivers can make a healthy salary and be home on a frequent basis. Mileage extremes over extended time periods tend to cause discontent with drivers leading to driver turnover.

Miles Per Week Per Driver	**Driver Turnover %**
2,099 and less	150%
2,100 to 2,199	140%
2,200 to 2,299	130%
2,300 to 2,399	110%
2,400 to 2,499	90%
2,500 to 2,599	70%
2,600 to 2,699	50%
2,700 to 2,799	30%
2,800 to 2,899	25%
2,900 to 2,999	20%
3,000 to 3,099	15%
3,100 to 3,199	25%
3,200 to 3,299	50%
3,300 to 3,399	70%
3,400 and more	90%

Table 7. Driver turnover % based on miles driven per driver each week

As an example from Table 7, if drivers average 2,099 miles or less per week, the driver turnover rate is 150% or if drivers average 2,899 miles per week, the driver turnover rate 25%. The mileage bands can be modified or incremented differently or include different ranges depending on the user and the application. The mileage bands are graphed and illustrated in Figure 15 in order to better visualize how driver turnover relates to the different mileage bands. As illustrated in the figure, the driver turnover percentage resembles roughly a u-shape since driver turnover tends to increase as average weekly miles extremely increase or decrease. The turnover cost per driver and turnover percentages are factored into the mathematical model to account for driver

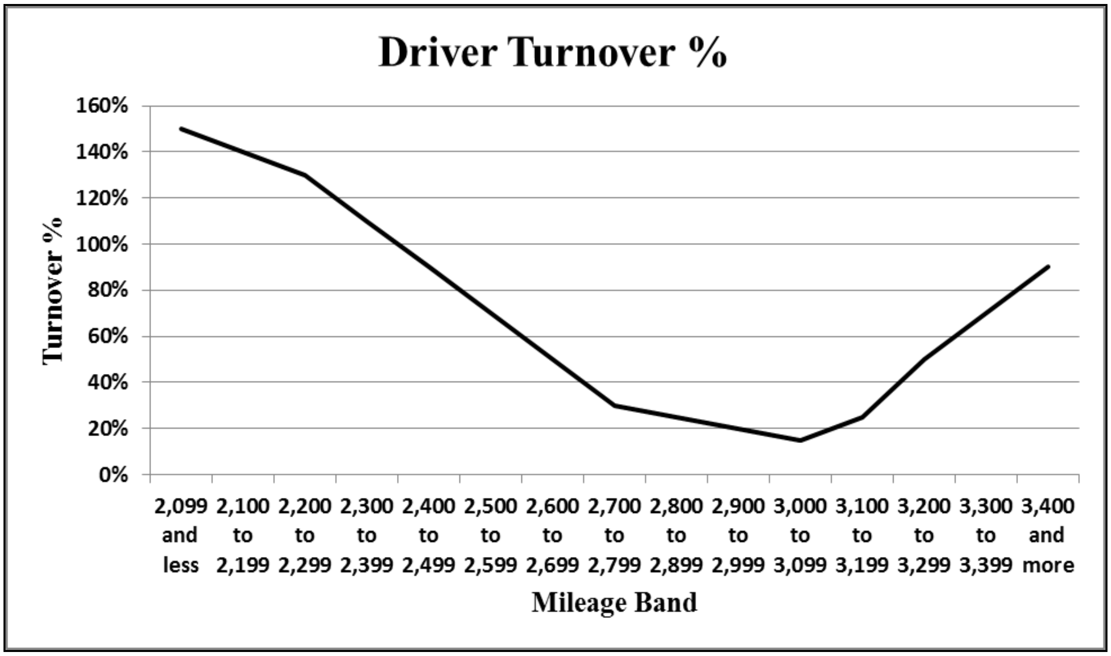

Figure 15. Driver turnover percentages at different mileage bands

turnover costs based on the average miles driven per week per driver. A driver turnover cost of $3,000 per driver turnover incident was used in the mathematical model, which can be specified by the user using the parameter interface noted in Appendix H. Driver turnover percentages may need to be modified as economic market conditions change causing an impact on driver turnover and employee turnover in general. As the overall unemployment rate increases and recessionary market conditions persist, voluntary employee turnover tends to decrease along with truck driver turnover, so adjustments to Table 7 would need to be made based on economic conditions.

5.2.4 Truck and Trailer Depreciation and Maintenance Costs

Truck and trailer depreciation and maintenance costs make up about 8%-15% of the total transportation cost. Since depreciation and maintenance costs are significant, the costs must be captured in the mathematical model. Truck and trailer depreciation costs are typically a fixed cost, but could be represented as a mileage based variable cost. In the mathematical model, equipment depreciation costs were treated as an annual fixed cost. Annual truck and trailer fixed depreciation costs were determined based on a day cab truck purchase cost of $79,736, sleeper cab purchase cost of $95,312, and a trailer purchase cost of $19,936, which was obtained from a large transportation company. Figure 16 and 17 illustrates an example of a day cab truck and sleeper cab truck, respectively. Figures 18 through Figure 21 show common trailers required by the various commodities hauled on the highway transportation network.

Figure 16. Picture of a day cab truck; Source: www.jbhunt.com [53]

Figure 17. Picture of a sleeper cab truck; Source: J.B. Hunt Transport, Inc. [54]

Figure 18. Picture of a standard box trailer; Source: J.B. Hunt Transport, Inc. [55]

Figure 19. Picture of a tanker trailer; Source: www.jbhunt.com [56]

Figure 20. Picture of a flatbed trailer; Source: J.B. Hunt Transport, Inc. [57]

Figure 21. Picture of a refrigerated trailer; Source: www.jbhunt.com [58]

The standard box trailer hauls palletized goods and materials that are typically packaged. Tanker trailers typically contain liquid materials such as gasoline/petroleum, food products such as milk, chemicals, etc. Flatbed trailers haul items that cannot be contained in a standard box trailer or configured to a tanker and require specialized material handling to load and unload product. Typical flatbed products include steel coils, long pipes, steel bars, etc. Refrigerated trailers haul product that must be chilled or frozen in a climate controlled atmosphere. In the study, all equipment is depreciated according to a 3-year property class (4-year class life) using MACRS-GDS depreciation. The average annual depreciation cost is $19,934 for day cab trucks and $23,828 for sleeper cab trucks. The average annual trailer depreciation cost is $4,984 per trailer. Equipment is usually sold at a certain point over the equipment life at a specified salvage value. Specific salvage values were not disclosed by the transportation company. The equipment salvage value was not factored into the mathematical model.

Truck and trailer maintenance costs are mileage based depending on the average miles accumulated per week per truck/trailer combination, and maintenance costs were obtained from a large transportation company. The truck and trailer costs are based on mileage ranges from 2,000 to 3,400 miles per week per truck/trailer combination. Table 8 shows a small portion of the maintenance cost per mile for various mileages. The maintenance cost per mile decreases as more miles are accumulated on the equipment with step increases at various mileages. In other words, the maintenance cost per mile decreases as a function of miles but increases at certain mileage points and then begins decreasing again. When miles are accumulated at certain mileage points, the equipment maintenance schedule is changed resulting in a step-wise increase followed by a steady decrease as miles increase. Figure 22 shows the truck and trailer maintenance cost as a function of mileage.

Average Weekly Miles	**Maintenance Cost Per Mile**
2,000	$0.060273
2,001	$0.060248
2,002	$0.060223
2,003	$0.060198
2,004	$0.060174

Table 8. Maintenance cost per mile example

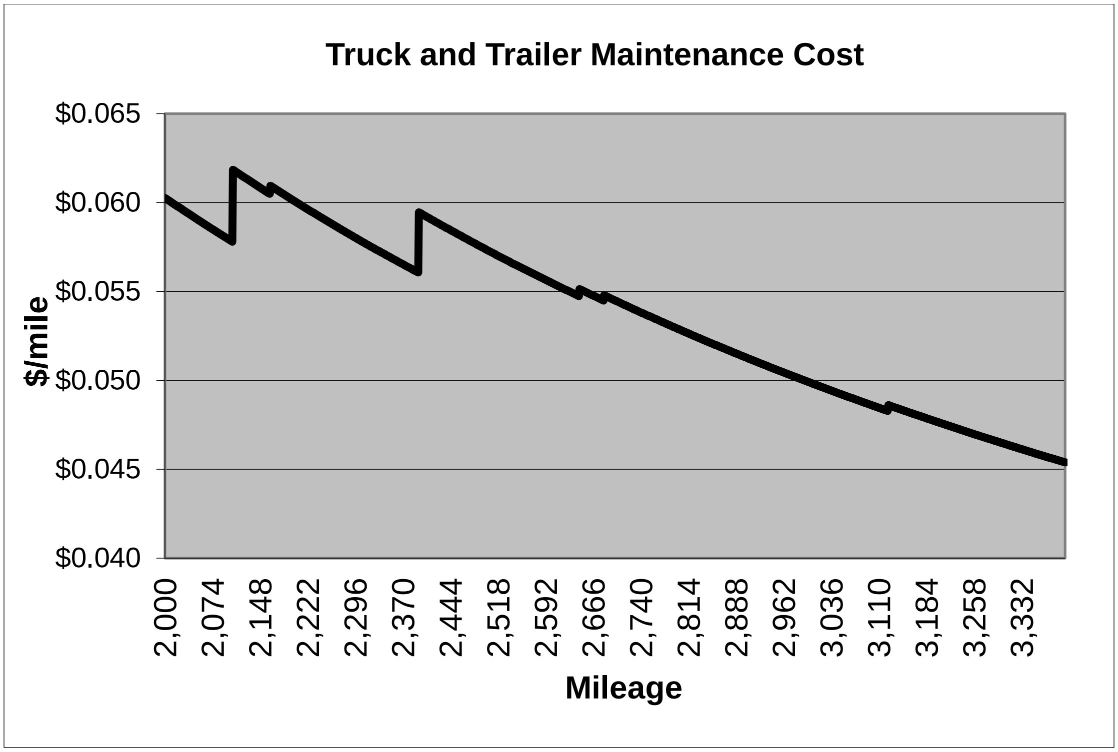

Figure 22. Truck and Trailer maintenance cost as a function of miles

5.2.5 Fixed Costs

Fixed costs are incurred to establish a facility such as a manufacturing plant, distribution center, warehouse, cross-dock facility, etc. In the mathematical model, the fixed cost may not necessarily represent the establishment of a new physical “brick and mortar” facility, but it could in order to establish a relay point in terms of fixed logistics costs, building/property leases, building/facility construction costs, etc. Fixed logistics costs include: information technology/system costs to establish a relay point; setup/membership fees to use a facility such as a hotel, a gravel lot to relay equipment, or a truck stop; setup fees to use a maintenance facility associated with a relay point; building a truck stop and/or maintenance facilities; etc. In some situations, a transportation company may sign a contract to become a member of an existing facility such as a truck stop or fueling station in order to receive benefits such as a fuel discount, maintenance service discount, shower service for drivers, etc. In situations where an existing facility can be used, fixed costs are lower compared to building a new facility. Existing facilities typically have the building amenities, parking area, utility services, etc. to serve truck drivers, but building a new facility requires property procurement, construction costs, and numerous other costs to create a facility. Fixed costs tend to be a significant cost incurred to establish or create a physical relay location and must be included in the mathematical model. Since the actual locational data of existing facilities is unknown for all the potential relay points existing in the highway transportation network, a worst case scenario will be considered where construction and establishment costs will serve as the fixed cost. Based on a thorough analysis of construction, establishment, and property costs associated with creating a facility to relay equipment, maintain equipment, equip facilities with showers, offer computing services, provide fueling services, provide food services, etc., the fixed cost averages $6.55 million per facility with a range from $3.1 million to $10 million per facility. In conjunction with typical financing practices of commercial properties, fixed costs were amortized annually over 20 years using a nominal annual interest rate of 6%. The 6% nominal interest rate is based on the value of current marketplace interest rates.

5.2.6 Dispatch Costs

A dispatch occurs when a driver or driver/truck combination is assigned to a truckload with the intent of picking up a truckload at a shipper and then delivering the truckload to a customer or to an intermediate location such as an intermediate customer stop or relay point. Drivers are often deadhead dispatched, which means, the driver is assigned to an empty trailer for the purpose of moving or transitioning a trailer to a new location. A dispatch typically occurs when a driver is assigned to a truckload or some kind of driving activity such as a deadhead or loaded move. Dispatching drivers is typically done via a computer transaction, which is done intrinsic to the computing network and system in place. Companies, such as Qualcomm and other companies, provide dispatching systems to transportation companies that can be utilized to dispatch drivers in a more automated fashion utilizing a satellite network. Most trucks today are equipped with satellite communication units, Wi-Fi, and mobile communication systems that allow for the ease of dispatching drivers. Dispatching can also be done manually by a dispatcher using a computer interface or via a cell phone, but these practices have typically been replaced with more efficient and faster automated systems. Driver dispatches can also be scheduled to occur automatically by preplanning or assigning a driver to a truckload order. With current technology, dispatching drivers is no longer a laborious and time consuming activity, so minimal time and effort are required to dispatch drivers on a driving activity. The relay point can present situations where the driver is dispatched on an empty trailer or on a return backhaul truckload. Additional dispatches will occur at the relay points, but these activities will not be an incremental system cost since systems are already in place to absorb additional dispatches. The dispatching cost is not a direct cost to transport truckload freight and is treated as an overhead cost associated with transporting truckload freight; therefore, the dispatch cost is not included in the mathematical model.

5.2.7 Fuel Costs

In the trucking industry, fuel costs make up approximately 35% or more of the total transportation cost. With the high degree of volatility in fuel prices over the last ten years, fuel is an on-going priority cost item that is monitored closely by transportation carriers in order to minimize fleet costs. Due to the rise in diesel prices over the years, transportation companies seek ways to manage fuel consumption better by: requiring drivers to idle equipment less, driving less out-of-route miles, driving less empty miles, establishing contracts with fueling stations to obtain fuel discounts, incorporating fuel surcharge contracts with customers, etc. Figure 23 illustrates the volatility of diesel prices per gallon from 2001 to mid-2011 with an overall upward trend in fuel prices while showing a significant upward trend in the summer of 2008 and a significant lower trend at the end of year 2008.

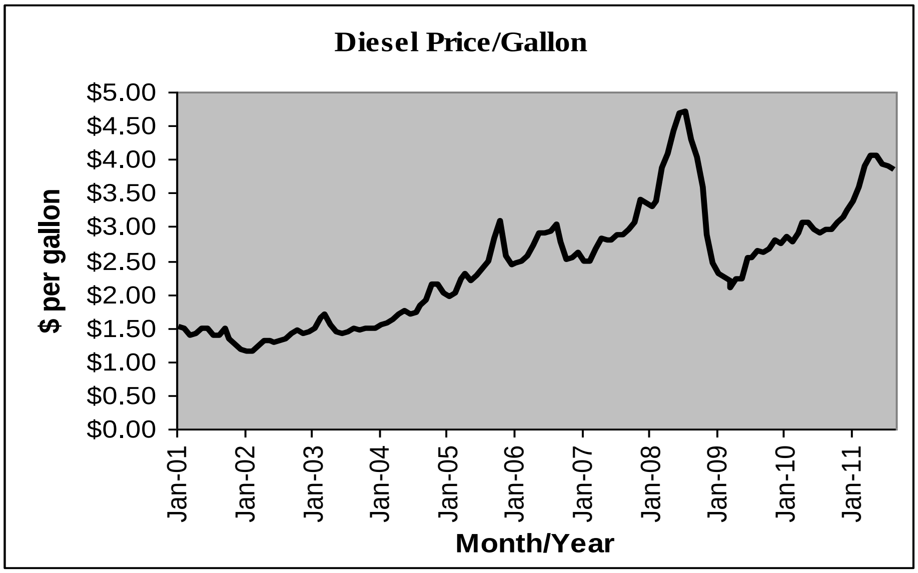

Figure 23. Diesel price per gallon from 2001-2011 [59]

Fuel costs are incurred in the model when trucks move truckloads along the transportation highway network. In order to determine the fuel costs, two components are required. First, the fuel cost per gallon is required and must be determined. Second, the average truck miles per gallon (mpg) is required and must be provided. Truck miles per gallon tend to vary depending on the truck age and truck type being utilized, trailer type being hauled, the payload weight on the trailing equipment, driving terrain (i.e. mountainous, level/flat, straight, crooked, etc.), truck speed, driving conditions, weather conditions, travel length-of-haul, etc. Typically, the truck miles per gallon range from 5.0 up to 6.4 with the average being closer to 6.0 for long length-of-hauls. The newer, environmental friendly truck engines are less fuel efficient and operate closer to 6.0 miles per gallon. Non-environmental truck engines can average from 6.8-7.0 miles per gallon on long length-of-hauls, but most non-environmental trucks are no longer available on the market and have been displaced with government mandated environmental friendly engines. In local environments where trucks travel shorter distances and in more populous areas, trucks may only get 5.0 miles or less per gallon. Longer driving paths with significant amounts of interstate and free flow driving are more fuel efficient driving routes and trucks can average up to 6.4 miles per gallon. In the model, where truckloads are shipped from an origin location to a relay point, an average mpg of 5.44 is used since this travel is typically done on two lane highways. On relay point to relay point moves, an average mpg of 6.4 is used because this travel is typically done on interstate and four lane highways. On relay point to final destination moves, an average mpg of 5.44 is used because a combination of interstate and two lane highways are typically used. Based on average mpg values from a large transportation company, the model mpg values are in-line with industry averages. A diesel fuel cost of $3.50 per gallon was used in the m model portraying current economic market conditions.

5.2.8 Driver Pay Costs

Driver pay costs are significant in the trucking industry accounting for about 25%-30% of the total transportation cost. Long-haul truckload drivers are usually paid based on miles driven and a mileage based wage rate (wage rate per mile). In most cases, truckload drivers target an average weekly mileage of 2,500 miles or more in order to obtain a healthy annual salary. Drivers are also paid for various activities such as: intermediate stops between the origin and final destination, manual loading and unloading activity, equipment monitoring, load strapping (flatbed), load tarping (flatbed), etc. Since a large portion of a driver's pay is mileage based, the driver wants to minimize the amount of time spent on activities extraneous to driving. In the mathematical model, driver pay is based on a mileage wage rate, and a driver wage of $0.42 per mile is used. The user interface in Appendix H allows the user to input the driver wage per mile. Driver pay typically starts at a certain wage rate depending on driving experience and progresses with time as the driver increases in tenure with the transportation company. Also, senior drivers with significant driving experience tend to have higher wage rates. The following represents a typical driver wage rate pay scale scheme over time based on driving experience:

- 1 year experience- starting pay is $0.40 per mile
- 2 years experience- starting pay is $0.41 per mile
- 3 years experience- starting pay is $0.42 per mile
- 4 years experience- starting pay is $0.43 per mile
- 5 years experience- starting pay is $0.44 per mile

Most transportation companies compete to recruit and hire drivers based on driver wage rates with a promise that the driver will be able to drive a certain amount of miles each week. Consistent miles along with pay are critical components to keep drivers satisfied. Inconsistent driving miles results in inconsistent driver pay and often transpires into low wages, typically resulting in driver turnover.

5.2.9 Relay Points

As previously mentioned, there are 134,296 potential relay points in the FMM highway transportation network, so there is a strong representation of relay points for all origin-destination paths. Figure 24 shows a path from Jacksonville, FL to Atlanta, GA and the endpoints (i.e. potential relay points) along the path. In the figure, the black dots represent potential relay points in the network and indicate a high density of potential points to relay equipment. Figure 25 illustrates a path from Oklahoma City, OK to Tulsa, OK showing potential points more clearly along the path. From Oklahoma City, OK to Tulsa, OK, there are 15 potential relay points along the path.

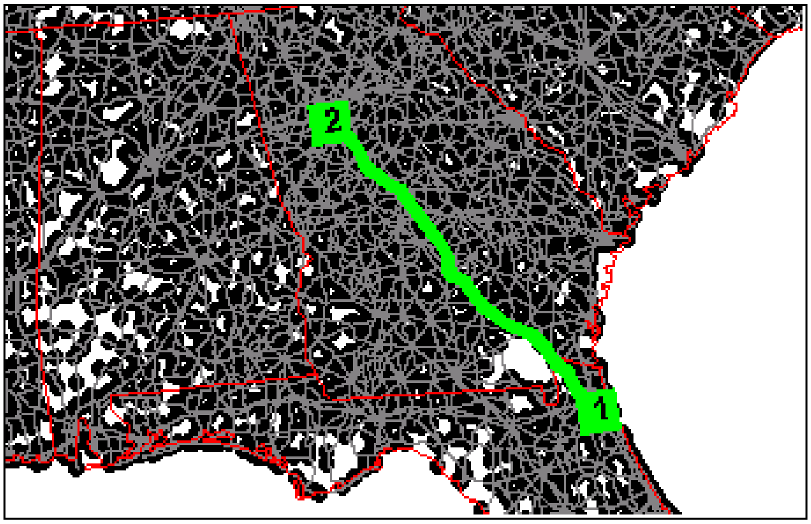

Figure 24. Jacksonville, FL (1) to Atlanta, GA (2) path

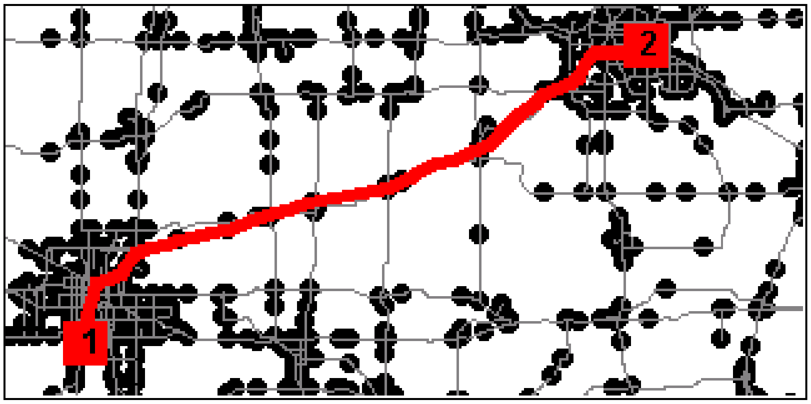

Figure 25. Oklahoma City, OK (1) to Tulsa, OK (2) path

As illustrated in Figures 24 and 25 above, there are numerous potential relay points surrounding the origin-destination paths, but candidate relay points are only considered along the direct path from the origin to the final destination. In other words, potential relay points circuitous (out-of-route) to the path are not considered as candidate relay points. A visual representation of the potential relay points are shown in Appendix I. Based on the figure in Appendix I, there is a high density of potential relay points within the highway transportation network across the U.S. Actual relay point locations, established on the highway network, are determined by the mathematical model in such a way to minimize transportation costs, while enhancing driver home time, developing consistent driving routes, and maintaining healthy driver pay. Relay points are established to benefit the drivers but not at the expense of the transportation carrier and customer.

5.3 Mathematical Model Overview

One goal of the mathematical model is to create relay points on a highway transportation network in such a way that creates driving routes, with consistent freight patterns, that can be driven consistently by a given set of drivers. Another goal is to establish relay points in order to create shorter driving routes, which allows for more driver home time and less long length-of-haul driving. The model aims to improve the driving job and reduce driver turnover by enhancing home time and shortening driving distances while keeping annual driver pay healthy. The objective of the model formulation is to create relay points while minimizing total transportation costs. The customer and transportation carrier are also considered with the driver, so the driving job will not be improved at the expense of the transportation carrier and customer.

The model locates relay points on a highway transportation network at certain distances from the origin location on given origin-destination paths in order to minimize total transportation related costs to limit driving distances.   The transportation costs include the following cost items: line-haul market-to-market costs, fuel, driver wages, truck and trailer depreciation, truck and trailer maintenance, driver turnover, and the fixed amortized costs to set up a relay point. Truckload flows are coordinated properly from an origin point location through relay point locations and then to the final destination. The length-of-haul that drivers can drive between location points can be specified by the modeler and is set as part of the constraints in the model. The model determines the quantity of drivers required- to move truckload flow volumes- to be domiciled at relay points and at origin and destination locations, assuming each driver can only drive a maximum of 60 hours over 7 consecutive days or 70 hours over 8 consecutive days. In the model, truckload flows must be completely used to meet customer demands, and flow conservation must be assured at relay points. To account for driver turnover, mileage bands- based on average miles driven per week per driver- are used with a driver turnover percentage associated with each mileage band. The model output consists of the location of relay points on origin-destination paths, driving routes associated with relay points on origin-destination paths, average length-of-haul for drivers on each origin-destination path, average driver home time for each origin-destination path, detailed transportation costs (i.e. fuel, driver wages, equipment maintenance, equipment depreciation, fixed costs, driver turnover, and line-haul market costs), and the total transportation cost. Truck and trailer quantities are equal to the driver quantity in the mathematical model. After the relay points are established and driver routes are created based on the location of the relay points, actual truck and trailer quantities are determined for each driving route using an equipment slip-seating methodology where truck and trailer equipment are shared on multiple work shifts. Therefore, the truck and trailer counts will not necessarily equal the driver count. The mathematical model will now be presented as a MIQP.

5.3.1 Mixed Integer Quadratic Programming Model

Model Sets:

- N- set of nodes in the network
- A- set of arcs in the network
- **P** - set of origin-destination pairs
- P^{ij}- set of nodes on the path from origin i to destination j

Model Parameters:

- d^{ij}_{kl}- distance from k to l on the path from i to j, for all (ij) ϵ **P** and k, l ϵ P^{ij} such that $k \prec l$; $k \prec l$ means that 'k' is before 'l' on the path from i to j
- c^{ij}_{kl}- line-haul cost per mile from k to l on the path from i to j, for all (ij) ϵ **P** and k, l ϵ P^{ij} such that $k \prec l$; the cost includes market-to-market costs, driver wages, fuel costs, and trailer and truck maintenance costs
- f^{ij}- annual truckload flow from i to j for all (ij) ϵ **P**
- θ- length-of-haul limit
- u- driver turnover cost /occurrence
- b- annual trailer and truck depreciation cost per combined unit
- e_k- annual amortized fixed cost for setting up a relay point at k ϵ N
- ρ^{ij}_{kl} - average driving speed from k to l on the path from i to j, for all (ij) ϵ **P** and k, l ϵ P^{ij} such that $k \prec l$
- h- legal hours/week limit
- w- weeks/year
- ψ- time to relay equipment at a relay point
- r- number of mileage bands
- turnover % is a piecewise linear function of the number of drivers per mile, described by the break-points (m_i, t_i) for i=0,…,r; (m_i, t_i) are the break-points of the piecewise linear turnover % which is a function of the average number of drivers per mile (the reciprocal of the average miles per driver)
    - t_i- driver turnover % associated with mileage band m_i
    - m_i - mileage band

Decision Variables:

- z_k= 1 if k is a relay point; = 0 otherwise
- y^{ij}_{kl} = 1 if k to l is a relay-point-free path segment with relay points at k and l on the path from i to j for all (ij) ϵ **P**, k, l ϵ P^{ij} such that $k \prec l$ and $d^{ij}_{kl} \leq \theta$
  = 0 otherwise
- q- driver quantity; truck quantity and trailer quantity equal the driver quantity
- τ- driver turnover %
- δ_i- binary variable associated with the mileage between m_i and m_{i+1}

- λ_i- ensures the correct mileage band is satisfied for the mileage banding

Objective:

minimize

(1) $\sum_{(ij)\epsilon \mathbf{P}} f^{ij} \sum_{k,l\epsilon P^{ij}:k\prec l} c_{kl}^{ij} d_{kl}^{ij} y_{kl}^{ij} +$

(2) $\sum_{k\epsilon \mathbf{N}} e_k z_k +$

(3) $\tau * u * q +$

(4) $b * q$

Where:

- (1) - annual cost from k to l on the path from i to j, for all (ij) ϵ **P** and k, l ϵ P^{ij} such that k ≺ l; the cost includes market-to-market costs, driver wages, fuel costs, and trailer and truck maintenance costs
- (2)- annual amortized fixed cost associated with setting up a relay point at k ϵ N
- (3)- annual driver turnover cost
- (4)- annual truck and trailer depreciation cost

Constraints:

(1) $\sum_{l\epsilon P^{ij}:k\prec l,\ d_{kl}^{ij} \leq \theta} y_{kl}^{ij} = z_k$ for all $(ij)\epsilon$ **P** and $k \epsilon P^{ij} \setminus \{i,j\}$

(2) $\sum_{l\epsilon P^{ij}:l\prec k,\ d_{lk}^{ij} \leq \theta} y_{lk}^{ij} = z_k$ for all $(ij)\epsilon$ **P** and $k \epsilon P^{ij} \setminus \{i,j\}$

(3) $\sum_{l\,\epsilon P^{ij}:l\prec j,\ d_{lj}^{ij} \leq \theta} y_{lj}^{ij} = 1$ for all $(ij)\epsilon$ **P**

(4) $\sum_{l\,\epsilon P^{ij}:i\prec l,\ d_{il}^{ij} \leq \theta} y_{il}^{ij} = 1$ for all $(ij)\epsilon$ **P**

(5) $\sum_{d=0}^{r} \lambda_d m_d = (1/[2\sum_{(ij)\epsilon \mathbf{P}} f^{ij} d_{ij}^{ij}]) * \sum_{(ij)\epsilon \mathbf{P}} [(2\sum_{k,l\,\epsilon P^{ij}:k\prec l} y_{kl}^{ij} d_{kl}^{ij} f^{ij}/(\rho_{kl}^{ij} * w * h)) + (2 * f^{ij}/(w * h)) + (\sum_{(ij)\epsilon \mathbf{P}} f^{ij} \sum_{k\,\epsilon P^{ij}} e_k z_k \psi / (w * h))]$

(6) $\sum_{i=0}^{r} \lambda_i = 1, \lambda_i \geq 0, i = 0, \dots, r$

(7) $\sum_{i=1}^{r} \delta_i = 1, \delta_i \epsilon \{0,1\}, i = 0, \dots, r$

(8) $\lambda_0 \leq \delta_1$

(9) $\lambda_i \leq \delta_i + \delta_{i+1}, i = 1, \dots, r-1$

(10) $\lambda_r \leq \delta_r$

(11) $\tau = \sum_{i=0}^{r} \lambda_i t_i$

(12) $q = \sum_{(ij)\epsilon \mathbf{P}} [(2 \sum_{k,l \,\epsilon\, P^{ij}:k<l} y_{kl}^{ij} d_{kl}^{ij} f^{ij}/(\rho_{kl}^{ij} * w * h)) + (2{*}f^{ij}/(w * h)) +$
$(\sum_{(ij)\epsilon \mathbf{P}} f^{ij} \sum_{k \,\epsilon\, P^{ij}} e_k z_k \psi \;/\; (w * h))]$

(13) $y_{kl}^{ij} \epsilon \{0,1\}$ for all $k, l \,\epsilon\, P^{ij}$ and for all $(ij) \epsilon\, \mathbf{P}$

(14) $z_k \epsilon \{0,1\}$ for all k; k ϵ N

Where:

- (1) and (2) represent flow conservation for truckload flow into and out of each relay point, respectively
- (3)- terminates truckload flow at destination (j) on the path from i to j
- (4)- initiates truckload flow from the origin (i) on the path from i to j
- (5)- determines the number of drivers/mile and sets the quantity equal to the average miles/week/driver; includes the miles/week/driver calculation
- (6)- ensures the correct mileage band is satisfied for the miles/week/driver
- (7)- binary variable associated with the mileage band between m_i and m_{i+1}
- (8) through (10)- aids in ensuring the proper mileage band is selected
- (11)- driver turnover % determined based on the mileage band selected
- (12)- driver count determination
- (13) and (14) are the integrality constraints for the variables

The MIQP consists of an objective function that minimizes key transportation costs. There are four parts to the objective function. The first is $\sum_{(ij)\epsilon \mathbf{P}} f^{ij} \sum_{k,l \epsilon P^{ij}:k<l} c_{kl}^{ij} d_{kl}^{ij} y_{kl}^{ij}$, which is the annual transportation cost between locations that considers annual truckload volume, transit distance, and line-haul costs (c_{kl}^{ij}), which includes market-to-market costs, truck and trailer maintenance costs, driver wages, and fuel costs. The second is $\sum_{k \epsilon N} e_k z_k$, which is the annual fixed amortized cost associated with setting up relay points. The third part is non-linear- $\tau * u * q$- and represents the annual driver turnover cost. The fourth is $b * q$, which is the annual truck and trailer depreciation cost. In the model, the truck and trailer quantity equals the driver quantity.

The MIQP consists of 14 model constraints. The first and second constraints are flow conservation constraints that ensure truckload flows entering a relay point exits the relay point and are given as $\sum_{l \epsilon P^{ij}: k \prec l,\ d_{kl}^{ij} \leq \theta} y_{kl}^{ij} = z_k$ (incoming flow) and $\sum_{l \epsilon P^{ij}: l \prec k,\ d_{lk}^{ij} \leq \theta} y_{lk}^{ij} = z_k$ (outgoing flow), respectively. The third constraint- $\sum_{l \epsilon P^{ij}: l \prec j,\ d_{lj}^{ij} \leq \theta} y_{lj}^{ij} = 1$- terminates truckload flow at destination (j) on the path from i to j. The fourth constraint- $\sum_{l \epsilon P^{ij}: i \prec l,\ d_{il}^{ij} \leq \theta} y_{il}^{ij} = 1$- initiates truckload flow from the origin (i) on the path from i to j. The fifth constraint- $\sum_{d=0}^{r} \lambda_d m_d = (1/[2 \sum_{(ij) \epsilon \mathbf{P}} f^{ij} d_{ij}^{ij}]) * \sum_{(ij) \epsilon \mathbf{P}} [(2 \sum_{k,l \epsilon P^{ij}: k \prec l} y_{kl}^{ij} d_{kl}^{ij} f^{ij} / (\rho_{kl}^{ij} * w * h)) + (2 * f^{ij} / (w * h)) + (\sum_{(ij) \epsilon \mathbf{P}} f^{ij} \sum_{k \epsilon P^{ij}} e_k z_k \psi / (w * h))]$- determines the number of drivers per mile and sets the quantity equal to the average miles per week per driver based on: the location of the relay points, annual truckload volumes, the legal weekly work hour limit, transit distance and speed between locations, load and unload time at shippers and receivers, time delay to relay equipment at relay points, and work weeks per year. The sixth constraint- $\sum_{i=0}^{r} \lambda_i = 1, \lambda_i \geq 0$- ensures the correct mileage band is satisfied for the miles per week per driver determination. The seventh constraint- $\sum_{i=1}^{r} \delta_i = 1, \delta_i \epsilon \{0,1\}$- is a binary variable associated with the mileage band between m_i and m_{i+1} based on the miles per week per driver. Constraints 8 through 10- $\lambda_0 \leq \delta_1, \lambda_i \leq \delta_i + \delta_{i+1}$, and $\lambda_r \leq \delta_r$, respectively- aid in ensuring the proper mileage band is selected based on the miles per week per driver. The eleventh constraint- $\tau = \sum_{i=0}^{r} \lambda_i t_i$ - is the driver turnover percentage based on the selected mileage band. The twelfth constraint- $q = \sum_{(ij) \epsilon \mathbf{P}} [(2 \sum_{k,l \epsilon P^{ij}: k \prec l} y_{kl}^{ij} d_{kl}^{ij} f^{ij} / (\rho_{kl}^{ij} * w * h)) + (2 * f^{ij} / (w * h)) + (\sum_{(ij) \epsilon \mathbf{P}} f^{ij} \sum_{k \epsilon P^{ij}} e_k z_k \psi / (w * h))]$- determines the total truck count. Constraint 13- $y_{kl}^{ij} \epsilon \{0,1\}$- and constraint 14- $z_k \epsilon \{0,1\}$- are integrality constraints. Overall, the MIQP contains 12,998,719 constraints (rows) and 7,847,923 variables (columns) for the considered data set.

In the MIQP, several parameters will need to be specified by the user. A user interface was created in order to enhance the flexibility of the model by giving the user a better way to input important parameters. The interface is illustrated in Appendix H. The interface allows the user to specify the following items: fuel cost per gallon, driver turnover cost, maximum driving length-of-haul, driver wage per mile, truck depreciation, trailer depreciation, truck miles per gallon, and average truck speed. These items were considered because they tend to be subject to more volatility and may need to be modified more often; therefore, the interface gives the flexibility to make changes. For example, fuel costs tend to be very volatile, driver wages may need to be changed depending on economic market conditions, depreciation is subject to equipment purchase costs and may need to be modified, etc. Driver turnover mileage bands may need to be changed depending on economic market conditions but tend to be less volatile, so the mileage bands are self-contained within the model. Also, driver quantities are determined in the model for each origin-destination path and depend on the location of relay points and federal hours-of-service rules. All costs and data in the model are expressed as annual values. The model assumes there are 50 work weeks per year, and drivers can drive 60 hours per week over 7 consecutive days and 70 hours per week over 8 consecutive days, in accordance with federal hours-of-service rules, before shutting down. The 50 work weeks per year are used assuming the two remaining weeks are consumed with holiday time off and driver vacation time. A major transportation company was consulted and it was determined that 50 work weeks per year is more realistic than 52 work weeks per year. The model can be adjusted to specify relay points at specific distances or used more dynamically with the inclusion of a maximum length-of-haul threshold limit.

An example will be shown to illustrate how the MIQP works in terms of the model decision variables and the establishment of relay points. The origin-destination path from Loomis, CA to Lowake, TX is considered with relay points established in Stockton, CA; Banning, CA; Tucson, AZ; and Sierra Blanca, TX (see Figure 26 below).

Figure 26. Loomis, CA to Lowake, TX path

In Figure 26, origin *i* is Loomis, CA (point A) and final destination *j* is Lowake, TX (point F). A relay point z_k is located at Stockton, CA; Banning, CA; Tucson, AZ; and Sierra Blanca, TX with unique values for *k* at each relay point. Decision variable z_k equals 1 when a relay point is established at some location *k*. Truckload flow between relay points is coordinated and sequenced properly using decision variable y_{kl}^{ij}, and y_{kl}^{ij} will equal 1when truckload flow is coordinated from relay point location *k* to relay point location *l* on origin-destination path *ij*. In Figure 26, y_{kl}^{ij} equals 1 between points B and C (*k* = Stockton, CA to *l* = Banning, CA), between points C and D (*k* = Banning, CA to *l* = Tucson, AZ), and between points D and E (*k* = Tucson, AZ to *l* = Sierra Blanca, TX) on origin-destination path *ij*. A variable y_{il}^{ij} coordinates truckload flow from origin *i* to the first relay point established at *l* (*i* = Loomis, CA to *l* = Stockton, CA). A variable y_{lj}^{ij} coordinates truckload flow from the final relay point *l* to the final destination at *j* (*l* = Sierra Blanca, TX to *j* = Lowake, TX). Both y_{il}^{ij} and y_{lj}^{ij} are decision variables and equal 1 when truckload flow is coordinated between the location points.   The truckload flow (f^{ij}) on the Loomis, CA to Lowake, TX origin-destination path equals 15,386 truckloads annually. Fixed costs are associated with establishing each relay point (z_k), and variable costs are established along the path in the form of equipment maintenance, equipment depreciation, fuel, line-haul market-to-market costs, driver pay, and driver turnover. The z and y decision variables ensure relay points are established and that truckload flow is coordinated and sequenced correctly between relay points, from origin points, and to the final destination points.

The location of relay points by the MIQP is dependent on several factors. First, the specified length-of-haul constraint prohibits the transit length-of-haul distance from being greater than a maximum threshold limit, so the model will locate relay points at certain dynamic distances to comply with the constraint. Second, markets have different costs associated with setting up relay points, so the model will try to locate relay points where the fixed costs are cheaper while complying with the length-of-haul constraint. Third, the line-haul market rate between locations is different depending on market conditions, so the model will locate relay points in such a way to keep the line-haul market rate to a minimum cost. Fourth, the average weekly miles driven per driver is a factor in determining driver turnover costs, so the model will establish an average weekly mileage to minimize annual driver turnover costs. The average weekly miles driven is also a function of the driver count, and annual trailer and truck depreciation costs are a function of driver count, therefore, these costs also factor into determining the location of relay points. Several key factors play an important role in determining the best location for relay points based on minimizing key transportation costs. The myriad of variable costs and the fixed cost to establish relay points are critical to the MIQP model and to the accuracy of the relay point output results. Without accurate cost data, relay points would likely be located hap hazardously and in such a way, that driver routes would be created poorly and would exhibit performance results at the same level or worse than the non-relay point scenario.

CHAPTER 6

IMPLEMENTATION AND ANALYSIS

6.1 Mixed Integer Quadratic Program Implementation

The MIQP was implemented in FICO Xpress Optimization Suite version 7.2 (64-bit) while utilizing the input data text files outlined in Chapter 5. The FICO Xpress implementation was executed on a Hewlett Packard/Microsoft Windows server. The server processor specifications are as follows: Processor Intel(R) Xeon(R) CPU E5410 @ 2.33GHz, 2333 Mhz, 4 Core(s), 4 Logical Processor(s). The server also has 6.0 GB of Physical Memory (RAM) and 17.1 GB of Virtual Memory. Using Microsoft Access, a user interface was created within a form in order to properly format the input data used in the MIQP, to execute the MIQP, and to output the results into Microsoft Access database tables. VBA code was used within the user interface to format data and output the MIQP results, and a Call statement was used to call and execute the MIQP in FICO Xpress. The interface is shown in Appendix J.

The MIQP was created using multiple data sources in order to build a fully integrated national highway transportation network. Due to the numerous data sources and large amounts of data associated with the highway transportation network, sparse data structures were used to limit computing memory requirements and to enhance execution speed. In other words, data was not stored in program memory unless the data was actually needed for use. For example, if an origin-destination combination was not part of the data associated with the MIQP, then it was not stored in memory but excluded from the modeling process. Or, if a certain origin to relay point combination, relay point to destination combination, or relay point to relay point combination was not part of the data set, then the MIQP did not consider the combination in order to create a sparser data set. The intention was to free up computing memory and enhance program run speed. Executing the MIQP without sparse data resulted in an out-of-memory error using FICO Xpress [60], so the program would not execute. With sparse data, the model executed properly. Data files were created in Microsoft Access and then exported and stored as text files, which serve as input to the MIQP. Output results from the MIQP were stored as text files and then imported into Microsoft Access to further manipulate and summarize the mathematical results. The mathematical optimization model consists of a single objective, that minimizes total transportation related costs, and multiple constraints. The MIQP solution will be presented next.

6.2 Mixed Integer Quadratic Program- Scenario Analysis

The maximum threshold distance between location points and relay points was deemed critically important in establishing a best relay point solution, which is used to compare against a non-relay point scenario. The maximum threshold distance represents the maximum allowable driving distance between an origin location and a relay point, between relay points, and between a relay point and a final destination location. In order to determine the best maximum threshold distance between relay points and location points in terms of minimizing costs, multiple maximum distance scenarios were executed and analyzed considering distances of 100 miles, 200 miles, 300 miles, 400 miles, and 500 miles. Mileages were chosen in 100 mile increments to scale down the number of scenarios and work required to generate different solutions, and the results were not significantly different using 10, 20, 30, etc. mileage increments. For example, a maximum threshold distance of 100 miles was not significantly different than a threshold distance of 110 miles or 120 miles. Also, the mileage was capped at 500 miles because mileages beyond 500 miles tend to start exhibiting a long-haul driving environment, which contradicts the goal of this study of developing a better driving job where drivers drive shorter distances and are home more often. The distance that produces the lowest total cost is considered the best scenario, and this best scenario is used as a comparison against the non-relay point scenario throughout this study.

6.2.1 Scenario Results

The five mileage threshold scenarios were executed. Scenario one includes a maximum threshold driving distance of 100 miles between relay and location points. In other words, relay points were spaced, at most, 100 miles apart. After the 100 mile scenario was executed, scenarios for 200, 300, 400, and 500 miles were executed in a similar fashion. All model components and parameters and data inputs are the same in each of the five scenarios. The only item that changed in the MIQP (see section 5.3.1) was the θ parameter in constraints 1, 2, 3, and 4 which were set equal to the mileage scenario. The model results are shown in Table 9, which includes program execution time, optimality gap, total cost, and individual costs (i.e. line-haul costs, depreciation costs, maintenance costs, fuel costs, driver wages, driver turnover costs, and fixed costs). The program was solved to optimality for 100, 200, 300, and 400 miles, so the optimality gap was 0%. For 500 miles, the program was not solved to optimality but the optimality gap was small (2%).

Cost Item	**θ = 100**	**θ = 200**	**θ = 300**	**θ = 400**	**θ = 500**
Depreciation Cost	$44,079,950,812	$43,208,301,336	$42,923,416,542	$42,778,083,778	$42,297,507,624
Driver Turnover Cost	$2,476,322,250	$2,427,354,750	$2,411,350,500	$2,403,186,000	$2,376,188,206
Driver Wages Cost	$204,865,941,640	$200,814,864,279	$199,490,833,954	$198,815,385,525	$196,581,860,204
Fixed Cost	$21,056,693,112	$14,568,100,478	$11,320,187,684	$9,488,634,480	$7,746,437,856
Fuel Cost	$276,170,431,500	$272,109,101,625	$268,047,771,750	$263,986,441,875	$259,925,112,000
Line-haul Cost	$255,126,448,000	$233,774,112,000	$224,870,596,000	$220,469,598,000	$218,078,318,000
Maintenance Cost	$13,167,437,833	$12,911,043,320	$12,824,460,869	$12,780,742,959	$12,754,403,600
Total Cost	**$816,943,225,147**	**$779,812,877,788**	**$761,888,617,299**	**$750,722,072,617**	**$739,759,827,490**
Optimality Gap	**0%**	**0%**	**0%**	**0%**	**2%**
Execute Time (min.)	**78**	**95**	**98**	**95**	**116**

Table 9. MIQP results (θ=100, 200, 300, 400, and 500 mile thresholds)

As shown in Table 9 above, five different maximum threshold distance scenarios were executed to determine which option resulted in the lowest total annual cost. Scenario one (100 miles) had a total annual cost of $816,943,225,147. Scenario two (200 miles) had a total annual cost of $779,812,877,788. Scenario three (300 miles) had a total annual cost of $761,888,617,299. Scenario four (400 miles) had a total annual cost of $750,722,072,617. Scenario five (500 miles) had a total annual cost of $739,759,827,490. Based on the total cost for each scenario, scenario five had the lowest total annual cost. Table 10 shows the percentage cost difference step-wise for each scenario, and Figure 27 graphically shows the annual total cost for each scenario.

Mileage Scenario	Annual Cost ($)	% Difference
100	$816,943,225,147	--
200	$779,812,877,788	-4.5%
300	$761,888,617,299	-2.3%
400	$750,722,072,617	-1.5%
500	$739,759,827,490	-1.5%

Table 10. Percentage difference in annual total costs

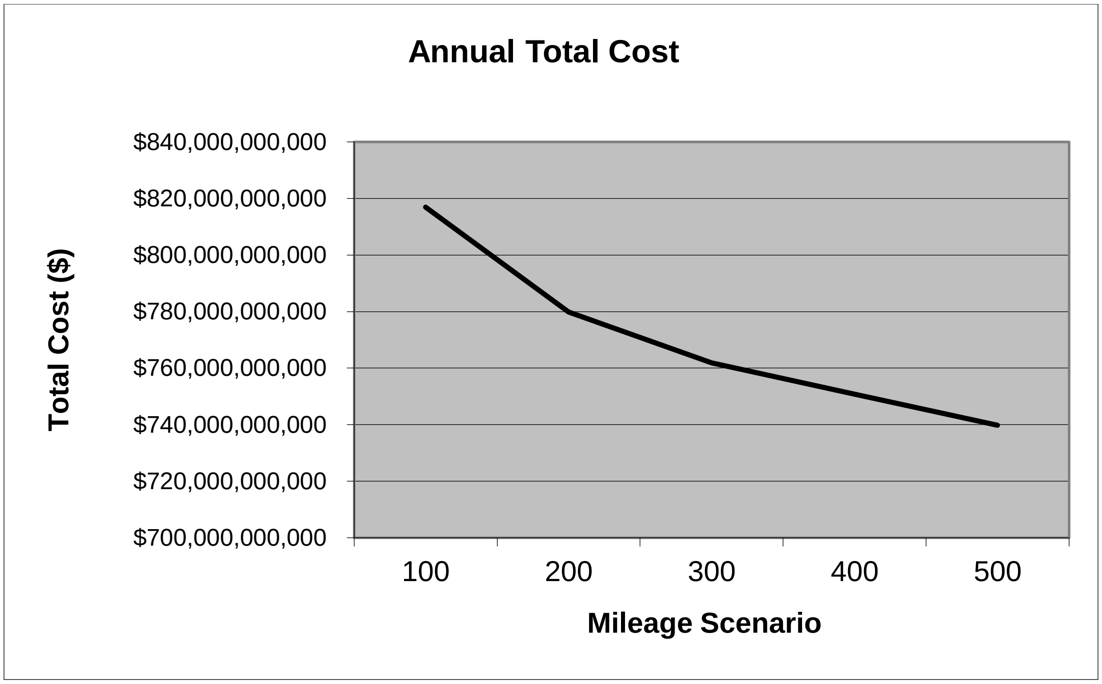

Figure 27. Annual total cost for each mileage scenario

From Figure 27 above, there is a sharp decline in the total annual cost from the 100 mile to the 200 mile scenario, and less pronounced cost declines from the 200 mile to the 500 mile scenario. The main reasons for the sharp cost decline from the 100 mile to the 200 mile scenario are due to a 30.8% decrease in annual fixed costs and an 8.4% decrease in annual line-haul costs. As the maximum threshold distance increases, fewer relay points are established; therefore, the fixed annual cost decreases. Since the annual line-haul costs are significantly larger than the annual fixed costs, the decrease in annual line-haul costs causes more impact on the total annual cost compared to the fixed cost. Scenario 5, utilizing a relay point threshold distance of 500 miles, will now be used throughout the study as the most optimal relay point solution because this scenario has the smallest total annual cost. Scenario 5 will now be compared to the non-relay point scenario throughout this paper.

CHAPTER 7

FINDINGS

7.1 Mixed Integer Quadratic Program- General Results

Due to the large amount of input data and the nature of solving a MIQP, the amount of time required to generate integer solutions and produce an optimal solution can be significant. While utilizing dynamic arrays in FICO Xpress to make the input data sparser, it took the MIQP approximately 116 minutes to execute. Of the 116 minutes, 25% of the time was required to read the input data, 10% of the time to build the problem, 60% of the time to solve, and 5% of the time to output the results. Since a quick solution was not crucial, the 116 minute completion time was sufficient. Maintaining sufficient computing memory in FICO Xpress was the most critical element, and the program had enough computing memory to determine a more optimal solution. The more optimal solution was reached due to a tighter lower bound.

There are 28,889 origin-destination paths included in the study and 135,594 available relay points. Available relay points are the endpoints associated with the highway links of the highway transportation network. The more optimal solution consists of 125,952 relay points, which is an average of 4.36 relay points per origin-destination path. Of the 125,952 relay points, there are 13,891 unique relay points because relay points are re-used or shared when feasible. A feasible relay point is a point that is in-route for a given origin-destination path; therefore, along a given origin-destination path, an out-of-route relay point would not be picked since circuitous miles are not allowed. The available number of unique relay points in the network is 135,594, which means 10.2% (13,891 of 135,594) of the total available relay points were picked by the MIQP. In regard to the MIQP results, the average length-of-haul for the driving routes is 214 miles, while the average home time per driver is 5.33 days per week. A driving route consists of driving from one location point to another location (e.g. origin location to a relay point, relay point to relay point, relay point to a final destination). The top 160 origin-destination paths with associated relay points are shown in Appendix K based on the greatest annual truckloads. From Appendix K, the origin-destination path from Three Rivers, CA to Chandler, AZ has the largest number of annual truckloads- 20,046 annual truckloads. The Three Rivers, CA to Chandler, AZ path consists of three relay points with the first relay point being in Bakersfield, CA, the second relay point in Los Angeles, CA, and the third relay point in Salome, AZ. Figure 28 illustrates the path along with the three relay points. As determined by the MIQP, Appendix L illustrates all the relay points (i.e. orange dots on the map) created across the U.S. on the highway transportation network. Based on the figure in Appendix L, there is a high density of relay points created along the highway transportation network throughout the U.S. with a greater density of relay points east of the Mississippi River because of the larger amount of annual outbound and inbound freight into states east of the Mississippi River. Of the total annual truckload freight, 65% of the annual truckloads originate or destinate in states east of the Mississippi River with the remaining 35% west of the Mississippi River. The average length-of-haul and average home time per driver

Figure 28. Three Rivers, CA to Chandler, AZ path (with relay points)

results for the top 300 origin-destination paths based on the greatest annual truckloads are shown in Appendix M in tables M.1 and M.2, respectively. Based on table M.1 in Appendix M, the average length-of-haul for the Three Rivers, CA to Chandler, AZ path is 150 miles using the relay point network and 601 miles using the non-relay point network. The non-relay point network requires drivers to traverse the entire path from Three Rivers to Chandler, while the relay point network requires drivers to drive between relay points or between origin or destination location points and relay points. Based on table M.2 in Appendix M, the average home time for the Three Rivers, CA to Chandler, AZ path is 6 days per week for relay point drivers and 2 days per week for non-relay point drivers. The most optimal annual transportation cost for the entire relay point network is $739,759,827,490. Table 11 shows an itemized list of the individual cost components from the MIQP results.

Cost Item	Annual Cost ($)	% of Total Cost	Cumulative %
Fuel Cost	$259,925,112,000	35.14%	35.14%
Line-haul Cost	$218,078,318,000	29.48%	64.62%
Driver Wages Cost	$196,581,860,204	26.57%	91.19%
Depreciation Cost	$42,297,507,624	5.72%	96.91%
Maintenance Cost	$12,754,403,600	1.72%	98.63%
Fixed Cost	$7,746,437,856	1.05%	99.68%
Driver Turnover Cost	$2,376,188,206	0.32%	100.00%
Total Cost	**$739,759,827,490**	**100.00%**	

Table 11. Costs from the MIQP results

As depicted in Table 11, fuel cost represents the largest percentage of the annual total cost while the fixed cost represents the smallest percentage of the annual total cost. The fixed cost is amortized over a 20 year schedule, so the annual impact is not that dramatic. The results also show that 98% of the total annual costs include fuel costs, line-haul costs, driver wages, depreciation costs, and maintenance costs. The MIQP results will now be analyzed holistically from the perspective of the driver, transportation carrier, and customer.

7.2 Mixed Integer Quadratic Program- Driver Results

The total number of drivers required to operate the non-relay point OTR transportation network is 3,256,834 drivers while 3,168,251 drivers are required for the relay point network as determined by the MIQP, which is a 2.7% decrease or 88,583 drivers. Using the relay point network, a driver quantity reduction was expected since relay point drivers experience less idle time associated with federal hours-of-service rules compliance. The increase in the driver quantity results in a decrease in driver wages per driver per year for the non-relay point network or a $1,687 per year per driver reduction compared to the relay point network drivers. The driver wage per year per driver for the non-relay network drivers is $60,360 and $62,047 for relay point network drivers, assuming drivers earn 52 weeks per year in salary and earn $0.42 per mile. For the relay and non-relay point networks, the drivers drive an average of 2,841 miles per week and 2,764 miles per week, respectively. The average length-of-haul for relay point drivers is 214 miles compared to 1,141 miles for non-relay point drivers, so the result is a much shorter driving distance for relay point drivers, but relay point drivers are able to maintain adequate utilization (2,841 miles/week/driver) and driver pay. A critical priority for relay point drivers is to maintain healthy driver pay, similar to non-relay point drivers, in spite of shorter driving distances, which was attained at $62,047 per driver per year. Driver pay significantly below the non-relay point scenario would be inadequate.

The key advantages of the relay point network are that drivers can slip-seat truck and trailer equipment frequently and day cab trucks can be utilized instead of sleeper cab trucks. Slip-seating means drivers can share the same truck and trailer on different work shifts or with another driver. For example, a driver would drive a truck for the first 12 hour work shift, and a different driver would drive the same truck for the second 12 hour work shift. Or, a driver could drive a truck with a loaded trailer and at the same time, transport another driver back home or to another in-route location. Slip-seating allows resources to be shared resulting in reduced truck and trailer equipment requirements and reduced equipment costs. Relay point drivers can slip-seat equipment more often than non-relay point drivers because relay point drivers typically drive 10 to 12 hours per day over a work shift allowing drivers on the next work shift to share equipment. Relay point drivers have more compatible work schedules and shift-type work, so drivers can share equipment. Non-relay point drivers drive long distances, are away from home often, and do not have compatible shift-type work, so driver schedules are incompatible and cannot be coordinated properly to allow for slip-seating. In order for slip-seating to occur, driver driving schedules must be setup properly each day over different work shifts and customer orders must be tendered properly to allow for order pick-ups and deliveries to be made on multiple work shifts. Customers are typically flexible, by allowing pick-ups and deliveries on multiple work shifts, realizing less equipment results in lower transportation costs. Figure 29 illustrates a driving schedule on a given day for 4 drivers and 2 trucks/2 trailers for a path from Tulsa, OK to Austin, TX with a relay point in McKinney, TX. There are 2 drivers and 1 truck/1 trailer domiciled in Tulsa and 2 drivers and 1 truck/1 trailer domiciled in Austin, and drivers are slip-seated at approximately 6:00 am on the morning work shift and 4:30 pm on the afternoon work shift.

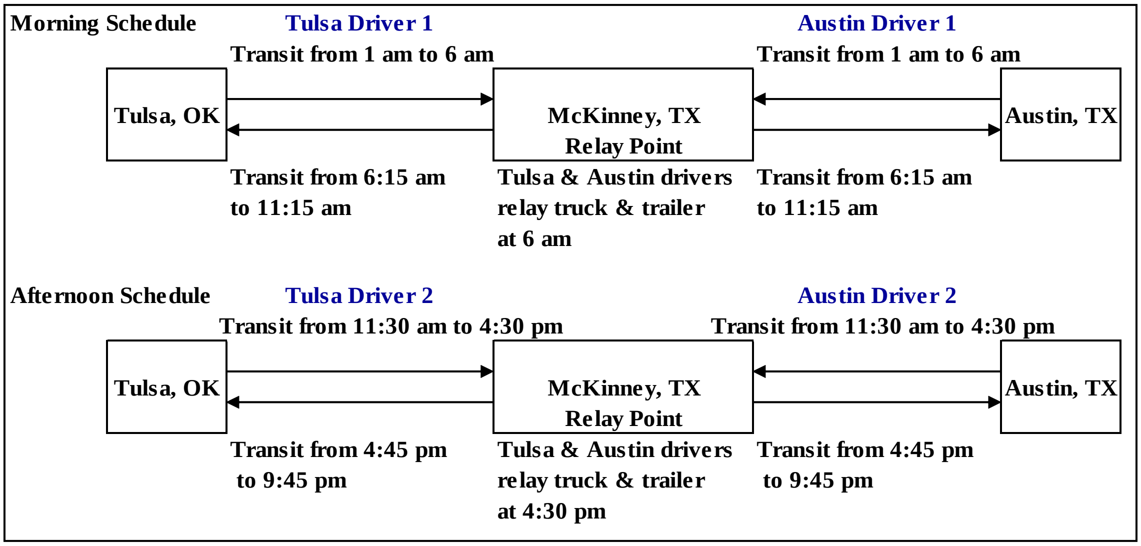

Figure 29. Slip-seating schedule for 4 drivers/2 trucks/2 trailers; Tulsa, OK to Austin, TX

In the example, the Tulsa drivers haul truckloads or empty trailers from Tulsa to the McKinney relay point, and the Austin drivers haul trailers or truckloads from Austin to McKinney where the Tulsa and Austin drivers exchange truck and trailer equipment. The morning and afternoon schedules are set up to show that drivers can slip-seat equipment. On the morning work shift, Driver 1 from Tulsa drives from Tulsa to McKinney and relays equipment with Austin Driver 1 and then Tulsa Driver 1 drives back to Tulsa. Also, on the morning shift, Driver 1 from Austin drives from Austin to McKinney and relays equipment with Tulsa Driver 1 and then Austin Driver 1 drives back to Austin. After Tulsa Driver 1 drives back to Tulsa and Austin Driver 1 drives back to Austin, the afternoon work shift would begin and both drivers (Tulsa Driver 1 and Austin Driver 1) would give their respective equipment to Driver 2. The slip-seating concept is done throughout the design of the relay point concept to take advantage of shorter driving distances. A more in-depth scheduling algorithm would be useful to more precisely schedule drivers and equipment, but this is outside the scope of this work. For the entire network, the relay point concept requires 1,697,468 trucks and 1,697,468 trailers because about 2.94 million drivers can be slip-seated. The non-relay point concept requires 3,254,648 trucks and 3,254,648 trailers because only about 4,373 drivers can be slip-seated. The relay point network requires 48% fewer trucks and trailers compared to the non-relay network resulting in 1,557,180 fewer required trucks and trailers utilizing the relay point network.

Driver hiring charges will be positively impacted as a result of fewer driver requirements using the relay point network. Driver turnover costs will be positively impacted due to improved driver home time, shorter driving distances, and adequate driver utilization and pay using the relay point network. Driver hiring charges include costs to hire and replace a driver plus driver orientation charges, and the total cost per driver is approximately $3,000 per driver based on previous research endeavors and information from a large transportation company. Since 88,583 less drivers are required for the relay point network, driver hiring costs are $265,750,190 less costly compared to the non-relay point network. Additionally, based on the average driver utilization and average driver home time, the driver turnover rate in the model was 25% percent utilizing the relay point network. A 25% annual turnover rate results in an annual cost of $2,376,188,206 assuming the cost to replace a driver is $3,000. In a typical OTR or non-relay point network, driver turnover is 100% or more on a consistent basis. A 100% annual turnover rate results in an annual cost of $9,770,503,015, which is $7,394,314,809 more compared to the relay network. Driver turnover costs are significantly better for relay point drivers.

Prior to creating the relay point network, drivers were required to drive long length-of-hauls to deliver truckload freight and adhere to the federal hours-of-service rules (see Table 12), which require drivers to shut-down and rest when hours-of-service thresholds are met. Since non-relay point drivers are required to shut-down and remain idle for either 10 hours to rest or 34 hours to reset the 60/70 hour rule, additional drivers are required in order to meet customer demand requirements. In order to establish driver and equipment quantities for the non-relay point network, federal hours-of-service rules were considered. Similar to the relay point network, non-relay point driver quantities were designed based on annual truckload flows for each origin-destination path, origin-destination path distances and congested transit times, average truckload loading time at each origin, and average truckload unloading time at each destination. For each origin-destination path, non-relay point drivers were domiciled at the origin, but drivers could also have been domiciled at the final destination or split between the origin and final destination. The domicile location does not impact the overall driver quantity requirements. Unlike the relay

Federal Hours-of-Service Rules
11-Hour Driving Limit May drive a maximum of 11 hours after 10 consecutive hours off duty.
14-Hour Limit May not drive beyond the 14th consecutive hour after coming on duty, following 10 consecutive hours off duty. Off-duty time does not extend the 14-hour period.
60/70-Hour On-Duty Limit May not drive after 60/70 hours on duty in 7/8 consecutive days. A driver may restart a 7/8 consecutive day period after taking 34 or more consecutive hours off duty.
Sleeper Berth Provision Drivers using the sleeper berth provision must take at least 8 consecutive hours in the sleeper berth, plus a separate 2 consecutive hours either in the sleeper berth, off duty, or any combination of the two.

Table 12. Truck driver federal hours-of-service rules

point network where driver and equipment quantity requirements were determined in the MIQP, non-relay point driver and equipment quantities were designed for each origin-destination path using a Microsoft Excel spreadsheet. As an example of determining driver and equipment requirements for the non-relay point network, the following shows an illustration of the Weston, FL to Battle Creek, MI path, which is an origin-destination path in the FMM data set.

- Origin-destination path- Weston, FL to Battle Creek, MI
- Annual truckloads- 9,436 truckloads
- Line-haul mileage- 1,400 miles (one-way transit) and 2,800 miles (roundtrip transit) based on mileage from the FMM model
- Congested transit time- 25.45 hours (one-way transit) and 50.91 hours (roundtrip transit) from the FMM model
- Annual drive time required- 480,387 hours (9,436 truckloads * 50.91 hours/truckload)
- Annual loading time- 9,436 hours (9,436 truckloads * 1 hour/truckload)
- Annual unloading time- 9,436 hours (9,436 truckloads * 1 hour/truckload)
- Total annual time- 499,259 hours (drive time + loading time + unloading time)
- Drivers required-166 drivers (499,259 annual hours / 3,000 annual hours/driver); assuming a driver drives 60 hours/week over 50 weeks/year
- This route requires 166 drivers, 166 trucks, and 166 trailers.

In the same fashion as the Weston, FL to Battle Creek, MI path, driver and equipment quantities were determined for all 28,889 origin-destination paths for the non-relay point network. Appendix N shows the number of drivers for the top 300 origin-destination paths based on driver quantities for the relay and non-relay point networks. Based on Appendix N, the Eagle River, AK to Ruskin, FL path has the largest driver quantity- 508 relay point and 506 non-relay point drivers. Appendix O shows the number of drivers required for each domicile for the non-relay point network. Based on Appendix O, Mount Hamilton, CA is the largest driver domicile with 35,962 drivers.

Relay point locations are determined in the MIQP for each origin-destination path along with driver quantities since driver quantities depend on the location of relay points. In section 5.3.1 with regard to the MIQP, constraint six determines the driver quantities for each origin-destination path. In the relay point network, drivers can be domiciled at origin locations, destination locations, and at relay points. Drivers domiciled at origin locations haul truckloads from the origin location to the first relay point, exchange truck and trailer equipment with another driver, and then drive back to the origin either with an empty or loaded trailer. Drivers domiciled at relay point locations haul truckloads from a relay point to another relay point, exchange equipment with another driver, and then drive back to the relay point either with an empty or loaded trailer. Drivers domiciled at final destination locations may drive either with an empty or loaded trailer to the relay point, exchange equipment with another driver, and then deliver the truckload to the final destination. Drivers are not necessarily required to return immediately back to a domicile location after equipment is exchanged. A driver could rest or sleep at a relay point, have equipment maintenance performed, re-fuel, etc., or the driver could exchange equipment and continue driving to another relay point. When exchanging equipment, minimal time is required and an exchange time of ten minutes was assumed. Figure 30 shows an example of a path from Weston, FL to Battle Creek, MI with multiple relay points where truck and trailer equipment are exchanged. The Weston, FL to Battle Creek, MI path has four established relay points in Marion Oaks, FL; Byron, GA; Manchester, TN; and Uniontown, IN. Drivers are domiciled in Marion Oaks, FL; Byron, GA; Manchester, TN; Uniontown, IN; and Battle Creek, MI. Driver and equipment quantities for the relay point network

Figure 30. Weston, FL to Battle Creek, MI path showing the relay points [61]

were determined similarly to the non-relay point network, with the additional requirement of exchanging equipment at relay points. The following shows the driver quantity design for the Weston, FL to Battle Creek, MI path using relay points.

- Origin-destination path- Weston, FL to Battle Creek, MI
- Annual truckloads- 9,436 truckloads
- Line-haul mileage, Weston, FL to Marion Oaks, FL route- 556 miles (roundtrip)
- Line-haul mileage, Marion Oaks, FL to Byron, GA route- 566 miles (roundtrip)
- Line-haul mileage, Byron, GA to Manchester, TN route- 550 miles (roundtrip)
- Line-haul mileage, Manchester, TN to Uniontown, IN route- 554 miles (roundtrip)
- Line-haul mileage, Uniontown, IN to Battle Creek, MI route- 574 miles (roundtrip)
- Congested transit time, Weston, FL to Marion Oaks, FL route- 10.11 hours (roundtrip)
- Congested transit time, Marion Oaks, FL to Byron, GA route- 10.29 hours (roundtrip)
- Congested transit time, Byron, GA to Manchester, TN route- 10 hours (roundtrip)
- Congested transit time, Manchester, TN to Uniontown, IN route- 10.07 hours (roundtrip)
- Congested transit time, Uniontown, IN to Battle Creek, MI route- 10.44 hours (roundtrip)
- Annual drive time required, Weston, FL to Marion Oaks, FL route- 95,398 hours (9,436 truckloads * 10.11 hours/truckload)
- Annual drive time required, Marion Oaks, FL to Byron, GA route- 97,096 hours (9,436 truckloads * 10.29 hours/truckload)
- Annual drive time required, Byron, GA to Manchester, TN route- 94,360 hours (9,436 truckloads * 10 hours/truckload)
- Annual drive time required, Manchester, TN to Uniontown, IN route- 95,021 hours (9,436 truckloads * 10.07 hours/truckload)
- Annual drive time required, Uniontown, IN to Battle Creek, MI route- 98,512 hours (9,436 truckloads * 10.44 hours/truckload)
- Annual loading time at the origin- 9,436 hours (9,436 truckloads * 1 hour/truckload)
- Annual unloading time at the destination- 9,436 hours (9,436 truckloads * 1 hour/truckload)
- Annual relaying time, Weston, FL to Marion Oaks, FL route- 1,576 hours (9,436 truckloads * 0.167 hour/truckload)
- Annual relaying time, Marion Oaks, FL to Byron, GA route- 1,576 hours (9,436 truckloads * 0.167 hour/truckload)
- Annual relaying time, Byron, GA to Manchester, TN route- 1,576 hours (9,436 truckloads * 0.167 hour/truckload)
- Annual relaying time, Manchester, TN to Uniontown, IN route- 1,576 hours (9,436 truckloads * 0.167 hour/truckload)
- Annual relaying time, Uniontown, IN to Battle Creek, MI route- 1,576 hours (9,436 truckloads * 0.167 hour/truckload)
- Total annual time- 507,147,869 hours (drive time + loading time + unloading time + relay time)
- Drivers required-169 drivers (assuming drivers average 3,000 hours/year)
- This route requires 169 drivers, 85 trucks, and 85 trailers; only 85 trucks and trailers are required because 168 drivers are slip-seated; 1 driver cannot be slip-seated

- Roundtrips involve: moving a headhaul truckload and then a backhaul return truckload, a headhaul truckload and then an empty trailer return, a headhaul empty trailer move and then a backhaul return truckload, or both headhaul and backhaul empty trailer moves

In both the relay and non-relay point network, the Weston, FL to Battle Creek, MI path required 169 drivers, but the relay point network required 84 fewer trucks and 84 fewer trailers because 168 drivers are slip-seated using the relay point network, which results in a purchase cost savings of $11,004,792. The relay point network requires all day cab trucks. The non-relay point network requires all sleeper cab trucks, which are more expensive, because drivers are required to shut-down and sleep in their truck to adhere to federal hours-of-service rules. With less trucks and trailers to maintain on the Weston to Battle Creek path, the annual maintenance cost is reduced by $671,448 and the annual depreciation cost decreases by $2,751,198 using the relay point network. In the same fashion as the Weston, FL to Battle Creek, MI path, driver and equipment quantities were determined for each origin-destination path for both the non-relay and relay point networks. Appendix N shows the number of drivers for the top 300 origin-destination paths based on driver quantities for the relay point network. Based on Appendix N, the Eagle River, AK to Ruskin, FL path contains the largest driver quantity- 508 relay point drivers.

The shut-down time associated with adhering to the federal hours-of-service rules increase the amount of time drivers and equipment were idle not transporting truckloads productively. Additionally, the idle time associated with the non-relay point network requires additional drivers and truck and trailer equipment to meet customer demand requirements. Idle time also involves time to load trailers at shippers and to unload trailers at final customers. For the relay point network, idle time is also associated with the time required to exchange equipment at relay points, but this time is minimal. Prior to the creation of relay points, the total amount of time that equipment sat idle, while adhering to federal hours-of-service rules and waiting for trailers to be loaded and unloaded, was 1,756,609,753 annual hours. The annual idle time associated with the relay point network is 556,678,957 hours, which is a reduction of 1,199,930,796 annual idle time hours (68.3% reduction). In regard to the relay point network, 99% of the idle time is associated with loading and unloading trailers and relaying equipment and 1% of the idle time is associated with adhering to the federal hours-of-service rules. Adherence to federal hours-of-service rules account for 37% of the annual idle time for the non-relay point network, which is significantly more than the relay point network. The average annual idle time per origin-destination path is 60,805 hours for the non-relay point network and 19,270 hours for the relay point network. Using the relay point network, the reduction in annual idle time is significant or dominant compared to the non-relay point network. There is a significant difference in the idle time per driver for each path comparing the relay and non-relay point networks.

As the idle time decreases, the driving fleet can turn more truckloads and deliver truckloads faster to the final customer. A turn is equivalent to a roundtrip from the shipper to the final destination and back to the shipper. The reduction in idle time also allows for more continuous movement of equipment, which improves driver, trailer, and truck equipment utilization allowing drivers to achieve the miles needed to earn an adequate salary. The driver utilization is more for the relay point drivers compared to the non-relay point drivers (2,841 miles per week per driver and 2,764 miles per week per driver, respectively), which means that relay point drivers are turning more truckloads and are achieving adequate miles and pay similar to the non-relay point network. A significant reduction in weekly driver miles and driver pay would not be acceptable from the perspective of the driver. It is not important for driver utilization to be significantly more than the non-relay point network, but that a high level of driver utilization is obtained in order for drivers to achieve adequate weekly pay. In other words, driver utilization for both the non-relay point and relay point networks should be similar. Significant equipment utilization improvement is important and means that equipment is being slip-seated more resulting in overall lower equipment costs. Equipment will be addressed in more detail in section 7.4.

The average length-of-haul for drivers becomes shorter in a relay point network because drivers are only required to drive a specified distance from one location point to another without traversing the entire origin-destination path. In addition to shorter length-of-hauls, drivers also have the advantage of driving consistent routes on a weekly basis. In order for drivers to drive consistent routes, routes must have sufficient and consistent truckload freight to maintain driver quantities, driver activity, and sufficient driver pay. Routes require consistent truckload freight on a daily and weekly basis distributed over 50 to 52 weeks per year. Inconsistent freight flow patterns require drivers to find other routes to run or other work to maintain a satisfactory quality of living in terms of driver pay. Figure 31 shows a short OTR path for the non-relay point network and the same path including a relay point and two routes.

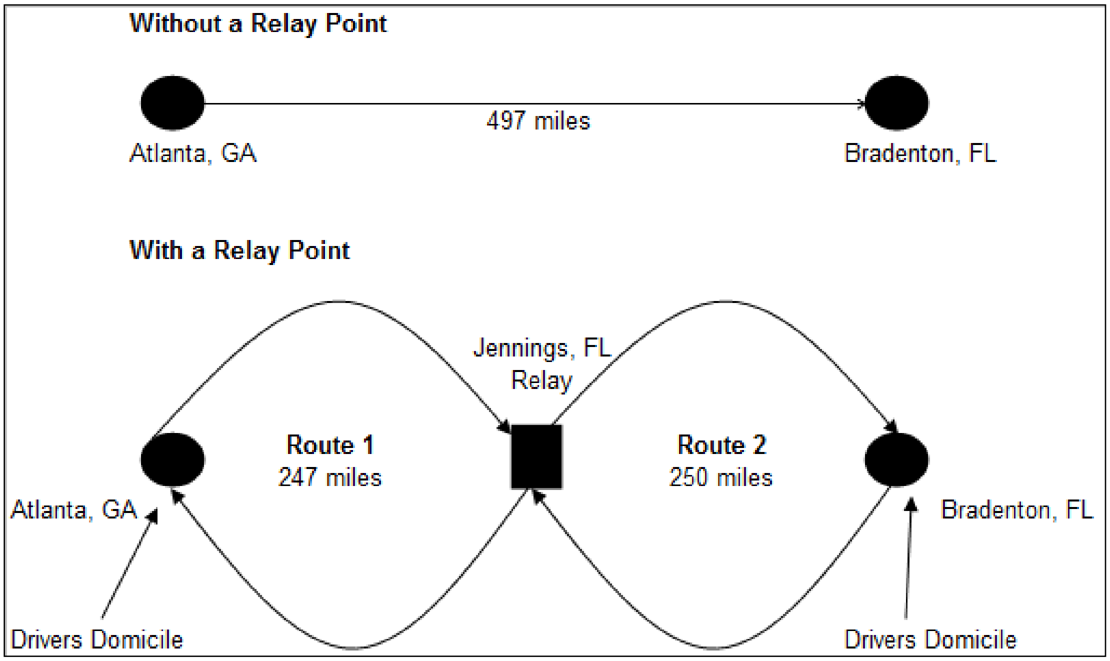

Figure 31. Driving routes with and without a relay point (Atlanta, GA to Bradenton, FL path)

For the Atlanta, GA to Bradenton, FL path shown in Figure 31 for the With a Relay Point scenario, there is one relay point- Jennings, FL- and drivers are domiciled in Atlanta, GA and Bradenton, FL. Drivers can also be domiciled in Jennings, FL. In this example, there are two routes. One route is from Atlanta, GA to Jennings, FL and the other route is from Jennings, FL to Bradenton, FL. The length-of-haul for the Without a Relay Point route is 497 miles, while the average length-of-haul for the With a Relay Point scenario is 248.5 miles. Both routes in the With a Relay Point scenario require consistent truckload freight flows in order to keep the drivers continuously moving trailers and exchanging equipment. Consistent freight is necessary to assure that drivers obtain enough weekly miles to maintain satisfactory driver pay. In the With a Relay point scenario, a balance of truck and trailer equipment and driver quantities is required to be assigned on both routes to meet pick-up and delivery schedules. Without equipment balance and freight consistency, an unbalanced origin-destination path will occur causing either an excessive or lack of equipment at the relay points and at origin and destination locations, which may require drivers to drop trailers and bobtail to different locations to reposition trailers. Bobtailing involves driving a truck without a trailer and is very costly since no trailing equipment or product is being transported and is also considered unsafe. Bobtailing is considered dangerous because there is no weight over the drive tires, which cause the truck to be more difficult to brake and stop, especially in wet and slippery conditions. For the Atlanta, GA to the Bradenton, FL path, Figure 32 shows truckload freight on a daily basis and Figure 33 shows truckload freight on a weekly basis.

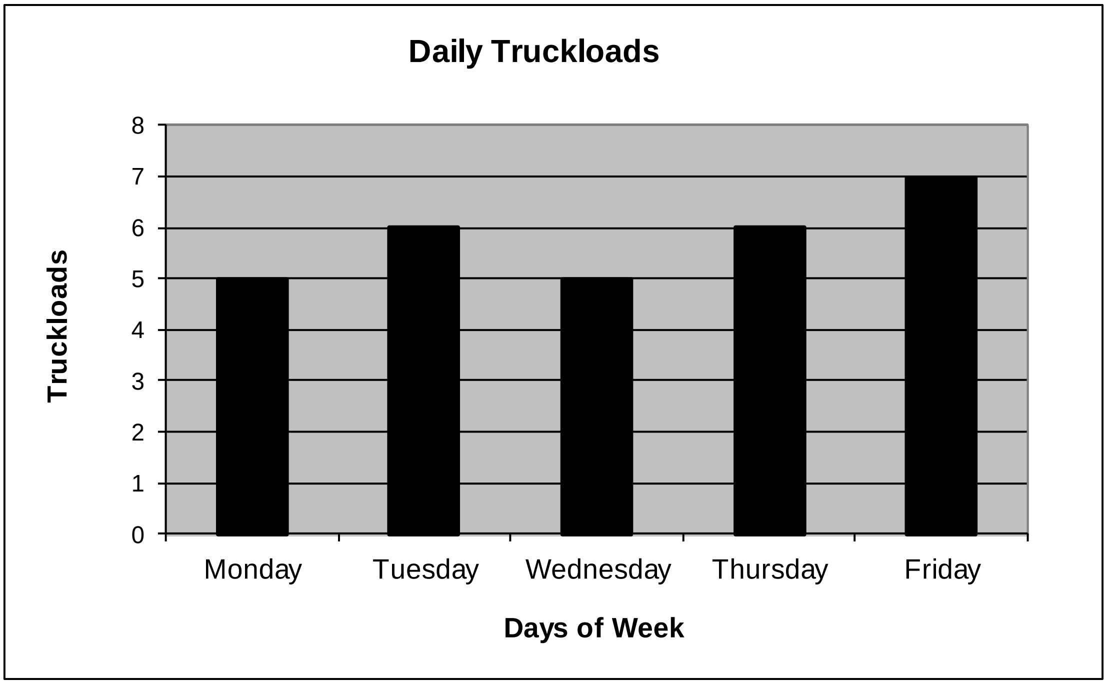

Figure 32. Daily truckloads (consistent)- Atlanta, GA to Bradenton, FL

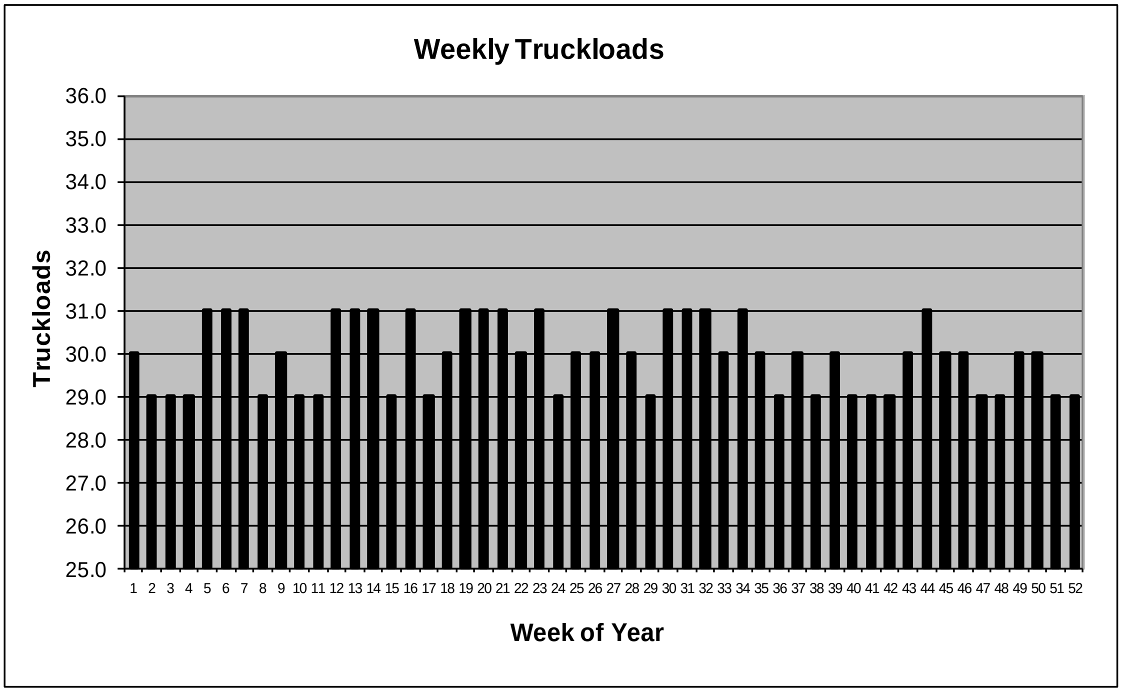

Figure 33. Weekly truckloads (consistent)- Atlanta, GA to Bradenton, FL

Figure 32 shows that freight is consistent on a daily basis, so the drivers will be able to move truckloads and exchange equipment at the relay points on the Atlanta, GA-Bradenton, FL path on a consistent basis each day. Drivers will be able to drive the same routes each day since daily truckload freight is consistent. Also, based on weekly truckload flows shown in Figure 33 for the Atlanta, GA-Bradenton, FL path, drivers will also be able to consistently move truckload freight on a weekly basis throughout the year. The Atlanta, GA-Bradenton, FL path has 6 truckloads per day on average, and requires 12 drivers, 6 trucks, and 6 trailers using the relay point design. Of the 12 drivers, 6 drivers are domiciled in Atlanta, GA and run the Atlanta, GA to Jennings, FL route, and 6 drivers are domiciled in Bradenton, FL and run the Jennings, FL to Bradenton, FL route. The drivers exchange truck and trailer equipment in Jennings, FL. Since the number of drivers domiciled in Atlanta and Bradenton are equivalent and congested route transit times are almost equivalent, the route has balanced equipment and driver quantities, and Atlanta and Bradenton drivers are able to meet at approximately the same time at the relay point to exchange equipment. The ultimate goal is to have drivers meet at the same time or in close proximity at the Jennings, FL relay point, so equipment can be exchanged as quick as possible with no or only minimal driver waiting or equipment queuing. Trucks are equipped with on-board computers (OBC), global positioning systems (GPS), and other communication devices that allow drivers to communicate location and any transit issues. From Figure 31, utilizing the With a Relay Point scenario, drivers domiciled at both Atlanta, GA and Bradenton, FL drive the same route each day (either Route 1 or Route 2), and drivers are home daily since the route mileage is roughly 500 miles per roundtrip. As a rule of thumb, if roundtrip mileage is a maximum of 500-550 miles, drivers are typically home daily and federal hours-of-service threshold limits are not attained. The 500-550 miles represent approximately 11 hours of driving, but driving time depends on the average miles per hour speed maintained by the driver over the travel terrain. In the Without a Relay Point scenario in Figure 31, drivers would either be domiciled in Atlanta, GA or Bradenton, FL, but drivers would be required to traverse the entire 497 mile path and would be required to shut-down and layover along the path to comply with federal hours-of-service rules. The shut-down time increases driver and equipment idle time, increases the order cycle time, and keeps drivers away from their home domicile more often. Without the relay point, the roundtrip congested transit time from Atlanta to Bradenton would be 29.1 hours (i.e. includes a 10 hour shut-down period), and 19.1 hours using the relay point in Jennings, FL (34% reduction in congested transit time).   Drivers are home daily using the relay point network and only 2 days using the non-relay point network.

As an example of inconsistent truckload freight patterns, Figure 34 shows a path from Lubbock, TX to Detroit, MI with inconsistent daily truckload volumes causing the path to be more difficult to manage. Figure 35 shows the Lubbock, TX to Detroit, MI path with inconsistent

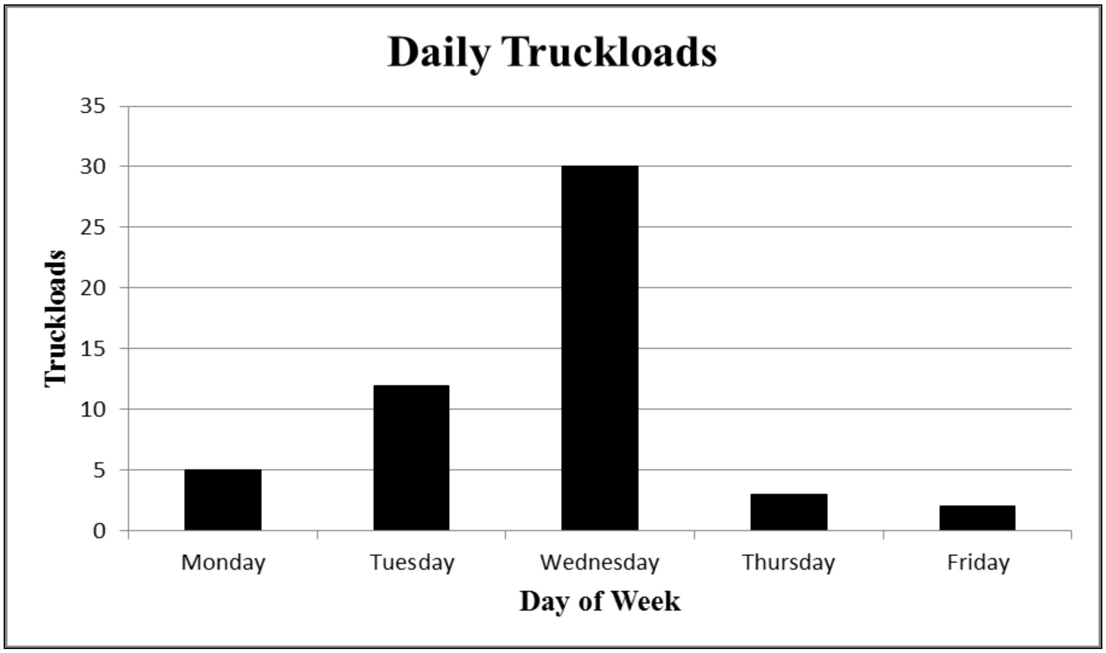

Figure 34. Inconsistent daily truckloads- Lubbock, TX to Detroit, MI

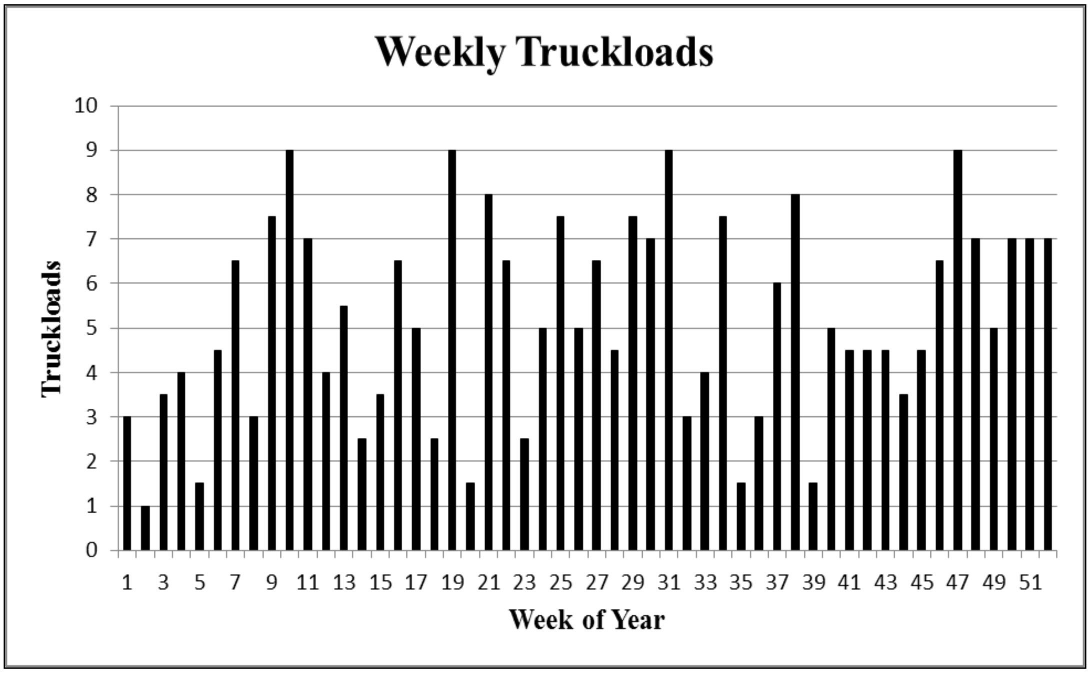

Figure 35. Inconsistent weekly truckloads- Lubbock, TX to Detroit, MI

weekly truckload shipments. From Figure 34, it can be seen that truck load freight is very inconsistent from Monday through Friday. Truckload shipments peak on Wednesday but are quite low the remainder of the week, especially on Thursday and Friday. In this scenario, drivers will be required to drive additional routes on low freight days or wait for truckloads to be tendered by the customer, which increases driver idle time and reduces the amount of miles drivers can drive. When freight patterns are inconsistent, drivers may sit idle a day or more waiting on a truckload shipment, and the wait time reduces weekly miles and weekly pay and may cause drivers to turnover, especially if the low weekly miles persist over an extended period of time. Also, truckload freight is quite sporadic (see Figure 35) on a weekly basis as illustrated from the substantial number of low and high periods throughout the graph from week 1 through week 52. Inconsistent truckload freight causes havoc for truck drivers in the form of inconsistent driving miles (i.e. some weeks have high miles and some weeks have low miles) resulting in inconsistent weekly driver pay. Consistent driving routes result in driver familiarity with the same customers, better understanding of road and weather conditions, more familiarity with traffic patterns, etc., which makes for a better and safer driving job and enhances driver productivity.

To combat inconsistent freight patterns on paths and to increase weekly miles per driver, drivers can run additional routes on multiple origin-destination paths. For example, the Atlanta, GA to Ruskin, FL path is 478 miles one-way with a weekly truckload volume of 234. The quantity of drivers required on the path is 78, which translates into 3 truckloads per driver per week. There are 39 drivers domiciled in Atlanta, GA and 39 drivers domiciled in Ruskin, FL. There are three relay points for this origin-destination path- Milner, GA; Arabi, GA; Adel, GA. Milner, GA and Arabi, GA serve as fueling and maintenance locations and Adel, GA serves as a location to exchange equipment. The path is shown in Figure 36. Figure 36 shows the location of the Adel, GA relay off interstate 75. Drivers domiciled in Atlanta haul truckload freight 205 miles to Adel, GA and exchange truck and trailer equipment with drivers domiciled

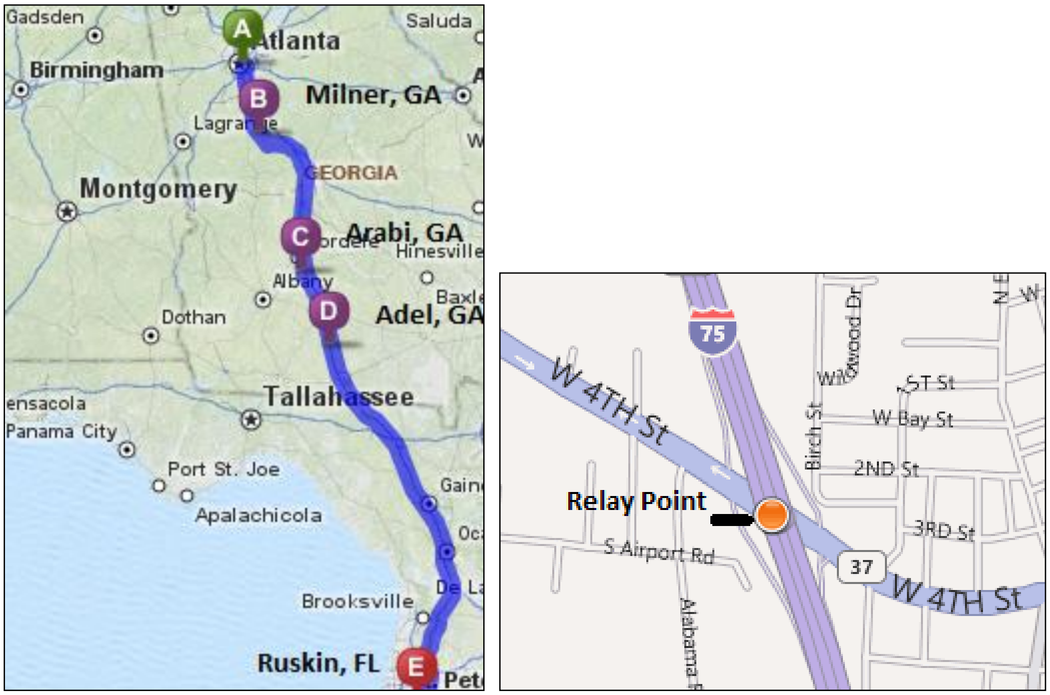

Figure 36. On the left, the Atlanta, GA to Ruskin, FL path [61]; on the right, the relay point in Adel, GA off interstate 75 [62]

in Ruskin, FL that travel 273 miles to Adel, GA. The Atlanta, GA drivers average 1,230 miles per week and the Ruskin, FL drivers average 1,638 miles per week, and both sets of drivers will be home on a daily basis. Figure 37 shows the miles per week per driver for different truckload quantities for the Atlanta, GA to Adel, GA routed drivers assuming drivers are domiciled in Atlanta, GA. As illustrated from the graph in Figure 37 below, drivers need to be tendered at service rules based on the weekly mileage (i.e. 3,280 miles per week per driver) and current driver quantities, so a target of 7 truckloads per week is needed for this route. Three truckloads per week does not generate enough driving miles to achieve adequate driver pay. In a similar fashion, Figure 38 shows the miles per week per driver for different truckload quantities for the Ruskin, FL to Adel, GA drivers. For the Ruskin, FL to Adel, GA route, drivers need to be tendered 5 truckloads per week in order to obtain quality miles (i.e. 2,730 miles per week per driver) and quality pay. Beyond 5 truckloads per week will result in a violation of federal hours-of-service rules based on the same driver quantity. Since drivers target roughly 2,500 or more

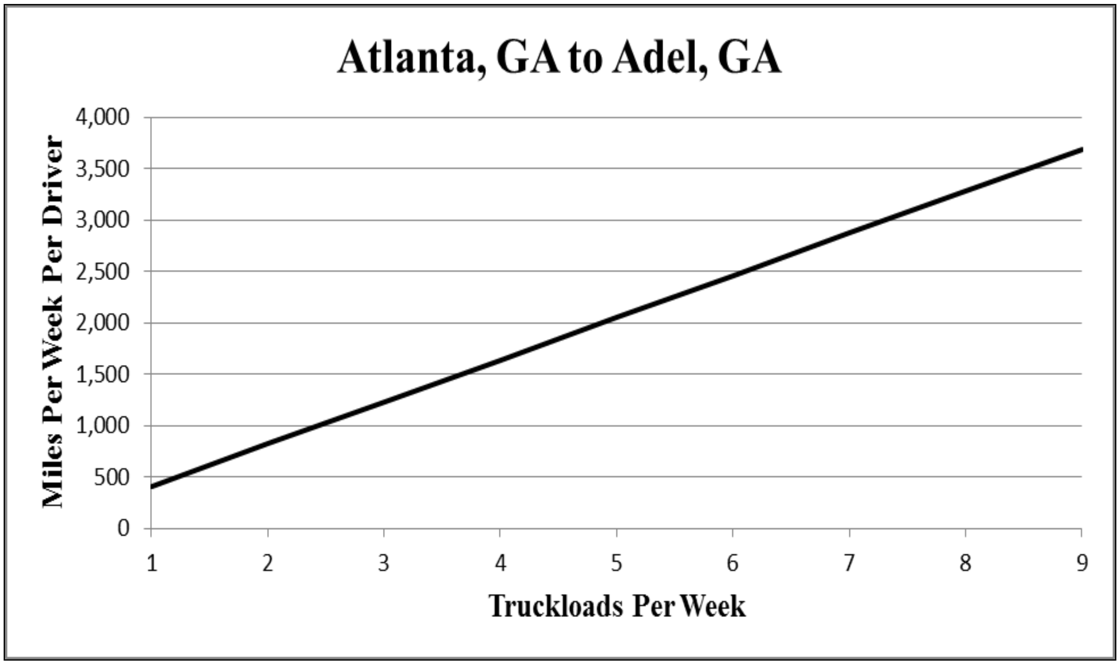

Figure 37. Atlanta, GA to Adel, GA path (truckloads and miles per week per driver)

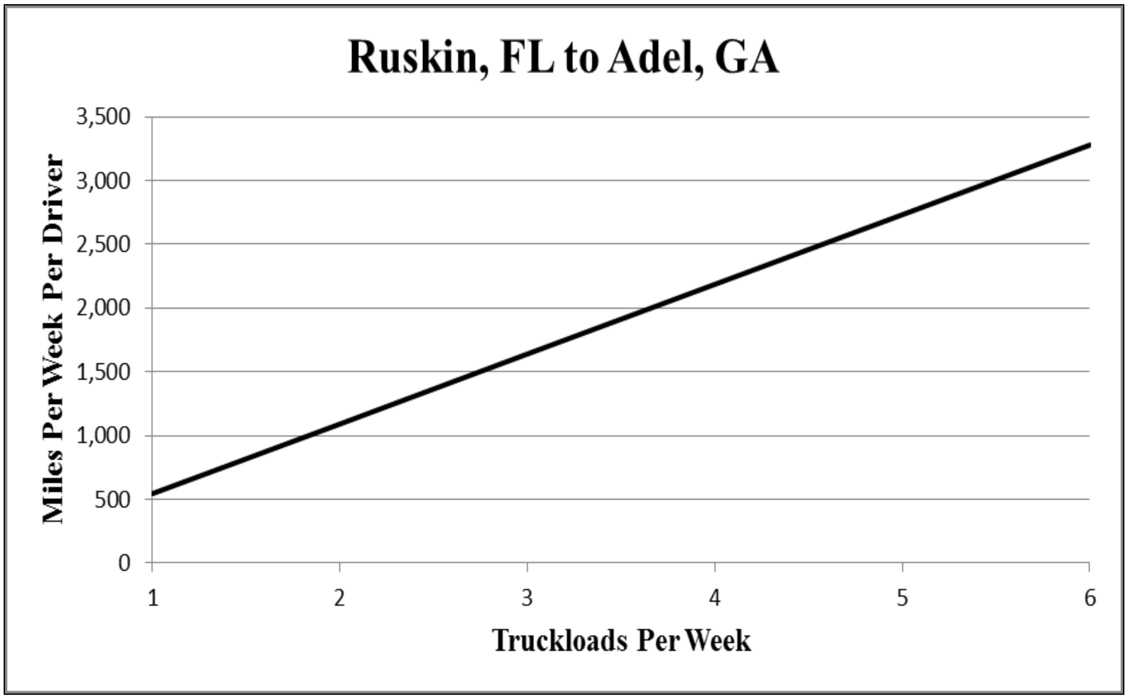

Figure 38. Ruskin, FL to Adel, GA path (truckloads and miles per week per driver)

miles per week to maintain satisfactory pay, additional routes will need to be run since 3 loads per week do not generate enough weekly miles to maintain healthy driver pay. To supplement the low miles associated with the Atlanta to Ruskin path, the 39 Atlanta, GA drivers can also haul truckloads for the Atlanta to Wacissa, FL origin-destination path (see Figure 39 below), which has a distance of 263 miles one way. Each of the 39 Atlanta drivers can haul 3 loads per week for the Atlanta to Wacissa path and increase weekly driving miles from 1,230 miles per driver to 2,808 miles per driver, and the drivers would still be home daily. The 39 Atlanta, GA drivers would consistently move truckloads on the Atlanta to Ruskin, FL and Atlanta to Wacissa, FL routes. The Atlanta to Wacissa, FL route contains one relay point in Warwick, GA (see Figure 39 below) that can be used as a relay point to exchange equipment, perform equipment maintenance, fuel trucks, etc. The Ruskin, FL drivers also require supplemental

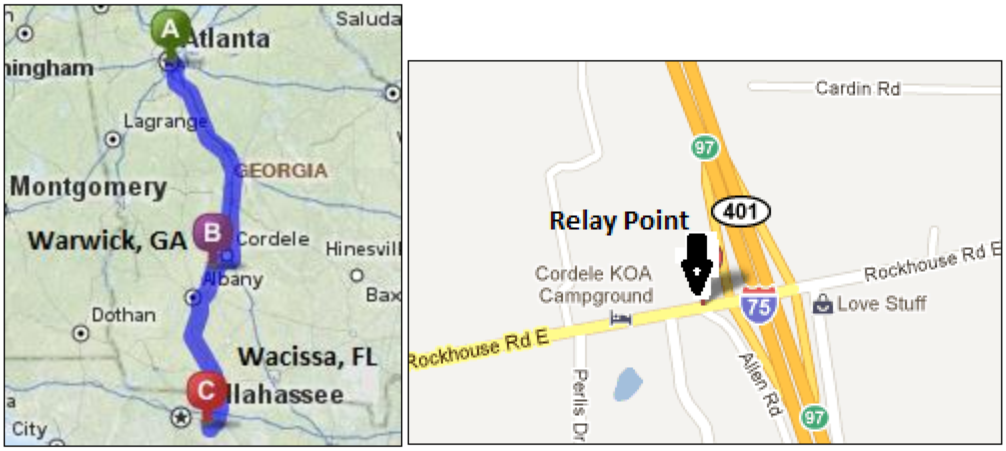

Figure 39. On the left, the Atlanta, GA to Wacissa, FL path [61]; on the right, the relay point in Warwick, GA off interstate 75 [62]

truckloads to generate additional weekly miles. The Ruskin, FL drivers can move truckloads on the Ruskin, FL to Atlanta, GA path. The 39 Ruskin drivers will move 2 additional loads per week per driver from Ruskin to the Adel, GA relay point, which generates an additional 1,092 miles per week per driver, so the 39 Ruskin drivers would earn 2,730 miles per week and be home daily. The Atlanta, GA to Ruskin, FL drivers would move the loads exchanged in Adel, GA back to Atlanta, GA. Different paths and routes can be combined to create consistent and regularized routes, so drivers can drive adequate miles and obtain a solid wage.

In addition to consistent freight patterns, drivers need to drive length-of-haul distances that allow for significant home time while maintaining enough driving miles to earn adequate pay. The relay point network allows for sufficient driving miles to be maintained while allowing drivers to be home frequently. The average driving length-of-haul for the relay point network is 214 miles compared to 1,141 miles for the non-relay point network, which is an 81% reduction in the average length-of-haul. The average driver home time per week was 0.91 days per week per driver using the non-relay point network and 5.33 days per week per driver using the relay point network, which is a 486% increase in driver home time. The improvement in the average length-of-haul allows drivers to be home more often and reduces the amount of time drivers spend sleeping in hotels or in the truck away from home. Table 13 summarizes the difference between the non-relay point and relay point networks considering the average length-of-haul and average driver home time metrics. Since the average driver home time is largely different comparing the non-relay and relay point networks, the average driver home time for the relay point network dominates the average home time for the non-relay point drivers. Also, the average length-of-haul for the relay point network is largely different than the average length-of-haul for the non-relay point network. The home time per week for the non-relay point network translates into 154,113,401 total days per year compared to 878,112,431 total days per year using the relay point network, which is a 723,999,030 days increase in annual driver home time. The increase in home time for the relay point network drivers gives each driver the ability to spend more quality time with friends, family, direct supervision, etc. and reduces fatigue associated with driving long distances. Even though the average length-of-haul drastically decreased using the relay point network, drivers are able to maintain a solid annual salary because drivers can turn equipment faster and maintain a utilization of 2,841 miles per week. More quality driver home time without sacrificing wages results in a more satisfied driver who will likely remain employed long term. Long term employment will enhance driver retention and reduce annual driver turnover and driver displacement costs.

Scenario	**Average Length-of-Haul (miles)**	**Average Driver Home Time (Days per Week)**
Non-Relay Point Network	1,141	0.91
Relay Point Network	214	5.33
% Difference	81% reduction	486% increase

Table 13. Average length-of-haul and average driver home time

Since the required number of hours per driver decreases because drivers spend less time on the road, driver pay per hour increases. Currently, OTR drivers typically work between 65-70 hours or more per week resulting in low hourly wages compared to other professions. Driver pay, as a function of work hours, is $17.60 per hour utilizing the non-relay point network and $20.57

per hour using the relay point network (a 16.8% increase). Since relay point network drivers work less hours due to shorter driving distances and less idle time, pay as a function of work hours is greater compared to non-relay point drivers.

Using the relay point network, the federal hours-of-service rules become less of an issue because drivers are able to be home more frequently due to shorter driving distances. Customer service, in the form of shorter order cycle times, is improved because drivers have the flexibility to exchange equipment at relay points, which keeps trailers continuously moving to the final customer. Since drivers drive shorter routes and are paid by the mileage, the drivers will need to turn more equipment each day in order to maintain an adequate annual salary. Driver pay is sensitive to weekly miles, especially if drivers are paid purely based on mileage. If drivers experience low weekly miles for an extended time period (over multiple weeks), drivers become disgruntled with pay and are more apt to turnover or seek other employment opportunities. Figure 40 shows annual pay per driver as a function of weekly mileage per driver assuming drivers are solely paid based on mileage. As illustrated in Figure 40, the annual driver pay significantly changes at different mileages along the x-axis. If a driver's weekly miles fluctuate

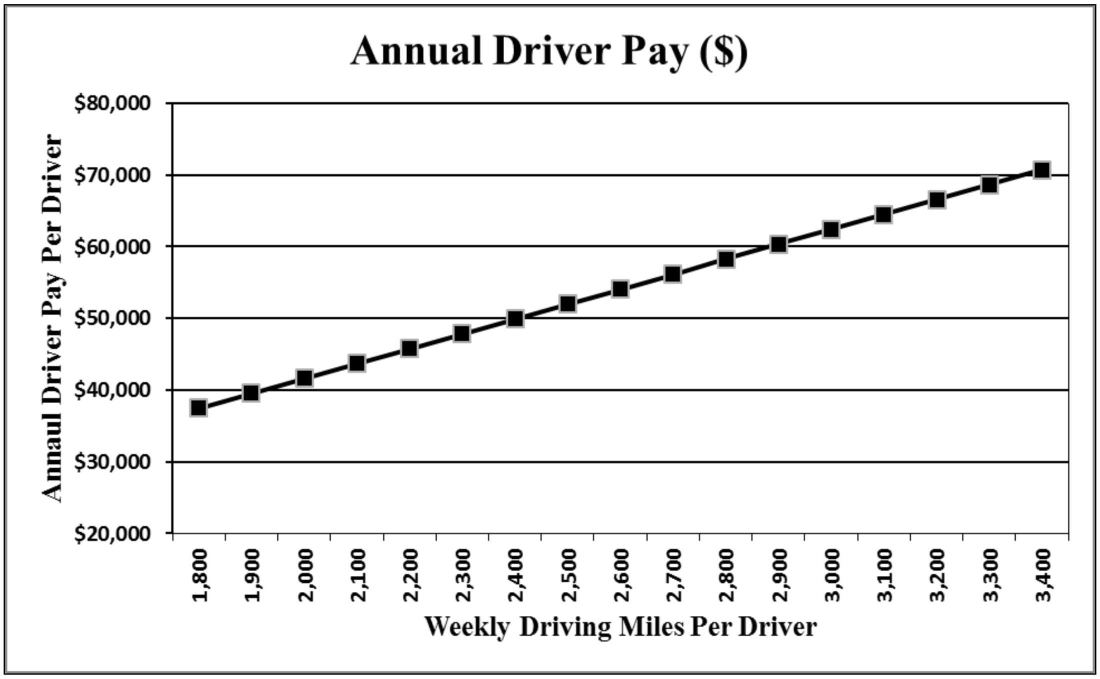

Figure 40. Weekly driving miles and annual pay per driver

significantly or are inconsistent on a weekly basis, then the driver may become dissatisfied realizing that a targeted annual salary may not be met. Table 14 shows the annual and average driver pay for both the non-relay point and relay point networks. From Table 14, the total annual driver pay and average annual driver pay remain strong for the relay point network.

Scenario	Total Annual Driver Pay	Average Annual Pay Per Driver
Non-Relay Point Network	$196,581,860,204.09	$60,360
Relay Point Network	$196,581,860,204.09	$62,047

Table 14. Total driver pay and average annual pay per driver

The average annual pay per driver is 2.8% more using the relay point network. In order for the relay point network to be feasible, annual pay per driver should be consistent with non-relay point drivers or drivers will turnover.

In summary, the relay point network provides more opportunities for drivers to be home due to shorter driving distances while realizing adequate levels of driver pay. For relay point drivers, an adequate level of driver pay is the byproduct of strong driver utilization and more equipment turns per driver. Relay point drivers can enjoy consistent and regularized driving routes on a weekly basis throughout the year by hauling freight on multiple routes. More home time, consistent driving routes, and healthy pay generates an environment to improve driver turnover and enhance driver retention.

7.3 Mixed Integer Quadratic Program- Customer Results

In a transportation environment, customers are typically concerned with service and cost metrics. Service is related to on-time pick-up and delivery of truckload shipments. On-time pick-up helps keep space available at shipping docks and warehousing areas, better ensures that congested transit times and on-time delivery requirements are met, and enables inventory to be turned faster. On-time delivery ensures that product requirements are fulfilled at facilities such as retail outlets, manufacturers, distribution centers, etc. If product is late at a final destination, then product may not be available for end customers causing a loss in profits, backlogs, loss of business, business opportunities forgone, etc. Sufficient on-time delivery performance not only maintains existing business, but helps companies grow business incrementally with customers. On-time service is a critical performance measure for all companies.

The order cycle time metric is used to measure delivery performance. The order cycle time includes the time to load a trailer at the shipper, congested transit time, and the time to unload a trailer at the final customer. For the relay point network, additional time is required to exchange equipment at relay points, and this time is included in the order cycle time. For the non-relay point network, additional time is required to adhere to federal hours-of-service rules. The results show that the average order cycle time from the origin to the final destination is much shorter for the relay point network compared to the non-relay point network because a significant amount of idle time- associated with adhering to federal hours-of-service rules- is eliminated using the relay point network. The average order cycle time per path for the non-relay point network is 39.03 hours and 25.11 hours for the relay point network (36% reduction). Table 15 shows the total order cycle time, the average order cycle time per path, and annual idle time for both the relay and non-relay point networks.

Network	**Annual Order Cycle Time (hours)**	**Avg. Cycle Time (hours)/ Order**	**Annual Idle Time (hours)**
Relay Point	5,148,496,945	25.11	556,678,957
Non-Relay Point	7,999,656,607	39.03	1,756,609,753
Difference (Non-Relay – Relay)	2,851,159,662	13.92	1,199,930,796

Table 15. Annual order cycle time and cycle time per order

Since the order cycle time is reduced using the relay point network, drivers can turn more truckloads and be home more consistently. On average, the non-relay point drivers can turn 2.39 truckload orders per week while relay point drivers can turn 3.09 truckload orders per week (29.3% increase). For each path, the average cycle time for the relay point network is much less compared to the non-relay point network. In other words, the relay point network dominates the non-relay point network in regard to cycle time reduction.

In order to understand how the order cycle time was impacted comparing the relay point network to the non-relay point network, three paths of different transit distances were considered. The three paths include a short length-of-haul path, a medium length-of-haul path, and a long length-of-haul path. A fourth scenario is shown as an illustration of different origin-destination paths sharing the same relay points in order to reduce the number of relay points required. In the analysis, the MIQP shares 9,526 relay points among the 28,889 different origin-destination paths. The short length-of-haul includes a 554 mile path from Madill, Oklahoma to Encino, New Mexico. The medium length-of-haul path includes an 848 mile path from Boalsburg, Pennsylvania to Pittsville, Wisconsin. The long length-of-haul path includes a 1,333 mile path from Quantico, Maryland to Tahlequah, Oklahoma. In addition to considering the order cycle time, other measures were considered including: driver and equipment quantity requirements, weekly driver and equipment idle time, average driving length-of-haul, weekly driver home time (days per week per driver), weekly driver work hours, and driver and truck utilization. Cost measures were also considered including equipment purchase costs, equipment depreciation costs, and equipment maintenance costs. Order cycle time was measured from the order pick-up time to the time when the order was delivered to the final customer. To determine the number of weekly resources (drivers, trucks, and trailers) required to transport weekly truckload orders, the results from the relay point MIQP were used along with resource quantities from the non-relay scenario. Weekly driver/equipment idle time includes the time to load and unload equipment, relaying time, and shut-down time to comply with federal hours-of-service rules. The average driving length-of-haul is the one way distance between stop locations (e.g. relay point to relay point, origin location to relay point, relay point to final destination). The weekly driver home time is expressed as the average number of days a driver spends at home. The weekly driver work hours includes the amount of time a driver drives and the time involved in loading and unloading product. Driver utilization includes the average amount of miles a driver accumulates on a weekly basis. Truck utilization includes the average amount of miles a truck accumulates on a weekly basis. At the equipment relay points, truck drivers exchange trailer and truck equipment, which is assumed to take approximately ten minutes. Multiple metrics were considered in the length-of-haul examples in order to determine the difference between the relay and non-relay point networks more holistically.

For a given truckload order on a given shortest path, the outbound driver picks up a loaded trailer at the shipper/origin location and drives to a relay point and then exchanges the truck and trailer with another incoming (i.e. inbound) driver from the opposite direction. The outbound driver will then drive back to the home domicile location loaded with a backhaul truckload order- provided the incoming driver had a loaded trailer- or will drive back with an empty trailer. The incoming driver will proceed back with the truckload order to another relay point or to the final destination. Each load and unload activity were assumed to take one hour, which is a typical industry average, assuming there is no significant driver loading and unloading requirements. Equipment relaying at relay points was assumed to take ten minutes. Congested transit times were included for each path. The different path results are given in the following.

7.3.1 554 Mile Path

The 554 mile path is from Madill, Oklahoma to Encino, New Mexico and has an annual flow of 4,368 truckload orders or 84 weekly truckload orders with consistent daily truckloads over a six day work week. The congested transit time for the path is 10.1 hours based on the shortest path. For the non-relay point scenario, the path requires a ten hour shut-down period after the 554 mile transit in order for the driver to rest and comply with federal hours-of-service rules. Table 16 shows annual and weekly truckload orders, weekly total congested transit time, weekly total load and unload times, total weekly relaying time, and driver and truck quantities for the 554 mile path utilizing one relay point.

Annual Truckload Orders	Weekly Truckload Orders	Total Weekly Transit Time (hours)	Total Weekly Relay Time (hours)	Total Weekly Load/Unload Time (hours)	Total Weekly Time (hours)	Drivers/ Trucks
4,368	84	1,697	42	168	1,907	35/19

Table 16. Activity associated with the 554 mile path (relay point network)

Figure 41 shows the Madill, OK to Encino, NM path. Three equipment relay points are established: Randlett, OK; Claude, TX; Bard, NM. The relay points and associated mileage are shown in Figure 42.

Figure 41. Madill, OK to Encino, NM path [61]

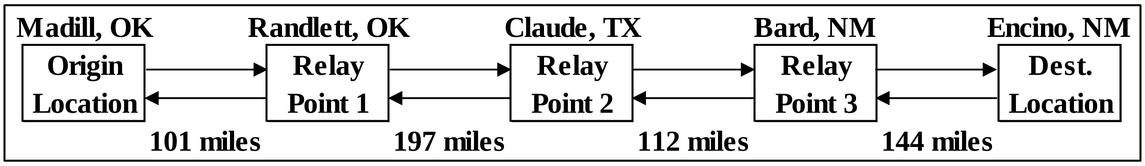

Figure 42. 554 mile path with three relay points

For the 554 mile path relay point scenario, 7 drivers are domiciled in each of the following cities: Madill, OK; Claude, TX; and Bard, NM. There are 14 drivers domiciled in Randlett, OK. For the relay point scenario, 6 drivers are slip-seated between consecutive 12 hour work shifts in each of the following locations: Madill, OK; Claude, TX; and Bard, NM. One driver cannot be slip-seated in Madill, Claude, and Bard because of scheduling issues. Also, 14 drivers can be slip-seated in Randlett, OK. Therefore, 19 day cab trucks and 19 trailers are required for the relay point scenario. A total of 35 drivers are required using the relay concept. Day cab trucks are used by the relay point drivers. For the 554 mile path non-relay point scenario, 35 drivers are also required and all drivers are domiciled in Madill, OK, but drivers cannot be slip-seated due to incompatible work schedules among the drivers, so 35 sleeper cab trucks and 35 trailers are required. The non-relay point network requires all sleeper cab trucks due to long driving distances. The performance measurement results for the 554 mile path relay point and non-relay point scenario are shown in Table 17. Table 18 also shows equipment cost differences between the relay point and non-relay point scenarios.

Metric	**Result (Relay Point)**	**Result (Non-Relay Point)**
Cycle Time Per Order (hours)	12.6	12.6
Driver Quantity	35	35
Truck Quantity	19 day cabs	35 sleeper cabs
Trailer Quantity	19	35
Average Length-of-Haul (miles)	138.5	554
Driver Home Time (days/week/driver)	7	2
Driver Work Hours (hours/week/driver)	57.2	67
Driver Utilization (miles/week/driver)	2,659	2,659
Truck Utilization (miles/week/truck)	4,899	2,659
Equipment Idle Time (hours/week)	210	2,835

Table 17. 554 mile path scenario performance measures (relay point/non-relay point)

Costs	**Result (Relay Point)**	**Result (Non-Relay Point)**
Truck Equipment Purchase Costs	\$1,514,984	\$3,335,920
Trailer Equipment Purchase Costs	\$378,784	\$697,760
Annual Truck Depreciation Costs	\$378,746	\$833,980
Annual Trailer Depreciation Costs	\$94,696	\$174,440
Annual Equipment Maintenance Costs	\$151,875	\$279,770

Table 18. 554 mile path scenario equipment costs (relay point/non-relay point)

The order cycle time is the same (12.6 hours) for the non-relay point and relay point scenarios because the transit distance is only 554 miles and non-relay point drivers are not required to shut-down until after the customer delivery is made. After transiting 554 miles, the non-relay point drivers are required to shut-down for 10 hours. The number of drivers required for the non-relay point and relay point scenarios are the same, but the non-relay point scenario requires 16 additional trucks and 16 additional trailers. The average length-of-haul is 415.5 miles shorter using the relay point scenario. The relay point driver home time is 5 days better than the non-relay point scenario. Relay point drivers work an average of 9.8 hours less each week compared to non-relay point drivers. The driver utilization is the same for both scenarios, while the truck utilization is 2,240 miles per week better for the relay point scenario. Utilizing the relay point concept, the weekly equipment idle time decreased from 2,835per week to 210. Using the non-relay concept, 35 drivers experience weekly idle time of 81 hours due to the 10 hour shut-down rule plus the 34 hour shut-down rule after accumulating 60 work hours over 7 consecutive days. In addition to the performance measures, the costs associated with having less equipment using the relay point network provide significant savings. Truck and trailer purchase costs are $2,139,912 less, annual depreciation costs are $534,978 less, and annual maintenance costs are $127,895 less expensive using the relay point concept. Overall, the results indicate better performance measures for the driver, transportation carrier, and customer.

7.3.2 848 Mile Path

The 848 mile path is from Boalsburg, Pennsylvania to Pittsville, Wisconsin and has an annual flow of 9,360 truckload orders or 180 weekly truckload orders over six days per week. The congested transit time for this path is 15.4 hours based on the shortest path. For the non-relay point network, drivers are required to shut-down one time for 10 hours to rest before completing the 848 mile transit. Using the relay point scenario, drivers do not shut-down because federal hours-of-service thresholds are never met, and truck and trailer equipment continuously move until delivery is made at the final customer. Table 19 shows annual and weekly truckload orders, weekly total congested transit time, weekly total load and unload times, total weekly relaying time, and driver and truck quantities for the 848 mile path utilizing two relay points.

Annual Truckload Orders	Weekly Truckload Orders	Total Weekly Transit Time (hours)	Total Weekly Relay Time (hours)	Total Weekly Load/Unload Time (hours)	Total Weekly Time (hours)	Drivers/ Trucks
9,360	180	5,544	90	360	5,994	120/60

Table 19. Activity associated with the 848 mile shortest path (relay point network)

Figure 43 shows the Boalsburg, PA to Pittsville, WI path. For the 848 mile path, three equipment relay points were established as shown in Figure 43. The three relay points are located in Newton Falls, OH; South Bend, IN; and Janesville, WI. The relay points were established in various increments from the origin to the final destination as shown in Figure 44.

Figure 43. Boalsburg, PA to Pittsville, WI path [61]

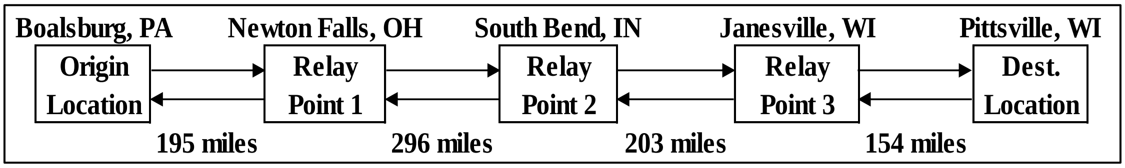

Figure 44. 848 mile path with three relay points

For the 848 mile path relay point scenario, 30 drivers are domiciled in each of the following locations: Boalsburg, PA; Newton Falls, OH; South Bend, IN; and Janesville, WI. For the relay point scenario, 120 drivers are slip-seated between consecutive 12 hour work shifts; therefore, only 60 day cab trucks and 60 trailers are required. Day cab trucks are used by the relay point drivers. For the 848 mile path non-relay point scenario, 120 drivers are also required and are domiciled in Boalsburg, PA. Due to incompatible driving schedules and a long driving distance, non-relay point drivers cannot be slip-seated; therefore, 120 sleeper cab trucks and 120 trailers are required. The non-relay point network uses sleeper cab trucks. The performance measurement results for the 848 mile path relay point and non-relay point scenario are shown in Table 20. Table 21 also shows equipment cost differences between the relay point and non-relay point scenarios.

Metric	**Result (Relay Point)**	**Result (Non-Relay Point)**
Cycle Time Per Order (hours)	17.9	27.4
Driver Quantity	120	120
Truck Quantity	60 day cabs	120 sleeper cabs
Trailer Quantity	60	120
Average Length-of-Haul (miles)	212	848
Driver Home Time (days/week/driver)	7	1.2
Driver Work Hours (hours/week/driver)	55.2	65.8
Driver Utilization (miles/week/driver)	2,544	2,544
Truck Utilization (miles/week/truck)	5,088	2,544
Equipment Idle Time (hours/week)	450	9,480

Table 20. 848 mile path scenario performance measures (relay point/non-relay point)

Costs	**Result (Relay Point)**	**Result (Non-Relay Point)**
Truck Equipment Purchase Costs	$4,784,160	$11,437,440
Trailer Equipment Purchase Costs	$1,196,160	$2,392,320
Annual Truck Depreciation Costs	$1,196,040	$2,859,360
Annual Trailer Depreciation Costs	$299,040	$598,080
Annual Equipment Maintenance Costs	$479,606	$959,212

Table 21. 848 mile path scenario equipment costs (relay point/non-relay point)

The order cycle time for the relay point scenario is 9.5 hours faster compared to the non-relay point scenario. The number of drivers required for both scenarios is the same, while there are 60 less truck and trailer units required for the relay point scenario. The average length-of-haul is 636 miles shorter using the relay point scenario. The relay point driver home time is 5.8 days better than the non-relay point scenario. Relay point drivers work an average of 10.6 hours less each week compared to the non-relay point drivers. The driver utilization is the same for both scenarios, while truck equipment utilization is 2,544 better using the relay point concept. Utilizing the relay point concept, the weekly equipment idle time decreased from 9,480 per week to 450. Using the non-relay concept, drivers experience a significant amount of weekly idle time due to the 10 hour shut-down rule plus the 34 hour shut-down rule after accumulating 60 work hours over 7 consecutive days. Seventy-nine idle hours are accumulated per driver each week using the non-relay point network. In addition to the performance measures, the costs associated with having less equipment using the relay point scenario provide significant savings. Truck and trailer purchase costs are $7,849,440 less, annual depreciation costs are $1,962,360 less, and annual maintenance costs are $479,606 less expensive using the relay point concept. Overall, the results indicate better performance measures for the driver, transportation carrier, and customer.

7.3.3 1,333 Mile Path

The 1,333 mile path is from Quantico, Maryland to Tahlequah, Oklahoma and has an annual flow of 8,320 truckload orders or 160 weekly truckload orders. The weekly orders are tendered consistently over a five day work week. The congested transit time for this path is 25.6 hours. For the non-relay point network, drivers are required to shut-down two times for 10 hours to rest before completing the 1,333 mile transit. Using the relay point scenario, drivers only shut-down on the Hopwood, PA to Eminence, IN and Eminence, IN to Joplin, MO routes because federal hours-of-service thresholds are not met on the remaining routes. Table 22 shows annual and weekly truckload orders, weekly total congested transit time, weekly total load and unload times, total weekly relaying time, and driver and truck quantities for the 1,333 mile path utilizing four relay points.

Annual Truckload Orders	Weekly Truckload Orders	Total Weekly Transit Time (hours)	Total Weekly Relay Time (hours)	Total Weekly Load/Unload Time (hours)	Total Weekly Time (hours)	Drivers/ Trucks
8,320	160	8,204	107	320	8,631	169/137

Table 22. Activity associated with the 1,333 mile shortest path (relay point network)

Figure 45 shows the path from Quantico, MD to Tahlequah, OK. For the 1,333 mile path, there are four equipment relay points established in Glen Burnie, MD; Hopwood, PA; Eminence, IN; and Joplin, MO as shown in Figure 45. For both the relay and non-relay point scenario, 169 drivers are required. For the relay point scenario, 16 drivers are slip-seated in Quantico, MD; 32 drivers are slip-seated in Glen Burnie, MD; and 16 drivers are slip-seated in Joplin, MO. Drivers cannot be slip-seated in Hopwood, PA and Eminence, IN because the length-of-hauls emanating from these two locations are long and have prohibitive driving schedules. Therefore, 137 day cab trucks and 137 trailers are required for the relay point concept. Long length-of-haul relay point drivers will rest in a hotel at the relay point locations; therefore, day cab trucks will suffice. For the non-relay point scenario, 169 sleeper cab trucks and 169 trailers are required because drivers cannot be slip-seated due to incompatible driving schedules and a long driving distance. Non-relay point drivers use sleeper cab trucks. The relay points were established in various mileage increments from the origin to the final destination location as shown in Figure 46.

Figure 45. Quantico, MD to Tahlequah, OK path [61]

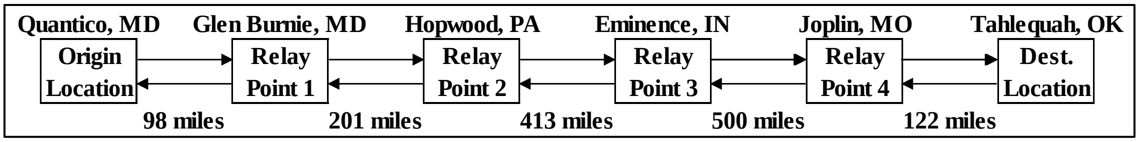

Figure 46. 1,333 mile path with four relay points (relay point network)

For the 1,333 mile path relay point scenario, 16 drivers are domiciled in Quantico, MD; 32 drivers in Glen Burnie, MD; 48 drivers in Hopwood, PA; 57 drivers in Eminence, IN; and 16 drivers in Joplin, MO. For the 1,333 mile path non-relay point scenario, 169 drivers are domiciled in Quantico, MD. The performance measurement results for the 1,333 mile path relay point and non-relay point scenario are shown in Table 23. Table 24 also shows equipment cost differences between the relay point and non-relay point scenarios.

Metric	Result (Relay Point)	Result (Non-Relay Point)
Cycle Time Per Order (hours)	29.0	45.8
Driver Quantity	169	169
Truck Quantity	137 day cabs	169 sleeper cabs
Trailer Quantity	137	169
Average Length-of-Haul (miles)	266.6	1,333
Driver Home Time (days/week/driver)	5.8	1
Driver Work Hours (hours/week/driver)	51.7	70
Driver Utilization (miles/week/driver)	2,524	2,524
Truck Utilization (miles/week/truck)	3,114	2,524
Equipment Idle Time (hours/week)	3,550	11,070

Table 23. 1,333 mile path scenario performance measures (relay point/non-relay point)

Costs	Result (Relay Point)	Result (Non-Relay Point)
Truck Equipment Purchase Costs	$10,923,832	$16,107,728
Trailer Equipment Purchase Costs	$2,731,232	$3,369,184
Annual Truck Depreciation Costs	$2,730,958	$4,026,932
Annual Trailer Depreciation Costs	$682,808	$842,296
Annual Equipment Maintenance Costs	$604,434	$1,208,869

Table 24. 1,333mile path scenario equipment costs (relay point/non-relay point)

The order cycle time for the relay point scenario is 16.8 hours faster compared to the non-relay point scenario. The number of drivers required for both scenarios is the same, while 32 less trucks and 32 less trailers are required for the relay point scenario. The average length-of-haul is 1,066.4 miles shorter using the relay point scenario. The relay point driver home time is 4.8 days better than the non-relay point scenario. Relay point drivers work an average of 18.3 hours less each week compared to non-relay point drivers. The driver utilization is the same for both scenarios, but truck utilization is 590 more using the relay point scenario. Utilizing the relay point concept, the weekly equipment idle time decreased from 11,070 per week to 3,550. Relay point drivers experience less idle time because only the Hopwood and Eminence drivers reach federal hours-of-service threshold limits, which require enforcement of the 10 hour shut-down rule. In addition to the performance measures, the costs associated with having less equipment using the relay point scenario provide significant savings. Truck and trailer purchase costs are $5,821,848 less, annual depreciation costs are $1,455,462 less, and annual maintenance costs are $604,434 less expensive using the relay point concept. Overall, the results indicate better performance measures for the driver, transportation carrier, and customer.

7.3.4 Two Paths Sharing a Relay Point

In order to minimize the fixed costs associated with establishing relay points, relay points are shared when feasible. Feasibility is based on relay points being in route from the origin to the final destination. In other words, traveling out-of-route to share a relay point with another path is not feasible. Out-of-route miles are non-revenue generating miles that add costs to the system and should be avoided. The MIQP created 125,952 relay points and 13,891 relay points are shared by multiple paths. On average, the distance between relay points are 214 miles, but in some cases, the distance between relay points is shorter or longer than 214 miles (e.g. 100 or 300 miles) because relay points can be shared with other paths. Additionally, all relay points on a given path are not required to serve as relay points where equipment is exchanged. Relay points can serve as multiple-purpose location points where equipment maintenance can be performed, computing services can be accessed, fueling can be done, drivers can shower, restaurants can be accessed, etc. To illustrate a shared relay point, a Luling, LA to Foxfield, CO path was considered along with a path from Birmingham, AL to Santa Fe, NM. Figure 47 illustrates the two origin-destination paths. As shown in Figure 47, the two paths share Amarillo, TX as a common relay point location. Figure 48 shows the detailed intersection of the two paths at highway interstates 40 and 27. Equipment would be relayed just south of the Amarillo location off of interstates 40 and 27 via exit 70 close to East 17th Avenue as shown on the map.

Figure 47. Luling, LA to Foxfield, CO path and Birmingham, AL to Santa Fe, NM path sharing a relay point in Amarillo, TX [61]

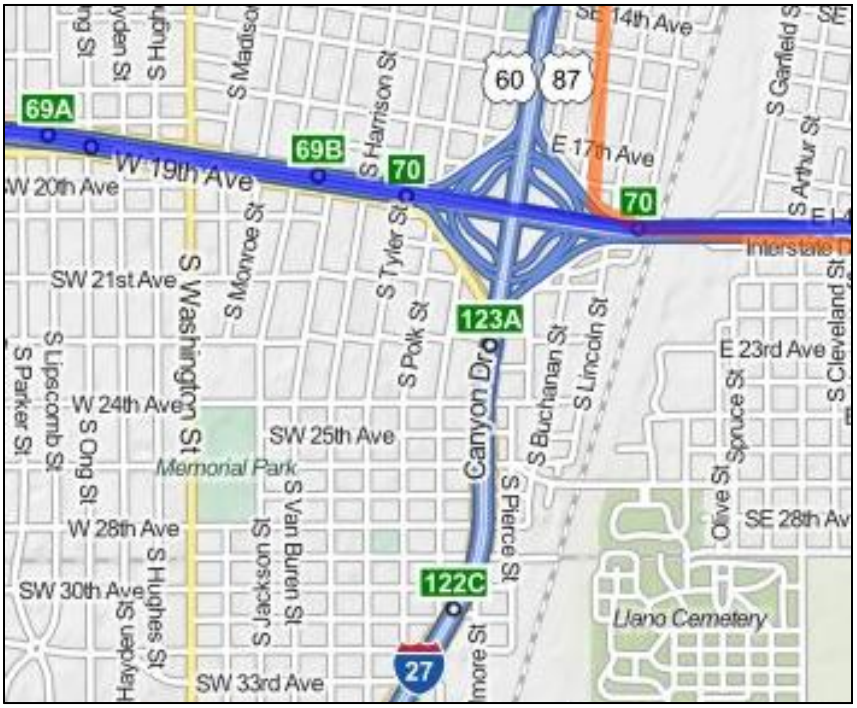

Figure 48. Luling, LA to Foxfield, CO path and Birmingham, AL to Santa Fe, NM path intersection at interstates 40 and 27 [61]

As another example, a path from Birmingham, AL to Basking Ridge, NJ and a path from Oaks, PA to Charlotte, NC were considered (see Figure 49). The Birmingham, AL to Basking Ridge, NJ path shares relay points in Max Meadows, VA and Shippensburg, PA with the Oaks, PA to Charlotte, NC path. Figure 49 illustrates the Birmingham, AL to Basking Ridge, NJ and Oaks, PA to Charlotte, NC paths along with the shared relay points. At both locations, drivers would exit the main paths and use a facility to relay equipment.

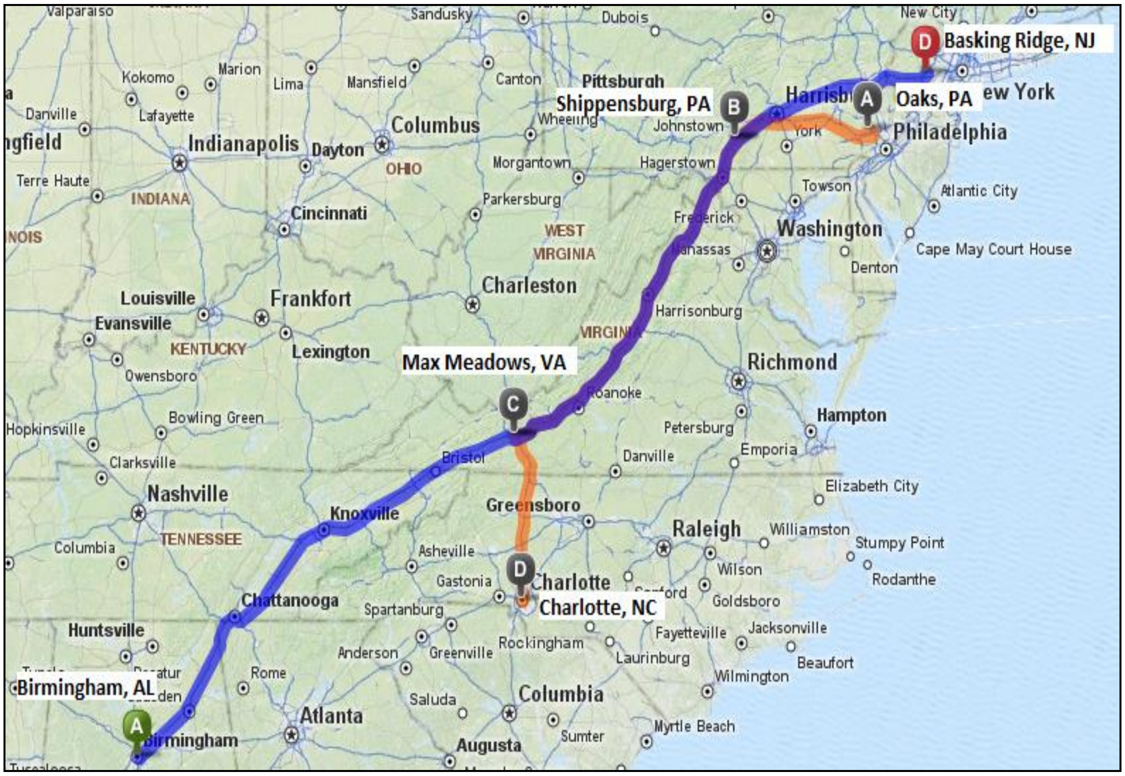

Figure 49. Birmingham, AL to Basking Ridge, NJ path and Oaks, PA to Charlotte, NC path sharing relay points in Max Meadows, VA and Shippensburg, PA [61]

Figure 50 shows in more detail the locations in Max Meadows, VA and Shippensburg, PA where the drivers would relay equipment. In the Max Meadows, VA vicinity, drivers would relay equipment off of exit 81 near interstate 81, and in the Shippensburg, PA area, drivers would relay equipment off of interstate 76.

Figure 50. Figure on the left shows the Max Meadows, VA area; figure on the right shows the Shippensburg, PA area [61]

Relay points can be shared to exchange equipment, and serve as fueling, equipment maintenance, showering, restaurant, and other purposes.

In regard to the short, medium, and long length-of-haul paths considered above, it was expected that the order cycle time would be better for the relay point network compared to the non-relay point network since the non-relay point network requires more frequent usage of federal hours-of-service rules requiring drivers to shut-down and rest. Using the relay point network, equipment continuously moves until trailers are delivered to the final destination with minimal time required to exchange equipment at relay points. Since driving and equipment idle time are reduced in the relay point network and truck and trailer equipment continuously move, the lead times required from the different origins and final destinations can be reduced. The reduction of lead times enhances customer service, increases inventory turns, and reduces inventory at shipping sites and inventory in-transit. When lead times are shorter, inventory replenishments can be executed faster and transportation carriers can react quicker to demand changes in the supply chain. Shorter lead times decrease costs and eliminate wasteful non-value-added activities, which can lead to increased levels of competitiveness and market share by serving customers quicker and with more flexibility. Also, performance metrics related to the driver and customer are enhanced in all three scenarios.

7.4 Mixed Integer Quadratic Program- Transportation Carrier Results

Since efficiencies are created utilizing the relay point network, overall transportation costs as a function of transported miles, transportation hours, and truckloads will decrease for the transportation carrier. Network efficiencies utilizing the relay point network translates into cost savings, especially in regard to truck and trailer equipment costs since equipment requirements are much less compared to the non-relay point network. Truck and trailer equipment requirements for the relay point network are much less than the non-relay point network because drivers are slip-seated. In the relay point network, 2,941566 drivers are slip-seated; therefore, only 1,697,468 trucks and 1,697,468 trailers are required. For the non-relay point network, 3,254,648 trucks and 3,254,648 trailers are required, and 4,373 drivers are slip-seated. A total of 1,557,180 fewer trucks and 1,557,180 fewer trailers are required for the relay point network resulting in an overall purchased cost savings of $205,901,642,208. Annual fixed costs associated with truck and trailer depreciation are $51,475,410,552 less costly using the relay point network while the annual maintenance costs are $12,447,214,774 less using the relay point network since less equipment is required. Table 25 summarizes the annual maintenance and depreciation costs associated with both the relay and non-relay point networks. Table 26 shows the equipment purchase costs for the relay and non-relay point networks.

Scenario	**Total Annual Depreciation Cost**	**Total Annual Maintenance Cost**
Non-Relay Point Network	$93,772,918,176	$26,015,812,346
Relay Point Network	$42,297,507,624	$13,568,597,572
Difference (Non-Relay – Relay)	$51,475,410,552	$12,447,214,774

Table 25. Total annual depreciation and maintenance costs

Scenario	**Total Purchase Cost (Trucks)**	**Total Purchase Cost (Trailers)**
Non-Relay Point Network	$310,207,010,176	$64,884,662,528
Relay Point Network	$135,349,308,448	$33,840,722,048
Difference (Non-Relay – Relay)	$174,857,701,728	$31,043,940,480

Table 26. Total purchase costs

To put the depreciation costs into perspective, depreciation costs are $0.0904 per mile and $0.2003 per mile using the relay point and non-relay point networks, respectively ($0.11per mile difference). Maintenance costs are $0.029 per mile and $0.056 per mile using the relay point and non-relay point networks, respectively ($0.027 per mile difference). The relay point concept is lucrative compared to the non-relay point network with regard to equipment purchase and depreciation costs and maintenance costs.

The relay point network results in higher productivity compared to the non-relay network in terms of truckloads delivered versus total hours and idle time hours. There are less hours required for the relay point network because of less idle time. Additional time is required for the relay point network to exchange equipment at relay points, but this time is small compared to the shut-down time required for the non-relay point network. As a percentage of total hours, equipment exchange time at relay points is 0.97%, while shut-down time to adhere to federal hours-of-service rules is 6.95%. Idle time is 68.3% less utilizing the relay point network. Table 27 shows the total productivity measure for the relay point and non-relay point networks. The output parameter is the total annual truckloads delivered and the input parameter includes the total hours (i.e. drive time, loading and unloading time, relaying time, and shut-down time to comply with federal hours-of-service rules). A partial productivity measure was also calculated where total annual delivered truckloads are the output parameter and idle time is the only input parameter (see Table 28). Using the partial productivity measure, there is a larger productivity percentage difference between the relay point and non-relay point networks since the input parameter only includes idle time, and idle time is significantly different between the relay and non-relay point networks. Productivity increases because of the more efficient use of resources (drivers, trailers, and trucks) with the relay point network.

Network	**Total Productivity (truckloads/total hours)**
Relay Point	0.0215
Non-Relay Point	0.0191
% difference	12.6%

Table 27. Total productivity measure (truckloads/total hours)

Network	**Partial Productivity (truckloads/idle hours)**
Relay Point	0.3685
Non-Relay Point	0.1168
% difference	215.5%

Table 28. Partial productivity measure (truckloads/idle hours)

As illustrated in Tables 27 and 28, the partial productivity measure shows a more pronounced increase in productivity using the relay point network because idle time is the only input parameter. The productivity results are shown as follows:

Non-relay point network:

Truckloads delivered = 205,119,400
Total hours = 10,757,610,678
    Driving hours = 9,001,000,925
    Idle time hours = 1,756,609,753
Total Productivity (Truckloads/Total hours) = 0.0191
Partial Productivity (Truckloads/Idle hours) = 0.1168

Relay point network:

Truckloads delivered = 205,119,400
Total hours = 9,557,679,882
    Driving hours = 9,001,000,925
    Idle time hours = 556,678,957
Total Productivity (Truckloads/Total hours) = 0.0215
Partial Productivity (Truckloads/Idle hours) = 0.3685

The total productivity and partial productivity difference between the non-relay point and relay point network is 12.6% and 215.5%, respectively. Also, the relay point network results in better driver and equipment utilization in terms of miles driven per hour. Utilizing the non-relay network, the average utilization is 43.51 miles per hour and 48.97 miles per hour using the relay point network (12.6% increase). Also, 10,757,610,678 total annual hours were consumed by the non-relay point network and 9,557,679,882 total annual hours by the relay point network (11.1% reduction). Table 29 shows the utilization (miles/hour) results and total annual hours consumed by both network scenarios.

Scenario	**Total Annual Hours**	**Utilization (miles/hour)**
Non-Relay Point Network	10,757,610,678	43.51
Relay Point Network	9,557,679,882	48.97
% Difference	11.1% reduction	12.6% increase

Table 29. Total annual hours and utilization

In addition to productivity, transportation related costs are critical to the transportation carrier; therefore, a detailed comparison of the costs associated with the non-relay point and relay point networks are provided. The results are given below.

Non-relay network costs:

Annual transportation mileage = 468,052,048,105
Annual transportation hours = 10,757,610,678
Annual truckloads = 205,119,400
Total annual network costs = $842,286,495,192
    Total annual line-haul costs = $255,096,987,451
    Total annual truck and trailer depreciation costs = $93,772,918,176
    Total annual fixed costs = $0
    Total annual maintenance costs = $26,015,812,346
    Total annual driver wages costs = $196,581,860,204
    Total annual fuel costs = $261,048,414,000
    Total annual turnover costs = $9,770,503,015
Total cost per hour = $78.30
Total cost per mile = $1.80
Total cost per truckload = $4,106.32
Total equipment purchase costs = $ 375,091,672,704
    Trailer purchase costs = $64,884,662,528
    Truck purchase costs = $310,207,010,176

Relay network costs:

Annual transportation mileage = 468,052,048,105
Annual transportation hours = 9,557,679,882
Annual truckloads = 205,119,400
Total annual network costs = $739,759,827,490
    Total annual line-haul costs = $218,078,318,000
    Total annual truck and trailer depreciation costs = $42,297,507,624
    Total annual fixed costs = $7,746,437,856
    Total annual maintenance costs = $12,754,403,600
    Total annual driver wages costs = $196,581,860,204
    Total annual fuel costs = $259,925,112,000
    Total annual turnover costs = $2,376,188,206
Total cost per hour = $77.40
Total cost per mile = $1.58
Total cost per truckload = $3,606.48
Total equipment costs = $169,190,030,496
    Trailer purchase costs = $33,840,722,048
    Truck purchase costs = $135,349,308,448

Cost difference (Non-relay – Relay network):

Cost savings per hour utilizing the relay network = $0.90
Cost savings per mile utilizing the relay network = $0.22
Cost savings per truckload utilizing the relay network = $499.84
Total annual cost savings utilizing the relay network = $102,526,667,702
Total truck/trailer purchase cost savings utilizing the relay network = $205,901,642,208

The relay point network is $0.22 per mile, $0.90 per hour, and $499.84 per truckload less costly than the non-relay point network with an annual cost savings of $102,526,667,702 (12.2% reduction). Truck and trailer purchase cost savings are $205,901,642,208 (54.9% reduction) using the relay point network. As a result of the annual cost savings, the transportation carrier will reap higher profit margins using the relay point network.

Using the relay point network, the MIQP shows that driver turnover is 25%, which is much less than the OTR average of 100% and more. Driver turnover is much less utilizing the relay point network because drivers are home 5.33 days per week compared to 0.91 days per week using the non-relay point network, and relay point drivers are able to achieve adequate driving miles and annual pay. As stated in section 7.2, annual driver turnover costs are $7,394,314,809 lower utilizing the relay point network, which is a significant cost savings to the transportation carrier. Driver turnover can be volatile depending on economic market conditions. When the overall U.S. unemployment rate is high, consumer spending is low, and economic market conditions are recessionary, driver turnover tends to be lower but still close to 100%. When the U.S. unemployment rate is low, consumer spending is high, and economic market conditions are healthy, driver turnover is typically between 150%-200% and drivers tend to seek new employment between transportation carriers or opt out of the transportation industry.

In summary, drivers are home more often using the relay point network compared to the non-relay point network and drive a much shorter length-of-haul, so driving fatigue and time away from home is minimal. Relay point drivers are able to turn more truckloads using the relay point network; therefore, driver pay remains healthy and at the same levels of the non-relay network. Transportation carriers will experience less driver turnover using the relay point network because drivers are home more often and drive shorter distances but with adequate pay levels. Since truck and trailer equipment can be slip-seated more using the relay point network, equipment purchase costs and annual equipment depreciation costs will be much less compared to the non-relay point network. Transportation carriers will experience less annual equipment maintenance costs using the relay network because equipment requirements are less. Productivity levels are also better using the relay point network. Since idle time is much less utilizing the relay point network, customers will experience shorter lead times as a result of reduced order cycle times. Due to shorter order cycle times, on-time delivery and inventory turns will improve. Overall, the relay point network provides benefits to the drivers as well as to the transportation carriers and customers. The result is a holistic solution.

CHAPTER 8

CONCLUSION

Relay points add significant benefits holistically to the driver, transportation carrier, and customer. In the case of the drivers, drivers are home 486% more using the relay network. Relay point drivers are home 5.33 days per week on average compared to 0.91 days per week for non-relay point drivers. Even though relay point drivers are home more often than non-relay point drivers, weekly driver utilization and driver pay are adequate for relay point drivers because drivers are able to turn more daily truckloads. Relay point and non-relay point drivers average $62,047 and $60,360 in annual pay per driver, respectively. Relay point and non-relay point drivers average 2,841 and 2,764 in weekly miles per driver, respectively. Also, the average driving length-of-haul for relay point drivers is 214 miles compared to 1,141 miles for non-relay point drivers, which is an 81% reduction. In the case of transportation carriers, truck and trailer equipment can be slip-seated more often using the relay point concept because driver schedules are more compatible for sharing equipment. As a result of slip-seating, 1,557,180 fewer trucks and 1,557,180 fewer trailers are required for the relay point network resulting in a purchase cost savings of $205,901,642,208. Also, annual depreciation cost savings of $51,475,410,552 are experienced along with a reduction of $12,447,214,774 in annual maintenance costs. The overall annual cost savings using the relay point network is $102,526,667,702, which is a 12.2% reduction in total annual costs. In the case of customers, relay point drivers are idle less often because federal hours-of-service thresholds are not reached, which improves customer service and order cycle times. The average order cycle time is 25.11 hours per order and 39.03 hours per order using the relay and non-relay point networks, respectively. As a result of less idle time associated with the federal hours-of-service rules, relay point drivers can turn 3.09 truckload orders per week compared to 2.39 truckload orders per week for non-relay point drivers (29.3% increase) resulting in improved order lead times. Relay point drivers are more productive than non-relay point drivers due to the overall reduction in idle time. Based on the results, the relay point network provides benefits holistically to the truck drivers, transportation carriers, and customers. The ultimate goal was to improve the truckload driving job but not at the expense of the transportation carrier and customer, and that has been illustrated.

8.1 Future Research

There still remains a gap in taking the results from the model and developing an operational plan that will realize the savings projection. Future research needs to determine- more optimally- locations where drivers should be domiciled along the relay point network based on driver labor availability and a cost of living index. Driver labor availability should be considered because certain locations may not have a sufficient population to provide an adequate quantity of drivers or labor to support a transportation fleet. Also, the cost of living index needs to be considered to more optimally determine where drivers should be based in order to minimize driver wage costs. The MIQP results also need to be simulated to validate the results from the perspective of the driver, transportation carrier, and customer in order to understand the operational feasibility of the relay point network. In order to simulate the model results, more data is needed including: the statistical distribution of customer orders, the impact of equipment failures and repair times, the statistical distribution of shipper loading times, the statistical distribution of customer unloading times, etc. A simulation model with appropriate data, statistical distributions, and operational parameters would give a better illustration of how the drivers, transportation carriers, and customers would potentially perform in an operational setting. Additionally, the relay point network needs to be simulated under different conditions and scenarios to determine any specific benefits and problems related to the driver, transportation carrier, and customer.

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APPENDICES

Appendix A

A.1. Freight Generation

The first phase of developing the highway transportation network consists of freight generation by establishing the freight production and consumption locations. The production locations are points where freight is produced and consumption locations are points where freight is consumed. Freight generation determines the tonnage amounts produced and consumed for particular commodities at different locations. Socio-economic data- payroll wages, population, establishments, and employment- at the U.S. Metropolitan Statistical Area (MSA) level is the main input data to generate freight. The Freight Analysis Framework (FAF2) database developed by the Federal Highway Administration (FHWA) [49] has data for 114 MSAs, and this data serves as the data source for the socio-economic data. Additionally, data is generated at the commodity level for the 43 Standard Classification of Transported Goods (SCTG) federal commodity codes for both freight production and consumption. Using the socio-economic and commodity data, production and consumption MSA locations and freight tonnages were determined, and regression models were developed to forecast future freight flow tonnages. The tonnage data is converted to truckloads using a payload factor for tonnage conversion factor developed by the U.S. Department of Transportation and the Federal Highway Administration.

The payload factor is based on the following formula:

$TEF_{ijk} = B_{ijk} / w_{ijk}$

Where

TEF_{ijk} = the factor that converts tons of commodity to equivalent number of trucks
B_{ijk} = represents the fraction of commodity i moved by truck type j with truck body type k; represents a tabular factor at the national level and is found in accordance to FAF2 [49]
w_{ijk} = represents the mean payload of truck type j with body type k transporting commodity i; represents a tabular factor at the national level and is found in accordance to FAF2 [49]

The truckload data is used to establish freight distribution in the second phase.

A.2. Freight Distribution

The freight distribution phase involves distributing freight production and consumption at an MSA to all other MSAs. The freight production and consumption data are inputs to the distribution model along with a MSA level distance-based friction factor matrix. A doubly constrained gravity model is used to model freight distribution between production and consumption locations. The basic notion of the gravity model assumes that the flow from one location to another is positively proportional to the "pull" of the locations and negatively proportional to the impedance between the locations [50]. The doubly constrained gravity model ensures the flow conservation of production and consumption for each state/MSA [50]. The equation for the doubly constrained gravity model is given as:

$T_{ij} = A_i B_j O_i D_j \, F(d_{ij})$

Where

T_{ij} = Trips distributed between MSA i and MSA j
A_i, B_j = Balancing factors
O_i = Production at MSA i
D_j = Consumption at MSA j
$F(d_{ij})$ = Friction Factors associated with MSA i and MSA j

The doubly constrained gravity model was coded and executed as a Visual Basic Application (VBA) in Microsoft Excel. Trip distances between MSAs, balancing factors, MSA production and consumption data, and friction factors associated with the MSAs are determined and tabularized. The output result includes the amount of freight volume flows between any two MSAs by commodity type. The pseudo-code for the VBA application and the interface are outlined in Appendix B.

A.3. Freight Assignment

The main purpose of the freight assignment phase is to determine more optimal truckload route assignments on a highway transportation network between the production and consumption locations such that transportation costs or distances are minimized. The freight assignment is carried out using an in-house created mathematical model using CPLEX/C++. The truckload volume flows, between a production and consumption location pair, are assigned to the transportation network on highway transportation links using a shortest congested travel time approach beginning with the production-consumption pairs with the greatest amount of total freight flow volume. This approach closely models shipper and carrier behavior as goods are transported. The freight assignment results consist of a network of origin-destination paths with associated travel distances, congested transit times, truckload flow volumes, and other network information. The shortest path congested travel times establish the congested transit times using a volume delay function or a travel time curve from the Bureau of Public Roads [51] in the U.S. along with a simplified (approximate) travel time curve that is piece-wise linear. The travel time flow curve (i.e. transit times) is incorporated into the mathematical program to model the shortest path congested travel time approach.

Appendix B

B.1. Pseudo-code for the Doubly Constrained Gravity Model

1. Create the production and consumption data for each MSA; freight generation
2. Create the distance matrix; the distance matrix is the distance between each MSA location
3. Create the friction factor matrix using an exponential function to compute the friction factors. The formula for the exponential function is:

   $F(d_{ij}) = e^{-0.03*dij}$,

   Where
   d_{ij} = distance between MSA i and MSA j

4. Make sure production and consumption are balanced for the MSAs. If the two are not balanced, then hold the production constant and adjust the consumptions accordingly until production and consumption are balanced.
5. Compute the trip distribution balancing factors A_i and B_j using the bi-proportional algorithm. The formulae used for calculating balancing factors are as follows:
   $A_i = 1/ (\Sigma B_j D_j F(d_{ij}))$
   $B_j = 1/ (\Sigma A_i O_i F(d_{ij}))$

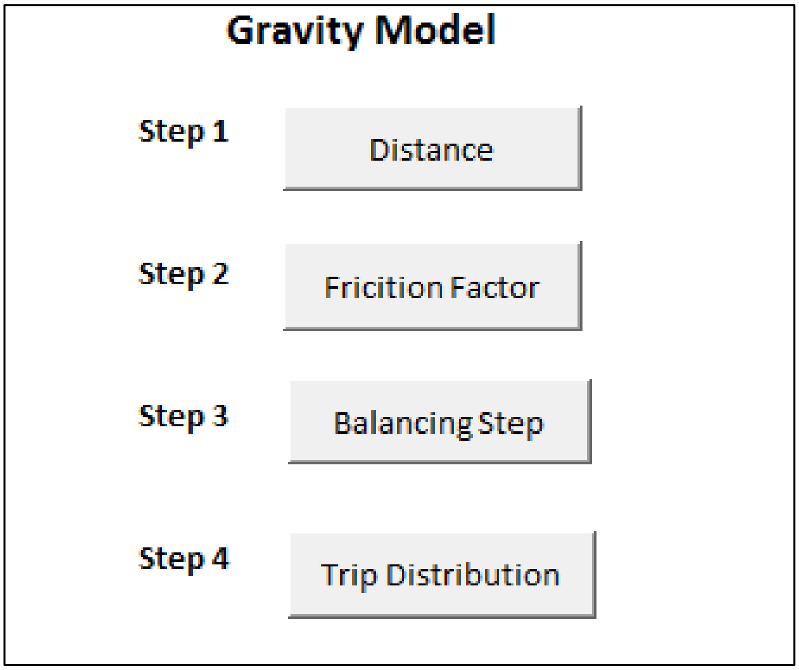
   Bi-proportional Algorithm works as follows:

   Initially, compute the value of A_i, substituting B_j =1 into the A_i equation. Then use the computed value of A_i to compute the value of B_j. Then use the new value of B_j to compute A_i. Repeat this iterative process until a convergence is reached. The convergence rule used is based on the A_i values being within 10% of each other between iterations and the B_j values being within 10% of each other between iterations.

6. The end result of convergence is a final trip distribution matrix between each MSA location.

Appendix B.2 below shows the user interface for the doubly constrained gravity model.

B.2. Doubly Constrained Gravity Model User Interface



Appendix C

C.1. Origin City/State and Annual Outbound Truckload Flow

Origin City/State	Annual Truckload Flow
SAN ANTONIO, TX	1,811,711
LA PORTE, TX	1,729,286
WARWICK, RI	1,714,238
FAYVILLE, MA	1,658,236
LINCOLNVILLE, ME	1,653,052
LOTHIAN, MD	1,634,195
WASHINGTON, DC	1,604,959
ATLANTA, GA	1,564,354
COLUMBUS, OH	1,553,385
BROOKFIELD, WI	1,552,513
AUSTIN, TX	1,546,302
HEBRON, CT	1,537,999
QUANTICO, MD	1,508,072
DAVANT, LA	1,501,875
WESTMORELAND, NH	1,499,911
PONTIAC, MI	1,499,543
RUSKIN, FL	1,495,387
LINCOLN, DE	1,494,563
TIPP CITY, OH	1,490,916
POMFRET, MD	1,490,401
CHESTERFIELD, MA	1,490,343
GENOA, NY	1,487,061
TWINSBURG, OH	1,478,382
NEW HAMPTON, NH	1,474,034
LEBANON JUNCTION, KY	1,470,571
EASLEY, SC	1,470,380
SOUTH ROXANA, IL	1,468,897
GALWAY, NY	1,468,356
LOVELAND, OH	1,468,195
MURRYSVILLE, PA	1,463,091

BEAUFORT, SC	1,460,269
GORDON, GA	1,450,016
BATTLE CREEK, MI	1,441,967
ROSEBUSH, MI	1,438,490
WILMINGTON, NC	1,430,823
WEST BLOOMFIELD, NY	1,429,176
BUFFALO, NY	1,424,621
ZELLWOOD, FL	1,424,334
HARWINTON, CT	1,415,962
WESTON, FL	1,414,899
BASKING RIDGE, NJ	1,411,783
WACISSA, FL	1,399,603
RHODELIA, KY	1,399,027
LORETTO, MN	1,395,440
NASHVILLE, TN	1,392,178
CHARLOTTE, NC	1,390,431
INDIANAPOLIS, IN	1,389,084
RICHMOND, VA	1,388,640
DELMONT, NJ	1,388,454
RALEIGH, NC	1,387,289
LOOMIS, CA	1,367,655
EOLA, IL	1,366,677
OAKS, PA	1,365,893
MOUNT HAMILTON, CA	1,364,265
JACKSONVILLE, FL	1,360,475
JACKSON, OH	1,358,584
STRATHMERE, NJ	1,355,298
PACOLET, SC	1,354,897
SUFFOLK, VA	1,354,372
CHANDLER, AZ	1,351,524
HIGH POINT, NC	1,349,941
BIRMINGHAM, AL	1,342,993
CHECK, VA	1,336,835
GREENVILLE, AL	1,331,439
TALLMANSVILLE, WV	1,321,933
SPOTSYLVANIA, VA	1,311,156

BOALSBURG, PA	1,297,437
VIOLA, TN	1,290,006
COLO, IA	1,289,150
KOUTS, IN	1,285,208
WALLKILL, NY	1,273,903
KNOB LICK, KY	1,265,748
GREENWOOD, MO	1,265,445
PACIFIC, MO	1,263,218
PITTSVILLE, WI	1,258,410
PERRY, LA	1,233,503
CLARKS GROVE, MN	1,232,675
LOHMAN, MO	1,227,012
ARLINGTON, TN	1,205,431
SAN DIEGO, CA	1,203,160
THREE RIVERS, CA	1,181,904
LOWAKE, TX	1,169,610
DALLAS, TX	1,146,457
MC CLURE, IL	1,140,054
NORTH LITTLE ROCK, AR	1,119,817
LAYTON, UT	1,115,132
APPLE VALLEY, CA	1,104,295
GOODMAN, MS	1,096,762
SUPAI, AZ	1,096,613
TUCSON, AZ	1,091,404
ROUND MOUNTAIN, NV	1,088,662
WELLSVILLE, KS	1,081,128
LITTLETON, CO	1,077,445
WEST LINN, OR	1,055,224
BUSHTON, KS	1,051,494
CRESCENT VALLEY, NV	1,045,175
SUN VALLEY, ID	1,029,269
BROTHERS, OR	1,028,818
ENCINO, NM	991,459
EMERY, UT	968,736
PUYALLUP, WA	968,134
MERNA, NE	946,540

CLE ELUM, WA	945,371
CRESTONE, CO	945,312
GUYMON, OK	941,649
BALKO, OK	940,134
LYSITE, WY	938,274
BOISE CITY, OK	916,459
DENHOFF, ND	910,215
MOCCASIN, MT	904,490
ALTUS AFB, OK	891,265
VINSON, OK	877,408
TERRAL, OK	874,937
PIERRE, SD	867,984
WATSON, OK	866,308
GAGE, OK	865,027
RANDLETT, OK	863,867
SWEETWATER, OK	862,513
THACKERVILLE, OK	862,322
CARDIN, OK	861,062
OAKS, OK	860,575
GRANDFIELD, OK	860,327
ROSSTON, OK	854,454
VINITA, OK	851,580
TEXOLA, OK	841,499
MARBLE CITY, OK	836,316
WILLOW, OK	835,595
MOORELAND, OK	835,353
TUSSY, OK	834,695
SHADY POINT, OK	832,477
BUNCH, OK	831,952
DUNCAN, OK	829,508
LEQUIRE, OK	825,571
FORT SILL, OK	824,828
SWINK, OK	820,680
TAHLEQUAH, OK	818,083
TUSKAHOMA, OK	817,302
WAGONER, OK	815,130

ROOSEVELT, OK	809,022
MUSKOGEE, OK	803,176
WANN, OK	802,899
ROSE, OK	802,299
FOSS, OK	801,668
ACHILLE, OK	800,627
MADILL, OK	800,595
BUTLER, OK	799,114
DAVIS, OK	796,389
CLAREMORE, OK	793,932
WASHITA, OK	793,058
HOPETON, OK	792,928
PANOLA, OK	792,457
FAY, OK	791,398
ELMORE CITY, OK	788,362
MILL CREEK, OK	786,951
TULSA, OK	782,817
WARDVILLE, OK	778,246
HANNA, OK	776,909
ATOKA, OK	776,643
PRESTON, OK	775,055
BARTLESVILLE, OK	769,875
LEHIGH, OK	767,893
CASTLE, OK	766,720
CHESTER, OK	760,648
OKLAHOMA CITY, OK	758,762
TECUMSEH, OK	757,536
BURLINGTON, OK	756,496
POCASSET, OK	754,766
LAMAR, OK	754,561
PURCELL, OK	753,526
PAWNEE, OK	752,977
NORMAN, OK	752,305
SLICK, OK	750,632
SASAKWA, OK	749,394
FITZHUGH, OK	748,411

GREENFIELD, OK	744,049
RED ROCK, OK	742,597
CONCHO, OK	740,221
BOWRING, OK	737,357
CHANDLER, OK	734,984
HILLSDALE, OK	733,008
STILLWATER, OK	731,494
OMEGA, OK	730,566
PONCA CITY, OK	727,661
ORLANDO, OK	721,506
MANCHESTER, OK	701,468
EAGLE RIVER, AK	583,843
LAQUEY, MO	15,719
KANSAS CITY, MO	12,485
GLENVIEW, KY	11,263
JONESTOWN, PA	11,189
VAILS GATE, NY	8,554
GRAY SUMMIT, MO	8,432
PARRYVILLE, PA	8,306
UTICA, NY	8,206
LEBANON, IN	8,123
CHESTERVILLE, OH	8,058
ARAPAHO, OK	7,287
DANDRIDGE, TN	6,690
WICHITA FALLS, TX	6,356
OKLAUNION, TX	5,594
FRANCIS, OK	5,435
GLENWOOD, AR	4,961
HAMMETT, ID	4,313

C.2. Destination City/State and Annual Inbound Truckload Flow

Destination City/State	Annual Truckload Flow
SAN ANTONIO, TX	1,813,062
WARWICK, RI	1,745,000
LA PORTE, TX	1,727,591
FAYVILLE, MA	1,665,127
LOTHIAN, MD	1,650,974
LINCOLNVILLE, ME	1,648,410
WASHINGTON, DC	1,609,254
AUSTIN, TX	1,559,246
HEBRON, CT	1,550,588
ATLANTA, GA	1,546,769
BROOKFIELD, WI	1,536,718
RUSKIN, FL	1,530,269
QUANTICO, MD	1,521,237
COLUMBUS, OH	1,516,387
CHESTERFIELD, MA	1,516,264
POMFRET, MD	1,510,622
PONTIAC, MI	1,509,431
LINCOLN, DE	1,507,244
WESTMORELAND, NH	1,504,446
DAVANT, LA	1,483,200
TIPP CITY, OH	1,477,706
GENOA, NY	1,475,687
NEW HAMPTON, NH	1,471,524
GALWAY, NY	1,468,727
LEBANON JUNCTION, KY	1,460,775
LOOMIS, CA	1,459,468
TWINSBURG, OH	1,452,540
EASLEY, SC	1,452,189
MURRYSVILLE, PA	1,451,110
LOVELAND, OH	1,450,162
ZELLWOOD, FL	1,449,824

DELMONT, NJ	1,449,447
STRATHMERE, NJ	1,442,985
WESTON, FL	1,442,531
MOUNT HAMILTON, CA	1,441,137
BASKING RIDGE, NJ	1,440,898
SOUTH ROXANA, IL	1,438,600
BEAUFORT, SC	1,436,682
GORDON, GA	1,432,740
COMSTOCK PARK, MI	1,426,767
ROSEBUSH, MI	1,421,340
CHANDLER, AZ	1,416,675
BUFFALO, NY	1,414,056
HARWINTON, CT	1,411,943
WEST BLOOMFIELD, NY	1,410,772
WILMINGTON, NC	1,400,809
RICHMOND, VA	1,399,735
WACISSA, FL	1,395,965
OAKS, PA	1,384,149
LORETTO, MN	1,381,592
JACKSONVILLE, FL	1,374,757
EOLA, IL	1,373,116
RHODELIA, KY	1,370,567
RALEIGH, NC	1,370,080
CHARLOTTE, NC	1,370,013
INDIANAPOLIS, IN	1,367,411
SUFFOLK, VA	1,365,389
NASHVILLE, TN	1,355,720
PACOLET, SC	1,341,344
SPOTSYLVANIA, VA	1,332,996
CHECK, VA	1,332,463
HIGH POINT, NC	1,328,764
JACKSON, OH	1,327,327
GREENVILLE, AL	1,305,612

TALLMANSVILLE, WV	1,299,586
BOALSBURG, PA	1,295,927
BIRMINGHAM, AL	1,288,112
WALLKILL, NY	1,281,442
KOUTS, IN	1,280,937
SAN DIEGO, CA	1,263,767
PITTSVILLE, WI	1,263,579
COLO, IA	1,258,191
GREENWOOD, MO	1,250,514
THREE RIVERS, CA	1,247,083
VIOLA, TN	1,245,285
KNOB LICK, KY	1,240,738
PERRY, LA	1,224,402
PACIFIC, MO	1,219,699
CLARKS GROVE, MN	1,214,484
LOHMAN, MO	1,193,986
LOWAKE, TX	1,173,790
APPLE VALLEY, CA	1,171,908
SUPAI, AZ	1,168,467
ARLINGTON, TN	1,162,210
DALLAS, TX	1,153,809
ROUND MOUNTAIN, NV	1,144,542
LAYTON, UT	1,131,246
TUCSON, AZ	1,118,940
MC CLURE, IL	1,100,334
NORTH LITTLE ROCK, AR	1,097,542
LITTLETON, CO	1,088,629
WEST LINN, OR	1,078,940
CRESCENT VALLEY, NV	1,071,528
GOODMAN, MS	1,071,385
WELLSVILLE, KS	1,067,475
BROTHERS, OR	1,063,838
SUN VALLEY, ID	1,052,599

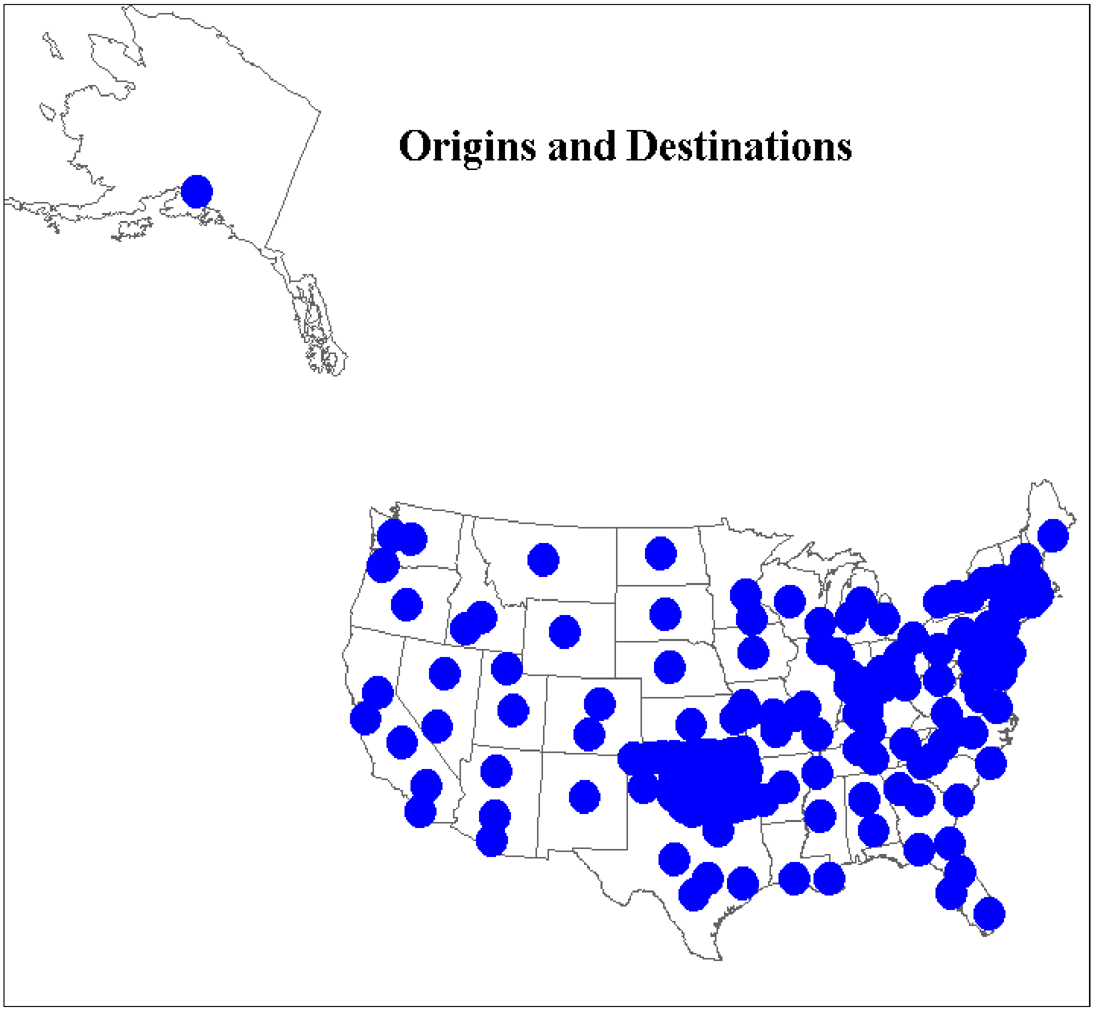
BUSHTON, KS	1,035,011
ENCINO, NM	1,033,733
PUYALLUP, WA	1,005,917
EMERY, UT	986,700
CLE ELUM, WA	974,155
CRESTONE, CO	957,158
GUYMON, OK	950,102
BALKO, OK	949,272
BOISE CITY, OK	934,926
MERNA, NE	930,681
LYSITE, WY	929,898
MOCCASIN, MT	904,324
ALTUS AFB, OK	891,423
VINSON, OK	888,681
SWEETWATER, OK	884,457
DENHOFF, ND	882,570
TERRAL, OK	876,617
GAGE, OK	873,899
ROSSTON, OK	864,224
RANDLETT, OK	862,890
GRANDFIELD, OK	862,126
THACKERVILLE, OK	857,408
PIERRE, SD	854,000
OAKS, OK	849,980
CARDIN, OK	846,939
VINITA, OK	843,602
WATSON, OK	842,833
MOORELAND, OK	842,308
WILLOW, OK	841,423
TEXOLA, OK	833,246
TUSSY, OK	830,117
DUNCAN, OK	826,603
MARBLE CITY, OK	823,623

SHADY POINT, OK	820,898
BUNCH, OK	820,462
FORT SILL, OK	817,298
TAHLEQUAH, OK	809,888
ROOSEVELT, OK	809,344
WAGONER, OK	809,056
BUTLER, OK	806,962
FOSS, OK	805,500
LEQUIRE, OK	805,380
HOPETON, OK	797,634
FAY, OK	795,994
ACHILLE, OK	795,655
WANN, OK	795,378
MUSKOGEE, OK	794,863
TUSKAHOMA, OK	794,421
SWINK, OK	793,836
MADILL, OK	793,835
ROSE, OK	792,852
WASHITA, OK	791,831
DAVIS, OK	791,541
CLAREMORE, OK	783,997
ELMORE CITY, OK	783,925
PANOLA, OK	782,215
TULSA, OK	779,751
PRESTON, OK	772,451
WARDVILLE, OK	769,808
BARTLESVILLE, OK	768,625
HANNA, OK	767,594
MILL CREEK, OK	765,428
NORMAN, OK	762,830
ATOKA, OK	762,598
LEHIGH, OK	762,124
CHESTER, OK	761,561

CASTLE, OK	760,880
OKLAHOMA CITY, OK	755,450
POCASSET, OK	753,053
TECUMSEH, OK	753,020
LAMAR, OK	752,429
SASAKWA, OK	751,853
PURCELL, OK	750,454
SLICK, OK	747,389
BURLINGTON, OK	746,702
PAWNEE, OK	746,157
FITZHUGH, OK	745,178
CONCHO, OK	739,450
GREENFIELD, OK	738,575
RED ROCK, OK	736,473
CHANDLER, OK	731,716
BOWRING, OK	729,227
OMEGA, OK	726,869
HILLSDALE, OK	725,722
STILLWATER, OK	722,397
PONCA CITY, OK	718,869
ORLANDO, OK	709,181
MANCHESTER, OK	693,298
EAGLE RIVER, AK	582,014
GROTON, CT	13,855
FREDERICK, MD	9,539
EMINENCE, IN	7,993
SHAWNEE, OK	7,137
LAKE OSWEGO, OR	6,744
AMARILLO, TX	5,377
PORTLAND, OR	5,176

Appendix D

Origin and Destination Locations



Appendix E

Top 300 Origin-Destination City/State Paths by Annual Truckload Flow

Origin City/State	Destination City/State	Annual Truckload Flow	% of Annual Truckload Flow
THREE RIVERS, CA	CHANDLER, AZ	20,046	0.0097727%
CHANDLER, AZ	THREE RIVERS, CA	19,997	0.0097491%
CHANDLER, AZ	LOOMIS, CA	19,826	0.0096657%
CHANDLER, AZ	MOUNT HAMILTON, CA	19,655	0.0095822%
MOUNT HAMILTON, CA	CHANDLER, AZ	19,522	0.0095173%
LOOMIS, CA	CHANDLER, AZ	19,258	0.0093889%
TUCSON, AZ	LOOMIS, CA	18,810	0.0091700%
CRESCENT VALLEY, NV	MOUNT HAMILTON, CA	18,776	0.0091535%
MOUNT HAMILTON, CA	CRESCENT VALLEY, NV	18,691	0.0091124%
THREE RIVERS, CA	TUCSON, AZ	18,646	0.0090901%
SAN DIEGO, CA	LOOMIS, CA	18,638	0.0090864%
TUCSON, AZ	THREE RIVERS, CA	18,596	0.0090659%
VIOLA, TN	GORDON, GA	18,534	0.0090355%
RICHMOND, VA	OAKS, PA	18,440	0.0089901%
THREE RIVERS, CA	SAN DIEGO, CA	18,302	0.0089225%
OAKS, PA	RICHMOND, VA	18,300	0.0089215%
TUCSON, AZ	MOUNT HAMILTON, CA	18,224	0.0088847%
SAN DIEGO, CA	THREE RIVERS, CA	18,221	0.0088829%
LOOMIS, CA	TUCSON, AZ	18,167	0.0088568%
SPOTSYLVANIA, VA	BASKING RIDGE, NJ	18,162	0.0088544%
BASKING RIDGE, NJ	SPOTSYLVANIA, VA	18,104	0.0088260%
MOUNT HAMILTON, CA	TUCSON, AZ	18,062	0.0088054%
BIRMINGHAM, AL	BASKING RIDGE, NJ	17,980	0.0087658%
TUCSON, AZ	SUPAI, AZ	17,961	0.0087566%
SUPAI, AZ	TUCSON, AZ	17,899	0.0087260%
LOOMIS, CA	SAN DIEGO, CA	17,811	0.0086831%
HEBRON, CT	SPOTSYLVANIA, VA	17,784	0.0086703%
RICHMOND, VA	FAYVILLE, MA	17,727	0.0086423%
GORDON, GA	VIOLA, TN	17,703	0.0086307%
SAN DIEGO, CA	MOUNT HAMILTON, CA	17,690	0.0086241%
MOUNT HAMILTON, CA	SAN DIEGO, CA	17,460	0.0085122%
RICHMOND, VA	WARWICK, RI	17,246	0.0084079%

HARWINTON, CT	SPOTSYLVANIA, VA	17,170	0.0083708%
SPOTSYLVANIA, VA	WARWICK, RI	17,164	0.0083676%
RICHMOND, VA	WESTMORELAND, NH	16,955	0.0082658%
NEW HAMPTON, NH	RICHMOND, VA	16,928	0.0082529%
SPOTSYLVANIA, VA	WESTMORELAND, NH	16,924	0.0082509%
ATLANTA, GA	CHARLOTTE, NC	16,889	0.0082335%
CHARLOTTE, NC	ATLANTA, GA	16,874	0.0082262%
WESTMORELAND, NH	RICHMOND, VA	16,872	0.0082255%
NEW HAMPTON, NH	SPOTSYLVANIA, VA	16,816	0.0081979%
SUN VALLEY, ID	MOUNT HAMILTON, CA	16,753	0.0081672%
NASHVILLE, TN	GORDON, GA	16,697	0.0081399%
THREE RIVERS, CA	LOOMIS, CA	16,653	0.0081187%
MOUNT HAMILTON, CA	SUN VALLEY, ID	16,648	0.0081160%
POMFRET, MD	CHESTERFIELD, MA	16,577	0.0080816%
OAKS, PA	FAYVILLE, MA	16,560	0.0080734%
RICHMOND, VA	CHESTERFIELD, MA	16,546	0.0080668%
CHESTERFIELD, MA	RICHMOND, VA	16,511	0.0080494%
FAYVILLE, MA	OAKS, PA	16,457	0.0080230%
RICHMOND, VA	HEBRON, CT	16,442	0.0080157%
CHESTERFIELD, MA	SPOTSYLVANIA, VA	16,422	0.0080061%
CHESTERFIELD, MA	POMFRET, MD	16,420	0.0080053%
SPOTSYLVANIA, VA	CHESTERFIELD, MA	16,413	0.0080017%
LINCOLNVILLE, ME	RICHMOND, VA	16,407	0.0079987%
FAYVILLE, MA	RICHMOND, VA	16,393	0.0079922%
POMFRET, MD	HEBRON, CT	16,369	0.0079803%
POMFRET, MD	FAYVILLE, MA	16,368	0.0079795%
RICHMOND, VA	LINCOLNVILLE, ME	16,360	0.0079757%
SPOTSYLVANIA, VA	HEBRON, CT	16,359	0.0079753%
HEBRON, CT	RICHMOND, VA	16,318	0.0079554%
STRATHMERE, NJ	CHESTERFIELD, MA	16,305	0.0079489%
LAYTON, UT	MOUNT HAMILTON, CA	16,300	0.0079465%
SPOTSYLVANIA, VA	FAYVILLE, MA	16,287	0.0079401%
FAYVILLE, MA	POMFRET, MD	16,281	0.0079373%
HEBRON, CT	POMFRET, MD	16,264	0.0079290%
SPOTSYLVANIA, VA	LINCOLNVILLE, ME	16,249	0.0079219%
FAYVILLE, MA	SPOTSYLVANIA, VA	16,221	0.0079080%
RICHMOND, VA	BASKING RIDGE, NJ	16,197	0.0078963%
ROUND MOUNTAIN, NV	SAN DIEGO, CA	16,166	0.0078812%
MOUNT HAMILTON, CA	LAYTON, UT	16,164	0.0078801%

EMERY, UT	CHANDLER, AZ	16,136	0.0078668%
CHANDLER, AZ	EMERY, UT	16,111	0.0078545%
CHESTERFIELD, MA	STRATHMERE, NJ	16,075	0.0078368%
BASKING RIDGE, NJ	RICHMOND, VA	16,073	0.0078360%
LOTHIAN, MD	CHESTERFIELD, MA	16,053	0.0078262%
DELMONT, NJ	CHESTERFIELD, MA	16,030	0.0078148%
GORDON, GA	NASHVILLE, TN	16,026	0.0078132%
HEBRON, CT	RALEIGH, NC	16,012	0.0078063%
CHESTERFIELD, MA	DELMONT, NJ	16,010	0.0078054%
STRATHMERE, NJ	FAYVILLE, MA	15,960	0.0077811%
CHESTERFIELD, MA	LOTHIAN, MD	15,948	0.0077751%
RICHMOND, VA	GALWAY, NY	15,939	0.0077706%
DELMONT, NJ	FAYVILLE, MA	15,925	0.0077639%
GALWAY, NY	RICHMOND, VA	15,914	0.0077586%
SAN DIEGO, CA	ROUND MOUNTAIN, NV	15,905	0.0077539%
LOTHIAN, MD	FAYVILLE, MA	15,901	0.0077520%
STRATHMERE, NJ	HEBRON, CT	15,856	0.0077302%
WILMINGTON, NC	FAYVILLE, MA	15,845	0.0077247%
FAYVILLE, MA	STRATHMERE, NJ	15,840	0.0077224%
VIOLA, TN	BEAUFORT, SC	15,836	0.0077201%
LOWAKE, TX	LOOMIS, CA	15,830	0.0077176%
FAYVILLE, MA	LOTHIAN, MD	15,790	0.0076980%
FAYVILLE, MA	DELMONT, NJ	15,777	0.0076918%
GALWAY, NY	SPOTSYLVANIA, VA	15,764	0.0076852%
BROTHERS, OR	MOUNT HAMILTON, CA	15,761	0.0076838%
ATLANTA, GA	HIGH POINT, NC	15,750	0.0076783%
RICHMOND, VA	NEW HAMPTON, NH	15,749	0.0076778%
BASKING RIDGE, NJ	RALEIGH, NC	15,745	0.0076760%
LOTHIAN, MD	HEBRON, CT	15,731	0.0076692%
HIGH POINT, NC	ATLANTA, GA	15,722	0.0076650%
WARWICK, RI	RICHMOND, VA	15,711	0.0076595%
RICHMOND, VA	HARWINTON, CT	15,710	0.0076590%
HEBRON, CT	STRATHMERE, NJ	15,695	0.0076514%
RICHMOND, VA	GENOA, NY	15,653	0.0076313%
LINCOLN, DE	CHESTERFIELD, MA	15,652	0.0076306%
WARWICK, RI	POMFRET, MD	15,641	0.0076255%
HARWINTON, CT	RICHMOND, VA	15,641	0.0076253%
GENOA, NY	RICHMOND, VA	15,638	0.0076241%
POMFRET, MD	WARWICK, RI	15,634	0.0076220%

RICHMOND, VA	DELMONT, NJ	15,615	0.0076128%
NEW HAMPTON, NH	POMFRET, MD	15,608	0.0076092%
HEBRON, CT	WILMINGTON, NC	15,602	0.0076061%
HEBRON, CT	LOTHIAN, MD	15,595	0.0076031%
POMFRET, MD	NEW HAMPTON, NH	15,590	0.0076007%
POMFRET, MD	WESTMORELAND, NH	15,584	0.0075976%
RALEIGH, NC	WESTMORELAND, NH	15,573	0.0075923%
SPOTSYLVANIA, VA	NEW HAMPTON, NH	15,570	0.0075906%
CHESTERFIELD, MA	LINCOLN, DE	15,561	0.0075865%
MOUNT HAMILTON, CA	BROTHERS, OR	15,553	0.0075825%
WARWICK, RI	SPOTSYLVANIA, VA	15,550	0.0075809%
EASLEY, SC	GREENVILLE, AL	15,542	0.0075768%
GREENVILLE, AL	EASLEY, SC	15,541	0.0075764%
WARWICK, RI	RALEIGH, NC	15,537	0.0075746%
WESTMORELAND, NH	POMFRET, MD	15,519	0.0075659%
WESTMORELAND, NH	SPOTSYLVANIA, VA	15,516	0.0075644%
DELMONT, NJ	RICHMOND, VA	15,513	0.0075630%
RALEIGH, NC	HARWINTON, CT	15,504	0.0075583%
POMFRET, MD	HARWINTON, CT	15,482	0.0075479%
SPOTSYLVANIA, VA	HARWINTON, CT	15,464	0.0075391%
HARWINTON, CT	RALEIGH, NC	15,461	0.0075377%
KNOB LICK, KY	GORDON, GA	15,456	0.0075352%
LINCOLN, DE	FAYVILLE, MA	15,451	0.0075328%
OAKS, PA	WARWICK, RI	15,444	0.0075295%
HARWINTON, CT	POMFRET, MD	15,444	0.0075294%
WASHINGTON, DC	CHESTERFIELD, MA	15,441	0.0075276%
BEAUFORT, SC	VIOLA, TN	15,397	0.0075064%
LINCOLN, DE	HEBRON, CT	15,393	0.0075043%
LOOMIS, CA	LOWAKE, TX	15,386	0.0075010%
MADILL, OK	SAN ANTONIO, TX	15,386	0.0075009%
WILMINGTON, NC	BASKING RIDGE, NJ	15,368	0.0074922%
NEW HAMPTON, NH	OAKS, PA	15,368	0.0074922%
THACKERVILLE, OK	SAN ANTONIO, TX	15,367	0.0074918%
SAN ANTONIO, TX	MADILL, OK	15,363	0.0074895%
CHESTERFIELD, MA	WASHINGTON, DC	15,355	0.0074859%
FAYVILLE, MA	LINCOLN, DE	15,354	0.0074853%
WARWICK, RI	OAKS, PA	15,353	0.0074850%
SAN ANTONIO, TX	THACKERVILLE, OK	15,337	0.0074770%
RALEIGH, NC	OAKS, PA	15,323	0.0074703%

OAKS, PA	NEW HAMPTON, NH	15,320	0.0074686%
OAKS, PA	WESTMORELAND, NH	15,305	0.0074616%
QUANTICO, MD	CHESTERFIELD, MA	15,289	0.0074538%
BROOKFIELD, WI	INDIANAPOLIS, IN	15,282	0.0074503%
WASHINGTON, DC	FAYVILLE, MA	15,276	0.0074473%
HEBRON, CT	LINCOLN, DE	15,269	0.0074441%
LINCOLNVILLE, ME	RALEIGH, NC	15,258	0.0074386%
LINCOLNVILLE, ME	POMFRET, MD	15,245	0.0074324%
WESTMORELAND, NH	OAKS, PA	15,234	0.0074269%
GENOA, NY	SPOTSYLVANIA, VA	15,234	0.0074268%
BASKING RIDGE, NJ	WILMINGTON, NC	15,233	0.0074266%
POMFRET, MD	LINCOLNVILLE, ME	15,222	0.0074209%
LINCOLNVILLE, ME	SPOTSYLVANIA, VA	15,201	0.0074109%
FAYVILLE, MA	WASHINGTON, DC	15,185	0.0074030%
CHESTERFIELD, MA	QUANTICO, MD	15,184	0.0074027%
SAN ANTONIO, TX	LOOMIS, CA	15,176	0.0073986%
AUSTIN, TX	LOOMIS, CA	15,166	0.0073939%
LAYTON, UT	CHANDLER, AZ	15,151	0.0073866%
WILMINGTON, NC	HARWINTON, CT	15,136	0.0073792%
DALLAS, TX	SAN ANTONIO, TX	15,136	0.0073792%
SPOTSYLVANIA, VA	GENOA, NY	15,130	0.0073762%
RALEIGH, NC	CHESTERFIELD, MA	15,115	0.0073689%
SAN ANTONIO, TX	DALLAS, TX	15,115	0.0073686%
WASHINGTON, DC	HEBRON, CT	15,107	0.0073652%
VIOLA, TN	WACISSA, FL	15,107	0.0073648%
LOTHIAN, MD	WARWICK, RI	15,105	0.0073639%
LOWAKE, TX	THREE RIVERS, CA	15,095	0.0073589%
INDIANAPOLIS, IN	BROOKFIELD, WI	15,086	0.0073547%
QUANTICO, MD	FAYVILLE, MA	15,085	0.0073541%
LOTHIAN, MD	NEW HAMPTON, NH	15,067	0.0073453%
LOTHIAN, MD	WESTMORELAND, NH	15,053	0.0073385%
ATLANTA, GA	CHECK, VA	15,052	0.0073380%
CHECK, VA	ATLANTA, GA	15,051	0.0073378%
THREE RIVERS, CA	LOWAKE, TX	15,049	0.0073365%
CHESTERFIELD, MA	RALEIGH, NC	15,041	0.0073326%
ATLANTA, GA	RALEIGH, NC	15,033	0.0073290%
RALEIGH, NC	ATLANTA, GA	15,026	0.0073253%
NASHVILLE, TN	ATLANTA, GA	15,010	0.0073176%
HEBRON, CT	WASHINGTON, DC	14,997	0.0073112%

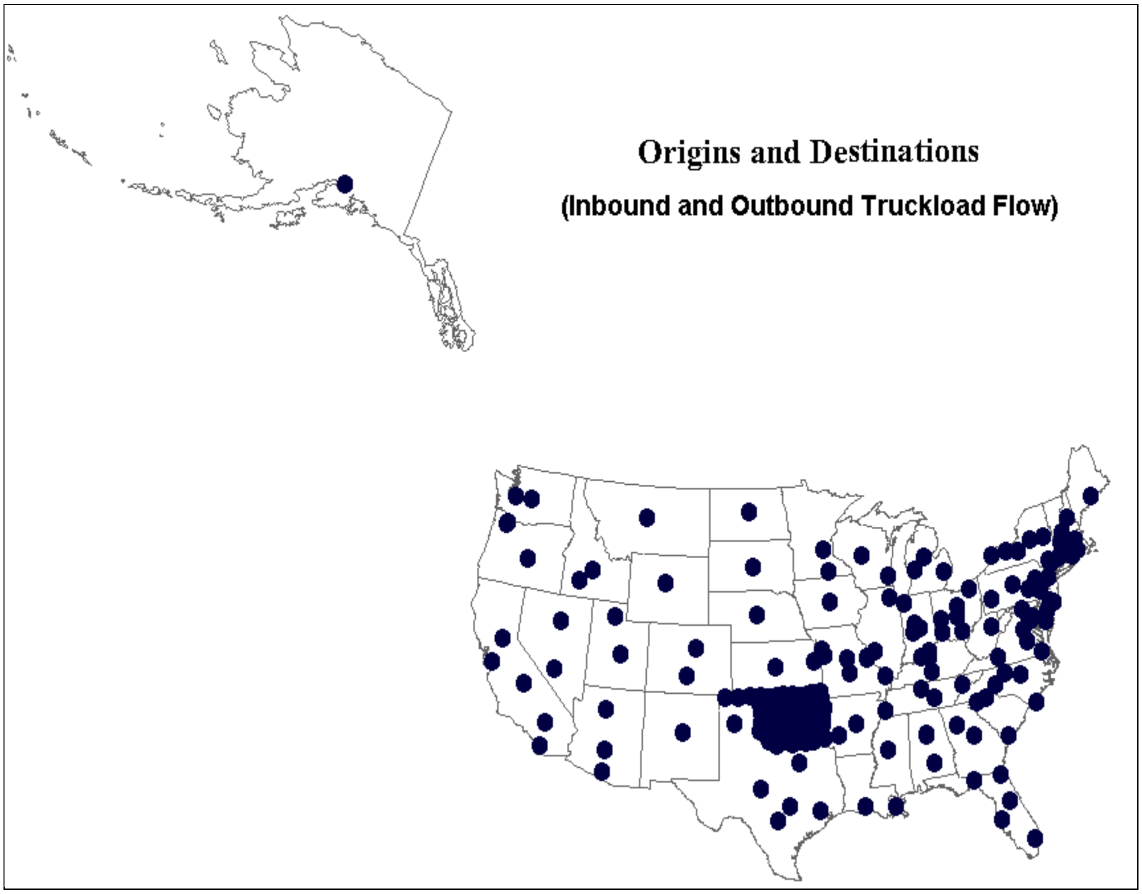
RALEIGH, NC	FAYVILLE, MA	14,994	0.0073098%
NEW HAMPTON, NH	LOTHIAN, MD	14,991	0.0073084%
HIGH POINT, NC	DELMONT, NJ	14,991	0.0073083%
CHANDLER, AZ	LAYTON, UT	14,983	0.0073046%
PACOLET, SC	GREENVILLE, AL	14,979	0.0073024%
FAYVILLE, MA	RALEIGH, NC	14,976	0.0073010%
LINCOLNVILLE, ME	WILMINGTON, NC	14,973	0.0072998%
FAYVILLE, MA	QUANTICO, MD	14,973	0.0072994%
GREENVILLE, AL	PACOLET, SC	14,972	0.0072993%
WESTMORELAND, NH	LOTHIAN, MD	14,966	0.0072962%
LINCOLNVILLE, ME	OAKS, PA	14,943	0.0072852%
LOWAKE, TX	MOUNT HAMILTON, CA	14,938	0.0072828%
LINCOLNVILLE, ME	BASKING RIDGE, NJ	14,933	0.0072804%
WARWICK, RI	LOTHIAN, MD	14,909	0.0072686%
ATLANTA, GA	WASHINGTON, DC	14,896	0.0072622%
MILL CREEK, OK	SAN ANTONIO, TX	14,889	0.0072585%
TUSSY, OK	SAN ANTONIO, TX	14,888	0.0072584%
BIRMINGHAM, AL	EASLEY, SC	14,879	0.0072539%
WASHINGTON, DC	ATLANTA, GA	14,870	0.0072493%
STRATHMERE, NJ	NEW HAMPTON, NH	14,866	0.0072473%
WILMINGTON, NC	CHESTERFIELD, MA	14,861	0.0072449%
SAN ANTONIO, TX	MILL CREEK, OK	14,860	0.0072444%
DELMONT, NJ	NEW HAMPTON, NH	14,852	0.0072408%
RALEIGH, NC	HEBRON, CT	14,851	0.0072402%
SAN ANTONIO, TX	TUSSY, OK	14,850	0.0072396%
STRATHMERE, NJ	WESTMORELAND, NH	14,842	0.0072356%
QUANTICO, MD	HEBRON, CT	14,835	0.0072325%
OAKS, PA	LINCOLNVILLE, ME	14,814	0.0072222%
NEW HAMPTON, NH	STRATHMERE, NJ	14,798	0.0072145%
EMERY, UT	TUCSON, AZ	14,793	0.0072119%
LINCOLNVILLE, ME	LOTHIAN, MD	14,792	0.0072115%
TUCSON, AZ	EMERY, UT	14,787	0.0072090%
MOUNT HAMILTON, CA	LOWAKE, TX	14,783	0.0072070%
GORDON, GA	TIPP CITY, OH	14,772	0.0072016%
WILMINGTON, NC	OAKS, PA	14,762	0.0071969%
WESTMORELAND, NH	STRATHMERE, NJ	14,758	0.0071950%
BROOKFIELD, WI	GORDON, GA	14,758	0.0071947%
LOOMIS, CA	SAN ANTONIO, TX	14,756	0.0071937%
NASHVILLE, TN	BEAUFORT, SC	14,755	0.0071932%

LOOMIS, CA	AUSTIN, TX	14,753	0.0071925%
BASKING RIDGE, NJ	LINCOLNVILLE, ME	14,751	0.0071915%
CHESTERFIELD, MA	WILMINGTON, NC	14,745	0.0071886%
MC CLURE, IL	GORDON, GA	14,742	0.0071869%
LOTHIAN, MD	HARWINTON, CT	14,735	0.0071836%
LEBANON JUNCTION,	GORDON, GA	14,735	0.0071835%
GORDON, GA	KNOB LICK, KY	14,732	0.0071821%
LOOMIS, CA	THREE RIVERS, CA	14,728	0.0071803%
APPLE VALLEY, CA	LOOMIS, CA	14,724	0.0071782%
STRATHMERE, NJ	WARWICK, RI	14,724	0.0071782%
LOTHIAN, MD	LINCOLNVILLE, ME	14,719	0.0071759%
DELMONT, NJ	WESTMORELAND, NH	14,716	0.0071743%
BROOKFIELD, WI	LEBANON JUNCTION, KY	14,714	0.0071733%
HEBRON, CT	QUANTICO, MD	14,694	0.0071636%
ACHILLE, OK	SAN ANTONIO, TX	14,683	0.0071585%
WASHINGTON, DC	NEW HAMPTON, NH	14,677	0.0071552%
HARWINTON, CT	LOTHIAN, MD	14,668	0.0071512%
WASHINGTON, DC	WESTMORELAND, NH	14,658	0.0071460%
TIPP CITY, OH	KNOB LICK, KY	14,651	0.0071429%
NEW HAMPTON, NH	DELMONT, NJ	14,650	0.0071421%
NEW HAMPTON, NH	LINCOLN, DE	14,639	0.0071366%
SAN ANTONIO, TX	ACHILLE, OK	14,637	0.0071360%
RICHMOND, VA	WALLKILL, NY	14,635	0.0071347%
NEW HAMPTON, NH	WASHINGTON, DC	14,620	0.0071274%
FAYVILLE, MA	WILMINGTON, NC	14,619	0.0071268%
WARWICK, RI	STRATHMERE, NJ	14,615	0.0071250%
BROOKFIELD, WI	RHODELIA, KY	14,612	0.0071237%
WESTMORELAND, NH	DELMONT, NJ	14,607	0.0071213%
LINCOLN, DE	NEW HAMPTON, NH	14,600	0.0071177%
WESTMORELAND, NH	WASHINGTON, DC	14,590	0.0071130%
DAVIS, OK	SAN ANTONIO, TX	14,585	0.0071107%
RHODELIA, KY	GORDON, GA	14,583	0.0071094%
BROOKFIELD, WI	TIPP CITY, OH	14,576	0.0071060%
LINCOLN, DE	WESTMORELAND, NH	14,575	0.0071056%
DELMONT, NJ	WARWICK, RI	14,566	0.0071014%
BROOKFIELD, WI	COLUMBUS, OH	14,557	0.0070969%
SAN ANTONIO, TX	DAVIS, OK	14,543	0.0070898%
RALEIGH, NC	NEW HAMPTON, NH	14,525	0.0070815%
SWINK, OK	SAN ANTONIO, TX	14,512	0.0070749%

WILMINGTON, NC	HEBRON, CT	14,508	0.0070731%
WESTMORELAND, NH	LINCOLN, DE	14,506	0.0070720%
LINCOLNVILLE, ME	STRATHMERE, NJ	14,498	0.0070682%
RHODELIA, KY	BROOKFIELD, WI	14,498	0.0070679%
RALEIGH, NC	WARWICK, RI	14,484	0.0070612%
LEBANON JUNCTION,	BROOKFIELD, WI	14,477	0.0070579%
GALWAY, NY	RALEIGH, NC	14,476	0.0070573%
NASHVILLE, TN	TIPP CITY, OH	14,474	0.0070562%
LINCOLNVILLE, ME	DELMONT, NJ	14,473	0.0070560%
WARWICK, RI	WASHINGTON, DC	14,472	0.0070554%
NEW HAMPTON, NH	RALEIGH, NC	14,470	0.0070546%
SAN ANTONIO, TX	SWINK, OK	14,468	0.0070536%
COLUMBUS, OH	BROOKFIELD, WI	14,468	0.0070532%
WACISSA, FL	VIOLA, TN	14,462	0.0070504%
WASHINGTON, DC	WARWICK, RI	14,462	0.0070504%
EASLEY, SC	BIRMINGHAM, AL	14,459	0.0070489%
STRATHMERE, NJ	LINCOLNVILLE, ME	14,455	0.0070473%
WESTMORELAND, NH	RALEIGH, NC	14,447	0.0070434%
ROUND MOUNTAIN, NV	MOUNT HAMILTON, CA	14,447	0.0070432%
TIPP CITY, OH	BROOKFIELD, WI	14,442	0.0070407%
LINCOLNVILLE, ME	WASHINGTON, DC	14,430	0.0070348%
WARWICK, RI	DELMONT, NJ	14,425	0.0070327%
LINCOLN, DE	WARWICK, RI	14,423	0.0070315%
LAYTON, UT	TUCSON, AZ	14,419	0.0070296%
BROOKFIELD, WI	LOVELAND, OH	14,417	0.0070283%
KNOB LICK, KY	TIPP CITY, OH	14,411	0.0070257%
WASHINGTON, DC	LINCOLNVILLE, ME	14,407	0.0070237%
ATOKA, OK	SAN ANTONIO, TX	14,399	0.0070200%
GORDON, GA	BROOKFIELD, WI	14,395	0.0070177%
ATLANTA, GA	NASHVILLE, TN	14,388	0.0070143%
SAN ANTONIO, TX	THREE RIVERS, CA	14,383	0.0070121%
ELMORE CITY, OK	SAN ANTONIO, TX	14,382	0.0070113%
BROOKFIELD, WI	TWINSBURG, OH	14,377	0.0070090%
BEAUFORT, SC	NASHVILLE, TN	14,377	0.0070089%

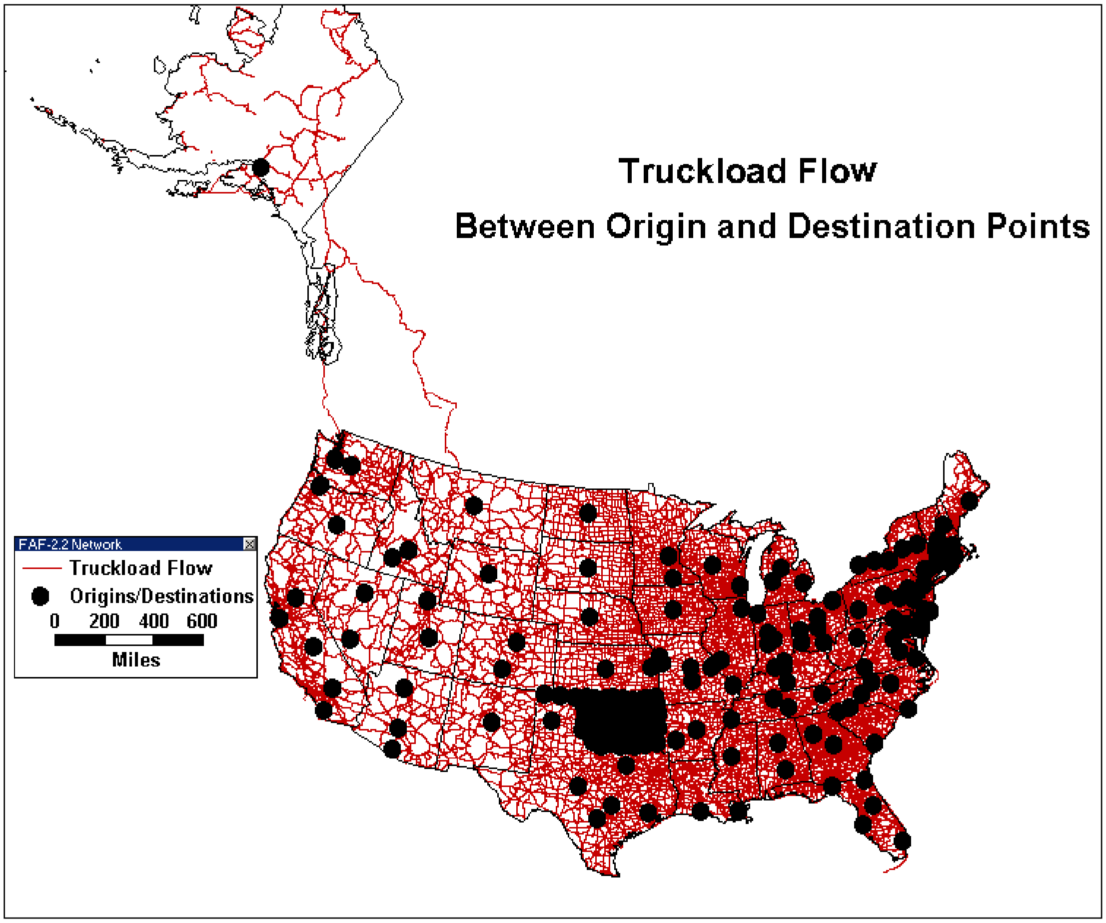
Appendix F

Origin and Destination Inbound and Outbound Truckload Flow Density



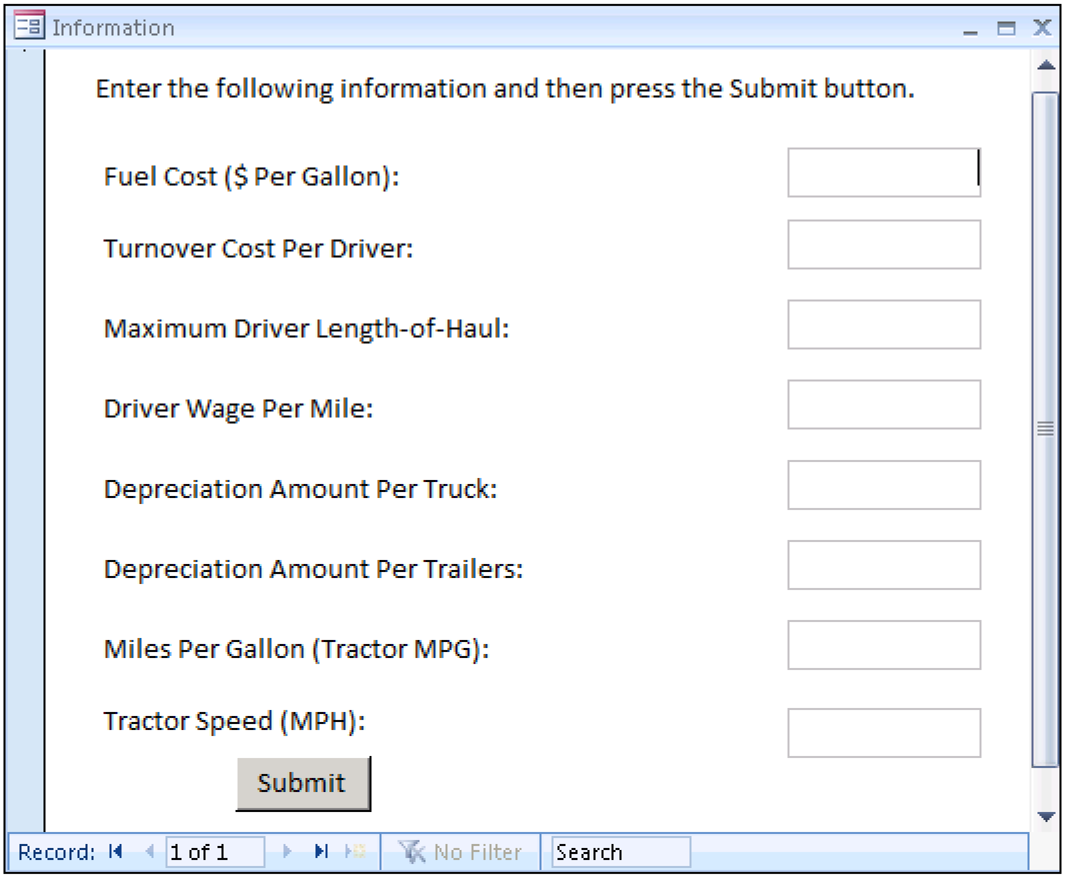
Appendix G

Truckload Flow Between Origins and Destinations



Appendix H

Parameter Input User Interface for the MIQP



Enter the following information and then press the Submit button.

Fuel Cost ($ Per Gallon):

Turnover Cost Per Driver:

Maximum Driver Length-of-Haul:

Driver Wage Per Mile:

Depreciation Amount Per Truck:

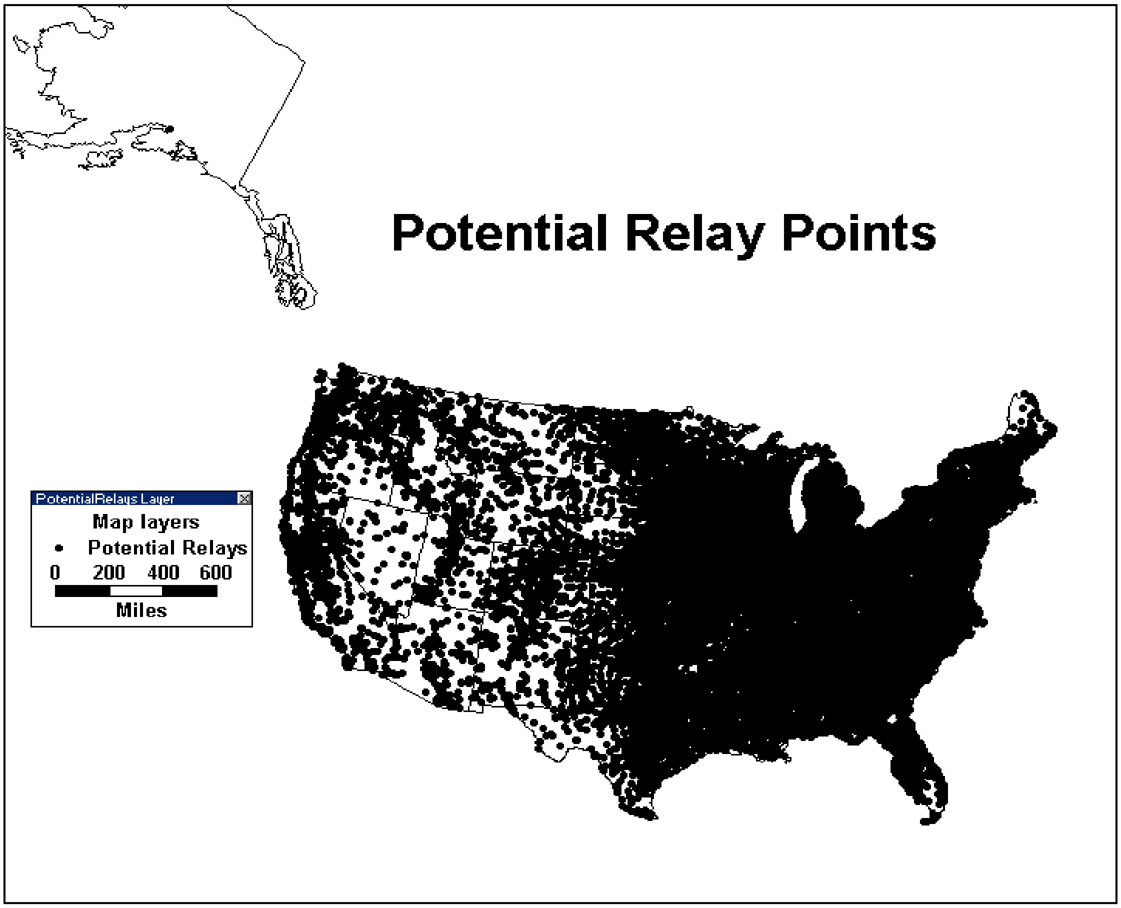
Depreciation Amount Per Trailers:

Miles Per Gallon (Tractor MPG):

Tractor Speed (MPH):

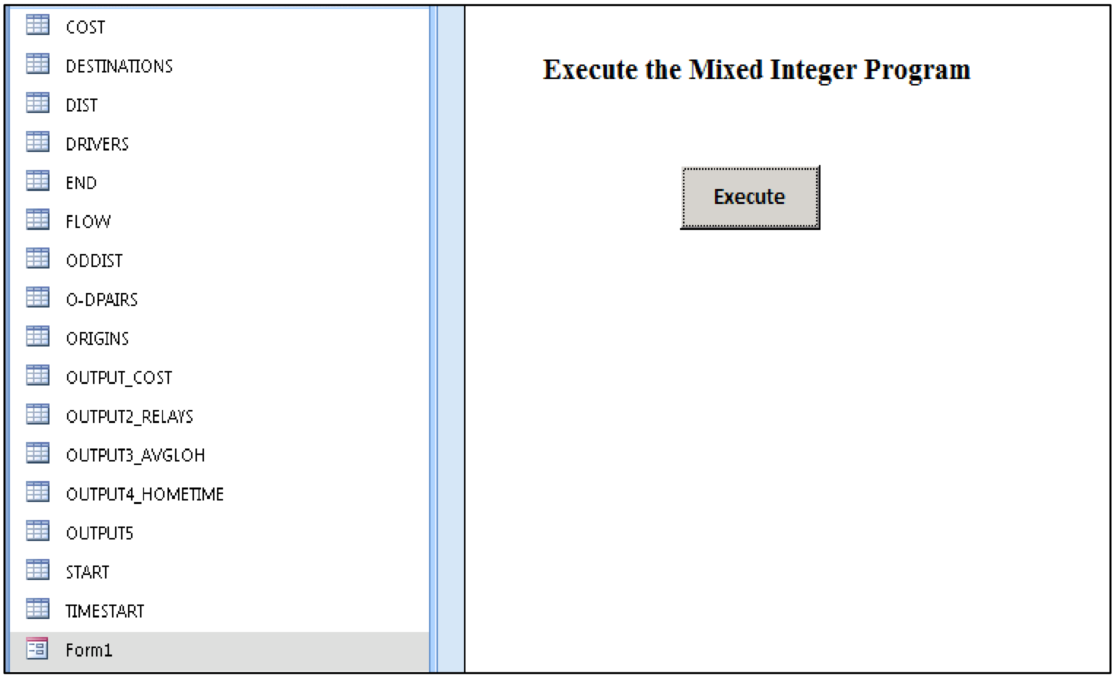
Appendix I

Potential relay Point Locations on the Highway Transportation Network



Appendix J

MIQP- User Interface



Appendix K

Origin-Destination Paths and Associated Relay Points (Top 160 Based on Greatest Truckload Flow)

Origin	Final Destination	First Relay Point	Subsequent Relay Points	Truckloads
THREE RIVERS, CA	CHANDLER, AZ	BAKERSFIELD, CA	LOS ANGELES, CA	20,046
			SALOME, AZ	20,046
			CHANDLER, AZ	20,046
CHANDLER, AZ	THREE RIVERS, CA	SALOME, AZ	WHITE WATER, CA	19,997
			THREE RIVERS, CA	19,997
CHANDLER, AZ	LOOMIS, CA	SALOME, AZ	DESERT CENTER, CA	19,826
			BAKERSFIELD, CA	19,826
			ROCKLIN, CA	19,826
			LOOMIS, CA	19,826
CHANDLER, AZ	MOUNT HAMILTON, CA	DESERT CENTER, CA	GILROY, CA	19,655
			MOUNT HAMILTON, CA	19,655
MOUNT HAMILTON, CA	CHANDLER, AZ	SOUTH DOS PALOS, CA	DESERT CENTER, CA	19,522
			CHANDLER, AZ	19,522
LOOMIS, CA	CHANDLER, AZ	STOCKTON, CA	LOS ANGELES, CA	19,258
			SALOME, AZ	19,258

			CHANDLER, AZ	19,258
TUCSON, AZ	LOOMIS, CA	DATELAND, AZ	BANNING, CA	18,810
			LOOMIS, CA	18,810
CRESCENT VALLEY, NV	MOUNT HAMILTON, CA	IMLAY, NV	WADSWORTH, NV	18,776
			MOUNT HAMILTON, CA	18,776
MOUNT HAMILTON, CA	CRESCENT VALLEY, NV	FAIRFIELD, CA	RENO, NV	18,691
			CRESCENT VALLEY, NV	18,691
THREE RIVERS, CA	TUCSON, AZ	BAKERSFIELD, CA	WHITE WATER, CA	18,646
			TUCSON, AZ	18,646
SAN DIEGO, CA	LOOMIS, CA		LOOMIS, CA	18,638
TUCSON, AZ	THREE RIVERS, CA	DATELAND, AZ	SALOME, AZ	18,596
			BANNING, CA	18,596
			THREE RIVERS, CA	18,596
VIOLA, TN	GORDON, GA	DALTON, GA	CONLEY, GA	18,534
			GORDON, GA	18,534
RICHMOND, VA	OAKS, PA		OAKS, PA	18,440
THREE RIVERS, CA	SAN DIEGO, CA	BAKERSFIELD, CA	MURRIETA, CA	18,302
			SAN DIEGO, CA	18,302
OAKS, PA	RICHMOND,	BALTIMORE,	FREDERICKSBU	18,300

	VA	MD	RG, VA	
			RICHMOND, VA	18,300
TUCSON, AZ	MOUNT HAMILTON, CA	DATELAND, AZ	BAKERSFIELD, CA	18,224
			MOUNT HAMILTON, CA	18,224
SAN DIEGO, CA	THREE RIVERS, CA	SILVERADO, CA	LEBEC, CA	18,221
			THREE RIVERS, CA	18,221
LOOMIS, CA	TUCSON, AZ	STOCKTON, CA	SAN JOAQUIN, CA	18,167
			SALOME, AZ	18,167
			DATELAND, AZ	18,167
			TUCSON, AZ	18,167
SPOTSYLVANIA, VA	BASKING RIDGE, NJ		BASKING RIDGE, NJ	18,162
BASKING RIDGE, NJ	SPOTSYLVANIA, VA		SPOTSYLVANIA, VA	18,104
MOUNT HAMILTON, CA	TUCSON, AZ	ALPAUGH, CA	DESERT CENTER, CA	18,062
			TUCSON, AZ	18,062
TUCSON, AZ	SUPAI, AZ	CHANDLER, AZ	COTTONWOOD, AZ	17,961
			SUPAI, AZ	17,961
SUPAI, AZ	TUCSON, AZ	COTTONWOOD, AZ	TUCSON, AZ	17,899
LOOMIS, CA	SAN DIEGO, CA		SAN DIEGO, CA	17,811

HEBRON, CT	SPOTSYLVANIA, VA		SPOTSYLVANIA, VA	17,784
RICHMOND, VA	FAYVILLE, MA	SPRINGFIELD, VA	SOUTHBRIDGE, MA	17,727
			FAYVILLE, MA	17,727
GORDON, GA	VIOLA, TN		VIOLA, TN	17,703
SAN DIEGO, CA	MOUNT HAMILTON, CA		MOUNT HAMILTON, CA	17,690
MOUNT HAMILTON, CA	SAN DIEGO, CA		SAN DIEGO, CA	17,460
RICHMOND, VA	WARWICK, RI	SPRINGFIELD, VA	WARWICK, RI	17,246
HARWINTON, CT	SPOTSYLVANIA, VA	NEWARK, NJ	LAUREL, MD	17,170
			SPOTSYLVANIA, VA	17,170
SPOTSYLVANIA, VA	WARWICK, RI		WARWICK, RI	17,164
RICHMOND, VA	WESTMORELAND, NH	SPRINGFIELD, VA	CRANBURY, NJ	16,955
			WESTMORELAND, NH	16,955
NEW HAMPTON, NH	RICHMOND, VA	WEST BOYLSTON, MA	NORTH HAVEN, CT	16,928
			RICHMOND, VA	16,928
SPOTSYLVANIA, VA	WESTMORELAND, NH	PEDRICKTOWN, NJ	KEARNY, NJ	16,924
			MERIDEN, CT	16,924
			WESTMORELAND, NH	16,924

ATLANTA, GA	CHARLOTTE, NC		CHARLOTTE, NC	16,889
CHARLOTTE, NC	ATLANTA, GA		ATLANTA, GA	16,874
WESTMORELAND, NH	RICHMOND, VA	EAST WINDSOR, CT	PERRY HALL, MD	16,872
			FREDERICKSBURG, VA	16,872
			RICHMOND, VA	16,872
NEW HAMPTON, NH	SPOTSYLVANIA, VA	WEST BOYLSTON, MA	NORTH HAVEN, CT	16,816
			CARTERET, NJ	16,816
			SPOTSYLVANIA, VA	16,816
SUN VALLEY, ID	MOUNT HAMILTON, CA	FILER, ID	WINNEMUCCA, NV	16,753
			RENO, NV	16,753
			SAN JOSE, CA	16,753
			MOUNT HAMILTON, CA	16,753
NASHVILLE, TN	GORDON, GA		GORDON, GA	16,697
THREE RIVERS, CA	LOOMIS, CA	SAN JOAQUIN, CA	WESTLEY, CA	16,653
			ROCKLIN, CA	16,653
			LOOMIS, CA	16,653
MOUNT HAMILTON, CA	SUN VALLEY, ID	RENO, NV	IMLAY, NV	16,648
			TUSCARORA, NV	16,648

			SUN VALLEY, ID	16,648
POMFRET, MD	CHESTERFIELD, MA		CHESTERFIELD, MA	16,577
OAKS, PA	FAYVILLE, MA		FAYVILLE, MA	16,560
RICHMOND, VA	CHESTERFIELD, MA	ELKTON, MD	BRIDGEPORT, CT	16,546
			CHESTERFIELD, MA	16,546
CHESTERFIELD, MA	RICHMOND, VA	EDISON, NJ	RICHMOND, VA	16,511
FAYVILLE, MA	OAKS, PA		OAKS, PA	16,457
RICHMOND, VA	HEBRON, CT		HEBRON, CT	16,442
CHESTERFIELD, MA	SPOTSYLVANIA, VA	ORANGE, CT	NEWARK, DE	16,422
			SPOTSYLVANIA, VA	16,422
CHESTERFIELD, MA	POMFRET, MD	ORANGE, CT	TAKOMA PARK, MD	16,420
			POMFRET, MD	16,420
SPOTSYLVANIA, VA	CHESTERFIELD, MA	LAUREL, MD	BRIDGEPORT, NJ	16,413
			MERIDEN, CT	16,413
			CHESTERFIELD, MA	16,413
LINCOLNVILLE, ME	RICHMOND, VA	SOUTH PORTLAND, ME	HARVARD, MA	16,407
			LEONIA, NJ	16,407
			WESTVILLE, NJ	16,407

			HALETHORPE, MD	16,407
			RICHMOND, VA	16,407
FAYVILLE, MA	RICHMOND, VA		RICHMOND, VA	16,393
POMFRET, MD	HEBRON, CT		HEBRON, CT	16,369
POMFRET, MD	FAYVILLE, MA	PERRY POINT, MD	WESTPORT, CT	16,368
			HOLLAND, MA	16,368
			FAYVILLE, MA	16,368
RICHMOND, VA	LINCOLNVILLE, ME	ELKTON, MD	GREENLAND, NH	16,360
			WISCASSET, ME	16,360
			LINCOLNVILLE, ME	16,360
SPOTSYLVANIA, VA	HEBRON, CT	LAUREL, MD	MERIDEN, CT	16,359
			HEBRON, CT	16,359
HEBRON, CT	RICHMOND, VA		RICHMOND, VA	16,318
STRATHMERE, NJ	CHESTERFIELD, MA	NEW BRUNSWICK, NJ	CHESTERFIELD, MA	16,305
LAYTON, UT	MOUNT HAMILTON, CA	IMLAY, NV	SAN JOSE, CA	16,300
			MOUNT HAMILTON, CA	16,300
SPOTSYLVANIA, VA	FAYVILLE, MA		FAYVILLE, MA	16,287
FAYVILLE, MA	POMFRET,	MIDDLEFIELD	LINTHICUM	16,281

	MD	, CT	HEIGHTS, MD	
			POMFRET, MD	16,281
HEBRON, CT	POMFRET, MD	MAPLE SHADE, NJ	BALTIMORE, MD	16,264
			POMFRET, MD	16,264
SPOTSYLVANIA, VA	LINCOLNVILLE, ME	LAUREL, MD	PEDRICKTOWN, NJ	16,249
			KEARNY, NJ	16,249
			LINCOLNVILLE, ME	16,249
FAYVILLE, MA	SPOTSYLVANIA, VA	MIDDLEFIELD, CT	NORTH ARLINGTON, NJ	16,221
			SPOTSYLVANIA, VA	16,221
RICHMOND, VA	BASKING RIDGE, NJ	ELKTON, MD	ROCKY HILL, NJ	16,197
			BASKING RIDGE, NJ	16,197
ROUND MOUNTAIN, NV	SAN DIEGO, CA	MOAPA, NV	HENDERSON, NV	16,166
			SAN DIEGO, CA	16,166
MOUNT HAMILTON, CA	LAYTON, UT	FAIRFIELD, CA	TUSCARORA, NV	16,164
			LAYTON, UT	16,164
EMERY, UT	CHANDLER, AZ	CIRCLEVILLE, UT	FREDONIA, AZ	16,136
			SEDONA, AZ	16,136
			CHANDLER, AZ	16,136
CHANDLER,	EMERY, UT	COTTONWOO	FLAGSTAFF, AZ	16,111

AZ		D, AZ		
			PAGE, AZ	16,111
			EMERY, UT	16,111
CHESTERFIELD, MA	STRATHMERE, NJ	ORANGE, CT	STRATHMERE, NJ	16,075
BASKING RIDGE, NJ	RICHMOND, VA	WILMINGTON, DE	HYATTSVILLE, MD	16,073
			ASHLAND, VA	16,073
			RICHMOND, VA	16,073
LOTHIAN, MD	CHESTERFIELD, MA		CHESTERFIELD, MA	16,053
DELMONT, NJ	CHESTERFIELD, MA		CHESTERFIELD, MA	16,030
GORDON, GA	NASHVILLE, TN		NASHVILLE, TN	16,026
HEBRON, CT	RALEIGH, NC	MAPLE SHADE, NJ	RALEIGH, NC	16,012
CHESTERFIELD, MA	DELMONT, NJ	ORANGE, CT	EDISON, NJ	16,010
			DELMONT, NJ	16,010
STRATHMERE, NJ	FAYVILLE, MA	NEW BRUNSWICK, NJ	ORANGE, CT	15,960
			NORTHBRIDGE, MA	15,960
			FAYVILLE, MA	15,960
CHESTERFIELD, MA	LOTHIAN, MD	ORANGE, CT	NEWARK, DE	15,948
			LOTHIAN, MD	15,948
RICHMOND,	GALWAY,	SPRINGFIELD,	PLATTEKILL, NY	15,939

VA	NY	VA		
			SCHENECTADY, NY	15,939
			GALWAY, NY	15,939
DELMONT, NJ	FAYVILLE, MA		FAYVILLE, MA	15,925
GALWAY, NY	RICHMOND, VA		RICHMOND, VA	15,914
SAN DIEGO, CA	ROUND MOUNTAIN, NV		ROUND MOUNTAIN, NV	15,905
LOTHIAN, MD	FAYVILLE, MA	EDISON, NJ	GRAFTON, MA	15,901
			FAYVILLE, MA	15,901
STRATHMERE, NJ	HEBRON, CT		HEBRON, CT	15,856
WILMINGTON, NC	FAYVILLE, MA	CALYPSO, NC	ELIZABETH, NJ	15,845
			SOUTHBOROUGH, MA	15,845
			FAYVILLE, MA	15,845
FAYVILLE, MA	STRATHMERE, NJ		STRATHMERE, NJ	15,840
VIOLA, TN	BEAUFORT, SC	DALTON, GA	DECATUR, GA	15,836
			BEAUFORT, SC	15,836
LOWAKE, TX	LOOMIS, CA	BARNHART, TX	LAS CRUCES, NM	15,830
			LORDSBURG, NM	15,830
			BLYTHE, CA	15,830

			HIGHLAND, CA	15,830
			PIRU, CA	15,830
			LOOMIS, CA	15,830
FAYVILLE, MA	LOTHIAN, MD		LOTHIAN, MD	15,790
FAYVILLE, MA	DELMONT, NJ	MIDDLEFIELD, CT	BUENA, NJ	15,777
			DELMONT, NJ	15,777
GALWAY, NY	SPOTSYLVANIA, VA		SPOTSYLVANIA, VA	15,764
BROTHERS, OR	MOUNT HAMILTON, CA	GILCHRIST, OR	DORRIS, CA	15,761
			LAKEHEAD, CA	15,761
			VALLEJO, CA	15,761
			MOUNT HAMILTON, CA	15,761
ATLANTA, GA	HIGH POINT, NC		HIGH POINT, NC	15,750
RICHMOND, VA	NEW HAMPTON, NH	SPRINGFIELD, VA	BRIDGEPORT, CT	15,749
			NEW HAMPTON, NH	15,749
BASKING RIDGE, NJ	RALEIGH, NC		RALEIGH, NC	15,745
LOTHIAN, MD	HEBRON, CT	NEWARK, DE	EDISON, NJ	15,731
			HEBRON, CT	15,731
HIGH POINT, NC	ATLANTA, GA	GASTONIA, NC	DULUTH, GA	15,722

			ATLANTA, GA	15,722
WARWICK, RI	RICHMOND, VA	DAYTON, NJ	ELK MILLS, MD	15,711
			RICHMOND, VA	15,711
RICHMOND, VA	HARWINTON, CT	ELKTON, MD	DANBURY, CT	15,710
			HARWINTON, CT	15,710
HEBRON, CT	STRATHMERE, NJ		STRATHMERE, NJ	15,695
RICHMOND, VA	GENOA, NY	GARDNERS, PA	TURBOTVILLE, PA	15,653
			SPENCER, NY	15,653
			GENOA, NY	15,653
LINCOLN, DE	CHESTERFIELD, MA	HADDONFIELD, NJ	HARTFORD, CT	15,652
			CHESTERFIELD, MA	15,652
WARWICK, RI	POMFRET, MD	DAYTON, NJ	ELK MILLS, MD	15,641
			WASHINGTON, DC	15,641
			POMFRET, MD	15,641
HARWINTON, CT	RICHMOND, VA	NEWARK, NJ	PEDRICKTOWN, NJ	15,641
			RICHMOND, VA	15,641
GENOA, NY	RICHMOND, VA		RICHMOND, VA	15,638
POMFRET, MD	WARWICK, RI	PERRY POINT, MD	WYOMING, RI	15,634
			WARWICK, RI	15,634

RICHMOND, VA	DELMONT, NJ	SPRINGFIELD, VA	ELKTON, MD	15,615
			DELMONT, NJ	15,615
NEW HAMPTON, NH	POMFRET, MD	WEST BOYLSTON, MA	CARTERET, NJ	15,608
			POMFRET, MD	15,608
HEBRON, CT	WILMINGTON, NC	NEW ROCHELLE, NY	FREDERICKSBURG, VA	15,602
			WRIGHTSVILLE BEACH, NC	15,602
			WILMINGTON, NC	15,602
HEBRON, CT	LOTHIAN, MD		LOTHIAN, MD	15,595
POMFRET, MD	NEW HAMPTON, NH	PERRY POINT, MD	HOLLAND, MA	15,590
			NEW HAMPTON, NH	15,590
POMFRET, MD	WESTMORELAND, NH		WESTMORELAND, NH	15,584
RALEIGH, NC	WESTMORELAND, NH	MEREDITHVILLE, VA	RUTHER GLEN, VA	15,573
			BRIDGEPORT, NJ	15,573
			KEARNY, NJ	15,573
			VERNON, VT	15,573
			WESTMORELAND, NH	15,573
SPOTSYLVANIA, VA	NEW HAMPTON,		NEW HAMPTON, NH	15,570

	NH			
CHESTERFIELD, MA	LINCOLN, DE	EDISON, NJ	NEW CASTLE, DE	15,561
			LINCOLN, DE	15,561
MOUNT HAMILTON, CA	BROTHERS, OR	FAIRFIELD, CA	MIDLAND, OR	15,553
			BROTHERS, OR	15,553
WARWICK, RI	SPOTSYLVANIA, VA	STRATFORD, CT	ELK MILLS, MD	15,550
			SPOTSYLVANIA, VA	15,550
EASLEY, SC	GREENVILLE, AL	BUFORD, GA	MONTGOMERY, AL	15,542
			GREENVILLE, AL	15,542
GREENVILLE, AL	EASLEY, SC	OPELIKA, AL	FAIR PLAY, SC	15,541
			EASLEY, SC	15,541
WARWICK, RI	RALEIGH, NC	STRATFORD, CT	ELK MILLS, MD	15,537
			RICHMOND, VA	15,537
			HENDERSON, NC	15,537
			RALEIGH, NC	15,537
WESTMORELAND, NH	POMFRET, MD	HARRISON, NY	PERRY HALL, MD	15,519
			POMFRET, MD	15,519
WESTMORELAND, NH	SPOTSYLVANIA, VA	EAST WINDSOR, CT	HARRISON, NY	15,516
			MOUNT LAUREL, NJ	15,516

			FREDERICKSBURG, VA	15,516
			SPOTSYLVANIA, VA	15,516
DELMONT, NJ	RICHMOND, VA	WHITE MARSH, MD	FREDERICKSBURG, VA	15,513
			RICHMOND, VA	15,513
RALEIGH, NC	HARWINTON, CT		HARWINTON, CT	15,504
POMFRET, MD	HARWINTON, CT	PERRY POINT, MD	TRENTON, NJ	15,482
			HARWINTON, CT	15,482
SPOTSYLVANIA, VA	HARWINTON, CT		HARWINTON, CT	15,464
HARWINTON, CT	RALEIGH, NC		RALEIGH, NC	15,461
KNOB LICK, KY	GORDON, GA		GORDON, GA	15,456
LINCOLN, DE	FAYVILLE, MA	HADDONFIELD, NJ	BRONX, NY	15,451
			FAYVILLE, MA	15,451
OAKS, PA	WARWICK, RI		WARWICK, RI	15,444
HARWINTON, CT	POMFRET, MD		POMFRET, MD	15,444
WASHINGTON, DC	CHESTERFIELD, MA	NEWARK, DE	CHESTERFIELD, MA	15,441
BEAUFORT, SC	VIOLA, TN	GIRARD, GA	EMERSON, GA	15,397
			WHITWELL, TN	15,397
			VIOLA, TN	15,397

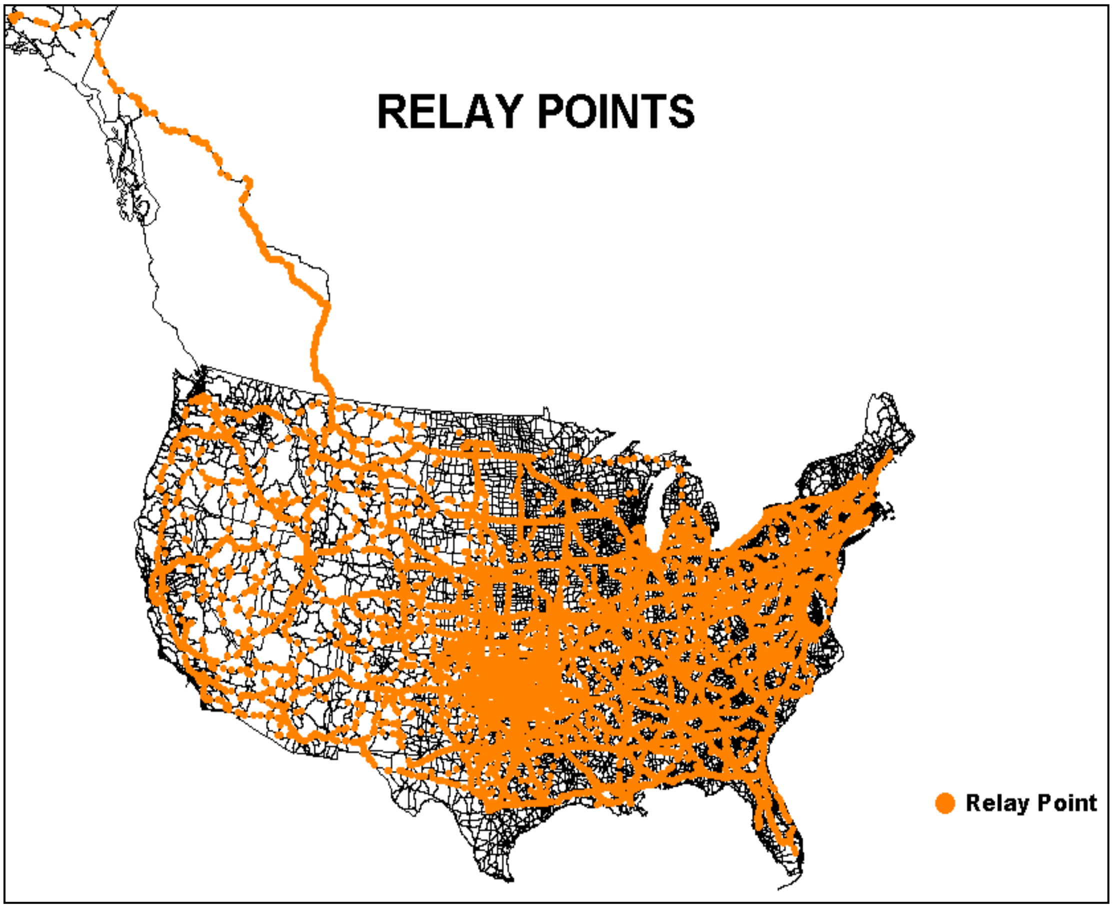
LINCOLN, DE	HEBRON, CT	BRONX, NY	MARLBOROUGH, CT	15,393
			HEBRON, CT	15,393
LOOMIS, CA	LOWAKE, TX	STOCKTON, CA	BANNING, CA	15,386
			TUCSON, AZ	15,386
			SIERRA BLANCA, TX	15,386
			LOWAKE, TX	15,386
MADILL, OK	SAN ANTONIO, TX		SAN ANTONIO, TX	15,386
WILMINGTON, NC	BASKING RIDGE, NJ	CALYPSO, NC	CLAYMONT, DE	15,368
			BASKING RIDGE, NJ	15,368
NEW HAMPTON, NH	OAKS, PA		OAKS, PA	15,368
THACKERVILLE, OK	SAN ANTONIO, TX		SAN ANTONIO, TX	15,367
SAN ANTONIO, TX	MADILL, OK	AUSTIN, TX	ELM MOTT, TX	15,363
			MADILL, OK	15,363
CHESTERFIELD, MA	WASHINGTON, DC	ORANGE, CT	NEWARK, DE	15,355
			WASHINGTON, DC	15,355
FAYVILLE, MA	LINCOLN, DE		LINCOLN, DE	15,354
WARWICK, RI	OAKS, PA		OAKS, PA	15,353
SAN ANTONIO,	THACKERVI		THACKERVILLE,	15,337

TX	LLE, OK		OK	
RALEIGH, NC	OAKS, PA	MEREDITHVILLE, VA	RUTHER GLEN, VA	15,323
			OAKS, PA	15,323
OAKS, PA	NEW HAMPTON, NH		NEW HAMPTON, NH	15,320
OAKS, PA	WESTMORELAND, NH		WESTMORELAND, NH	15,305
QUANTICO, MD	CHESTERFIELD, MA		CHESTERFIELD, MA	15,289
BROOKFIELD, WI	INDIANAPOLIS, IN		INDIANAPOLIS, IN	15,282
WASHINGTON, DC	FAYVILLE, MA		FAYVILLE, MA	15,276
HEBRON, CT	LINCOLN, DE	NEW ROCHELLE, NY	CHERRY HILL, NJ	15,269
			LINCOLN, DE	15,269
LINCOLNVILLE, ME	RALEIGH, NC	HARVARD, MA	THORNBURG, VA	15,258
			ALBERTA, VA	15,258
			CARY, NC	15,258
			RALEIGH, NC	15,258
LINCOLNVILLE, ME	POMFRET, MD	HARVARD, MA	LEONIA, NJ	15,245
			WESTVILLE, NJ	15,245
			BALTIMORE, MD	15,245
			POMFRET, MD	15,245
WESTMORELA	OAKS, PA	EAST	HARRISON, NY	15,234

ND, NH		WINDSOR, CT		
			OAKS, PA	15,234
GENOA, NY	SPOTSYLVANIA, VA		SPOTSYLVANIA, VA	15,234
BASKING RIDGE, NJ	WILMINGTON, NC	WILMINGTON, DE	SILVER SPRING, MD	15,233
			STUDLEY, VA	15,233
			WILMINGTON, NC	15,233
POMFRET, MD	LINCOLNVILLE, ME	PERRY POINT, MD	WESTPORT, CT	15,222
			SEABROOK, NH	15,222
			LINCOLNVILLE, ME	15,222

APPENDIX L

Relay Points across the U.S. as Determined by the MIQP



APPENDIX M

M.1. Origin-Destination Paths with the Average Length-of-Haul for the Relay and Non-Relay Point Network (Top 300 Based on Greatest Truckload Flow)

Origin City/State	**Destination City/State**	**Annual Truckload Flow**	**Relay Point Avg. LOH**	**Non-Relay Point Avg. LOH**	**Difference (Relay-Non-Relay)**
THREE RIVERS, CA	CHANDLER, AZ	20,046	150	601	451
CHANDLER, AZ	THREE RIVERS, CA	19,997	200	601	401
CHANDLER, AZ	LOOMIS, CA	19,826	161	806	645
CHANDLER, AZ	MOUNT HAMILTON, CA	19,655	243	729	486
MOUNT HAMILTON, CA	CHANDLER, AZ	19,522	243	729	486
LOOMIS, CA	CHANDLER, AZ	19,258	202	806	605
TUCSON, AZ	LOOMIS, CA	18,810	300	899	599
CRESCENT VALLEY, NV	MOUNT HAMILTON, CA	18,776	166	498	332
MOUNT HAMILTON, CA	CRESCENT VALLEY, NV	18,691	166	498	332
THREE RIVERS, CA	TUCSON, AZ	18,646	231	693	462
SAN DIEGO, CA	LOOMIS, CA	18,638	275	550	275
TUCSON, AZ	THREE RIVERS, CA	18,596	173	693	520
VIOLA, TN	GORDON, GA	18,534	98	294	196
RICHMOND, VA	OAKS, PA	18,440	131	261	131
THREE RIVERS, CA	SAN DIEGO, CA	18,302	115	344	229
OAKS, PA	RICHMOND, VA	18,300	87	261	174
TUCSON, AZ	MOUNT HAMILTON, CA	18,224	274	822	548

SAN DIEGO, CA	THREE RIVERS, CA	18,221	115	344	229
LOOMIS, CA	TUCSON, AZ	18,167	180	899	719
SPOTSYLVANIA, VA	BASKING RIDGE, NJ	18,162	145	290	145
BASKING RIDGE, NJ	SPOTSYLVANIA, VA	18,104	145	290	145
MOUNT HAMILTON, CA	TUCSON, AZ	18,062	274	822	548
TUCSON, AZ	SUPAI, AZ	17,961	77	307	230
SUPAI, AZ	TUCSON, AZ	17,899	102	307	205
LOOMIS, CA	SAN DIEGO, CA	17,811	275	550	275
HEBRON, CT	SPOTSYLVANIA, VA	17,784	213	426	213
RICHMOND, VA	FAYVILLE, MA	17,727	180	539	359
GORDON, GA	VIOLA, TN	17,703	147	294	147
SAN DIEGO, CA	MOUNT HAMILTON, CA	17,690	237	473	237
MOUNT HAMILTON, CA	SAN DIEGO, CA	17,460	237	473	237
RICHMOND, VA	WARWICK, RI	17,246	167	502	335
HARWINTON, CT	SPOTSYLVANIA, VA	17,170	132	397	265
SPOTSYLVANIA, VA	WARWICK, RI	17,164	234	467	234
RICHMOND, VA	WESTMORELAND, NH	16,955	189	567	378
NEW HAMPTON, NH	RICHMOND, VA	16,928	208	624	416
SPOTSYLVANIA, VA	WESTMORELAND, NH	16,924	133	532	399
ATLANTA, GA	CHARLOTTE, NC	16,889	136	271	136
CHARLOTTE, NC	ATLANTA, GA	16,874	136	271	136
WESTMORELAND, NH	RICHMOND, VA	16,872	142	567	425

NEW HAMPTON, NH	SPOTSYLVANIA, VA	16,816	147	589	442
SUN VALLEY, ID	MOUNT HAMILTON, CA	16,753	164	821	657
NASHVILLE, TN	GORDON, GA	16,697	177	354	177
THREE RIVERS, CA	LOOMIS, CA	16,653	77	306	230
MOUNT HAMILTON, CA	SUN VALLEY, ID	16,648	164	821	657
POMFRET, MD	CHESTERFIELD, MA	16,577	212	423	212
OAKS, PA	FAYVILLE, MA	16,560	151	301	151
RICHMOND, VA	CHESTERFIELD, MA	16,546	171	512	341
CHESTERFIELD, MA	RICHMOND, VA	16,511	171	512	341
FAYVILLE, MA	OAKS, PA	16,457	151	301	151
RICHMOND, VA	HEBRON, CT	16,442	230	460	230
CHESTERFIELD, MA	SPOTSYLVANIA, VA	16,422	159	477	318
CHESTERFIELD, MA	POMFRET, MD	16,420	141	423	282
SPOTSYLVANIA, VA	CHESTERFIELD, MA	16,413	119	477	358
LINCOLNVILLE, ME	RICHMOND, VA	16,407	125	747	623
FAYVILLE, MA	RICHMOND, VA	16,393	269	538	269
POMFRET, MD	HEBRON, CT	16,369	186	371	186
POMFRET, MD	FAYVILLE, MA	16,368	112	449	337
RICHMOND, VA	LINCOLNVILLE, ME	16,360	187	747	560
SPOTSYLVANIA, VA	HEBRON, CT	16,359	142	425	283
HEBRON, CT	RICHMOND, VA	16,318	230	460	230
STRATHMERE, NJ	CHESTERFIELD, MA	16,305	101	302	201

LAYTON, UT	MOUNT HAMILTON, CA	16,300	272	815	543
SPOTSYLVANIA, VA	FAYVILLE, MA	16,287	252	504	252
FAYVILLE, MA	POMFRET, MD	16,281	150	449	299
HEBRON, CT	POMFRET, MD	16,264	124	371	247
SPOTSYLVANIA, VA	LINCOLNVILLE, ME	16,249	178	712	534
FAYVILLE, MA	SPOTSYLVANIA, VA	16,221	168	504	336
RICHMOND, VA	BASKING RIDGE, NJ	16,197	108	324	216
ROUND MOUNTAIN, NV	SAN DIEGO, CA	16,166	166	497	331
MOUNT HAMILTON, CA	LAYTON, UT	16,164	272	815	543
EMERY, UT	CHANDLER, AZ	16,136	138	553	415
CHANDLER, AZ	EMERY, UT	16,111	138	553	415
CHESTERFIELD, MA	STRATHMERE, NJ	16,075	101	303	202
BASKING RIDGE, NJ	RICHMOND, VA	16,073	81	324	243
LOTHIAN, MD	CHESTERFIELD, MA	16,053	198	396	198
DELMONT, NJ	CHESTERFIELD, MA	16,030	147	293	147
GORDON, GA	NASHVILLE, TN	16,026	177	354	177
HEBRON, CT	RALEIGH, NC	16,012	209	626	417
CHESTERFIELD, MA	DELMONT, NJ	16,010	98	293	195
STRATHMERE, NJ	FAYVILLE, MA	15,960	82	329	247
CHESTERFIELD, MA	LOTHIAN, MD	15,948	132	396	264
RICHMOND, VA	GALWAY, NY	15,939	129	516	387
DELMONT, NJ	FAYVILLE, MA	15,925	160	319	160

GALWAY, NY	RICHMOND, VA	15,914	258	516	258
SAN DIEGO, CA	ROUND MOUNTAIN, NV	15,905	249	497	249
LOTHIAN, MD	FAYVILLE, MA	15,901	141	422	281
STRATHMERE, NJ	HEBRON, CT	15,856	126	251	126
WILMINGTON, NC	FAYVILLE, MA	15,845	202	809	607
FAYVILLE, MA	STRATHMERE, NJ	15,840	165	329	165
VIOLA, TN	BEAUFORT, SC	15,836	152	456	304
LOWAKE, TX	LOOMIS, CA	15,830	239	1,670	1,431
FAYVILLE, MA	LOTHIAN, MD	15,790	211	422	211
FAYVILLE, MA	DELMONT, NJ	15,777	106	319	213
GALWAY, NY	SPOTSYLVANIA, VA	15,764	241	482	241
BROTHERS, OR	MOUNT HAMILTON, CA	15,761	119	594	475
ATLANTA, GA	HIGH POINT, NC	15,750	164	328	164
RICHMOND, VA	NEW HAMPTON, NH	15,749	208	624	416
BASKING RIDGE, NJ	RALEIGH, NC	15,745	245	490	245
LOTHIAN, MD	HEBRON, CT	15,731	115	344	229
HIGH POINT, NC	ATLANTA, GA	15,722	109	328	219
WARWICK, RI	RICHMOND, VA	15,711	167	502	335
RICHMOND, VA	HARWINTON, CT	15,710	144	432	288
HEBRON, CT	STRATHMERE, NJ	15,695	126	251	126
RICHMOND, VA	GENOA, NY	15,653	110	438	329
LINCOLN, DE	CHESTERFIELD, MA	15,652	119	357	238

WARWICK, RI	POMFRET, MD	15,641	103	413	310
HARWINTON, CT	RICHMOND, VA	15,641	144	432	288
GENOA, NY	RICHMOND, VA	15,638	219	438	219
POMFRET, MD	WARWICK, RI	15,634	138	413	275
RICHMOND, VA	DELMONT, NJ	15,615	89	268	179
NEW HAMPTON, NH	POMFRET, MD	15,608	178	534	356
HEBRON, CT	WILMINGTON, NC	15,602	183	731	548
HEBRON, CT	LOTHIAN, MD	15,595	172	344	172
POMFRET, MD	NEW HAMPTON, NH	15,590	178	535	357
POMFRET, MD	WESTMORELAND, NH	15,584	239	477	239
RALEIGH, NC	WESTMORELAND, NH	15,573	122	732	610
SPOTSYLVANIA, VA	NEW HAMPTON, NH	15,570	295	589	295
CHESTERFIELD, MA	LINCOLN, DE	15,561	119	357	238
MOUNT HAMILTON, CA	BROTHERS, OR	15,553	198	594	396
WARWICK, RI	SPOTSYLVANIA, VA	15,550	156	467	311
EASLEY, SC	GREENVILLE, AL	15,542	115	344	229
GREENVILLE, AL	EASLEY, SC	15,541	115	344	229
WARWICK, RI	RALEIGH, NC	15,537	133	667	534
WESTMORELAND, NH	POMFRET, MD	15,519	159	477	318
WESTMORELAND, NH	SPOTSYLVANIA, VA	15,516	106	531	425
DELMONT, NJ	RICHMOND, VA	15,513	89	268	179
RALEIGH, NC	HARWINTON, CT	15,504	299	597	299

POMFRET, MD	HARWINTON, CT	15,482	114	343	229
SPOTSYLVANIA, VA	HARWINTON, CT	15,464	199	397	199
HARWINTON, CT	RALEIGH, NC	15,461	299	597	299
KNOB LICK, KY	GORDON, GA	15,456	214	428	214
LINCOLN, DE	FAYVILLE, MA	15,451	128	384	256
OAKS, PA	WARWICK, RI	15,444	133	265	133
HARWINTON, CT	POMFRET, MD	15,444	172	343	172
WASHINGTON, DC	CHESTERFIELD, MA	15,441	134	402	268
BEAUFORT, SC	VIOLA, TN	15,397	114	456	342
LINCOLN, DE	HEBRON, CT	15,393	102	305	203
LOOMIS, CA	LOWAKE, TX	15,386	334	1,670	1,336
MADILL, OK	SAN ANTONIO, TX	15,386	195	390	195
WILMINGTON, NC	BASKING RIDGE, NJ	15,368	198	595	397
NEW HAMPTON, NH	OAKS, PA	15,368	194	387	194
THACKERVILLE, OK	SAN ANTONIO, TX	15,367	185	370	185
SAN ANTONIO, TX	MADILL, OK	15,363	130	390	260
CHESTERFIELD, MA	WASHINGTON, DC	15,355	134	402	268
FAYVILLE, MA	LINCOLN, DE	15,354	192	384	192
WARWICK, RI	OAKS, PA	15,353	133	265	133
SAN ANTONIO, TX	THACKERVILLE, OK	15,337	185	370	185
RALEIGH, NC	OAKS, PA	15,323	142	425	283
OAKS, PA	NEW HAMPTON, NH	15,320	194	387	194

OAKS, PA	WESTMORELAND, NH	15,305	165	329	165
QUANTICO, MD	CHESTERFIELD, MA	15,289	199	397	199
BROOKFIELD, WI	INDIANAPOLIS, IN	15,282	149	297	149
WASHINGTON, DC	FAYVILLE, MA	15,276	214	428	214
HEBRON, CT	LINCOLN, DE	15,269	102	305	203
LINCOLNVILLE, ME	RALEIGH, NC	15,258	183	913	730
LINCOLNVILLE, ME	POMFRET, MD	15,245	132	658	526
WESTMORELAND, NH	OAKS, PA	15,234	110	329	219
GENOA, NY	SPOTSYLVANIA, VA	15,234	202	404	202
BASKING RIDGE, NJ	WILMINGTON, NC	15,233	149	595	446
POMFRET, MD	LINCOLNVILLE, ME	15,222	164	657	493
LINCOLNVILLE, ME	SPOTSYLVANIA, VA	15,201	178	712	534
FAYVILLE, MA	WASHINGTON, DC	15,185	214	428	214
CHESTERFIELD, MA	QUANTICO, MD	15,184	99	397	298
SAN ANTONIO, TX	LOOMIS, CA	15,176	221	1,770	1,549
AUSTIN, TX	LOOMIS, CA	15,166	164	1,799	1,635
LAYTON, UT	CHANDLER, AZ	15,151	141	704	563
WILMINGTON, NC	HARWINTON, CT	15,136	140	702	562
DALLAS, TX	SAN ANTONIO, TX	15,136	96	288	192
SPOTSYLVANIA, VA	GENOA, NY	15,130	202	404	202
RALEIGH, NC	CHESTERFIELD, MA	15,115	113	677	564
SAN ANTONIO, TX	DALLAS, TX	15,115	144	288	144

WASHINGTON, DC	HEBRON, CT	15,107	117	350	233
VIOLA, TN	WACISSA, FL	15,107	226	451	226
LOTHIAN, MD	WARWICK, RI	15,105	129	386	257
LOWAKE, TX	THREE RIVERS, CA	15,095	244	1,464	1,220
INDIANAPOLIS, IN	BROOKFIELD, WI	15,086	149	297	149
QUANTICO, MD	FAYVILLE, MA	15,085	141	423	282
LOTHIAN, MD	NEW HAMPTON, NH	15,067	127	507	380
LOTHIAN, MD	WESTMORELAND, NH	15,053	113	450	338
ATLANTA, GA	CHECK, VA	15,052	200	399	200
CHECK, VA	ATLANTA, GA	15,051	133	399	266
THREE RIVERS, CA	LOWAKE, TX	15,049	209	1,464	1,255
CHESTERFIELD, MA	RALEIGH, NC	15,041	169	677	508
ATLANTA, GA	RALEIGH, NC	15,033	128	383	255
RALEIGH, NC	ATLANTA, GA	15,026	192	383	192
NASHVILLE, TN	ATLANTA, GA	15,010	128	255	128
HEBRON, CT	WASHINGTON, DC	14,997	175	350	175
RALEIGH, NC	FAYVILLE, MA	14,994	234	703	469
NEW HAMPTON, NH	LOTHIAN, MD	14,991	169	507	338
HIGH POINT, NC	DELMONT, NJ	14,991	160	479	319
CHANDLER, AZ	LAYTON, UT	14,983	176	704	528
PACOLET, SC	GREENVILLE, AL	14,979	130	389	259
FAYVILLE, MA	RALEIGH, NC	14,976	234	703	469

LINCOLNVILLE, ME	WILMINGTON, NC	14,973	254	1,017	763
FAYVILLE, MA	QUANTICO, MD	14,973	106	423	317
GREENVILLE, AL	PACOLET, SC	14,972	195	389	195
WESTMORELAND, NH	LOTHIAN, MD	14,966	225	450	225
LINCOLNVILLE, ME	OAKS, PA	14,943	170	510	340
LOWAKE, TX	MOUNT HAMILTON, CA	14,938	227	1,592	1,365
LINCOLNVILLE, ME	BASKING RIDGE, NJ	14,933	148	444	296
WARWICK, RI	LOTHIAN, MD	14,909	129	386	257
ATLANTA, GA	WASHINGTON, DC	14,896	215	644	429
MILL CREEK, OK	SAN ANTONIO, TX	14,889	137	412	275
TUSSY, OK	SAN ANTONIO, TX	14,888	101	403	302
BIRMINGHAM, AL	EASLEY, SC	14,879	145	289	145
WASHINGTON, DC	ATLANTA, GA	14,870	129	644	515
STRATHMERE, NJ	NEW HAMPTON, NH	14,866	138	414	276
WILMINGTON, NC	CHESTERFIELD, MA	14,861	196	782	587
SAN ANTONIO, TX	MILL CREEK, OK	14,860	206	412	206
DELMONT, NJ	NEW HAMPTON, NH	14,852	135	405	270
RALEIGH, NC	HEBRON, CT	14,851	208	625	417
SAN ANTONIO, TX	TUSSY, OK	14,850	101	403	302
STRATHMERE, NJ	WESTMORELAND, NH	14,842	119	357	238
QUANTICO, MD	HEBRON, CT	14,835	86	345	259
OAKS, PA	LINCOLNVILLE, ME	14,814	170	510	340

NEW HAMPTON, NH	STRATHMERE, NJ	14,798	138	414	276
EMERY, UT	TUCSON, AZ	14,793	131	655	524
LINCOLNVILLE, ME	LOTHIAN, MD	14,792	210	631	421
TUCSON, AZ	EMERY, UT	14,787	218	655	437
MOUNT HAMILTON, CA	LOWAKE, TX	14,783	265	1,592	1,327
GORDON, GA	TIPP CITY, OH	14,772	204	613	409
WILMINGTON, NC	OAKS, PA	14,762	133	530	398
WESTMORELAND, NH	STRATHMERE, NJ	14,758	179	357	179
BROOKFIELD, WI	GORDON, GA	14,758	151	908	757
LOOMIS, CA	SAN ANTONIO, TX	14,756	221	1,770	1,549
NASHVILLE, TN	BEAUFORT, SC	14,755	172	516	344
LOOMIS, CA	AUSTIN, TX	14,753	360	1,799	1,439
BASKING RIDGE, NJ	LINCOLNVILLE, ME	14,751	148	443	295
CHESTERFIELD, MA	WILMINGTON, NC	14,745	261	782	521
MC CLURE, IL	GORDON, GA	14,742	184	553	369
LOTHIAN, MD	HARWINTON, CT	14,735	105	316	211
LEBANON JUNCTION, KY	GORDON, GA	14,735	240	480	240
GORDON, GA	KNOB LICK, KY	14,732	214	428	214
LOOMIS, CA	THREE RIVERS, CA	14,728	77	306	230
APPLE VALLEY, CA	LOOMIS, CA	14,724	118	473	355
STRATHMERE, NJ	WARWICK, RI	14,724	146	292	146
LOTHIAN, MD	LINCOLNVILLE, ME	14,719	210	630	420

DELMONT, NJ	WESTMORELAND, NH	14,716	174	347	174
BROOKFIELD, WI	LEBANON JUNCTION, KY	14,714	143	430	287
HEBRON, CT	QUANTICO, MD	14,694	86	345	259
ACHILLE, OK	SAN ANTONIO, TX	14,683	97	389	292
WASHINGTON, DC	NEW HAMPTON, NH	14,677	171	513	342
HARWINTON, CT	LOTHIAN, MD	14,668	158	316	158
WASHINGTON, DC	WESTMORELAND, NH	14,658	152	455	303
TIPP CITY, OH	KNOB LICK, KY	14,651	136	271	136
NEW HAMPTON, NH	DELMONT, NJ	14,650	135	405	270
NEW HAMPTON, NH	LINCOLN, DE	14,639	117	469	352
SAN ANTONIO, TX	ACHILLE, OK	14,637	130	389	259
RICHMOND, VA	WALLKILL, NY	14,635	134	403	269
NEW HAMPTON, NH	WASHINGTON, DC	14,620	128	513	385
FAYVILLE, MA	WILMINGTON, NC	14,619	202	808	606
WARWICK, RI	STRATHMERE, NJ	14,615	146	292	146
BROOKFIELD, WI	RHODELIA, KY	14,612	104	417	313
WESTMORELAND, NH	DELMONT, NJ	14,607	116	347	231
LINCOLN, DE	NEW HAMPTON, NH	14,600	235	469	235
WESTMORELAND, NH	WASHINGTON, DC	14,590	228	455	228
DAVIS, OK	SAN ANTONIO, TX	14,585	204	408	204
RHODELIA, KY	GORDON, GA	14,583	272	543	272
BROOKFIELD, WI	TIPP CITY, OH	14,576	200	399	200

LINCOLN, DE	WESTMORELAND, NH	14,575	206	411	206
DELMONT, NJ	WARWICK, RI	14,566	142	283	142
BROOKFIELD, WI	COLUMBUS, OH	14,557	107	427	320
SAN ANTONIO, TX	DAVIS, OK	14,543	82	408	326
RALEIGH, NC	NEW HAMPTON, NH	14,525	263	788	525
SWINK, OK	SAN ANTONIO, TX	14,512	209	417	209
WILMINGTON, NC	HEBRON, CT	14,508	146	730	584
WESTMORELAND, NH	LINCOLN, DE	14,506	137	411	274
LINCOLNVILLE, ME	STRATHMERE, NJ	14,498	179	538	359
RHODELIA, KY	BROOKFIELD, WI	14,498	209	417	209
RALEIGH, NC	WARWICK, RI	14,484	222	666	444
LEBANON JUNCTION, KY	BROOKFIELD, WI	14,477	143	430	287
GALWAY, NY	RALEIGH, NC	14,476	136	681	545
NASHVILLE, TN	TIPP CITY, OH	14,474	168	336	168
LINCOLNVILLE, ME	DELMONT, NJ	14,473	132	528	396
WARWICK, RI	WASHINGTON, DC	14,472	98	391	293
NEW HAMPTON, NH	RALEIGH, NC	14,470	263	788	525
SAN ANTONIO, TX	SWINK, OK	14,468	139	417	278
COLUMBUS, OH	BROOKFIELD, WI	14,468	142	427	285
WACISSA, FL	VIOLA, TN	14,462	150	451	301
WASHINGTON, DC	WARWICK, RI	14,462	130	391	261
EASLEY, SC	BIRMINGHAM, AL	14,459	96	289	193

STRATHMERE, NJ	LINCOLNVILLE, ME	14,455	179	537	358
WESTMORELAND, NH	RALEIGH, NC	14,447	183	731	548
ROUND MOUNTAIN, NV	MOUNT HAMILTON, CA	14,447	242	483	242
TIPP CITY, OH	BROOKFIELD, WI	14,442	133	399	266
LINCOLNVILLE, ME	WASHINGTON, DC	14,430	159	636	477
WARWICK, RI	DELMONT, NJ	14,425	142	283	142
LINCOLN, DE	WARWICK, RI	14,423	116	347	231
LAYTON, UT	TUCSON, AZ	14,419	134	806	672
BROOKFIELD, WI	LOVELAND, OH	14,417	105	419	314
KNOB LICK, KY	TIPP CITY, OH	14,411	135	270	135
WASHINGTON, DC	LINCOLNVILLE, ME	14,407	106	636	530
ATOKA, OK	SAN ANTONIO, TX	14,399	105	419	314
GORDON, GA	BROOKFIELD, WI	14,395	227	908	681
ATLANTA, GA	NASHVILLE, TN	14,388	128	255	128
SAN ANTONIO, TX	THREE RIVERS, CA	14,383	313	1,565	1,252
ELMORE CITY, OK	SAN ANTONIO, TX	14,382	212	424	212
BROOKFIELD, WI	TWINSBURG, OH	14,377	156	467	311
BEAUFORT, SC	NASHVILLE, TN	14,377	129	516	387
WATSON, OK	SAN ANTONIO, TX	14,369	237	474	237

M.2. Origin-Destination Paths with the Average Driver Home Days per Week for the Relay and Non-Relay Point Network (Top 300 Based on Greatest Truckload Flow)

Origin City/State	Destination City/State	Annual Truckload Flow	Relay Point Avg. Driver Days Home/Week	Non-Relay Point Avg. Driver Days Home/Week	Difference (Relay-Non-Relay)
THREE RIVERS, CA	CHANDLER, AZ	20,046	6	2	4
CHANDLER, AZ	THREE RIVERS, CA	19,997	5.5	2	3.5
CHANDLER, AZ	LOOMIS, CA	19,826	5.5	2	3.5
CHANDLER, AZ	MOUNT HAMILTON, CA	19,655	5	2	3
MOUNT HAMILTON, CA	CHANDLER, AZ	19,522	5	2	3
LOOMIS, CA	CHANDLER, AZ	19,258	5	2	3
TUCSON, AZ	LOOMIS, CA	18,810	3.5	1	2.5
CRESCENT VALLEY, NV	MOUNT HAMILTON, CA	18,776	5.5	3	2.5
MOUNT HAMILTON, CA	CRESCENT VALLEY, NV	18,691	7	3	4
THREE RIVERS, CA	TUCSON, AZ	18,646	5	2	3
SAN DIEGO, CA	LOOMIS, CA	18,638	3	3	0
TUCSON, AZ	THREE RIVERS, CA	18,596	6	2	4
VIOLA, TN	GORDON, GA	18,534	7	4	3
RICHMOND, VA	OAKS, PA	18,440	7	4	3
THREE RIVERS, CA	SAN DIEGO, CA	18,302	7	4	3
OAKS, PA	RICHMOND, VA	18,300	7	4	3

TUCSON, AZ	MOUNT HAMILTON, CA	18,224	5	2	3
SAN DIEGO, CA	THREE RIVERS, CA	18,221	7	4	3
LOOMIS, CA	TUCSON, AZ	18,167	6	1	5
SPOTSYLVANIA, VA	BASKING RIDGE, NJ	18,162	7	4	3
BASKING RIDGE, NJ	SPOTSYLVANIA, VA	18,104	7	4	3
MOUNT HAMILTON, CA	TUCSON, AZ	18,062	4	2	2
TUCSON, AZ	SUPAI, AZ	17,961	7	4	3
SUPAI, AZ	TUCSON, AZ	17,899	7	4	3
LOOMIS, CA	SAN DIEGO, CA	17,811	3	3	0
HEBRON, CT	SPOTSYLVANIA, VA	17,784	4	3	1
RICHMOND, VA	FAYVILLE, MA	17,727	5	3	2
GORDON, GA	VIOLA, TN	17,703	7	4	3
SAN DIEGO, CA	MOUNT HAMILTON, CA	17,690	3	3	0
MOUNT HAMILTON, CA	SAN DIEGO, CA	17,460	3	3	0
RICHMOND, VA	WARWICK, RI	17,246	5	3	2
HARWINTON, CT	SPOTSYLVANIA, VA	17,170	7	3	4
SPOTSYLVANIA, VA	WARWICK, RI	17,164	3	3	0
RICHMOND, VA	WESTMORELAND, NH	16,955	5.5	2	3.5
NEW HAMPTON, NH	RICHMOND, VA	16,928	5	2	3

SPOTSYLVANIA, VA	WESTMORELAND, NH	16,924	7	3	4
ATLANTA, GA	CHARLOTTE, NC	16,889	7	4	3
CHARLOTTE, NC	ATLANTA, GA	16,874	7	4	3
WESTMORELAND, NH	RICHMOND, VA	16,872	6	2	4
NEW HAMPTON, NH	SPOTSYLVANIA, VA	16,816	6	2	4
SUN VALLEY, ID	MOUNT HAMILTON, CA	16,753	5.5	2	3.5
NASHVILLE, TN	GORDON, GA	16,697	7	3	4
THREE RIVERS, CA	LOOMIS, CA	16,653	7	4	3
MOUNT HAMILTON, CA	SUN VALLEY, ID	16,648	7	2	5
POMFRET, MD	CHESTERFIELD, MA	16,577	4	3	1
OAKS, PA	FAYVILLE, MA	16,560	7	4	3
RICHMOND, VA	CHESTERFIELD, MA	16,546	7	3	4
CHESTERFIELD, MA	RICHMOND, VA	16,511	5.5	3	2.5
FAYVILLE, MA	OAKS, PA	16,457	7	4	3
RICHMOND, VA	HEBRON, CT	16,442	3	3	0
CHESTERFIELD, MA	SPOTSYLVANIA, VA	16,422	7	3	4
CHESTERFIELD, MA	POMFRET, MD	16,420	5.5	3	2.5
SPOTSYLVANIA, VA	CHESTERFIELD, MA	16,413	7	3	4
LINCOLNVILLE, ME	RICHMOND, VA	16,407	7	2	5

FAYVILLE, MA	RICHMOND, VA	16,393	3	3	0
POMFRET, MD	HEBRON, CT	16,369	4	3	1
POMFRET, MD	FAYVILLE, MA	16,368	7	3	4
RICHMOND, VA	LINCOLNVILLE, ME	16,360	5.67	2	3.67
SPOTSYLVANIA, VA	HEBRON, CT	16,359	5.5	3	2.5
HEBRON, CT	RICHMOND, VA	16,318	3	3	0
STRATHMERE, NJ	CHESTERFIELD, MA	16,305	7	4	3
LAYTON, UT	MOUNT HAMILTON, CA	16,300	5	2	3
SPOTSYLVANIA, VA	FAYVILLE, MA	16,287	3	3	0
FAYVILLE, MA	POMFRET, MD	16,281	5.5	3	2.5
HEBRON, CT	POMFRET, MD	16,264	7	3	4
SPOTSYLVANIA, VA	LINCOLNVILLE, ME	16,249	5.67	2	3.67
FAYVILLE, MA	SPOTSYLVANIA, VA	16,221	5.5	3	2.5
RICHMOND, VA	BASKING RIDGE, NJ	16,197	7	4	3
ROUND MOUNTAIN, NV	SAN DIEGO, CA	16,166	5.5	3	2.5
MOUNT HAMILTON, CA	LAYTON, UT	16,164	5	2	3
EMERY, UT	CHANDLER, AZ	16,136	7	2	5
CHANDLER, AZ	EMERY, UT	16,111	6	2	4
CHESTERFIELD, MA	STRATHMERE, NJ	16,075	7	4	3

BASKING RIDGE, NJ	RICHMOND, VA	16,073	7	4	3
LOTHIAN, MD	CHESTERFIELD, MA	16,053	4	3	1
DELMONT, NJ	CHESTERFIELD, MA	16,030	7	4	3
GORDON, GA	NASHVILLE, TN	16,026	4	3	1
HEBRON, CT	RALEIGH, NC	16,012	5	2	3
CHESTERFIELD, MA	DELMONT, NJ	16,010	7	4	3
STRATHMERE, NJ	FAYVILLE, MA	15,960	7	4	3
CHESTERFIELD, MA	LOTHIAN, MD	15,948	7	3	4
RICHMOND, VA	GALWAY, NY	15,939	6	3	3
DELMONT, NJ	FAYVILLE, MA	15,925	7	4	3
GALWAY, NY	RICHMOND, VA	15,914	3	3	0
SAN DIEGO, CA	ROUND MOUNTAIN, NV	15,905	3	3	0
LOTHIAN, MD	FAYVILLE, MA	15,901	7	3	4
STRATHMERE, NJ	HEBRON, CT	15,856	7	4	3
WILMINGTON, NC	FAYVILLE, MA	15,845	5.67	2	3.67
FAYVILLE, MA	STRATHMERE, NJ	15,840	7	4	3
VIOLA, TN	BEAUFORT, SC	15,836	5.5	3	2.5
LOWAKE, TX	LOOMIS, CA	15,830	5	0	5
FAYVILLE, MA	LOTHIAN, MD	15,790	7	3	4

FAYVILLE, MA	DELMONT, NJ	15,777	7	4	3
GALWAY, NY	SPOTSYLVANIA, VA	15,764	7	3	4
BROTHERS, OR	MOUNT HAMILTON, CA	15,761	7	2	5
ATLANTA, GA	HIGH POINT, NC	15,750	7	4	3
RICHMOND, VA	NEW HAMPTON, NH	15,749	5.5	2	3.5
BASKING RIDGE, NJ	RALEIGH, NC	15,745	3	3	0
LOTHIAN, MD	HEBRON, CT	15,731	7	4	3
HIGH POINT, NC	ATLANTA, GA	15,722	7	4	3
WARWICK, RI	RICHMOND, VA	15,711	7	3	4
RICHMOND, VA	HARWINTON, CT	15,710	7	3	4
HEBRON, CT	STRATHMERE, NJ	15,695	7	4	3
RICHMOND, VA	GENOA, NY	15,653	7	3	4
LINCOLN, DE	CHESTERFIELD, MA	15,652	7	3	4
WARWICK, RI	POMFRET, MD	15,641	7	3	4
HARWINTON, CT	RICHMOND, VA	15,641	7	3	4
GENOA, NY	RICHMOND, VA	15,638	4	3	1
POMFRET, MD	WARWICK, RI	15,634	5.5	3	2.5
RICHMOND, VA	DELMONT, NJ	15,615	7	4	3
NEW HAMPTON, NH	POMFRET, MD	15,608	7	3	4

HEBRON, CT	WILMINGTON, NC	15,602	5	2	3
HEBRON, CT	LOTHIAN, MD	15,595	7	4	3
POMFRET, MD	NEW HAMPTON, NH	15,590	5.5	3	2.5
POMFRET, MD	WESTMORELAND, NH	15,584	3	3	0
RALEIGH, NC	WESTMORELAND, NH	15,573	7	2	5
SPOTSYLVANIA, VA	NEW HAMPTON, NH	15,570	3	2	1
CHESTERFIELD, MA	LINCOLN, DE	15,561	7	3	4
MOUNT HAMILTON, CA	BROTHERS, OR	15,553	5.5	2	3.5
WARWICK, RI	SPOTSYLVANIA, VA	15,550	7	3	4
EASLEY, SC	GREENVILLE, AL	15,542	7	4	3
GREENVILLE, AL	EASLEY, SC	15,541	7	4	3
WARWICK, RI	RALEIGH, NC	15,537	7	2	5
WESTMORELAND, NH	POMFRET, MD	15,519	7	3	4
WESTMORELAND, NH	SPOTSYLVANIA, VA	15,516	7	3	4
DELMONT, NJ	RICHMOND, VA	15,513	7	4	3
RALEIGH, NC	HARWINTON, CT	15,504	4	2	2
POMFRET, MD	HARWINTON, CT	15,482	7	4	3
SPOTSYLVANIA, VA	HARWINTON, CT	15,464	7	3	4
HARWINTON, CT	RALEIGH, NC	15,461	3	2	1

KNOB LICK, KY	GORDON, GA	15,456	7	3	4
LINCOLN, DE	FAYVILLE, MA	15,451	7	3	4
OAKS, PA	WARWICK, RI	15,444	7	4	3
HARWINTON, CT	POMFRET, MD	15,444	7	4	3
WASHINGTON, DC	CHESTERFIELD, MA	15,441	5.5	3	2.5
BEAUFORT, SC	VIOLA, TN	15,397	7	3	4
LINCOLN, DE	HEBRON, CT	15,393	7	4	3
LOOMIS, CA	LOWAKE, TX	15,386	3	0	3
MADILL, OK	SAN ANTONIO, TX	15,386	7	3	4
WILMINGTON, NC	BASKING RIDGE, NJ	15,368	5	2	3
NEW HAMPTON, NH	OAKS, PA	15,368	4	3	1
THACKERVILLE, OK	SAN ANTONIO, TX	15,367	4	3	1
SAN ANTONIO, TX	MADILL, OK	15,363	7	3	4
CHESTERFIELD, MA	WASHINGTON, DC	15,355	7	3	4
FAYVILLE, MA	LINCOLN, DE	15,354	7	3	4
WARWICK, RI	OAKS, PA	15,353	7	4	3
SAN ANTONIO, TX	THACKERVILLE, OK	15,337	4	3	1
RALEIGH, NC	OAKS, PA	15,323	7	3	4
OAKS, PA	NEW HAMPTON, NH	15,320	4	3	1

OAKS, PA	WESTMORELAND, NH	15,305	7	4	3
QUANTICO, MD	CHESTERFIELD, MA	15,289	7	3	4
BROOKFIELD, WI	INDIANAPOLIS, IN	15,282	7	4	3
WASHINGTON, DC	FAYVILLE, MA	15,276	4	3	1
HEBRON, CT	LINCOLN, DE	15,269	7	4	3
LINCOLNVILLE, ME	RALEIGH, NC	15,258	6	1	5
LINCOLNVILLE, ME	POMFRET, MD	15,245	7	2	5
WESTMORELAND, NH	OAKS, PA	15,234	7	4	3
GENOA, NY	SPOTSYLVANIA, VA	15,234	7	3	4
BASKING RIDGE, NJ	WILMINGTON, NC	15,233	6	2	4
POMFRET, MD	LINCOLNVILLE, ME	15,222	7	2	5
LINCOLNVILLE, ME	SPOTSYLVANIA, VA	15,201	5.67	2	3.67
FAYVILLE, MA	WASHINGTON, DC	15,185	4	3	1
CHESTERFIELD, MA	QUANTICO, MD	15,184	7	3	4
SAN ANTONIO, TX	LOOMIS, CA	15,176	5.57	0	5.57
AUSTIN, TX	LOOMIS, CA	15,166	6.1	0	6.1
LAYTON, UT	CHANDLER, AZ	15,151	6	2	4
WILMINGTON, NC	HARWINTON, CT	15,136	6	2	4
DALLAS, TX	SAN ANTONIO, TX	15,136	7	4	3

SPOTSYLVANIA, VA	GENOA, NY	15,130	4	3	1
RALEIGH, NC	CHESTERFIELD, MA	15,115	7	2	5
SAN ANTONIO, TX	DALLAS, TX	15,115	7	4	3
WASHINGTON, DC	HEBRON, CT	15,107	7	4	3
VIOLA, TN	WACISSA, FL	15,107	3	3	0
LOTHIAN, MD	WARWICK, RI	15,105	7	3	4
LOWAKE, TX	THREE RIVERS, CA	15,095	5	1	4
INDIANAPOLIS, IN	BROOKFIELD, WI	15,086	7	4	3
QUANTICO, MD	FAYVILLE, MA	15,085	7	3	4
LOTHIAN, MD	NEW HAMPTON, NH	15,067	7	3	4
LOTHIAN, MD	WESTMORELAND, NH	15,053	7	3	4
ATLANTA, GA	CHECK, VA	15,052	4	3	1
CHECK, VA	ATLANTA, GA	15,051	7	3	4
THREE RIVERS, CA	LOWAKE, TX	15,049	5.67	1	4.67
CHESTERFIELD, MA	RALEIGH, NC	15,041	5.67	2	3.67
ATLANTA, GA	RALEIGH, NC	15,033	7	3	4
RALEIGH, NC	ATLANTA, GA	15,026	4	3	1
NASHVILLE, TN	ATLANTA, GA	15,010	7	4	3
HEBRON, CT	WASHINGTON, DC	14,997	7	4	3

RALEIGH, NC	FAYVILLE, MA	14,994	5	2	3
NEW HAMPTON, NH	LOTHIAN, MD	14,991	5.5	3	2.5
HIGH POINT, NC	DELMONT, NJ	14,991	7	3	4
CHANDLER, AZ	LAYTON, UT	14,983	5.67	2	3.67
PACOLET, SC	GREENVILLE, AL	14,979	7	3	4
FAYVILLE, MA	RALEIGH, NC	14,976	5.5	2	3.5
LINCOLNVILLE, ME	WILMINGTON, NC	14,973	5.67	1	4.67
FAYVILLE, MA	QUANTICO, MD	14,973	7	3	4
GREENVILLE, AL	PACOLET, SC	14,972	7	3	4
WESTMORELAND, NH	LOTHIAN, MD	14,966	4	3	1
LINCOLNVILLE, ME	OAKS, PA	14,943	7	3	4
LOWAKE, TX	MOUNT HAMILTON, CA	14,938	5.33	0	5.33
LINCOLNVILLE, ME	BASKING RIDGE, NJ	14,933	5.5	3	2.5
WARWICK, RI	LOTHIAN, MD	14,909	7	3	4
ATLANTA, GA	WASHINGTON, DC	14,896	5	2	3
MILL CREEK, OK	SAN ANTONIO, TX	14,889	7	3	4
TUSSY, OK	SAN ANTONIO, TX	14,888	7	3	4
BIRMINGHAM, AL	EASLEY, SC	14,879	7	4	3
WASHINGTON, DC	ATLANTA, GA	14,870	7	2	5

STRATHMERE, NJ	NEW HAMPTON, NH	14,866	7	3	4
WILMINGTON, NC	CHESTERFIELD, MA	14,861	5.67	2	3.67
SAN ANTONIO, TX	MILL CREEK, OK	14,860	4	3	1
DELMONT, NJ	NEW HAMPTON, NH	14,852	5.5	3	2.5
RALEIGH, NC	HEBRON, CT	14,851	5	2	3
SAN ANTONIO, TX	TUSSY, OK	14,850	7	3	4
STRATHMERE, NJ	WESTMORELAND, NH	14,842	7	3	4
QUANTICO, MD	HEBRON, CT	14,835	7	4	3
OAKS, PA	LINCOLNVILLE, ME	14,814	5	3	2
NEW HAMPTON, NH	STRATHMERE, NJ	14,798	5.5	3	2.5
EMERY, UT	TUCSON, AZ	14,793	7	2	5
LINCOLNVILLE, ME	LOTHIAN, MD	14,792	5.5	2	3.5
TUCSON, AZ	EMERY, UT	14,787	5.5	2	3.5
MOUNT HAMILTON, CA	LOWAKE, TX	14,783	4.8	0	4.8
GORDON, GA	TIPP CITY, OH	14,772	5	2	3
WILMINGTON, NC	OAKS, PA	14,762	7	3	4
WESTMORELAND, NH	STRATHMERE, NJ	14,758	4	3	1
BROOKFIELD, WI	GORDON, GA	14,758	6.4	1	5.4
LOOMIS, CA	SAN ANTONIO, TX	14,756	5.43	0	5.43

NASHVILLE, TN	BEAUFORT, SC	14,755	5.5	3	2.5
LOOMIS, CA	AUSTIN, TX	14,753	4	0	4
BASKING RIDGE, NJ	LINCOLNVILLE, ME	14,751	7	3	4
CHESTERFIELD, MA	WILMINGTON, NC	14,745	3.5	2	1.5
MC CLURE, IL	GORDON, GA	14,742	5	2	3
LOTHIAN, MD	HARWINTON, CT	14,735	7	4	3
LEBANON JUNCTION, KY	GORDON, GA	14,735	3	3	0
GORDON, GA	KNOB LICK, KY	14,732	4	3	1
LOOMIS, CA	THREE RIVERS, CA	14,728	7	4	3
APPLE VALLEY, CA	LOOMIS, CA	14,724	7	3	4
STRATHMERE, NJ	WARWICK, RI	14,724	7	4	3
LOTHIAN, MD	LINCOLNVILLE, ME	14,719	5	2	3
DELMONT, NJ	WESTMORELAND, NH	14,716	7	4	3
BROOKFIELD, WI	LEBANON JUNCTION, KY	14,714	7	3	4
HEBRON, CT	QUANTICO, MD	14,694	7	4	3
ACHILLE, OK	SAN ANTONIO, TX	14,683	7	3	4
WASHINGTON, DC	NEW HAMPTON, NH	14,677	5.5	3	2.5
HARWINTON, CT	LOTHIAN, MD	14,668	7	4	3
WASHINGTON, DC	WESTMORELAND, NH	14,658	5.5	3	2.5

TIPP CITY, OH	KNOB LICK, KY	14,651	7	4	3
NEW HAMPTON, NH	DELMONT, NJ	14,650	7	3	4
NEW HAMPTON, NH	LINCOLN, DE	14,639	7	3	4
SAN ANTONIO, TX	ACHILLE, OK	14,637	7	3	4
RICHMOND, VA	WALLKILL, NY	14,635	5.5	3	2.5
NEW HAMPTON, NH	WASHINGTON, DC	14,620	6	3	3
FAYVILLE, MA	WILMINGTON, NC	14,619	5.67	2	3.67
WARWICK, RI	STRATHMERE, NJ	14,615	7	4	3
BROOKFIELD, WI	RHODELIA, KY	14,612	7	3	4
WESTMORELAND, NH	DELMONT, NJ	14,607	7	4	3
LINCOLN, DE	NEW HAMPTON, NH	14,600	3	3	0
WESTMORELAND, NH	WASHINGTON, DC	14,590	7	3	4
DAVIS, OK	SAN ANTONIO, TX	14,585	4	3	1
RHODELIA, KY	GORDON, GA	14,583	7	3	4
BROOKFIELD, WI	TIPP CITY, OH	14,576	7	3	4
LINCOLN, DE	WESTMORELAND, NH	14,575	4	3	1
DELMONT, NJ	WARWICK, RI	14,566	7	4	3
BROOKFIELD, WI	COLUMBUS, OH	14,557	7	3	4
SAN ANTONIO, TX	DAVIS, OK	14,543	7	3	4

RALEIGH, NC	NEW HAMPTON, NH	14,525	5	2	3
SWINK, OK	SAN ANTONIO, TX	14,512	7	3	4
WILMINGTON, NC	HEBRON, CT	14,508	6	2	4
WESTMORELAND, NH	LINCOLN, DE	14,506	7	3	4
LINCOLNVILLE, ME	STRATHMERE, NJ	14,498	5	3	2
RHODELIA, KY	BROOKFIELD, WI	14,498	7	3	4
RALEIGH, NC	WARWICK, RI	14,484	5	2	3
LEBANON JUNCTION, KY	BROOKFIELD, WI	14,477	5.5	3	2.5
GALWAY, NY	RALEIGH, NC	14,476	7	2	5
NASHVILLE, TN	TIPP CITY, OH	14,474	7	4	3
LINCOLNVILLE, ME	DELMONT, NJ	14,473	7	3	4
WARWICK, RI	WASHINGTON, DC	14,472	7	3	4
NEW HAMPTON, NH	RALEIGH, NC	14,470	5	2	3
SAN ANTONIO, TX	SWINK, OK	14,468	7	3	4
COLUMBUS, OH	BROOKFIELD, WI	14,468	7	3	4
WACISSA, FL	VIOLA, TN	14,462	7	3	4
WASHINGTON, DC	WARWICK, RI	14,462	7	3	4
EASLEY, SC	BIRMINGHAM, AL	14,459	7	4	3
STRATHMERE, NJ	LINCOLNVILLE, ME	14,455	5	3	2

WESTMORELAND, NH	RALEIGH, NC	14,447	5.67	2	3.67
ROUND MOUNTAIN, NV	MOUNT HAMILTON, CA	14,447	4	3	1
TIPP CITY, OH	BROOKFIELD, WI	14,442	7	3	4
LINCOLNVILLE, ME	WASHINGTON, DC	14,430	5.67	2	3.67
WARWICK, RI	DELMONT, NJ	14,425	7	4	3
LINCOLN, DE	WARWICK, RI	14,423	7	4	3
LAYTON, UT	TUCSON, AZ	14,419	7	2	5
BROOKFIELD, WI	LOVELAND, OH	14,417	7	3	4
KNOB LICK, KY	TIPP CITY, OH	14,411	7	4	3
WASHINGTON, DC	LINCOLNVILLE, ME	14,407	7	2	5
ATOKA, OK	SAN ANTONIO, TX	14,399	7	3	4
GORDON, GA	BROOKFIELD, WI	14,395	4.67	1	3.67
ATLANTA, GA	NASHVILLE, TN	14,388	7	4	3
SAN ANTONIO, TX	THREE RIVERS, CA	14,383	4	0	4
ELMORE CITY, OK	SAN ANTONIO, TX	14,382	4	3	1
BROOKFIELD, WI	TWINSBURG, OH	14,377	7	3	4
BEAUFORT, SC	NASHVILLE, TN	14,377	6	3	3
WATSON, OK	SAN ANTONIO, TX	14,369	3	3	0

APPENDIX N

Origin-Destination Path Driver Quantities for the Top 300 Paths Based on Driver Quantities (Non-Relay Point Network)

Origin City/State	Destination City/State	Relay Point Driver Quantity	Non-Relay Point Driver Quantity
EAGLE RIVER, AK	RUSKIN, FL	508	506
EAGLE RIVER, AK	WESTON, FL	504	502
RUSKIN, FL	EAGLE RIVER, AK	498	496
WESTON, FL	EAGLE RIVER, AK	495	493
EAGLE RIVER, AK	ZELLWOOD, FL	489	487
ZELLWOOD, FL	EAGLE RIVER, AK	480	478
EAGLE RIVER, AK	JACKSONVILLE, FL	471	469
JACKSONVILLE, FL	EAGLE RIVER, AK	464	462
EAGLE RIVER, AK	WACISSA, FL	461	459
WACISSA, FL	EAGLE RIVER, AK	459	458
EAGLE RIVER, AK	GORDON, GA	454	452
GORDON, GA	EAGLE RIVER, AK	450	448
DAVANT, LA	LOOMIS, CA	446	449
LOOMIS, CA	DAVANT, LA	436	439
PERRY, LA	LOOMIS, CA	429	432
LINCOLNVILLE, ME	MOUNT HAMILTON, CA	427	427
MOUNT HAMILTON, CA	LINCOLNVILLE, ME	425	426
FAYVILLE, MA	MOUNT HAMILTON, CA	421	422

MOUNT HAMILTON, CA	FAYVILLE, MA	420	420
LOOMIS, CA	PERRY, LA	418	422
CHESTERFIELD, MA	MOUNT HAMILTON, CA	410	411
NEW HAMPTON, NH	MOUNT HAMILTON, CA	409	410
DAVANT, LA	MOUNT HAMILTON, CA	408	411
MOUNT HAMILTON, CA	NEW HAMPTON, NH	407	407
MOUNT HAMILTON, CA	CHESTERFIELD, MA	407	407
WESTMORELAND, NH	MOUNT HAMILTON, CA	406	407
LOTHIAN, MD	MOUNT HAMILTON, CA	405	406
MOUNT HAMILTON, CA	DAVANT, LA	404	408
MOUNT HAMILTON, CA	LOTHIAN, MD	404	405
MOUNT HAMILTON, CA	WESTMORELAND, NH	403	403
EAGLE RIVER, AK	FAYVILLE, MA	402	400
QUANTICO, MD	MOUNT HAMILTON, CA	399	400
GALWAY, NY	MOUNT HAMILTON, CA	398	399
LINCOLN, DE	MOUNT HAMILTON, CA	398	399
MOUNT HAMILTON, CA	QUANTICO, MD	397	398
POMFRET, MD	MOUNT HAMILTON, CA	396	397
EAGLE RIVER, AK	LINCOLNVILLE, ME	396	395
FAYVILLE, MA	EAGLE RIVER, AK	396	394
MOUNT HAMILTON, CA	GALWAY, NY	396	397
WASHINGTON, DC	MOUNT HAMILTON, CA	396	397
WARWICK, RI	MOUNT HAMILTON, CA	396	396

MOUNT HAMILTON, CA	POMFRET, MD	395	396
HEBRON, CT	MOUNT HAMILTON, CA	395	396
MOUNT HAMILTON, CA	LINCOLN, DE	395	396
MOUNT HAMILTON, CA	WASHINGTON, DC	394	396
MOUNT HAMILTON, CA	WARWICK, RI	394	395
LINCOLNVILLE, ME	EAGLE RIVER, AK	392	391
MOUNT HAMILTON, CA	HEBRON, CT	392	393
EAGLE RIVER, AK	MOUNT HAMILTON, CA	392	392
MOUNT HAMILTON, CA	EAGLE RIVER, AK	392	392
GENOA, NY	MOUNT HAMILTON, CA	391	392
PERRY, LA	MOUNT HAMILTON, CA	389	393
MOUNT HAMILTON, CA	GENOA, NY	388	390
LOOMIS, CA	WESTON, FL	387	388
RALEIGH, NC	EAGLE RIVER, AK	387	386
ATLANTA, GA	EAGLE RIVER, AK	387	386
HARWINTON, CT	MOUNT HAMILTON, CA	386	387
MOUNT HAMILTON, CA	PERRY, LA	386	389
WILMINGTON, NC	EAGLE RIVER, AK	385	384
WESTON, FL	LOOMIS, CA	385	385
EAGLE RIVER, AK	ATLANTA, GA	384	383
MOUNT HAMILTON, CA	HARWINTON, CT	384	385
LOOMIS, CA	RUSKIN, FL	382	383
EAGLE RIVER, AK	CHESTERFIELD, MA	382	380

STRATHMERE, NJ	MOUNT HAMILTON, CA	382	382
CHARLOTTE, NC	EAGLE RIVER, AK	381	380
DELMONT, NJ	MOUNT HAMILTON, CA	381	382
MOUNT HAMILTON, CA	STRATHMERE, NJ	380	381
LA PORTE, TX	LOOMIS, CA	380	384
MOUNT HAMILTON, CA	DELMONT, NJ	379	380
RUSKIN, FL	LOOMIS, CA	379	380
WEST LINN, OR	WESTON, FL	378	379
BASKING RIDGE, NJ	MOUNT HAMILTON, CA	378	379
WESTON, FL	WEST LINN, OR	377	378
BEAUFORT, SC	EAGLE RIVER, AK	377	376
CHESTERFIELD, MA	EAGLE RIVER, AK	376	374
HIGH POINT, NC	EAGLE RIVER, AK	376	375
MOUNT HAMILTON, CA	BASKING RIDGE, NJ	375	376
WEST BLOOMFIELD, NY	MOUNT HAMILTON, CA	374	376
OAKS, PA	MOUNT HAMILTON, CA	374	375
WEST LINN, OR	RUSKIN, FL	373	374
MOUNT HAMILTON, CA	OAKS, PA	372	373
WALLKILL, NY	MOUNT HAMILTON, CA	372	373
PUYALLUP, WA	WESTON, FL	372	373
EAGLE RIVER, AK	WESTMORELAND, NH	372	371
BUFFALO, NY	MOUNT HAMILTON, CA	372	373
BROTHERS, OR	WESTON, FL	372	372

WESTON, FL	PUYALLUP, WA	372	372
RUSKIN, FL	WEST LINN, OR	371	372
CHECK, VA	EAGLE RIVER, AK	371	370
MOUNT HAMILTON, CA	WEST BLOOMFIELD, NY	371	372
WESTON, FL	BROTHERS, OR	371	371
MOUNT HAMILTON, CA	WALLKILL, NY	371	372
LOOMIS, CA	LA PORTE, TX	370	373
AUSTIN, TX	LOOMIS, CA	369	374
EAGLE RIVER, AK	BEAUFORT, SC	369	368
MOUNT HAMILTON, CA	BUFFALO, NY	369	370
EAGLE RIVER, AK	NEW HAMPTON, NH	368	367
PUYALLUP, WA	RUSKIN, FL	368	368
RUSKIN, FL	PUYALLUP, WA	367	368
LOOMIS, CA	ZELLWOOD, FL	367	368
WESTMORELAND, NH	EAGLE RIVER, AK	367	365
EAGLE RIVER, AK	LOTHIAN, MD	366	365
BROTHERS, OR	RUSKIN, FL	366	367
ZELLWOOD, FL	LOOMIS, CA	365	366
CLE ELUM, WA	WESTON, FL	364	364
SAN ANTONIO, TX	LOOMIS, CA	364	368
RUSKIN, FL	BROTHERS, OR	363	364
EAGLE RIVER, AK	GALWAY, NY	362	361
NEW HAMPTON, NH	EAGLE RIVER, AK	362	361

BOALSBURG, PA	MOUNT HAMILTON, CA	361	362
LOOMIS, CA	AUSTIN, TX	359	364
TWINSBURG, OH	MOUNT HAMILTON, CA	359	361
LOTHIAN, MD	EAGLE RIVER, AK	359	358
WEST LINN, OR	ZELLWOOD, FL	359	359
CLE ELUM, WA	RUSKIN, FL	359	359
MOUNT HAMILTON, CA	BOALSBURG, PA	359	360
ZELLWOOD, FL	WEST LINN, OR	358	359
LOWAKE, TX	LOOMIS, CA	358	363
GALWAY, NY	EAGLE RIVER, AK	357	356
WESTON, FL	CLE ELUM, WA	356	357
MOUNT HAMILTON, CA	TWINSBURG, OH	356	358
CRESCENT VALLEY, NV	WESTON, FL	356	357
WARWICK, RI	THREE RIVERS, CA	356	356
MURRYSVILLE, PA	MOUNT HAMILTON, CA	355	356
EAGLE RIVER, AK	RALEIGH, NC	355	354
EAGLE RIVER, AK	GENOA, NY	355	354
ZELLWOOD, FL	PUYALLUP, WA	354	355
EAGLE RIVER, AK	POMFRET, MD	354	353
LOOMIS, CA	SAN ANTONIO, TX	354	358
WESTON, FL	CRESCENT VALLEY, NV	354	355
EAGLE RIVER, AK	WASHINGTON, DC	353	352
PUYALLUP, WA	ZELLWOOD, FL	353	354

EAGLE RIVER, AK	WARWICK, RI	353	351
MOUNT HAMILTON, CA	MURRYSVILLE, PA	352	354
LOOMIS, CA	JACKSONVILLE, FL	352	353
BROTHERS, OR	ZELLWOOD, FL	352	353
EAGLE RIVER, AK	WILMINGTON, NC	351	350
ZELLWOOD, FL	BROTHERS, OR	351	352
EAGLE RIVER, AK	HEBRON, CT	351	350
JACKSONVILLE, FL	LOOMIS, CA	351	352
COLUMBUS, OH	EAGLE RIVER, AK	351	350
RUSKIN, FL	CLE ELUM, WA	351	352
EASLEY, SC	EAGLE RIVER, AK	350	349
GENOA, NY	EAGLE RIVER, AK	349	348
CRESCENT VALLEY, NV	RUSKIN, FL	349	351
THREE RIVERS, CA	WARWICK, RI	349	350
KNOB LICK, KY	EAGLE RIVER, AK	349	348
EAGLE RIVER, AK	CHARLOTTE, NC	348	347
LOOMIS, CA	LOWAKE, TX	348	353
EAGLE RIVER, AK	QUANTICO, MD	347	346
SUN VALLEY, ID	WESTON, FL	347	349
BEAUFORT, SC	LOOMIS, CA	347	348
WARWICK, RI	EAGLE RIVER, AK	346	345
EAGLE RIVER, AK	SUFFOLK, VA	346	345
POMFRET, MD	EAGLE RIVER, AK	346	345

WASHINGTON, DC	EAGLE RIVER, AK	346	345
EAGLE RIVER, AK	LINCOLN, DE	345	344
RUSKIN, FL	CRESCENT VALLEY, NV	345	347
COLUMBUS, OH	MOUNT HAMILTON, CA	344	346
JACKSONVILLE, FL	WEST LINN, OR	344	345
CLE ELUM, WA	ZELLWOOD, FL	344	345
HEBRON, CT	EAGLE RIVER, AK	344	343
WEST LINN, OR	JACKSONVILLE, FL	344	345
WESTON, FL	SUN VALLEY, ID	344	345
EAGLE RIVER, AK	KNOB LICK, KY	343	342
EAGLE RIVER, AK	EASLEY, SC	343	342
LEBANON JUNCTION, KY	EAGLE RIVER, AK	342	341
LOOMIS, CA	BEAUFORT, SC	342	343
EAGLE RIVER, AK	HIGH POINT, NC	342	341
SUN VALLEY, ID	RUSKIN, FL	341	342
EAGLE RIVER, AK	PACOLET, SC	340	339
JACKSONVILLE, FL	PUYALLUP, WA	340	341
MOUNT HAMILTON, CA	COLUMBUS, OH	340	342
WARWICK, RI	SAN DIEGO, CA	340	341
QUANTICO, MD	EAGLE RIVER, AK	340	339
LA PORTE, TX	MOUNT HAMILTON, CA	340	344
BEAUFORT, SC	WEST LINN, OR	339	340
ZELLWOOD, FL	CLE ELUM, WA	339	340

SUFFOLK, VA	EAGLE RIVER, AK	339	337
ROSEBUSH, MI	MOUNT HAMILTON, CA	339	340
WACISSA, FL	WEST LINN, OR	338	339
PUYALLUP, WA	JACKSONVILLE, FL	338	339
PONTIAC, MI	MOUNT HAMILTON, CA	338	340
LINCOLN, DE	EAGLE RIVER, AK	338	337
GREENVILLE, AL	EAGLE RIVER, AK	338	337
GORDON, GA	LOOMIS, CA	337	339
BROTHERS, OR	JACKSONVILLE, FL	337	338
RUSKIN, FL	SUN VALLEY, ID	337	338
EAGLE RIVER, AK	CHECK, VA	337	336
EAGLE RIVER, AK	GREENVILLE, AL	336	335
JACKSONVILLE, FL	BROTHERS, OR	336	337
MOUNT HAMILTON, CA	LA PORTE, TX	336	340
WEST LINN, OR	WACISSA, FL	336	337
EAGLE RIVER, AK	LEBANON JUNCTION, KY	336	335
LOOMIS, CA	GORDON, GA	335	337
JACKSON, OH	MOUNT HAMILTON, CA	335	337
CRESCENT VALLEY, NV	ZELLWOOD, FL	335	337
MOUNT HAMILTON, CA	PONTIAC, MI	334	336
MOUNT HAMILTON, CA	ROSEBUSH, MI	334	336
EAGLE RIVER, AK	HARWINTON, CT	334	333
WACISSA, FL	PUYALLUP, WA	334	335

SAN DIEGO, CA	WARWICK, RI	334	335
WEST LINN, OR	BEAUFORT, SC	333	334
OAKS, PA	EAGLE RIVER, AK	332	331
ZELLWOOD, FL	CRESCENT VALLEY, NV	332	334
WARWICK, RI	APPLE VALLEY, CA	332	333
BEAUFORT, SC	PUYALLUP, WA	332	333
AUSTIN, TX	MOUNT HAMILTON, CA	331	336
BROTHERS, OR	WACISSA, FL	331	332
EAGLE RIVER, AK	RICHMOND, VA	331	330
BEAUFORT, SC	BROTHERS, OR	330	332
WACISSA, FL	BROTHERS, OR	330	332
PUYALLUP, WA	WACISSA, FL	330	331
MOUNT HAMILTON, CA	JACKSON, OH	330	332
CLE ELUM, WA	JACKSONVILLE, FL	329	330
LOVELAND, OH	EAGLE RIVER, AK	329	328
LINCOLNVILLE, ME	THREE RIVERS, CA	329	329
COMSTOCK PARK, MI	MOUNT HAMILTON, CA	329	331
TIPP CITY, OH	MOUNT HAMILTON, CA	328	330
GORDON, GA	WEST LINN, OR	328	330
MOCCASIN, MT	WESTON, FL	328	330
EAGLE RIVER, AK	SAN DIEGO, CA	328	328
MOUNT HAMILTON, CA	AUSTIN, TX	328	333
FAYVILLE, MA	THREE RIVERS, CA	328	328

JACKSON, OH	EAGLE RIVER, AK	327	327
HARWINTON, CT	EAGLE RIVER, AK	327	326
PUYALLUP, WA	BEAUFORT, SC	327	327
SUN VALLEY, ID	ZELLWOOD, FL	327	328
SAN ANTONIO, TX	MOUNT HAMILTON, CA	327	331
APPLE VALLEY, CA	WARWICK, RI	326	327
BROTHERS, OR	BEAUFORT, SC	326	328
WEST LINN, OR	GORDON, GA	326	327
SAN ANTONIO, TX	LINCOLNVILLE, ME	326	328
LAYTON, UT	WESTON, FL	325	327
THREE RIVERS, CA	LINCOLNVILLE, ME	325	325
EAGLE RIVER, AK	BUFFALO, NY	325	324
MOUNT HAMILTON, CA	COMSTOCK PARK, MI	325	327
SAN DIEGO, CA	EAGLE RIVER, AK	325	324
RICHMOND, VA	EAGLE RIVER, AK	324	323
MOUNT HAMILTON, CA	TIPP CITY, OH	324	326
JACKSONVILLE, FL	CLE ELUM, WA	324	325
THREE RIVERS, CA	FAYVILLE, MA	324	324
ZELLWOOD, FL	SUN VALLEY, ID	324	325
EMERY, UT	WESTON, FL	323	325
EAGLE RIVER, AK	WEST BLOOMFIELD, NY	323	322
GORDON, GA	PUYALLUP, WA	323	324
MOUNT HAMILTON, CA	SAN ANTONIO, TX	323	328

GORDON, GA	BROTHERS, OR	322	324
LOWAKE, TX	MOUNT HAMILTON, CA	322	327
TIPP CITY, OH	EAGLE RIVER, AK	322	321
CLE ELUM, WA	WACISSA, FL	322	323
WESTON, FL	LAYTON, UT	321	323
MOCCASIN, MT	RUSKIN, FL	321	323
WESTON, FL	MOCCASIN, MT	321	322
EAGLE RIVER, AK	LOVELAND, OH	321	320
PUYALLUP, WA	GORDON, GA	320	321
CRESCENT VALLEY, NV	JACKSONVILLE, FL	320	322
BUFFALO, NY	EAGLE RIVER, AK	320	319
BROTHERS, OR	GORDON, GA	319	321
LA PORTE, TX	THREE RIVERS, CA	319	324
EAGLE RIVER, AK	BASKING RIDGE, NJ	319	318
MOUNT HAMILTON, CA	LOWAKE, TX	319	324
WEST BLOOMFIELD, NY	EAGLE RIVER, AK	318	317
JACKSONVILLE, FL	CRESCENT VALLEY, NV	318	320
CLE ELUM, WA	BEAUFORT, SC	318	319
THREE RIVERS, CA	LA PORTE, TX	318	322
EAGLE RIVER, AK	JACKSON, OH	318	317
WESTON, FL	EMERY, UT	318	320
WARWICK, RI	CHANDLER, AZ	318	319
WACISSA, FL	CLE ELUM, WA	317	319

LAYTON, UT	RUSKIN, FL	317	320
BEAUFORT, SC	CLE ELUM, WA	317	318
LOWAKE, TX	LINCOLNVILLE, ME	316	319
EMERY, UT	RUSKIN, FL	315	317
LINCOLNVILLE, ME	SAN ANTONIO, TX	314	317
EAGLE RIVER, AK	TIPP CITY, OH	314	313
WACISSA, FL	CRESCENT VALLEY, NV	314	315
CHANDLER, AZ	WARWICK, RI	313	315
BEAUFORT, SC	CRESCENT VALLEY, NV	313	315
RUSKIN, FL	MOCCASIN, MT	313	315
BASKING RIDGE, NJ	EAGLE RIVER, AK	313	312
RUSKIN, FL	LAYTON, UT	313	315
CRESCENT VALLEY, NV	WACISSA, FL	313	314
LYSITE, WY	WESTON, FL	312	314
SUN VALLEY, ID	JACKSONVILLE, FL	312	313
EAGLE RIVER, AK	STRATHMERE, NJ	311	310
CHESTERFIELD, MA	THREE RIVERS, CA	311	312
CLE ELUM, WA	GORDON, GA	311	313
EAGLE RIVER, AK	DELMONT, NJ	311	310
LINCOLNVILLE, ME	SAN DIEGO, CA	311	312
CRESCENT VALLEY, NV	BEAUFORT, SC	311	312
JACKSONVILLE, FL	SUN VALLEY, ID	310	311
AUSTIN, TX	THREE RIVERS, CA	309	314

LINCOLNVILLE, ME	APPLE VALLEY, CA	309	310
RUSKIN, FL	EMERY, UT	309	311
GORDON, GA	CLE ELUM, WA	309	310
THREE RIVERS, CA	AUSTIN, TX	309	314
THREE RIVERS, CA	CHESTERFIELD, MA	309	309
BIRMINGHAM, AL	EAGLE RIVER, AK	308	308

APPENDIX O

Driver Quantities for Each Driver Domicile (Non-Relay Point Network)

Domicile City/State	Driver Pool Quantity
MOUNT HAMILTON, CA	35,962
LINCOLNVILLE, ME	35,219
LOOMIS, CA	35,022
EAGLE RIVER, AK	33,009
WARWICK, RI	32,906
FAYVILLE, MA	32,338
WEST LINN, OR	30,471
NEW HAMPTON, NH	29,859
WESTMORELAND, NH	29,144
THREE RIVERS, CA	29,044
HEBRON, CT	28,606
CHESTERFIELD, MA	28,488
WESTON, FL	28,419
PUYALLUP, WA	28,156
SAN DIEGO, CA	27,904
BROTHERS, OR	27,596
GALWAY, NY	27,291
RUSKIN, FL	27,204
CLE ELUM, WA	26,765
HARWINTON, CT	26,372
LOTHIAN, MD	25,900
CHANDLER, AZ	25,848
QUANTICO, MD	25,826
GENOA, NY	25,688
LINCOLN, DE	25,416
APPLE VALLEY, CA	25,220
WASHINGTON, DC	25,163
BASKING RIDGE, NJ	25,101
ZELLWOOD, FL	24,825
CRESCENT VALLEY, NV	24,451
ROUND MOUNTAIN, NV	24,444

DELMONT, NJ	24,081
SUN VALLEY, ID	23,777
POMFRET, MD	23,746
WALLKILL, NY	23,654
SAN ANTONIO, TX	23,631
WEST BLOOMFIELD, NY	23,528
STRATHMERE, NJ	23,396
OAKS, PA	23,187
WILMINGTON, NC	23,120
TUCSON, AZ	22,733
BUFFALO, NY	22,571
BEAUFORT, SC	22,521
SUFFOLK, VA	22,315
JACKSONVILLE, FL	22,181
WACISSA, FL	21,775
LAYTON, UT	21,767
BOALSBURG, PA	21,265
SUPAI, AZ	21,139
MURRYSVILLE, PA	21,117
RALEIGH, NC	20,982
RICHMOND, VA	20,829
LA PORTE, TX	20,773
PONTIAC, MI	20,584
SPOTSYLVANIA, VA	20,385
GORDON, GA	20,275
TWINSBURG, OH	20,257
MOCCASIN, MT	20,107
EASLEY, SC	20,099
ROSEBUSH, MI	20,080
DAVANT, LA	19,929
CHARLOTTE, NC	19,735
HIGH POINT, NC	19,720
ATLANTA, GA	19,510
COLUMBUS, OH	19,486

EMERY, UT	19,482
TALLMANSVILLE, WV	19,357
COMSTOCK PARK, MI	19,267
AUSTIN, TX	19,177
BROOKFIELD, WI	19,102
CHECK, VA	18,960
PACOLET, SC	18,863
LORETTO, MN	18,789
TIPP CITY, OH	17,834
LOVELAND, OH	17,789
LYSITE, WY	17,645
JACKSON, OH	17,626
GREENVILLE, AL	17,573
PERRY, LA	17,220
LEBANON JUNCTION, KY	17,098
LOWAKE, TX	17,076
PITTSVILLE, WI	16,968
LITTLETON, CO	16,935
DENHOFF, ND	16,448
BIRMINGHAM, AL	16,255
CRESTONE, CO	16,079
EOLA, IL	15,961
ENCINO, NM	15,897
CLARKS GROVE, MN	15,780
RHODELIA, KY	15,755
INDIANAPOLIS, IN	15,655
NASHVILLE, TN	15,315
VIOLA, TN	15,074
KOUTS, IN	14,887
KNOB LICK, KY	14,813
SOUTH ROXANA, IL	14,724
COLO, IA	14,623
PIERRE, SD	14,240
DALLAS, TX	14,226

BOISE CITY, OK	13,575
GUYMON, OK	13,435
MERNA, NE	13,434
GREENWOOD, MO	13,273
GOODMAN, MS	13,079
BALKO, OK	13,074
BUSHTON, KS	13,053
ARLINGTON, TN	12,915
LOHMAN, MO	12,865
ALTUS AFB, OK	12,671
PACIFIC, MO	12,637
RANDLETT, OK	12,519
VINSON, OK	12,505
WELLSVILLE, KS	12,459
GRANDFIELD, OK	12,398
TERRAL, OK	12,335
MC CLURE, IL	12,215
DUNCAN, OK	12,140
NORTH LITTLE ROCK, AR	12,101
WILLOW, OK	12,088
FORT SILL, OK	12,084
THACKERVILLE, OK	12,003
TUSSY, OK	11,984
SWEETWATER, OK	11,908
WASHITA, OK	11,902
ROOSEVELT, OK	11,891
GAGE, OK	11,869
TEXOLA, OK	11,853
FOSS, OK	11,633
DAVIS, OK	11,595
MOORELAND, OK	11,544
ELMORE CITY, OK	11,517
ROSSTON, OK	11,444
BUTLER, OK	11,376

FAY, OK	11,301
WATSON, OK	11,252
PURCELL, OK	11,246
MADILL, OK	11,229
POCASSET, OK	11,195
CHESTER, OK	11,012
SWINK, OK	11,008
MILL CREEK, OK	10,982
NORMAN, OK	10,959
ACHILLE, OK	10,959
OKLAHOMA CITY, OK	10,905
TUSKAHOMA, OK	10,902
CONCHO, OK	10,896
GREENFIELD, OK	10,860
TECUMSEH, OK	10,850
HOPETON, OK	10,831
FITZHUGH, OK	10,779
LEHIGH, OK	10,768
SHADY POINT, OK	10,752
LAMAR, OK	10,738
SASAKWA, OK	10,727
PANOLA, OK	10,697
LEQUIRE, OK	10,687
OMEGA, OK	10,681
RED ROCK, OK	10,646
PAWNEE, OK	10,620
CASTLE, OK	10,619
HILLSDALE, OK	10,617
MARBLE CITY, OK	10,612
WARDVILLE, OK	10,599
ATOKA, OK	10,595
WAGONER, OK	10,563
TAHLEQUAH, OK	10,561
BUNCH, OK	10,559

PRESTON, OK	10,553
ORLANDO, OK	10,548
OAKS, OK	10,539
TULSA, OK	10,514
MUSKOGEE, OK	10,509
STILLWATER, OK	10,489
BURLINGTON, OK	10,472
CHANDLER, OK	10,467
SLICK, OK	10,433
HANNA, OK	10,399
VINITA, OK	10,316
CLAREMORE, OK	10,266
ROSE, OK	10,255
CARDIN, OK	10,242
PONCA CITY, OK	10,192
WANN, OK	10,087
BOWRING, OK	10,041
MANCHESTER, OK	9,983
BARTLESVILLE, OK	9,952

VITA

Kerry D. Melton

Candidate for the Degree of

Doctor of Philosophy/Engineering

Thesis: TRUCKLOAD FREIGHT TRANSPORTATION UTILIZING RELAY POINTS TO IMPROVE THE DRIVING JOB

Major Field: Industrial Engineering and Management

Biographical:

Education:

Completed the requirements for the Doctor of Philosophy/Engineering in Industrial Engineering and Management at Oklahoma State University, Stillwater, Oklahoma in July, 2012

Completed the requirements for the Master of Science/Engineering in Industrial Engineering at the University of Arkansas, Fayetteville, Arkansas/USA in 1994

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Experience:

J.B. Hunt Transport, Inc. (1997-2008)
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Name: Kerry D. Melton Date of Degree: July, 2012

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: TRUCKLOAD FREIGHT TRANSPORTATION UTILIZING RELAY POINTS TO IMPROVE THE DRIVING JOB

Pages in Study: 248 Candidate for the Degree of Doctor of Philosophy/Engineering

Major Field: Industrial Engineering and Management

Scope and Method of Study:

- A mathematical model was developed and used to establish equipment relay points on a highway transportation network. Relay points are locations to exchange truck and trailer equipment to shorten driving distances and increase driver home time.
- The 4-step urban planning approach was used to establish freight production and consumption locations, distribute freight, and assign freight to a highway transportation network. The Freight Movement Model (FMM) was used.
- Performance metrics and costs related to the customer, driver, and transportation carrier were measured. Key transportation and facility costs were included.

Findings and Conclusions:

- Performance and cost metrics related to the driver, customer, and transportation carrier were significantly improved utilizing the relay point concept.

Abstract:

We propose a relay point based approach on a highway transportation network to obtain robust solutions for the truck driver turnover and driver retention problem. We exploit the characteristics of the driver routing problem and truckload freight moved over a highway transportation network and introduce a new approach to route drivers over shorter distances and to move trailers continuously while holistically considering important performance measures as related to the truck driver, transportation carrier, and customer. The amount of time drivers spend driving and the time spent at home are exploited to determine a balance between driver home time and driver pay. A mathematical program is introduced to determine where relay points should be more optimally located to exchange equipment, perform equipment maintenance, access resting facilities, etc. while considering important costs related to transporting truckload freight. The intention is to propose a method to improve the truckload driving job but not at the expense of the transportation carrier and customer. We discuss some of the desirable characteristics of this approach and also investigate the sensitivity of the solutions via a numerical experiment.

ADVISER’S APPROVAL: Dr. Ricki Ingalls