USING AN AHP/ANP HYBRID METHODOLOGY FOR FREIGHT TRANSPORT NETWORKS SELECTION TOWARDS SUSTAINABLE TRANSPORTATION

by

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ABSTRACT

USING AN AHP/ANP HYBRID METHODOLOGY FOR FREIGHT TRANSPORT NETWORKS SELECTION TOWARDS SUSTAINABLE TRANSPORTATION

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The selection of an effective transportation network for the transport of container freight is one of the most important factors in supply chain and logistics planning. The current transport networks, hub-and-spoke and point-to-point, although optimal in many aspects are still plagued with issues in route optimization, empty travel, and bad intermodal synchronization. The trucking industry, the most utilized of all modes, offers unsustainable components in its current state that continually introduce negative impacts to an ever evolving supply chain network.

This research investigates a third potentially more sustainable distributed multi-segment transportation network. This network will be compared to the traditional hub-and-spoke and point-to-point networks by use of a hybrid decision support system containing Analytical Hierarchical Process (AHP) and the Analytical Network Process (ANP). Through an exhaustive literature review of recent surveys conducted by public and private stakeholders of the transportation industry, seven measures have been identified to assess performance: energy,

safety, environmental, accessibility, costs, time and quality of life. For each measure, specific metrics have been captured to evaluate the networks to ensure they meet the goals of stakeholders as well as address several sustainability issues discussed in this study.

In addition to the use of a methodological analysis, an empirical quantitative study using a well traveled interstate corridor is conducted for the three networks and their identified performance measures. Each transport network configuration is modeled individually and a simulation of the route is performed from a predetermined point of origin to destination. The resulting output of both analysis methods suggests that the distributed multi-segment network is a viable alternative but has tradeoffs with economic challenges that may make it difficult to implement.

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CHAPTER 1

INTRODUCTION

Sustainability has been identified as one of the global grand challenges of the 21st century. Due to population growth and expanded global development, the next generation of engineers must be able to design with fewer resources for a wider variety and greater number of end users (Davidson et al, 2007). In order to secure a more comfortable future for generations to enjoy a satisfactory life, emerging technological solutions must be environmentally, economically, and socially sustainable.

One key area of concern is that of transportation networks. Transportation networks are essential to the functioning of societies and economies and provide infrastructure for the movement of people and goods over space and time. The existence and utilization of transportation networks are fundamental to the modern age and the negative effects of congestion and pollution associated with their increasing usage demand urgent attention (Nagurney, 2000).

The logistics and transportation components within the supply chain accounts for 50% of the total supply chain costs (Tompkins Associates, 20011) and are among the major contributors of supply chain variability and uncertainty due to the inherent dependence on external and internal factors that cause fluctuations in performance. Freight transportation, specifically motor carriers (or trucks), is the single most used mode over land to move products to the consumer. Hauling 68.8 percent, or 10.2 billion tons, of all freight transported in the U.S. in 2008 equating to a $660 billion industry, the motor carrier mode segment represents 83.1 percent of the nation’s freight bill according to the 2009-2010 report in American Trucking Trends. With this significant demand, the decision makers that select this mode of freight transportation expect that the *right* product is being delivered at the *right* or agreed upon time and at the *right* place to ensure high levels of customer satisfaction.

However even with this mode of transportation's ability to satisfy the requirements placed on the logistics system through time and place utilities, the motor carrier industry is still plagued with numerous issues that are un-sustainable in practice. In taking a closer look, some of these issues and challenges include:

1. The highest producer of greenhouse gases among all the transport modes is trucking.
2. Trucking has caused over 93,000 highway crashes and 2,900 highway fatalities in 2011 per the Federal Motor Carrier Safety Administration of which at least 30% of those occurrences can be attributed to fatigue according to the National Transportation Safety Board (NTSB)
3. The instability of diesel fuel prices are causing many companies to decrease fleet size or in some cases, pass the cost onto the consumer.
4. Adhering and adjusting to new governmental regulations which call for tighter capacity and restrictions of drivers' hours.
5. Driver shortages due to the increase in demand for trucks
6. Poor synchronization and design of distribution networks which have not responded well to the evolution of supply chains.
7. Empty travel. Trucking experts estimate that as many as one-third of all trucks on the road are empty. They have delivered their loads and are headed either back to home base, or to their next pickup. Many shippers are focusing on ways to fill those empty miles, thereby reducing transportation costs while also bolstering capacity (Nuzum, 2007).
8. Poor routing configurations.

While some of the aforementioned issues stem from the need for the trucking industry to be more aggressive in equipment innovation among its aging fleet, other issues originate from the transport network distribution configurations that direct the product from point of origin to destination.

Utilizing two most common network transportation designs of point-to-point and hub-and-spoke, logistics managers and ultimately supply chains are able to increase inventory turns, improve delivery times and accuracy and reduce operating costs. However with the evolution of supply chains, distribution networks have become more complicated. Supply chains today stretch thousands of miles, cross multiple borders and utilize a variety of transport modes (Nuzum, 2007). The potential risk of failure is not only high but certain. Stakeholders now seek capacity, reliability and rate stability. Shippers alike are now faced with identifying ways to leverage high demand with keeping operating costs low while maintaining high levels of customer satisfaction.

In Gartner Research's recently released Supply Chain Top 25 for 2012 list, the top producers have taken notice to the dynamic changes that have come with managing the supply chain. The notable trends that have emerged with these high performing companies have been growth, resiliency, simplification and shifting more towards multi-local operations, with the latter being a point of focus for this research.

Multilocal operations shifts work from a more centralized model to a regionalized approach (Hofman and Aronow, 2012). This focus has lined up to be parallel with the shift that motor carriers have seen over the last few years. A market segment once synonymous with long-haul trucking, truckload carriers are increasingly engaged in moving much shorter, often regionalized hauls. This push has resulted from a confluence of factors — from shippers lengthening supply chains, to private carriers exiting the "last mile," to for-hire carriers addressing the driver shortage. Today, the trend is being accelerated by the ever-dragging economy (Cullen, 2011), opening the door for a greater penetration of for-hire carriers, usually small owner operator fleets, to participate in competing for dedicated contracts which have been traditionally enjoyed by company owned high volume fleets.

In transitioning to a multilocal, regionalized based system of operations, many shippers have begun to reconfigure their distribution networks. Companies are reorganizing distribution networks to ensure that freight is transported as full container loads and full truckloads (Nuzum, 2007), from origin to final destination, and with the fewest possible handoffs. Several scenarios can be considered in this approach which are usually driven by volume and may involve consolidation to deconsolidation networks, direct-to distribution center networks (much like point-to-point), deconsolidation to consolidation networks, or consolidation networks (hub and spoke) all of which utilize the concept of risk pooling as introduced in most supply chain management courses.

To address this reconfiguring of transport distribution networks to eliminate multiple issues facing the industry, leading researcher Benoit Montreuil (2007) has proposed a distributed multi-segmented network solution. This network resembles in its most basic illustration a “daisy chain” of routing, consisting of multiple driver-truck duos and integrated container yards. While the architecture of this network ultimately seeks to decrease carbon dioxide output, lessen drivers’ hours thereby decreasing the incidents of accidents, eliminating empty travel and optimizing routing patterns, the comparisons with existing networks have not been performed to determine its viability or reliability.

The research question of this dissertation is *whether or not a distributed multi-segment transport network, when compared with the existing networks of point-to-point and hub-and-spoke, can provide a viable sustainable alternative for shippers to transport goods from origin to destination*. The term *viable* for purposes of this study refers to environmental, economic, and social metrics that will be outlined in later chapters.

The hypothesis statement for this study is that *a distributed multi-segment network is a proven viable freight transport network alternative for truckload shipping that will address the* *environmental, economic and social challenges faced by the supply chain industry in the 21st century*.

This dissertation evaluates three different transport networks in comparison format and provides both a multiple attribute analysis and an empirical simulation study. The three transport networks are: point-to-point, hub-and-spoke and distributed multi-segment.

Seven performance measures (time, cost, energy, accessibility, safety, quality of life, and environment) for the freight transportation industry will be utilized in a hybrid AHP/ANP decision tool using relative weights extracted from studies completed by Department of Transportation agencies of multiple states and the Transportation Research Board. In this process, many criteria are considered and interdependencies between and among the criteria are explored. The goal of the methodology and its decision criteria, using performance measures, is to find the best system capable of meeting the goals and expectations of the stakeholders and providing some level of resolution to sustainability challenges.

Following the AHP/ANP analysis, an empirical simulation study using MS Excel will be performed using a highly utilized regional US highway segment to simulate the typical origin to destination route of a motor carrier. This study will be used to eliminate any potential bias inherent within the AHP/ANP analysis not ascertained during the study. Each transport network case will be configured and quantitative results will be gathered based on the measures presented in the AHP/ANP study. The results of both studies will then be compared to ensure that there is a consistency in the selection process and results.

Following discussion of the results, recommendations will be made regarding future usage of this dissertation study and its limitations determined during the research process.

CHAPTER 2

BACKGROUND

Transportation has long been an essential component of society that plays a major role in how we live and function in everyday life. From automobiles to school buses to passenger airliners, the constant demand for transportation has always been birthed out of a need for movement and the constant desire for faster, cleaner, and more economical means of getting people and goods from one point to another. In America, transportation is synonymous with opportunities in that it connects workers with jobs, products with markets and families with each other. A progressive and productive transportation infrastructure can ultimately be the cornerstone in creating a society of economic vitality and global influence. On the other hand, the lack of transportation, especially in geographical areas that are very rural and impoverished can prove detrimental to the economy and consequently the quality of education and way of life.

The efficient movement of goods to the consumer on time and without defect at the lowest cost possible is the overall goal of any successful supply chain. Within the construct of the supply chain, a resilient logistics network is the backbone for the movement of goods and services. Logistics systems, offer an architecturally substantial support to the national economy construct; its reliability and stability has a direct impact on the health of economic development both domestically and globally. The key element in any particular logistics chain is the transportation system, which joins the separated activities. Transportation accounts for one-third of logistics costs and largely influences the performance of the logistics system. Transporting is required during the whole production process, from manufacturing through delivery to the final consumers as well as product returns if necessary. (Tseng, Yue and Taylor, 2005)

Accounting for 50% of the total supply chain costs (Thompkins Associates, 2011), transportation operations is a key driver in a company's profitability margin. Estimates show that in 2007, nearly 18.6 billion tons of goods worth about $16.5 trillion were moved on the transportation network, which equates to 51 million tons of goods valued at more than $45 billion a day moved throughout the country on all transportation modes(U.S. Department of Transportation, 2010).

After declines in 2008 and 2009, preliminary estimates indicate a return to growth in 2010. Freight Analysis Framework projections show tonnage will continue increasing 1.6 percent per year, reaching 27.1 billion tons by 2040, which is a 61 percent increase in tons between 2010 and 2040.

Overall, modern economies have increased their dependence on transportation and logistics. Based on the 2009 Department of Transportation report , transportation represents about 10% of the U.S. Gross Domestic Product or roughly $1.4T (trillion). Expenditures on freight transportation, packaging, and commercial warehousing are $500B (billion), $125B and $33B, respectively, excluding all costs directly incurred by manufacturers, distributors and retailers (Montreuil, 2011)

Trucks are still the single most-used mode to move freight, especially for distances less than 500 miles - they moved 69 percent of the weight and 65 percent of the value in 2007. Intermodal goods movement accounted for 18 percent of the value of freight transportation in 2007 and is forecast to grow to nearly 27 percent by 2040 (U.S. Department of Transportation, 2010).

Still, with all of the growth in the transportation industry, the issue of sustainability is an ever present cause of concern for governmental entities and the public as a whole. In taking a closer look, while trucks are the most utilized, they are also the highest producers of greenhouse gases among all the transport modes. The sustainability challenges of logistics across the globe displays numerous symptoms that are unavoidable and must be addressed at some level. To expose the unsustainable elements of logistics and offer a more pragmatic approach to the way we transport physical objects, Benoit Montreuil, Canada Research Chair in Enterprise Engineering has introduced an open innovation initiative entitled *The Physical Internet*. The Physical Internet Initiative is a paradigm shift that has the potential to challenge traditional design in the fields of logistics, facility design and material handling. The motivation for such a radical mind shift is based on the assertion that, "the way physical objects are currently transported, handled, stored, realized, supplied and used throughout the world is not sustainable economically, environmentally and socially" (Montreuil, 2011)

In substantiating his claim, Montreuil presents thirteen "un-sustainability symptoms". Some of these include:

- *"Truckers have become the modern cowboys.* Road based transportation dominates continental transport means. This results in a high demand for truck drivers. Based on estimates by the American Trucking Association, driver shortage in the US will grow to 111,000 by 2014. Yet the current mode of operation has truckers who are nearly always on the road, away from their homes for long durations. Consequently, their family life, social life and personal health are precarious." The US National Transportation and Safety Board study found that 58% of the accidents reported by drivers were deemed to be caused by fatigue and sleep deprivation" (Montreuil, 2011).
- *"Fast and reliable intermodal transport is still a dream or joke*. Even though there are some great intermodal designs, notably in association with cargo container transport and logistics, synchronization in general is poor and interfaces are so badly designed, that intermodal routes are mostly time and cost inefficient and risky "(Montreuil, 2011).

- *"Products unnecessarily move, crisscrossing the world.* Products commonly travel thousands of miles that could have been avoided through route optimization and/or making them much closer to their point of use. The outsourcing of product manufacturing to developing countries has accentuated the phenomenon. Yet, even without it, such factors as hub and spoke networks and the centralization leading to one or a few large distribution centers covering wide geographical areas leads to excessive travel" (Montreuil, 2011).
- *"Empty travel is the norm rather than the exception.* Vehicles and containers often return empty, or incur extra travel routes to find return shipments. In 2009, the US industry average was 20% of all miles are driven with a completely empty trailer" (Montreuil, 2011).

Regardless of the mode chosen to transport goods, whether single-mode or intermodal, there are both internal and external forces that will affect the successful implementation of the transport design chosen. However, implementation of a resilient, reliable, and sustainable transportation network is critical to ensuring the stability of the economy and the ability to compete both domestically and globally.

2.1 Intermodal Freight Transportation

In defining the concept of an intermodal freight transport system, we adopt the definition provided by Muller (1999) and define "intermodal" as the concept of transporting freight using more than one mode of travel in such a way that all parts of the transportation process are effectively connected and coordinated, safe, environmentally sound, and offering flexibility. Intermodalism has been used in many applications that include passenger transportation and the containerization of freight. A more descriptive term for this process would be "multimodal," because of a lack of effective and efficient connectivity for both freight and information among and between the various modes on shipments under a single freight bill (Dewitt and Clinger, 2002). However "intermodal" and "multimodal" are not the same. In intermodal transportation, as shown in figure 2.1, each mode has its own service characteristic for the purpose of moving the container from origin to destination.

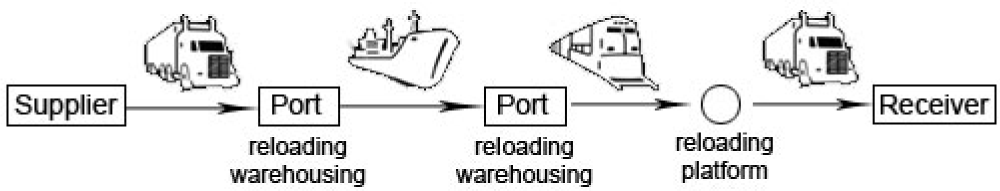


Figure 2.1: Intermodal Transit Chain (Transportation-Logistics, 2008)

Conversely, a multimodal transport chain a set of transport modes which provide connection from origin to destination as shown in figure 2.2.

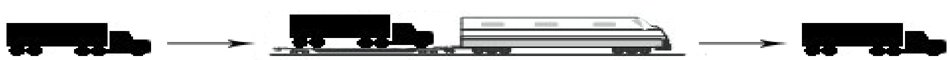


Figure 2.2 Multimodal Transit Chain (Transportation-Logistics, 2008)

While there have been great efficiencies introduced into the transport industry due to the implantation of an intermodal network, synchronization, in general is poor and interfaces so badly designed that intermodal routes are mostly time and cost inefficient and risky. This is exacerbated by the fact that the least energy efficient transportation modes are more used (Montreuil, 2011).

2.2 Freight Transportation: The Trucking Industry

Of all the transportation modes available to use in the movement of freight, trucks are still the single mode most widely used. Nearly every good consumed in the U.S. is put on a truck at some point. According to *American Trucking Trends 2009-2010*, trucking hauled 68.8 percent, or 10.2 billion tons, of all freight transported in the U.S. in 2008 and was a $660 billion industry, representing 83.1 percent of the nation’s freight bill. Since 1980, overall truck vehicle miles have doubled from 108 billion to 216 billion in 2003 and continue to rise as shown in figure 2.3. “Put another way, on average, trucking collected 83.1 cents of every dollar spent on freight transportation. Both the tonnage and revenue figures included for-hire (truckload and less-than-truckload) and private carriage” (American Trucking Association, 2010).

Trucking is the vital transportation link not only for domestic goods, but also international products. Imported goods from overseas have to be moved multiple times from port to final destination. But, perhaps even more important, is the role that trucks play in the enormous amount of trade that flows over our northern and southern borders. Canada and Mexico now rank one and three, respectively, in terms of the top U.S. trading partners, since China surpassed Mexico as our second largest trading partner in 2006. In 2008, trucks hauled nearly 54 percent of the goods (in terms of value) between the U.S. and Canada, and over 63 percent between the U.S. and Mexico. As the North American economies become more interrelated, as well as global, trucking’s importance in international trade should only grow (American Trucking Association (ATA), 2010).

Other important statistics released by ATA in the latest edition of Trucking Trends (2009-2010) include the following:

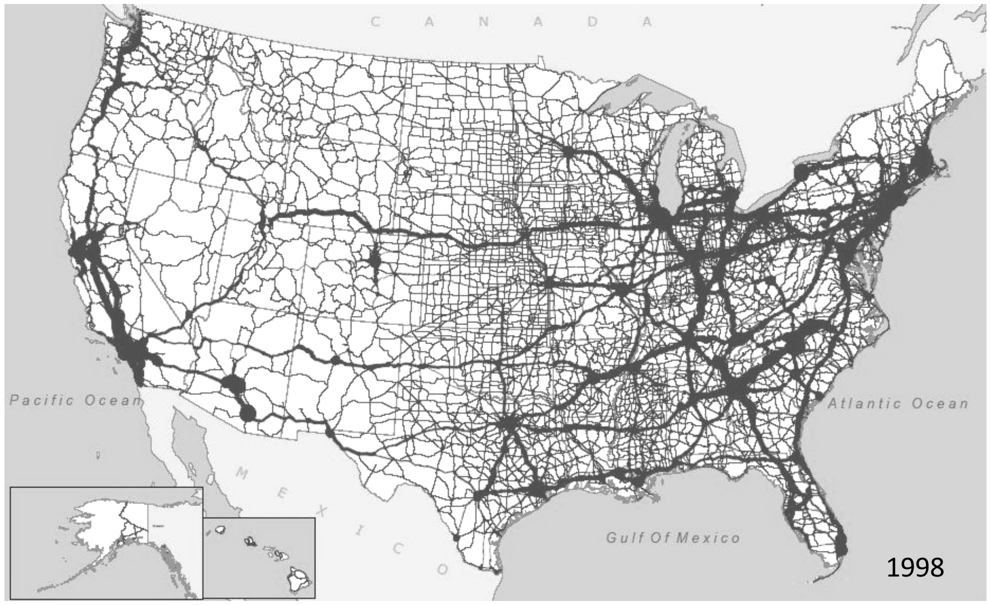
• The trucking industry employs nearly 7 million people – including more than 3 million drivers, 164,000 of who are women;

• Texas has the greatest number of people employed in the trucking industry, but on a percentage basis Nebraska ranks first;

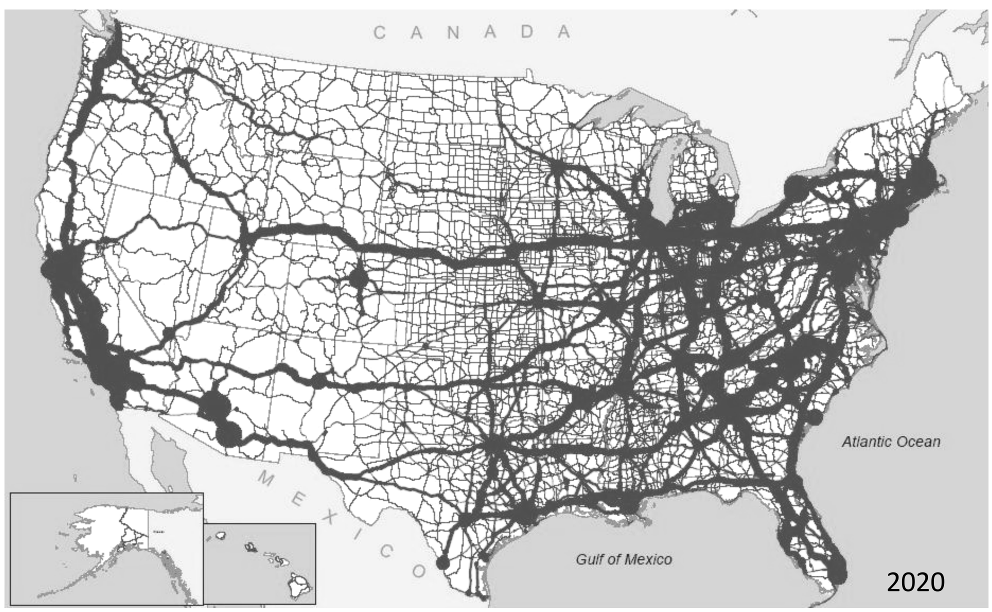
• Trucks consumed 33.9 billion gallons of diesel fuel in 2010;

•Class 8 trucks traveled more than 108 billion miles; and

• Commercial trucks of all classes paid $34.3 billion in federal and state highway-user taxes.



(a)



(b)

Figure 2.3 estimated average annual daily truck traffic for (a) 1998 and (b) 2020 (Hejazi, 2009).

2.2.1 Segmentation

From an operational perspective, the trucking industry operates in one of two modes: TL (truckload) and LTL (less-than truckload). In summary, truckload trucking offers a typical example of door-to-door transportation, where a truck is assigned to each customer. When a customer request for pickup and delivery of a load, the carrier decides whether to accept or reject the request. If the carrier accepts the load, a truck moves empty to its origin to pick it up and then moves it to its destination. After unloading, the truck is ready for a new assignment. The carrier may assign a new load to the truck, move the truck empty to a new location to handle future demands, or keep it idle at the same location. Unlike truckload operations, in less-than-truckload trucking several customers are served simultaneously by using the same truck. LTL is characterized by relatively small freight. An example of a typical LTL carrier is Conway Carriers. The scope of this research will consider both segments of the industry.

The complexities of the trucking industry over the years has been quite dynamic in growth and consequently has created a myriad of external forces that have been imposed and created that has challenged owners in every category to struggle for survival.

2.2.2 Regulations

- **Tighter Capacity**. In December 2010, the government began publicizing the safety ratings of trucking firms under tougher inspections that took effect in 2009. The new ratings have the potential to drive some carriers out of business and reduce fleets 5% to 10% in the coming years (Davidson, 2011).
- **Restrictions on drivers' hours**. The U.S. Department of Transportation and the Federal Motor Carrier Administration regulates truckers on the number of hours driven per day. Currently, for property carrying interstate commercial drivers, a truck driver can legally drive for a maximum of eleven hours during any fourteen hour period of time. Once that eleventh hour has been reached, the driver must rest for a

minimum of ten hours. In addition there is a weekly clock that the driver has to abide by as well. No truck driver can legally drive more than sixty hours over a period of one full week (Federal Motor Carrier Safety Administration, 2010). In a new proposed rule put forth by the administration in December of 2010, there would be increased restriction on drivers' hours, limiting the number of hours driver can work. This could force carriers to hire more drivers and buy more trucks even amid a looming driver shortage (Davidson, 2011).

2.2.3 Safety

Ensuring the proper operation of large trucks is a critical component in ensuring the safety of our roadways. As shown in table 1, the Federal Motor Carrier Safety Administration in 2010, reported that in 2009, there were 3,380 fatalities involving large trucks. That was a decrease from the previous year but still alarming for the public.

Table 2.1 Motor Carrier Safety Progress Report (as of December 31, 2010)

SAFETY OUTCOMES	**2008**	**2009**	**2010**
Fatalities Involving Large Trucks	4,245	3,380**	****
Fatalities Involving Single-Unit Trucks	1,173	972**	****
Fatalities Involving Combination-Unit Trucks	3,173	2,470**	****
Injuries Involving Large Trucks	90,000	74,000	****

** **Preliminary. ****Data not available ***Includes all occupants and non-occupants killed in all bus crashes.* Source: Federal Motor Carrier Safety Administration, 2010

2.2.3.1 Accidents and Fatigue

The direct link between drivers' hours and fatigue has been researched and documented over many years. In the USA, a series of studies by the National Transportation Safety Board (NTSB) have pointed to the significance of sleepiness as a factor in accidents involving heavy vehicles.

The NTSB came to the conclusion that 52% of 107 single-vehicle accidents involving heavy trucks were fatigue-related; "in nearly 18 per cent of the cases, the driver admitted to falling asleep. Summarizing the US Department of Transportation's investigations into fatigue in the 1990s, the extent of fatigue-related fatal accidents is estimated to be around 30%. Research shows that driver fatigue is a significant factor in approximately 20% of commercial road transport crashes and over 50% of long haul drivers have fallen asleep at the wheel.

Recently The National Highway Traffic Safety Administration (NHTSA) estimate that there are 56,000 sleep related road crashes annually in the USA, resulting in 40,000 injuries and 1,550 fatalities" (Smart Motorist).

2.2.4 Diesel Fuel Fluctuations

In 2008 the cost of diesel rose 26%, compared to an 18% increase in the price of regular gas. The national average price for diesel reached a record high of $4.25 a gallon on May 1, 2008 while gasoline reached a record $3.62 a gallon, according to AAA (Goldman, 2008).

Rising diesel costs have dug into the profits of the trucking industry, whose trucks run on the fuel.

The American Trucking Association predicted that truckers will have to shell out $140 billion for diesel in 2008, sharply higher than the $112 billion they spent in 2007 (Goldman, 2008). "The same is true for current day. With the national average price of diesel nearing $4/gallon, the cost of fuel is showing its effects on the trucking industry. Many trucking companies are unable to maintain the same size fleet as they had months ago, reducing the number of trucks they operate, some to the point of having to close their business completely. A reduction in trucks also means more capacity issues as well, as companies are not able to provide enough trucks to meet the growing demand of manufacturers" (Road Scholar Transport, 2010).

2.2.5 *Carbon Emissions*

Since the trucking industry is the biggest consumer of diesel fuel, this also equates to it being the largest emitter of CO_2 gases into the atmosphere which is a great environmental concern. However, recognizing the need to make substantial improvements to address this national dilemma, The American Trucking Association (ATA) has taken an aggressive role to lead this effort. The Sustainability Task Force unveiled recommendations that will reduce fuel consumption by 86 billion gallons and CO_2 emissions by 900 million tons for all vehicles over the next 10 years. The program's initial goal of reducing the industry's carbon footprint was dovetailed onto our economic need to reduce fuel consumption.

Those recommendations are to enact a national speed limit of 65 mph and govern new truck speeds to no more than 65 mph; to pursue a federal solution to reduce both non-discretionary and discretionary idling through incentives for new technology; to encourage participation in the EPA SmartWay program; to advocate for initiatives to improve highway infrastructure and reduce congestion; to advance policies and positions that will allow the use of more productive trucks and to oppose the application of a cap-and-trade regulatory approach for mobile sources (Graves, 2008).

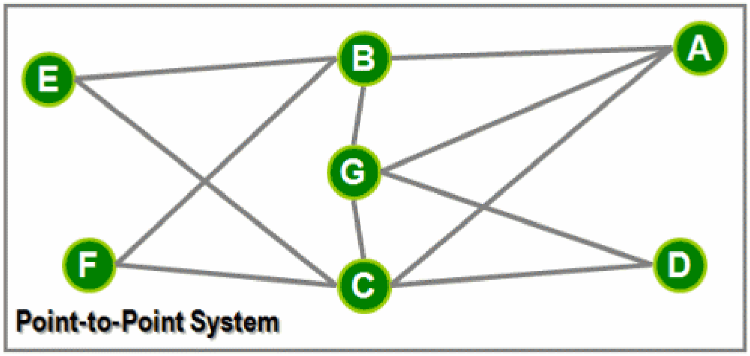
CHAPTER 3

OVERVIEW OF FREIGHT TRANSPORT NETWORKS IN LITERATURE

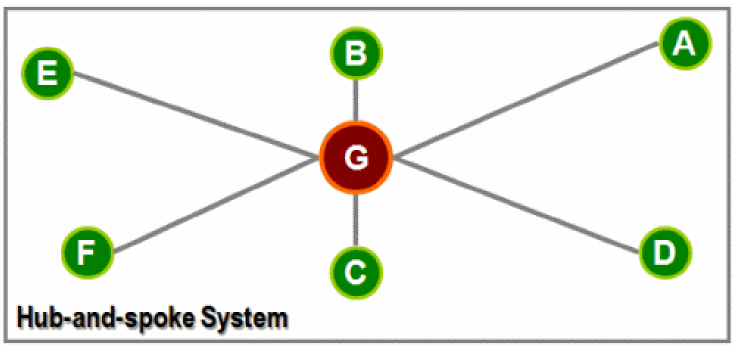
3.1 Transportation Distribution Networks (Current)

Critical to any supply chain success is its ability to deliver goods on time. A function of that on time delivery is the cost and routing variables that continually are being optimized. Utilizing the production and inventory control concept of economic order quantity or EOQ, there must exist a balance between shipping time, demand and inventory stock. Transportation cost might not affect the ordering policy in the application of the EOQ model. However, it affects the constantly carried inventory, the safety stock. This is obvious as a longer transit time would increase the risk of running out of stock (stockout) and necessitate the need for a larger safety stock. Therefore, transportation affects the total logistical costs in a very fundamental way (Wang and Wittwer, 2008).

With millions of miles of roadway to navigate the trucking industry like other transportation industries have to implement a strategic routing plan to ensure it accounts for all potential variabilities. Two such logistics configurations are the point-to-point and hub-and-spoke distribution models shown below in figure 3.1.



(a)



(b)

Figure 3.1 Transport Distribution Models: (a) Point-to-Point and (b) Hub-and-Spoke (Coyle, Bardi and Novak 1994)

3.1.1 Point-to-Point

The Point to Point transportation network architecture is one that dates back to the beginning of transportation itself. Before cars, trains and other modes of transportation were created, people walked from their point of origin to destination. A look into the history of transportation reveals that from the initial use of animals (7000 BC) to transport food and other goods across land to the first wheeled source created in Mesopotamia, which is modern-day Iraq, northeastern Syria, southeastern Turkey and southwestern Iran, around 2500 BC (Biblical history) to horses pulling carriages, all used the very basic concept of the movement of goods from their point of origin to its destination by whatever transportation means was available. The point to point network is very simplistic in its design and implementation. As its name suggests, this transit network takes the product from point A to point B. As in the case of the airline industry, which essentially coined the terms of transport networks as we know them today, a Point to Point network is a typical route network where an airline focuses mainly on its Origin and Destination (O&D) traffic. This means that the carrier is more interested in transportation of passengers originating from one city (A) to another (B) and vice versa, but not in connecting passengers between C and B via A. Low Cost Carriers are considered to be pioneers of this paradigm with a classic example being Southwest Airlines (Sandaruwan, 2010). The advantage of a point-to-point system is that it may minimize connections and travel time, but only if the airline serves the destination via the origination point. However, if a city is not served by the airline, then the potential passengers in that market segment would be lost. In the trucking industry, point to point could include short or long haul trips and truckload (TL) and less than truckload (LTL) carriers. This network is the most common routing configuration used by truckload carriers in the industry today.

3.1.2 Hub-and-Spoke

The hub-and-spoke distribution paradigm as defined by Bosner (2001) is a system of connections arranged like a chariot wheel, in which all traffic moves along *spokes* connected to the *hub* at the center. The concept of hub and spoke is not a new phenomenon. Pioneered in 1955 by Delta Airlines in Atlanta, GA, the hub and spoke model was born out of a need for the airline to compete with Eastern Airlines. While it was not immediately accepted by the airline industry, FedEx, in the mid 1970s adopted the concept for its overnight delivery service. After deregulation of the airline industry in 1978, many other airlines adopted the model coined by Delta. This distribution network which is named and patterned after a bicycle wheel, in its simplest form, is made of two parts. A **hub** is a central airport that flights are routed through, and **spokes** are the routes that planes take out of the hub airport, as shown in figure 3.2. Most major airlines have multiple hubs (Bonsor, 2001).

Figure 3.2 Hub and Spoke Network.

In general the Hub-and-Spoke model is a mutation of the point-to-point model. The hub-and-spoke model reduces the number of routes and consequently minimizes time between most origins and destinations. Although the implementation of this distribution structure reduces costs, the inherit disadvantage is because the model is centralized, day-to-day operations may be relatively inflexible. Changes at the hub, which is a possible single point of failure, or even in a single route, could have unexpected consequences throughout the network. It may be difficult or impossible to handle occasional periods of high demand between two spokes.

While the airline and LTL industry uses this network to its advantage and achieve many benefits in operational efficiency, hubbing in truckload (TL) shipping is not as clear cut in its benefits and consequently the industry has to have other motivating factors. As Taylor, Harit and English point out in the study "*Hub and Spoke Networks in Truckload Trucking: Configuration and Operational Concerns", a* primary motivating factor for using hub and spoke in truckload trucking is to reduce tour length. However, the challenge in this case is to identify and quantify the tradeoffs between savings associated with tour length and driver turnover relative to costs as well configuring the topology of the network in such a way as to minimize deadhead miles and any excess circuitry. The authors outline two limited experimental implementations in their study for the trucking industry to consider to assess economic feasibility and operational efficiency. “The first experiment was designed with “zone” drivers. In this methodology, drivers are dispatched only within a certain zone and are guaranteed to be home at least one day each week. The second experiment is with very limited hub and spoke implementation consisting of regularly scheduled trips between two hub cities along one lane or spoke. The authors conjectured that both of these strategies present viable options for truckload trucking companies if implemented on a partial basis. In other words, the system would likely fail if all drivers are converted to either zone or lane drivers, yet the optimal percentages of drivers that should operate using alternative methods is unknown” (Taylor, Harit and English, 1995). The results of the study found that hub and spoke networks perform well in some areas and poorly in others with the key improvement being driver tour length. That improvement however was at the expense of other criteria such as average miles per driver per day, which essentially reduces driver wages, circuitry and first dispatch empty miles.

3.2 Distributed Multi-Segment Transport (Proposed)

There is another transportation distribution network that has the potential to introduce an alternative that addresses at some level the disadvantages experienced by both the point to point and hub and spoke networks while simultaneously transforming the existing architecture into an algorithm with more sustainable components. Introduced by Benoit Montreuil in 2011, the distributed multi-segment intermodal transport network brings the concept of a physical internet to the traditional freight transportation arena.

3.2.1 Digital to Physical Internet Design

The vision of the Physical Internet, outlined by Montreuil (2011) addresses the issue of transport in container freight. Specifically, the proposal set forth is to evolve from a point-to-point hub-and-spoke transport to distributed multi-segment intermodal transport similar to the digital internet.

“In the Digital Internet, as Montreuil explains in his proposal, the data packets that constitute an overall transmission, such as an email, do not travel directly from source node A to destination node B. The packets travel through a series of routers and cables (copper or fiber optic), dynamically moved from origin to destination in the best way possible provided the routing algorithms and the congestion of the networks. Packets forming a message are not restricted to travel together. Each may end up traveling its distinct route, and then the overall message is reconstituted upon the arrival of packets at final destination" (Kurose, Ross, and Wesley, 2009).

A simple pictorial illustration of this type of network is much like a "daisy chain". Daisy chains whether made of out of daisies, pearls or any group of individual items or activities are made by threading these items together on a string which could represent a highway in transportation or through a series of connected events, activities, or experiences as one would image when encountering a succession of occurrences.

To illustrate the current mode in which the transportation industry moves foods, Montreuil uses the example of a shipper who wants to have a trailer fully loaded with containers transported from Quebec to Los Angeles. "According to the current way, there is a high probability that (1) the driver and a truck will be assigned to the multi-day trip, (2) the driver will drive all the way to the destination, sleeping in the truck, and (3) once having delivered the trailer in Los Angeles the driver will move the truck to some location nearby to pick up a trailer returning towards Quebec so as to avoid empty travel.

In the Physical Internet, the scenario would most like unfold as follows as envisioned in the author's proposal. A first driver-truck duo would be assigned to transport the trailer to a transit point or yard station two to six hours away. The trailer would then be deposited to a predetermined trailer or slot. The first duo would then pick up another trailer required to return to Quebec. A second driver-truck duo would soon afterward pick up the trailer and move it another segment forward, or better yet, the containers could be transferred to other trailers, trucks, trains, ships, or planes as pertinent given the opportunities." The process would then repeat until all containers have reached Los Angeles as shown in figure 3.3 below. The shipper or its representative would have a prior arranged transportation on each segment and the routing decisions would be dynamic and/or distributed as opportunities unfold throughout the trip.

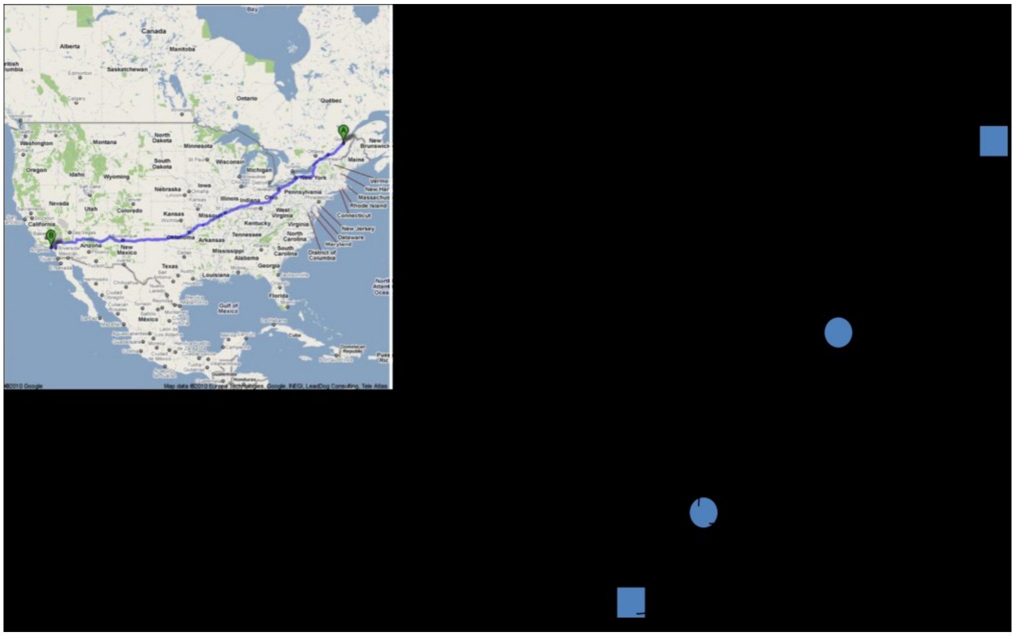


Figure 3.3 Physical Internet enabled distributed transport. Adapted from Benoit Montreuil, Canada Research Chain Enterprise Engineering.

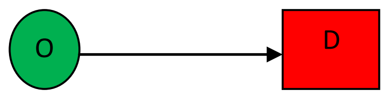
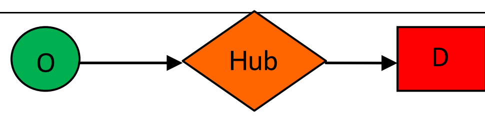
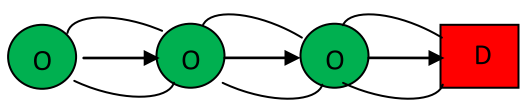
To contrast the two methods based on a typical route between Quebec and Los Angeles, the following explanation is provided. In the current method, the single driver would travel over 6213miles round trip for a duration of at least 240 hours, with the containers reaching Los Angeles after 120 hours or 10.9 days (based on an 11 hour driving day as required by the Department of Transportation). In the proposed multi-segment distributed method, seventeen drivers would each drive an average of about 6 hours each, thus returning home with his truck in a single day, yet collectively getting the containers in Los Angeles in roughly 60 hours (5.45 days), about half the current time.

3.3 Transport Networks Summary Comparison

As set forth in the beginning of this research, the framework of study will involve the analysis of the three aforementioned transport networks, point to point, hub and spoke and distributed multi-segment, using a predetermined methodology that will be discussed in a future chapter. The attributes of these networks are marginally dissimilar but all seek the same goals of providing routes that deliver goods to the end users at the fastest time possible and for the shipper at the lowest possible cost.

To summarize their general configuration and characteristics as we move into the next chapter, below is a table and graphical depiction, in table 3.1, of the networks side by side along with functionality.

Table 3.1 Summary Comparison of Transport Networks

Point to Point (P2P)		• Transit network that takes the product from point A to point B. • Minimizes travel time.
Hub and Spoke (H&S)		• System of connections arranged like a chariot wheel. • Multiple spokes connected to a hub in the center • Hub could be single point of failure.
Distributed Multi-Segment (DMS)		• “Daisy Chain” design • Breaks up route into a series of short segments • Multiple truck and driver duos complete shipment

To better assess the performance of the networks when compared to each other, a set of performance measures or metrics must be established as to not create a bias within the study. This will be accomplished in the next chapter.

CHAPTER 4

OVERVIEW OF FREIGHT TRANSPORT PERFORMANCE MEASURES

4.1 The Importance of Freight Performance Measures

"A comprehensive, objective, and consistent set of measures of performance of the U.S. freight transportation system is important for assessing the condition of that system, identifying its problems, and setting priorities on actions to resolve those problems. Freight system performance measures are important to support decisions about investments, operations, and policies for both the public and private sectors, and for the system as a whole and its critical components–corridors, links, and nodes (terminals). Performance measures for the freight system that are applicable and comparable at various geographic levels will also help educate planners, decision makers, and the public about the importance of freight transportation to our economy and quality of life." (*Schofield and Harrison 2007*).

The method by which any product or process is judged is based on the metrics and measures established by the stakeholder by whom it is used. As Schofield and Harrison quoted, performance measures aid decision makers generate long terms goals and plans about the transportation system they oversee. This is especially critical as economic growth in the future is predicted to place severe strains on the transportation system and policymakers need to be able to assess the impact of state multimodal investment decisions on the performance of the overall freight transportation system (McMullen and Monsere, 2010).

4.2 Data Accuracy and Collection Methods Reliability

"In order to quantify freight issues through modeling, the data itself—and how efficiently it is collected—is critical, especially for: (1) improvement strategies evaluation for freight mobility; (2) system performance forecasting; (3) mitigating the impacts of truck traffic; (4)

determining the impacts on air quality; and (5) improving the safety and security performance of the road network" (Holguín-Veras and Ban, 2010).

The freight transportation industry faces some difficult obstacles in the area of data collections which threatens to hinder critical decision making for governmental and corporate authorities instrumental in developing policies for the improvement of the system. These issues include:

1. Varied sources of transportation information exist for different modes, commodities, etc.
2. Little consistency between sources generally collected for system monitoring purposes, not planning
3. Timeliness
4. Few efforts underway to improve data
5. Collection methods and reporting formats and requirements make comparisons across databases difficult
6. Differences between internal and external statistics
7. Freight information is largely single purpose in nature and not directly comparable by mode
8. Varying measures of activity: shipments, value, tonnage, movements, truckloads, ton-miles, volumes, carloads, containers, cubic feet, load densities, on-time performance, per acre, per square feet
9. Data needs are not clearly identifiable so data gathering is not focused.

4.2.1 Data Sources

At a national level, states, metropolitan planning organizations (MPOs), ports and airports use data and information compiled and published by the US federal government and/or private commercial sources for data related to freight movements and transportation (US Department of Transportation, 2002). The summary of initiatives undertaken to collect data for use in analyzing freight performance are thorough but many in number as shown in figure 4.1 below (Haider, Ewing, and Patterson, 2007).

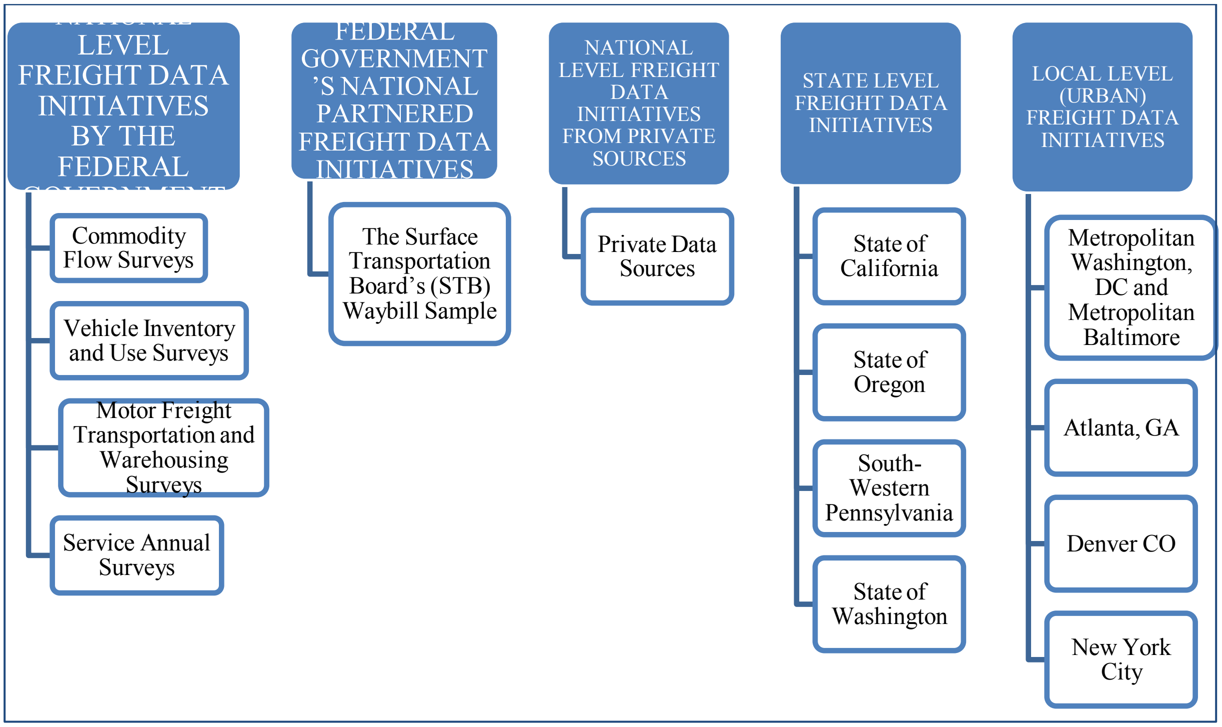


Figure 4.1 Summary of Data Sources used for Freight Transportation Performance

4.2.2 Data Collections Methods: An Overview

Surveys: **“**Freight transportation surveys present very different and major challenges not faced by passenger surveys. Ironically, the bulk of research that has focused on addressing the methodological issues of travel surveys has mainly focused on passenger travel. Some of the key issues involved in freight transportation that affect the possible type of surveys to be implemented are: (1) multiplicity of metrics to define and measure freight; (2) multiplicity of factors determine freight generation, freight trip generation, distribution and the other factors that determine demand; (3) multiplicity of economic agents involved; and (4) agents that only have a partial view of the freight system” (Holguín-Veras and Ban, 2010).

The development of surveys must be careful to address all the inherent complexities that comes with measuring freight while maintaining a level of simplicity that those who are asked to complete will not be overwhelmed by all the information being asked. One such issue is huge number of vehicle types, tens of thousands of different commodities that are transported, and multiple ways to measure them (e.g., tons, ton-miles, vehicle-trips, cargo value). All these aspects complicate tremendously the development of freight surveys.

In order to address the multiple potential issues of freight data collection, the 2010 report written and published by Jose Holguín-Veras, and Jeff Ban of Rensselaer Polytechnic Institute to the New York Metropolitan Transportation Council entitled “Feasibility Study for Freight Data Collection” outline 4 main types of survey based methods by which freight transport data was collected for metropolitan area of New York City. In this study, the different types of data collection techniques or surveys were found to be grouped depending on how the sampling frame is defined (i.e., on the basis of the establishments at the origin or the destination of the shipment, the truck traffic, cargo tour). This translates into data collection procedures that focus on the origin or destination of the cargo, or en-route as in a truck intercept survey, or along the chain of the shipment. After the sampling frame was established then the following surveys could be utilized.

Establishment based surveys: “This type of survey, establishments engaged in freight activity at either end of the transaction (i.e. shippers, carriers, receivers, etc.) is the main focus. These data collection methods involve surveying owners, operators, or fleet managers of key establishments, which may include manufacturing facilities, warehouses, retail distribution centers, truck terminals, and trans-loading facilities. These surveys can be used to collect comprehensive information about economic, land use, and modal freight activity characteristics of the facilities. Types of surveys include **receiver** based, **shipper** based and **carrier** based. Tools used to gather data from these entities can involve mailouts-mailback, telephone interviews, personal interviews and/or a combination” (Holguín-Veras and Ban, 2010).

Trip intercept based surveys: “This type of survey focus on truck/vehicle trips, instead of pre-selecting establishments involved in freight activities. Truck intercept surveys (i.e.

roadside interviews) tend to be relatively short to minimize the traffic disruptions they produce. For that reason, data are collected for the current trip (the one being intercepted) with complementary question aimed at assessing the length of the trip chain, and other pertinent information. Some of the key strengths of performing roadside intercept surveys for gathering truck travel information are: (1) that they offer the best statistical control and reliability, since sample is from known traffic population; (2) they have high response rates compared to mail or telephone surveys, due to direct one-on-one interview with the driver; (3) surveys at external stations provide a good statistical representation of trucks entering, exiting, and passing through the study area; (4) they have low investment costs (compared to productivity), if managed and administered properly" (Holguín-Veras and Ban, 2010). The type of survey conducted in the category is roadside interviews.

Cordon survey: "Cordon surveys collect travel pattern information including origins and destinations at the perimeter of a region. External cordon surveys are designed to obtain information on trips that cross the external boundary of a study area. External cordon surveys are usually conducted using one of these three methods: (1) roadside interviews, (2) roadside postcard survey distribution to be mailed back, or (3) license plate recording/matching with a survey mailed out to be returned" (Holguín-Veras and Ban, 2010).

Vehicle Based Surveys: "These surveys have individual vehicles as the sampling unit. They try to collect information regarding the vehicles' freight specific operations. Surveys in this category are travels diary and data collected with the assistance of Global Positioning Systems (GPS)" (Holguín-Veras and Ban, 2010).

Travel diary surveys: "Travel diary surveys are useful for understanding internal-internal truck trips in an urban area. This data collection method involves selecting a representative sample of trucks operating in the region and obtaining travel diaries from truck drivers for pre-selected time duration (usually 24 hours)" (Holguín-Veras and Ban, 2010). .

Surveys and freight data collection assisted by Global Positioning Systems (GPS). These surveys make use of Global Positioning Systems (GPS) to track the routing patterns of trucks while they travel in the study area. This type of survey is more of an automated method and will be further outlined in the next section.

Each survey method as identified above has its own level at which data is detailed as shown below in Table 4.1).

Table 4.1 Sampling frame of different data collection methods (Holguín-Veras and Ban, 2010)

■ Excellent level of detail
◘ Good level of detail
▣ Some level of detail
⊡ Low level of detail
□ Only general information

Unit/ Sampling Frame		Freight generation data		Delivery tours				Economic characteristics of participating agents			Spatial distribution / Location of participating agents			Network				Special choice processes			Other economic data		
		Production	Consumption	Sequence	Location	OD flows	Empty flows	Shippers	Carriers	Receivers	Shippers	Carriers	Receivers	Travel times, costs	Use restrictions	Capacity	Traffic volumes	Mode choice	Delivery time	Mode attributes	Production functions	Demand functions	IO tech. coeffs.
Establishment	Shipper	■				◘		■	▣	▣	■	▣	▣					□		⊡			
	Carrier			■	■	■	■	⊡	■	⊡	◘	■	◘	▣	□				▣	▣			
	Receiver		■			◘		▣	▣	■	▣	▣	■					▣		⊡			
Trip intercepts		⊡	⊡	⊡	⊡	◘	▣	⊡	▣	⊡	⊡	▣	⊡	▣	⊡	⊡			⊡	⊡			
Vehicle				■	■	■	■	⊡	■	⊡	◘	■	◘	▣	□				▣				
Tour				■	■	■	■	⊡	■	⊡	◘	■	◘	▣	□				▣				

Automated methods of data collection in freight transportation are still a rather evolving option. While they offer, in most cases, a higher level of accuracy in location and time based data, the inherent limitations brought on by cost, privacy issues and technical mishaps may hinder their optimal usage. A few of these methods are discussed below.

Automatic Vehicle Location: Automatic Vehicle Location (AVL) systems calculate the real-time location of any vehicle equipped with a Global Positioning Satellite (GPS) receiver. Data are then transmitted to the transit center with use of radio or cellular communications and can be used immediately for daily operations as well as archived for further analysis. As a stand-alone technology, an AVL system can be used to monitor on-time performance. When combined with other technologies, AVL can deliver many benefits in the areas of fleet management, service planning, safety and security, traveler information, fare payment, vehicle component monitoring, and data collection (US Department of Transportation, 2007).

Radio frequency Identification Device (RFID): "Radio frequency identification (RFID) is a generic term that is used to describe a system that transmits the identity (in the form of a unique serial number) of an object or person wirelessly, using radio waves. It's grouped under the broad category of automatic identification technologies. Auto-ID technologies include bar codes, optical character readers and some biometric technologies, such as retinal scans. The auto-ID technologies have been used to reduce the amount of time and labor needed to input data manually and to improve data accuracy. Some auto-ID technologies, such as bar code systems, often require a person to manually scan a label or tag to capture the data. RFID is designed to enable readers to capture data on tags and transmit it to a computer system—without needing a person to be involved" (RFID Journal, 2005).

4.2.2.1 Advantages and Disadvantages.

Table 4.2 below outlines some of the benefits and issues related to the data collection as described above.

Table 4.2 Truck trip data collection approaches and implementation techniques (adapted from Jessup, Casanvant, and Lawson, 2004)

Survey Approach	Implementation Technique	Advantages	Disadvantages
	Manual Counts (direct observation)	-May be more accurate than automated counters -No traffic disruption -Low risk to individual observers	-High personnel requirement -Potential for human error -No information regarding O-D, trip purpose, route, commodity, etc.
Vehicle Classification Counts	Automated or electronic data (WIM, Loop Detectors, **RFID** etc)	-No traffic disruption -Able to collect traffic counts at many sites efficiently with low labor requirement	-Potential for equipment failure -Limited to location and availability of electrical transponders -Costly
	Video Surveillance	-No traffic disruption -Better information on type of commodity hauled compared with automatic counters	-High equipment cost requirement - Potential for equipment failure or recording during adverse weather
Surveys (establishment, trip intercept, vehicles based)	Road side Interview	-Complete information, especially related to regarding O-D, trip purpose, route, commodity, etc. -High response rate -Good sampling control -Ability to expand to total truck traffic population	- High labor requirement -Significant risk to labor personnel -Potential disruption of traffic -Limited locations where surveys must be implemented. -Only captures truck traffic that passes through interview sites.
	Phone Survey	-Higher response rate when compared with mail surveys -Quick turnaround	-Difficulty obtaining correct phone numbers -Can only call during regular business hours
Travel Diary	Mailout-Mailback Survey (Owners, Operators, or receivers)	-Inexpensive	-Low response -Difficulty ensuring complete survey -Requires access to vehicle registration list file.
	Combination Phone Mailout-Mailback survey	-Improved response rate over mail only survey -Better identification of appropriate survey respondent	-Relatively low response -Follow-up calls maybe time consuming and costly --Requires access to vehicle registration list file (DMV or third party list)
	Personal Interview	-Complete information	-High labor requirement -Expensive

4.2.3 Data Collection Method Accuracy

To assess the accuracy of the data collection methods used through the freight transportation industry, Samuel W. Lau performed and submitted a study for the Metropolitan Transportation Commission entitled, “Travel Truck Surveys: A Review of Literature and State-of-the-Art” (Lau 1995). In this study, eight major urban truck travel studies and their experiences were captured and analyzed (Jessup, Casanvant, and Lawson, 2004). Of interest in this research is the results published for typical response rate of surveys given as shown in table 4.3 below.

Table 4.3 Summary of truck travel surveys in urban areas (Jessup, Casanvant, and Lawson, 2004)

Survey Method	Place of Survey & Year	Typical Completed Surveys (% of total population)	Typical Response Rate
Telephone Interview	N.Y. (1964), Calgary (1971) El Paso (1994)	4%-15%	40%-50%
Mailout-Mailback	Chicago (1986), Vermont (1995)	1%-5%	10%-45%
Combined Telephone and Mailout-Mailback	Phoenix (1991) Houston (1994) Alameda, CA (1991)	3%-10%	30%-80%
Roadside Intercept/Interview	Calgary(1991-1994) Alameda, CA (1991), Vermont (1995)	8%-35%	95%-100%

There were generally three types of data collection methodologies employed in these early studies, with roadside interviews and the combined telephone-mailout-mailback approach being the most common, followed by mailout-mailback surveys and telephone surveys. Response rates for each of these approaches varied widely; the mailout-mailback survey had the lowest response rate and roadside surveys and the combined telephone-mailout-mailback approaches had higher response rates. Most of the mail or telephone related surveys utilized the state department of motor vehicles registration file for selecting a random sample of commercial vehicle owners to survey. Roadside interviews were generally conducted at the available weigh stations on interstate highways and freeways or at toll and bridge crossings (Jessup, Casanvant, and Lawson, 2004). The report showed that the most common types of information solicited for each data collection approach were origin-destination (O-D), truck type, number of axles, odometer reading, commodity category and land use. Only one study collected information concerning routes and one on the driver.

Table 4.4 Data Accuracy of Automatic Technology (Turner et al, 1998)

Technique	Data Accuracy	Constraints
Signpost based AVL *	Low	No of signpost sites, transit routes and probes
Global Positioning System (GPS)*	High (horizontal positioning accuracy of 5 meters 95% of time)**	No. of probes
Automatic Vehicle Identification (AVI) /RFID*	High (99.5%-99.9% detection accuracy under good conditions)**	No. of antenna sites and tag distribution

Data on the accuracy rates of automated methods in freight transport show that radio frequency identification detection (RFID) is the most accurate, as shown in table 4.4 above. Trucking fleet operators commonly use the AVL technology to track their vehicles throughout the course of delivering products. Other operators use it for more sophisticated purposes, including granting customers access to information on shipment locations, monitoring the mechanical performance and security of the fleet vehicles during transit, and conducting dynamic vehicle routing and scheduling. This is similar in nature to the usage of RFID in tracking inventory and fleet between origin and destination. Due to real time tracking capability the accuracy of the automated methods introduced have become increasingly more reliable. However these devices may not provide all of the data that the traditional surveys are able to provide.

4.3 Freight Performance Measures Stakeholders

Critical to comparing freight transport networks with the end goal of selecting a more sustainable choice as set forth in this study, a very important first step would be to establish an unbiased set of measures and metrics for a basis of design. Research on performance measures in freight transport has gained traction in recent years and the literature found show a positive progress in that direction but the subject is still quite convoluted.

Dr. Wayne Cottrell (2008) in his research of performance metrics used by all freight providers revealed that articles on performance measures have increased since 2000 due to the world's dependence of transportation to move people and goods. However, the tradeoff of the increase in dependence is the increase in the number of stakeholders that set goals and expectations on the freight industry. Cottrell found through literature review that the creation and implementation of freight performance measures is subject to the interpretation of the stakeholder group. In his assessment of over 10 publications prior to 2000, Cottrell found a range of performance measures used with differing objectives. These included: supply chain excellence, efficiency and effectiveness, customer service, freight terminal capacity, and inventory control. The most common objectives were customer service and operational efficiency. Customer service performance was measured generally in terms of "on time pickup %", "on time delivery %" and "loss and damage rate". Common operational efficiency measures included "total kilometers per vehicle per year", "kilometers traveled empty as a proportion of total kilometers traveled ", "average actual load as a proportion of full load capacity", "number of kilometers per driver per year " and "fuel usage by vehicle type".

Post-2000 publications highlighted by Cottrell discussed a more concerted effort on a federal and state level from the Transportation Research Board conference which in 2001 brought together the Federal Highway Administration (FHWA) and State Department of Transportation officials to focus on moving towards standardizing performance measures in freight movement. The key points of focus in their work together were data gathering, ensuring that whatever measures were used were traceable and representative of the constraints of data availability. The performance measures after the year 2000 based on Cottrell's overview maintained the focus of customer service ("customer facing") and operational efficiency(internal facing") but seem to take a more deliberate effort at identifying stakeholders and their transport needs. As outlined by Lai, et al (2002), the primary concerns of customer facing were identified as reliability, flexibility and responsiveness, while the main concerns of internal facing were costs and assets. One final takeaway from Cottrell publication was work done by Jones & Sedor (2006) which summarized the efforts of the FHWA to facilitate the development of reliability measures for freight travel. The authors pointed out that the Department of Transportation recognized that "timely and reliable movement of freight is critical to the Nation's economy." Essentially, the FHWA's efforts began to concentrate on reliability. As a result, the following measures were proposed: fill rate, delay, travel time, travel time reliability (speed & buffer time index), profitability, and return on investment.

The Transportation Research Board's (TRB) National Cooperative Freight Research Program (NCFRP) Report 10 (2011): "Performance Measures for Freight Transportation" (NCFRP 03) explores a set of measures to gauge the performance of the freight transportation system on a national level. It is a concerted effort by multiple agencies including the American Transportation Research Institute (ATRI). The performance measures and Freight System Report Card in the NCFRP 03 reflect local, regional, national, and global perspectives and are intended to serve as a resource for a range of stakeholders who need to make investment, operations, and policy decisions. An immediate delineation that the report makes is that there are two classes of stakeholders: public and private.

There are differences in how the public and private sectors perceive performance. As noted by the TRB, typically, the public agency's focus is on safety, security, durability, and capacity of the infrastructure as well as congestion, bottlenecks, or accidents. Conversely, the private sector's focus is on door to door travel time; reliability of service they provide to their customers; safety and security of product, vehicle, and operator; and availability of the right equipment and route with adequate capacity and strength.

Poister (*2004*) in his discussion on performance measures in transportation argues that most performance measures used by transportation agencies fall into one of the following three categories: agency performance, system performance, and the impact on broader social performance measures. Agency performance focuses on service delivery, projects completed, etc. System performance focuses on capacity and conditions of the transportation system as well as issues such as travel times, cost, safety, etc. Finally, societal performance measures deal with broader societal concerns such as economic development and the environment.

The report published by the NCFRP addressed freight performance by a multi level approach: national, state and metropolitan. Utilizing a balanced scorecard methodology to address competing objectives and complexity of the freight industry, the report outlined six components: freight demand, freight efficiency, freight system condition, freight environmental impacts, freight safety, and the adequacy of investment in the freight system in which to collect data. The freight performance measures report looked at several perspectives on the collection and use of performance measures. Those of the States and Trucking Industry are worth noting here in this study. Although the national study encompassed all modes of freight transport, this scope of work in this dissertation will focus on truck freight mode only.

4.3.1 Trucking Industry Perspective

The authors of the NCFRP report surveyed a small number of trucking companies, their managers and executives, to understand the performance measures being utilized by at least a small cross section of the industry. The overall objectives, as outlined in the report, as to the primary reasons why measures were used included (in order of frequency) as shown in figure 4.2 below.

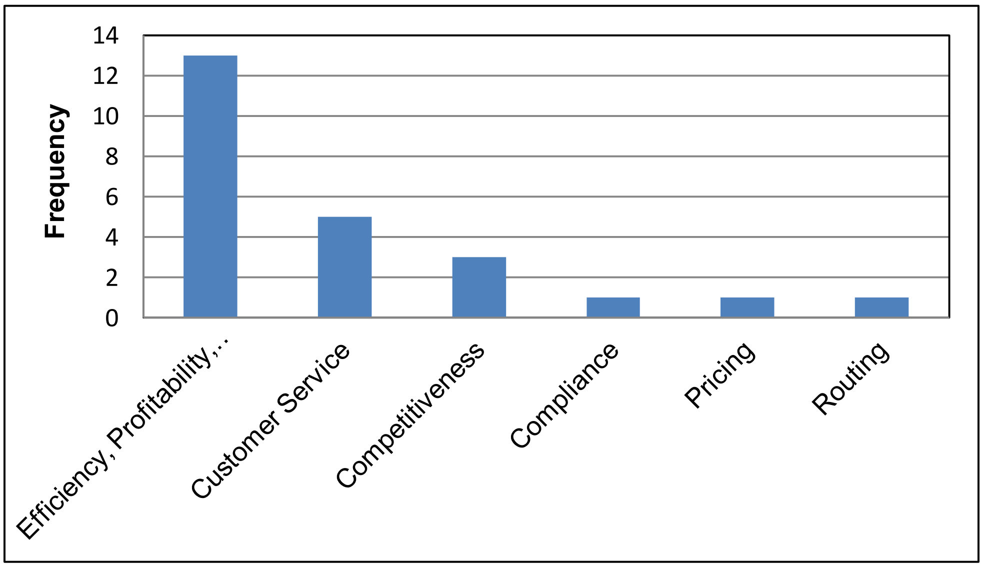


Figure 4.2 Objectives of Trucking Companies (Survey Results)

Further, the report captures the most important performance measures used by the trucking companies which were:

- Labor productivity;
- On-time pickup and delivery;
- Revenue yield by shipment or by mile;
- Shipments per truck/ truck productivity;
- Fuel economy;
- Profit or loss per truck;

- Equipment utilization;
- Maintenance costs;
- Out-of-route and loaded miles;
- Loading and unloading times; and
- Border crossing time/delays.

4.3.2 State Perspectives

The NCRFP Report found in general that the states are not equal when it comes to use of performance measures. A minority of the states use only a handful of measures while more mature states use between 5 and 10. To create a better profile of just what measures states utilize, the authors sent surveys to all 50 State Department of Transportation (DOT) agencies. Targeted were officials within the state freight offices. State officials overall expressed greatest interest in measures that captured information regarding the performance of local and regional freight networks on an annual or quarterly basis with the exception of travel-time data which could be used for planning and project-selection purposes. Most states expressed that no national targets be set, instead allowing states to set targets that meet their needs.

Taking a closer look at five individual state generated reports (Georgia, Minnesota, California, Washington and Oregon) that were created in response to the NCFRP's project, there really were no two states that approached the task the same way. However, there were measures among them that were commonly used in the assessments of trucking in their own states. The eight main metrics were:

1. **Network Supply**
2. **Travel Times**
3. **Travel Safety**
4. **Energy Security**
5. **Mobile Source Emissions**
6. **Monetary Travel Costs**

7. **Regional Accessibility**
8. **Congestion**

To gain a better understanding of what performance measures were important to all individual states, the state of Oregon Department of Transportation commissioned a study to be performed which was eventually entitled "Freight Performance Measures: Approach Analysis" (McMullen and Monsere,2010). The investigators found that there was a list of general performance measures/goals being used by states. Those measures and their frequency are shown in Table 4.5 below.

Table 4.5 State Goals and Performance Measures (McMullen and Monsere, 2010).

Goals	***# of states citing this as a goal***
Safety	42
Environmental stewardship/quality of life	32
Protection/Maintenance of Transportation Investment	29
Mobility of people and/or goods (only 11 explicitly mentioned freight movement of goods)	28
Accessibility	21
System Efficiency	18
Promotion of interconnectedness/multimodal system	16
Security	15
Economic Vitality	15
Economic Development	13
Revenue Enhancement	12
Congestion Management	8

While national/federal standards are established for the governing of the trucking industry for freight hauls, as suggested in the perspectives outlined in the NCFRP's report, the states prefer to set their own standards of performance. These standards do not always encompass all of the policies that all public and private stakeholders desire but they do give the decision maker enough applicable variables to potentially optimize, especially from a quantitative perspective, the performance of freight movements within the state and assess the volume of truck traffic to begin to address congestion issues.

4.3.3 Industry Critical Issues Perspective

For another perspective on performance among commercial carriers, the American Transportation Research Institute (ATRI) identified the trucking industry's critical issues in 2007, based on a survey of trucking companies. The issues point toward performance measures that might be used to assess how well the needs of the trucking industry are being addressed. The critical issues can be grouped into eight subject areas:

1. Hours of service regulations
2. Driver availability and shortages
3. Fuel costs
4. Highway congestion
5. Toll costs
6. Tort and other liability matters
7. Environmental controls
8. On-board technology

4.4 Truck Freight Transportation Goals

As the literature clearly conveys, there are varying perspectives that drive the importance of certain performance measures. Every stakeholder has their own goals and objectives and a preference at how those are met. However, in order to assess the performance of the proposed transport networks as set forth in this study, it is imperative that a general set of measures are established that will address the goals, objectives, and concerns of all stakeholders invested in the truck freight transport system as a whole as well address the sustainability challenges as outlined within the challenge of this study.

Performing a side by side comparison of the results found in literature, as shown in figure 4.3, we can develop a general listing of goals to assess the truck freight transport network as shown in table 4.6.

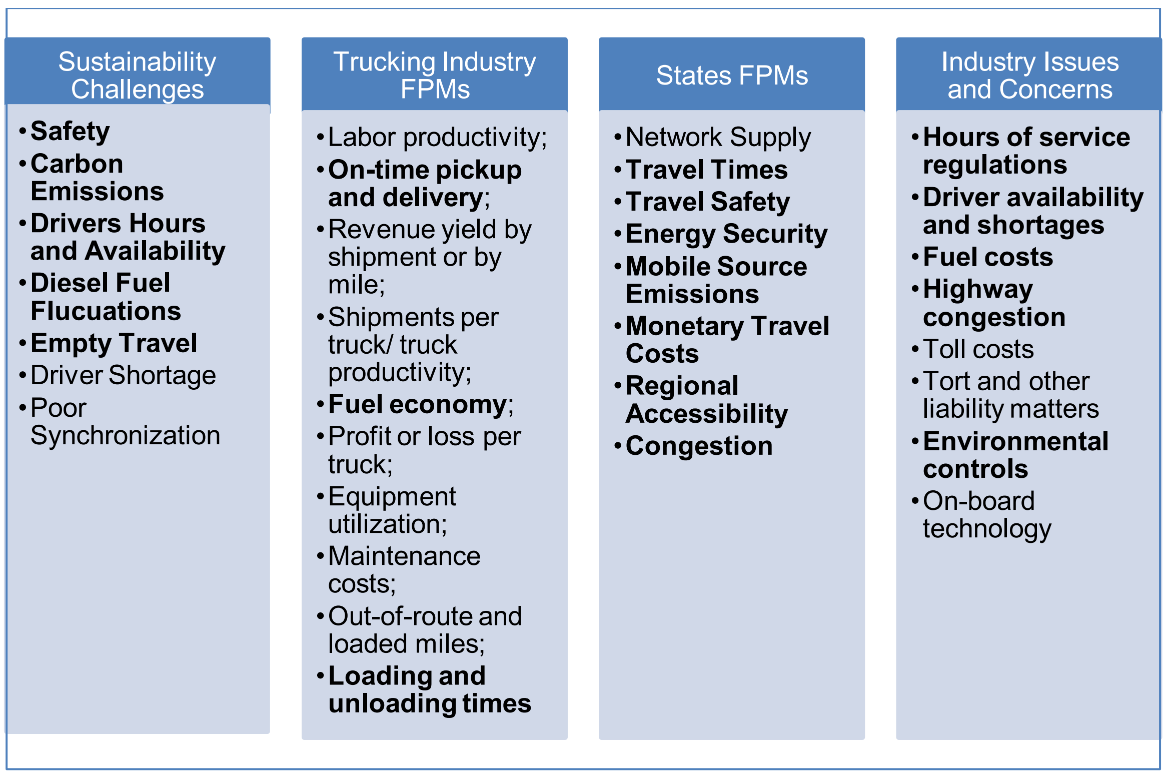


Figure 4.3.Trucking Freight Transportation Goals and Challenges Summary Matrix

Table 4.6 Common Performance Measures

Performance Measures
Travel Time (Mobility)
Travel Costs
Accessibility
Safety
Energy
Emissions
Driver Quality of Life

4.5 Discussion and Evaluation of Truck Freight Performance Measures in Literature

Safety: Safety is an inherent performance measure the trucking industry deals with on a continuing basis. According to a performance report by the U.S. Department of Transportation, the most common indicators with respect to safety are fatalities per 100 million vehicle-mile of travel and number of accidents per 100 million vehicle-miles of travel. This performance measure, by far, is a critical component in ensuring the safety of our roadways. The fatality, injury, and crash rates that involve commercial vehicles or large trucks are the ones most obviously related to freight performance as reported by the Federal Motor Carrier Safety Administration and individual states all across the US.

Mobility and Accessibility: The overall basic goal of any freight transportation system is the movement of goods from origin to destination by a specified mode. As highlighted by McMullen and Monsere (2010) many of the mobility measures used by both private and public stakeholders have to do with travel times. It is not intuitively obvious how the measures are calculated. The travel time index (TTI) developed by the Texas Transportation Institute is one example of a measure applied to a specific corridor using a known methodology. The travel time index is defined as the peak-period travel rate divided by the free-flow speed or posted speed travel rate. So a TTI of 1.30 indicates that it takes, on average, 30 percent longer to travel in the peak than it does in the off-peak period. Researchers at the Texas Transportation Institute also point out that in consideration of the TTI measure that observed truck speeds are affected by not only congestion levels and time-of-day patterns, but also the urgency of the driver (i.e., an owner/operators incentive is productivity, and he may likewise be driven to deliver more shipments, while a private company driver may be paid hourly), commodity type, weight, and truck type (size). Grade also has a larger effect than with passenger vehicles, and there may be speed restrictions that meter truck speeds. The aspect of congestion is included in the consideration of this performance measure.

Accessibility is the ease of access in which a truck is able to get from one place to another. From the manufacturing facility to the distribution warehouse, is usually measured in terms of journey time and monetary cost (or freight weight) between the two places.

Environmental Emissions: One major tradeoff to the increase in the dependence of transportation in the movement of freight is the impact that it has on the environment. The trucking industry is the biggest consumer of diesel fuel, which in turn also equates to it being the largest emitter of CO_2 gases into the atmosphere which is a great environmental concern and in direct conflict with sustainability efforts. The DOT uses "Tons (in millions) of mobile source emissions from one-road vehicles" as one of the major performance measures (National Environment Research Institute, 2000).Some studies also define the performance measure based on the type of emissions from the transportation sources. For example, the DOT has given metric tons (in millions) of carbon equivalent emissions or green house gas emissions from transportation sources. The Environment Protection Agency (EPA) also determines the impact on the environment based on a criterion of pollutants (Federal Highway Administration, 2002).

Energy or Fuel Usage: The extreme fluctuations of the price of diesel fuel have invariably altered the entire landscape of the trucking industry over the last 8 years. Southworth and Gillett (2011) in their research of freight performance measures for the state of Georgia suggest that the principal energy performance measure of interest when looking at energy security is the average miles per gallon, or MPG, that trucks experience on the state's highways. This difference is considerable across truck classes, with some of the longer and heavier single unit as well as combination trucks operating at relatively low fuel efficiencies.

Travel Costs (Delay): The trucking industry incurs varying operating costs throughout its business model that in some aspects is just the costs of doing business. One particular, sometimes unavoidable occurrence is congestion. Congestion can drive up the cost associated with delay.

Driver Quality of Life: A performance that is not necessarily tracked by stakeholders for long term planning but is a critical issue outlined in our un-sustainable factors and an industry concern is driver quality of life. This freight performance measure is directly linked to hours of service that a driver is tasked with being away from his/her home base and consequently, his/her family. The U.S. Department of Transportation and the Federal Motor Carrier Administration regulates truckers on the number of hours driven per day. Currently, for property carrying interstate commercial drivers, a truck driver can legally drive for a maximum of eleven hours during any fourteen hour period of time. Once that eleventh hour has been reached, the driver must rest for a minimum of ten hours. In addition there is a weekly clock that the driver has to abide by as well. No truck driver can legally drive more than sixty hours over a period of one full week (Federal Motor Carrier Safety Administration, 2010). In a new proposed rule put forth by the administration in December of 2010, there would be increased restriction on drivers' hours, limiting the number of hours a driver can work. This could force carriers to hire more drivers and buy more trucks even amid a looming driver shortage (Davidson, 2011).

In response to the grand challenge as outlined in the beginning of this study of addressing regulations relating to restrictions on drivers' hours and quality of life, safety (accidents and fatigue), diesel fluctuations and negative environmental impacts, table 4.7 and figure 4.3 below give a summary of performance measures that will be used to perform analysis of the three transport networks in the upcoming chapters.

Table 4.7 Transport Analysis Performance Measures

Performance Measure	**Metrics**
Travel Time	• Mean Travel Time • Travel Delays
Travel Costs	• Delay Costs
Accessibility	• Demand Weighted Average Travel Time
Safety	• Truck Accident Rates

Table 4.7 -*Continued*

Energy	• Average Fuel Use
Emissions	• Average Daily Emissions Rate
Quality of Life	• Drivers' Hours of Service (away from home)

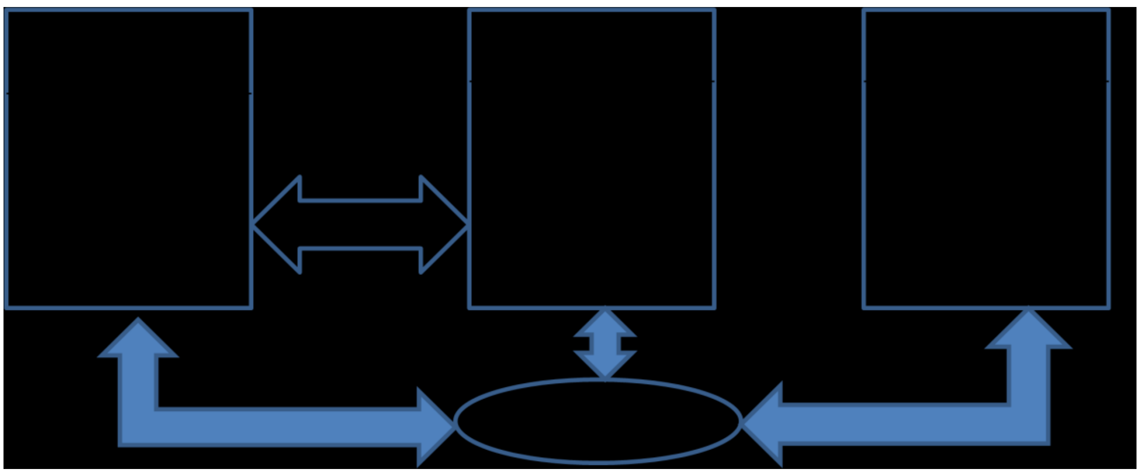


Figure 4.4 Sustainability Objectives Mapping

CHAPTER 5

RESEARCH METHODOLOGY

In this study, the principles and processes of decision analysis will be adopted. Keeney (1982) defines "Decision Analysis" as a philosophy, articulated by a set of logical axioms, and a methodology and collection of systematic procedures, based upon those axioms, for responsibly analyzing the complexities inherent in decision problems." These axioms as mentioned by Keeney provide principles for analyzing decision problems and imply that the attractiveness of alternatives should depend on (1) the likelihoods of the possible consequences of each alternative, and (2) the preferences of the decision makers for those consequences. Keeney also elaborates that decision analysis focuses on aspects fundamental to all decision problems, namely

1. A perceived need to accomplish some objectives,
2. Several alternatives, one of which must be selected,
3. The consequences associated with alternatives are different,
4. Uncertainty usually about the consequences of each alternative,
5. The possible consequences are not all equally valued.

Harris (2009) gives further content to the definition by explaining that decision making is the study of identifying and choosing alternatives based on the values and preferences of the decision maker. Making a decision implies that there are alternative choices to be considered, and in such a case we want not only to identify as many of these alternatives as possible but to choose the one that (1) has the highest probability of success or effectiveness and (2) best fits with our goals, desires, lifestyle, values, and so on.

5.1 Methodology of Decision Analysis

The literature review exposed that most decision analysis models are based on ethics as one's decision to choose any given alternative can be quite subjective. There are steps however that every decision maker can use in the approach to identifying the problem and coming to a conclusion that yields an optimum solution. The number of steps outlined in the decision making process should be enough to encourage a thorough assessment of the problem. Too few steps, the problem may not be properly assessed and too many steps may lead to overanalyzing.

According to Baker et.al (2001) decision making should start with the identification of the decision maker(s) and stakeholder(s) in the decision, reducing the possible disagreement about problem definition, requirements, goals and criteria. Then, a general decision making process can be divided into several other steps that lead to an optimal outcome.

In this study, several tasks will be performed in choosing a specific freight transportation network. The major tasks, which are loosely based on steps in the decision making process as outlined by Baker et al include:

Task 1: Define the problem facing the freight transportation system industry. This process must, as a minimum, identify root causes, limiting assumptions, system and organizational boundaries and interfaces, and any stakeholder issues.

Task 2: Determine requirements. Research literature to determine what conditions are required to be met based on Federal guidelines, state mandates and stakeholder requirements of the transportation network.

Task 3: Identify alternatives. Based on the problem statement and the goal of what the study is set to accomplish, outline all transport networks currently being used.

Task 4: **Identify and establish freight performance measures**. Search available open literature and benchmark studies representing the goals and objectives of both public and private stakeholders to establish key measures used to assess performance of the trucking industry.

Task 5: **Outline and define the associated** metrics of measurement through literature review for each performance measure identified.

Task 6: Gather performance data both quantitative and qualitative, through varying sources including current US Department of Transportation Freight Transportation data (last published 2011), Federal Motor Carrier Safety Administration, American Trucking Association and surveys to determine performance measures relevant importance and weights as communicated by stakeholders.

Task 7: Develop model, AHP/ANP hybrid in his study, to aid in decision making and analysis of transport networks comparison.

Task 8: Validate and verify model to ensure no errors, oversights or bugs exist.

In this study, the selection of a single freight transportation network or a multi-network design for long haul truck load usage will be chosen from three different network architectures. The transport networks are point to point, hub and spoke and multi-segment distributed networks. Using data results compiled from the survey analysis to both public and private sector stakeholders and experts on performance measures done in the NCFRP report as introduced and discussed in chapter 3, the criteria elements used will be energy, cost, travel time, safety, environment, quality of life and accessibility.

For determining the most feasible and viable alternative, the methodology brought forth for study will be the Analytic Hierarchy Process (AHP), a multi-criteria decision making tool and Analytic Network Process (ANP). While the AHP tool allows the user to consider both quantitative and qualitative elements of study, the addition of ANP for analysis allows interdependencies between and among the criteria to be explored.

5.1.1 Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP), developed by Thomas L. Saaty in the 1970s, is a powerful and flexible multi-criteria decision making process to help people set priorities and make the best decision when both tangible and non-tangible aspects of a decision need to be considered. By reducing complex decisions to a series of one-on-one comparisons, then synthesizing the results, AHP not only helps decision makers arrive at the best decision, but also provides a clear rationale that it is the best (Saaty, 1980 and Saaty, 1990). Designed to reflect the decision-makers knowledge and experience, AHP continues to be the most highly regarded and widely used decision-making method.

The process by which to solve an AHP involves the following phases (Saaty 1980, Saaty 1990, Al-Subhi Al-Harbi, 2001 and Vaidya & Kumar, 2006).

Phase 1: Define the problem

Phase 2: Decompose the problem into a hierarchy. AHP starts with an identification of the criteria (the objectives from a decision-makers viewpoint) through the intermediate levels (criteria on which subsequent levels depend) to the lowest level which usually contains the list of alternatives which are organized in a tree-like hierarchy.

Phase 3: Collect input data and develop ratings by pair wise comparisons, normalization, or averaging the row values of criteria at each level of the hierarchy and alternatives. A set of pair-wise comparison matrices (size $n \times n$) is constructed for each of the lower levels with one matrix for each element in the level immediately above by using the relative scale measurement shown in Table 5.1.

Table 5.1 Pair-Wise comparison scale for AHP preference (Al-Harbi, 2001)

Numerical Rating	Verbal Judgments of Preferences
9	Extremely Preferred
8	Very strongly to extremely
7	Very strongly preferred
6	Strongly to very strongly
5	Strongly Preferred
4	Moderately to strongly
3	Moderately preferred
2	Equally to Moderately
1	Equally Preferred

Phase 4: There are n(n-1)/2 judgments required to develop the set of matrices in Phase 3. Reciprocals are automatically assigned in each pair-wise comparison

Phase 5: Hierarchical synthesis is now used to weight the eigenvectors by the weights of the criteria and the sum is taken over all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy.

Phase 6: Having made all the pair-wise comparisons, the consistency is determined by using the eigenvalue, λ_{max}, to calculate the consistency index, CI as follows: CI = $(\lambda_{max} - n) / (n-1)$, where n is the matrix size. Judgment consistency can be checked by taking the consistency ratio (CR) of CI with the appropriate value in Table 4.2. The CR is acceptable if it does not exceed 0.10

Table 5.2 Average random consistency (Al-Harbi, 2001)

Size of matrix	1	2	3	4	5	6	7	8	9	10
Random Consistency	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Phase 7: Normalized values are calculated for each criteria/alternative and decision is made based on normalized values.

AHP has its advantages and disadvantages. Some of the advantages are: It permits the use of data, experience, insight, and intuition in a more logical and thorough manner. It allows for inconsistency in judgment. However, the AHP also measures the degree to which the judgments are inconsistent and establishes an acceptable tolerance level for the degree of inconsistency (Liberatore & Nydick, 2008). Some noted disadvantages of AHP are it does not consider interdependencies among the criteria, of they exist, the use of subjective judgment is subject to human error and biases, and the rank reversal is not consistent when one of criteria is added or removed.

5.1.2 Analytic Network Process (ANP)

Built upon the foundational seven pillars of AHP, the Analytic Network Process (ANP) as defined and developed by Saaty (1999) provides a general framework to deal with decisions without making assumptions about the independence of the elements within a level. Ideally one can use ANP without defining hierarchical levels. Influence, as stated by Saaty, is the central concept in the ANP.

Saaty developed the ANP framework as a coupling made up of two parts. The first is a control hierarchy or network of criteria and sub criteria that control the interactions. The second is a network of influences among the elements and clusters. ANP is a decision making process tool that allows one to include all the factors and criteria, tangible and intangible which have bearing on making a best decision. The Analytic Network Process allows both interaction and feedback within clusters of elements (inner dependence) and between clusters (outer dependence). Such feedback best captures the complex effects of interplay in human society, especially when risk and uncertainty are involved.

5.1.3 Benefits of using AHP/ANP

Some of the benefits to using this methodological approach have been outlined by Taslicali and Ercan, (2006) in their comparative study of AHP and ANP in multicriteria decision making. The list of benefits includes:

1. As compared to other MCDM approaches, AHP/ANP is not proportionately complicated, and this helps improve management understanding and transparency of the modeling technique.
2. They have the supplemental power of being able to mix quantitative and qualitative factors into a decision.
3. This approach can be fit together with other solution approach such as optimization, and goal programming.
4. AHP/ANP may use a hierarchical structuring of the factors involved. The hierarchical structuring is universal to the composition of virtually all complex systems, and is a natural problem-solving paradigm in the face of complexity.
5. In AHP/ANP, judgment elicitations are completed using a decomposition approach, which

   has been shown in experimental studies to reduce decision-making errors.
6. AHP has also been validated from the decision makers' perspective as well in recent empirical studies.
7. AHP/ANP is a technique that can prove valuable in helping multiple parties (stakeholders) arrive at an agreeable solution due to its structure, and if implemented appropriately can be used as a consensus-building tool.

5.2 Description of Model Main Criteria

In the analysis to derive a selection of a transport network, a set of criteria has been chosen that is both basic to all modes of freight transport and meets the goals of all stakeholders within the highway industry moving freight. Based on the research, these factors are some of the most important to decision makers.

The criteria which will be used in the model of this study include:

Energy: The consumption of energy through the use of diesel fuel is statistically one of the greatest variables affecting the trucking industry today. "With the national average price of diesel nearing $4/gallon, the cost of fuel is showing its effects on the trucking industry. Many trucking companies are unable to maintain the same size fleet as they had months ago, reducing the number of trucks they operate, some to the point of having to close their business completely. A reduction in trucks also means more capacity issues as well, as companies are not able to provide enough trucks to meet the growing demand of manufacturers" (Road Scholar Transport, 2010).

The principal energy performance measure of interest as used by the Georgia Transportation Institute (Southworth and Gillett, 2011) is the average miles per gallon, or MPG, that trucks experience on the state's highways. This difference is considerable across truck classes, with some of the longer and heavier single unit as well as combination trucks operating at relatively low fuel efficiencies.

- **Average Daily MPG** = Average Daily Miles Per Gallon For Trucks Operating in a

Given Vehicle Size Class or Gallons of fuel and per mile fuel consumption used on typical day.

Travel Costs: The cost criteria is a very broad variable encompassing several facets of the operations of freight transport including installation costs, fixed costs, maintenance cost and usage costs. From the perspective of economic theory, as expressed by Southworth and Gillett (2011), avoidable time spent traveling is a nonproductive activity against which there is an opportunity cost. Working time lost due to delays in delivery is a good example of this, and may include additional driver wages and costs associated with additional cargo handling time.

In its published study of freight performance measures, the Georgia Transportation Institute found that a common approach to placing a dollar cost on any extra time spent in travel is to assess the value of such time in terms of the hours lost multiplied by some fraction (or all) of the gross hourly wage of the workers (e.g. truck drivers) concerned, including worker's compensation and other fringe benefits paid for by employers. Recent ATRI studies have used truck speed data from its FHWA supported GPS tracking research to estimate an average marginal truck operating cost of just over $83 per hour, or $1.73 per truck mile. This rate is a loaded rate and includes several operating cost components including: driver wages, fuel-oil costs, repairs and maintenance, fuel taxes, truck insurance premiums, tires, licensing, tolls, and driver related pay and benefits and truck/trailer costs.

With one of the more frequent causes of unexpected costs being contributed to congestion, this study will focus on costs related to shipping delays and will utilize the following quantitative definition:

- **Direct Shipping Delay Costs** = the extra dollar costs per truck-mile or per ton-mile due to delay.

Travel Time: Delivering products to customers in the shortest possible time is a goal that most shippers and carriers alike use as a key measure in performance. Any delays encountered can be costly to shippers and ultimately passed along to consumers. The quantitative equations used to define travel will be as follows:

- **Average Travel Times:** An obvious truck based performance measure is travel time, the time it takes to get from a specific location to another. The key measure here is origin-to-destination (O-D) time,
- *Average Travel Time (in minutes)* = $Tavg = (1/r) * D$

where r = the speed in miles per minute and D = the distance in miles of the selected highway section, corridor, or O-D route.

- *Free Flow Travel Time (in minutes):* $Tff = (1/r) * D$

  where r = the free flow speed (posted speed limit) in miles per minute and D = the distance in miles of the selected highway section, corridor, or O-D route as defined in the Georgia study (Southworth and Gillett,2011).

Travel Delay-Based Measures: A useful performance measure is one that compares such mean travel times to either free flow (i.e. light traffic) or posted speed limit times. Travel time delays due to congestion, for whatever reasons, can be computed for a round trip truck route by using the same travel time or speed data, by similarly relating delay to a baseline of free-flow speeds and times, i.e.

- **Total daily delay (in minutes)** = $Tavg - Tff$ (Average Travel Time – Free Flow Travel Time)

The travel time index developed by Texas Transportation Institute is another important measure that considers delays due to congestion and is defined as the peak-period travel rate divided by the free-flow speed or posted speed travel rate. So a TTI of 1.30 indicates that it takes, on average, 30 percent longer to travel in the peak than it does in the off-peak period

- **Travel Time Index =** $Tavg/\,Tff$ (Average travel time / Free flow travel time)

Safety: According to a performance report by the U.S. Department of Transportation, the most common indicators with respect to safety are fatalities per 100 million vehicle-miles of travel and number of accidents per 100 million vehicle-miles of travel. A study conducted for the Oregon Department of Transportation by McMullen and Monsere (2010) found that “fatality rate” (fatalities per 100 million vehicle miles traveled (VMT)) was the most frequently used measure by states (19 total).

- Number Of Truck-Inclusive Traffic Accidents Per Year (by Truck Size Class)
- ***Truck Accident Rate*** = Number Of Accidents Involving A Truck Per Million Truck Miles Of Truck Travel (by Truck Size Class)

Environmental: Since the trucking industry is the biggest consumer of diesel fuel, this also equates to it being the largest emitter of CO_2 gases into the atmosphere which is a great environmental concern. The most common form of environmental impact assessments applied to truck movements are directed at air pollution, in the form carbon dioxide emissions. States including Georgia and Oregon use the following measure to quantify the environmental impact.

- **Average Daily Emissions Rate =** Emissions per Vehicle Mile for Trucks in a given Vehicle Size Class or Metric tons of carbon dioxide equivalent motor fuel based emissions produced daily

Quality of Life: The Grand Challenge addressed in this study outlines the effect that long haul trips have on the driver and their personal lives. The number of days a driver is away from home maybe good measure to track in relation to quality of life.

- **Drivers' Hours of Service** = Total hours to complete shipment route (roundtrip)

Accessibility: The ease and ability of the truck to navigate not only on major interstates but along secondary corridors to access warehouses, manufacturing facilities, etc. to pick up a shipment or deliver measures the accessibility of the transport network.

- **Interstate Accessibility** = Typical number of truck trips and travel time between origin and destination

This measure is also computed quantitatively by Southworth and Gillett (2011) as

Demand Weighted Average Travel Time = $\Sigma_{j=1,J} V_{ij} * T_{ij}$, where V_{ij} = the number of truck trips between origin location i and destination location j; and where T_{ij} = i-to-j travel time.

5.3 Application of AHP/ANP Methodologies

In order to aid the decision maker in choosing a transport network for use in the logistics profile of the supply chain, the decision support system based on a combination of AHP and ANP was used. The first step, beyond problem definition is establishing a hierarchy. Goal, criteria, sub criteria and alternatives for problem resolution explored in this study is showed in figure 5.1.

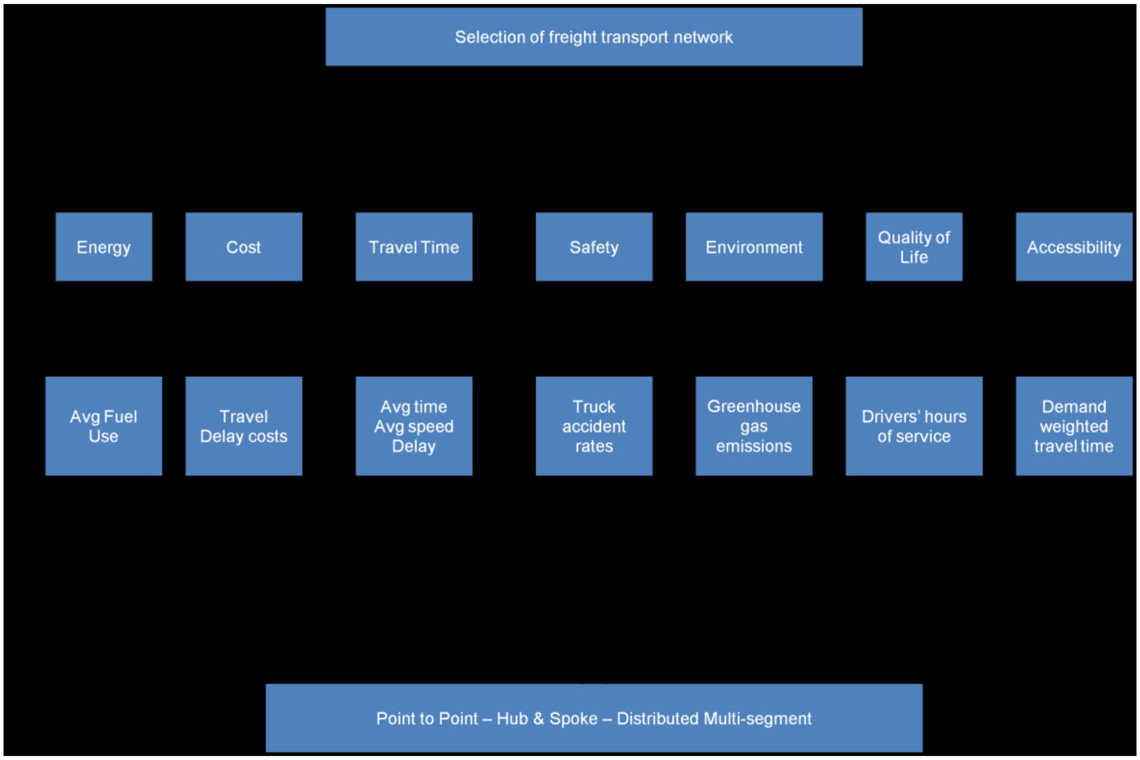


Figure 5.1 Analytical Hierarchical structure of the problem application

The hierarchical structure is a very straightforward, basic depiction of the connections between criteria and sub criteria and their high level relationships in choosing an alternative. With the addition of ANP, the ability to show interdependencies among the control criteria (parent) and associated sub criteria (children) are able to be explored. Using *Super Decisions* software developed by William J. L. Adams and Rozann Saaty, which is built on a C++ programming platform that allows for dependence and feedback resulting in an ANP model as shown below in figure 5.2.

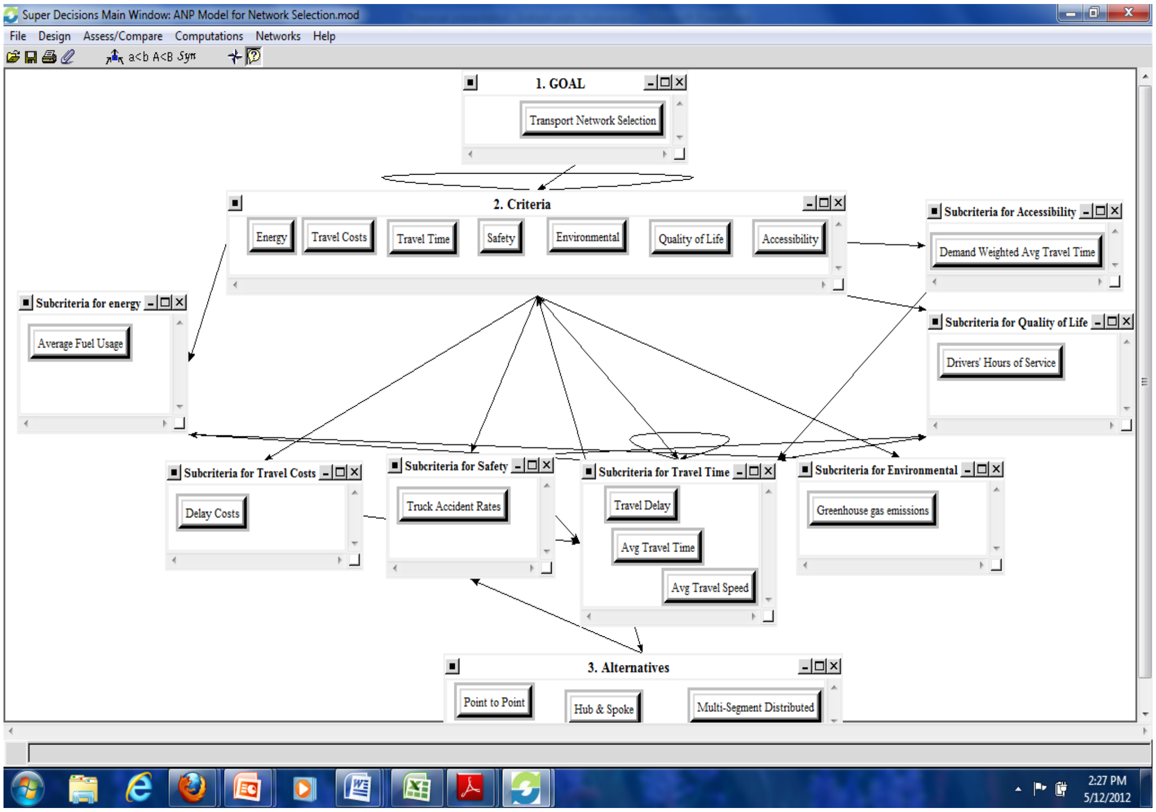


Figure 5.2 ANP Model in Super Decisions Software

5.3.1 Pair-wise Comparisons

The relation of each criterion to the alternatives and even to one another is mainly driven by the goals that are set by the user stakeholder groups. In this dissertation, it is also critical to consider the goals of a sustainable transport system as well as the goals of the transport network designs. It is believed that the consideration of all goals will give this study a fair and unbiased weighting system for analysis.

As previously outlined in Chapter 4 discussion of freight performance measures (see figure 4.2), the goals of the stakeholders, issues of the industry and sustainability challenges are interdependent. Because of this, each transport design will be analyzed individually and criteria weighted based on the goals and concerns of that network. Each alternative will be weighted equally against one another. Figure 5.3 below gives a graphical depiction of the transport networks and what common goals and performance measures (PMs) they share. Typically, the goals of any supply chain network are two-fold: minimize cost and maximize service levels. These common goals drive the identified performance measures (criteria) of travel time, costs, energy usage and accessibility. The relative weights assigned to these criteria will depend on the network. The additional PMs connected to the distributed multi-segment network (DMS), are not solely isolated to this network but carry a higher level of importance than with the other two.

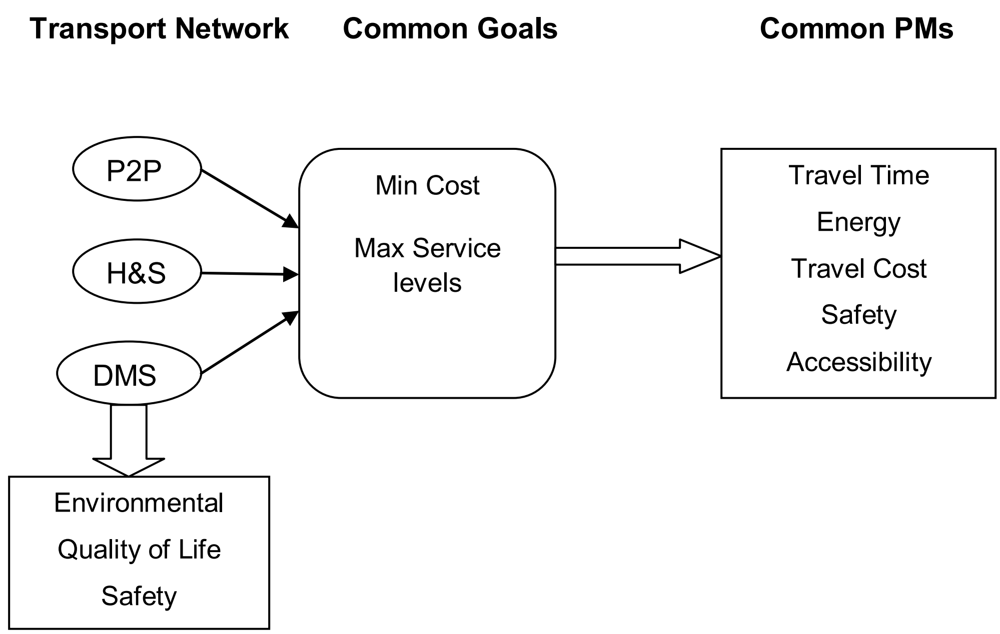


Figure 5.3 Transport Networks to Criteria Relationships

The weights for the pair-wise comparisons for each of the transport network for shown in tables 5.3-5.5 below. The inconsistency index for the point-to-point, hub-and-spoke and distributed multi-segment networks were .0351, .0271 and .0325 respectively. It is desirable to have a value of less than 0.1.

Table 5.3 Pair-wise Comparisons of Point-to-Point and Criteria

	Accessibility	**Energy**	**Environment**	**Quality of life**	**Safety**	**Travel Time**	**Travel Cost**
Accessibility	1	1/2	2	2	1/2	1/2	1/2
Energy	2	1	3	3	2	1	1/2
Environment	1/2	1/3	1	2	1/3	1/2	1/3
Quality of life	1/2	1/3	1/2	1	1/3	1/3	1/3
Safety	2	1/2	3	3	1	2	1/2
Travel Costs	2	1	2	3	1/2	1	1
Travel Time	2	2	3	3	2	1	1

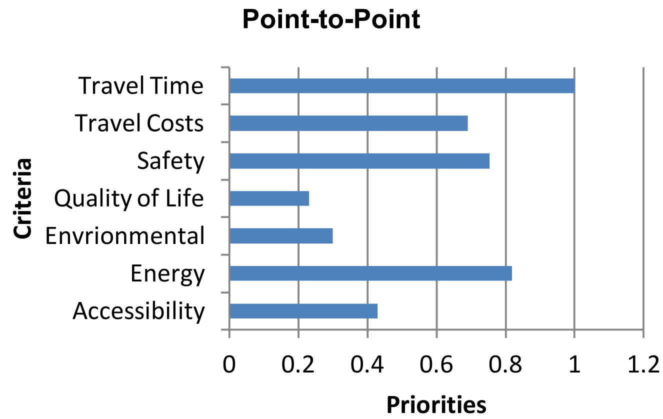
Table 5.4 Pair-wise Comparisons of Hub-and-Spoke and Criteria

	Accessibility	**Energy**	**Environment**	**Quality of life**	**Safety**	**Travel Time**	**Travel Cost**
Accessibility	1	1	3	3	2	1/2	1/3
Energy	1	1	3	3	2	1	1/2
Environment	1/3	1/3	1	2	1/3	1/4	1/4
Quality of life	1/3	1/3	1/2	1	1/3	1/4	1/4
Safety	1/2	1/2	3	3	1	1/2	1/2
Travel Costs	2	1	4	4	2	1	1
Travel Time	3	2	4	4	2	1	1

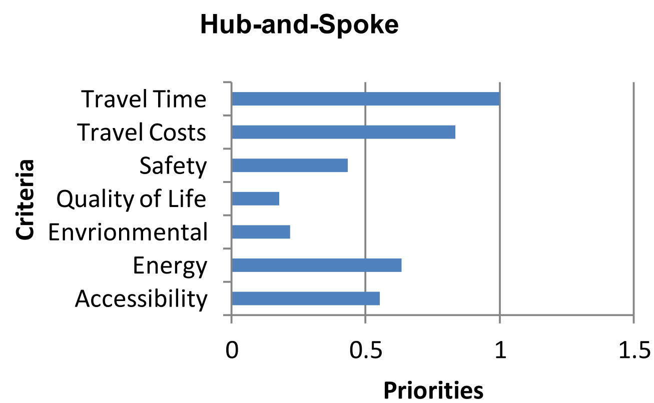
Table 5.5 Pair-wise Comparisons of Distributed Multi-Segment and Criteria

	Accessibility	**Energy**	**Environment**	**Quality of life**	**Safety**	**Travel Time**	**Travel Cost**
Accessibility	1	1/3	1/3	1/4	1/4	1/3	1/3
Energy	3	1	1	1	1/2	2	1
Environment	3	1	1	2	1/2	2	3
Quality of life	4	1	1/2	1	1	2	1
Safety	4	2	2	1	1	2	2
Travel Costs	3	1/2	1/2	1/2	1/2	1	1
Travel Time	3	1	1/3	1	1/2	1	1

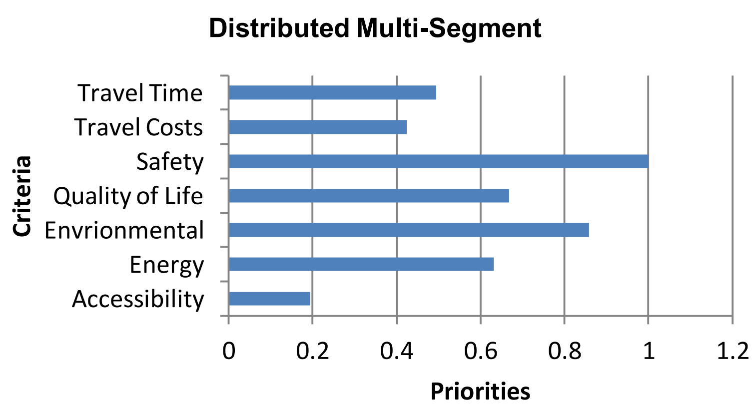
The priorities are the scores normalized by dividing by the total of all the alternatives scores as shown in figure 5.4.



(a)



(b)



(c)

Figure 5.4 Priorities of Transport Networks Alternatives for (a) Point-to-Point, (b) Hub-and-Spoke and (c) Distributed Multi-Segment

5.4 Summary Results

The unweighted super matrix of the ANP model is made up of the local priority vectors from the comparison groups and inputted by the decision maker. The resulting output in table form is shown below in table 5.6.

Table 5.6 Unweighted Super Matrix

	Energy	**Travel Time**	**Safety**	**Environmental**	**Travel Delay Costs**	**Quality of Life**	**Accessibility**
Point to Point	.19393	.23681	.17858	.07083	.16369	.05471	.10145
Hub and Spoke	.16464	.25946	.11267	.05658	.21675	.04625	.14364
Distributed Multi-Segment	.14779	.11565	.23415	.20116	.09933	.15634	.04560

The weighted super matrix is then generated by multiplying the local priority vectors in the unweighted super matrix with the cluster weights. The cluster weights were generated through a comparisons questionnaire built into the analysis mode of the ANP software.

Table 5.7 Weighted Super Matrix

	Energy	**Travel Time**	**Safety**	**Environmental**	**Travel Delay Costs**	**Quality of Life**	**Accessibility**
Point to Point	.19393	.23681	.17858	.07083	.16369	.05471	.10145
Hub and Spoke	.16464	.25946	.11267	.05658	.21675	.04625	.14364
Distributed Multi-Segment	.07390	.05783	.11707	.10058	.04967	.07817	.02280

The Limit Matrix output is a simple straightforward network. The process of obtaining the limit matrix is to raise the weighted super matrix to powers until it stabilizes - that is, all the columns in the matrix have the same values. This matrix produces the global preferences of the decision elements. These preferences serve as the best decision for the decision maker. There were several options available in computing the limit matrix in the software. For this study, the "New Hierarchy without limits" was chosen due to its ability to give the intermediate results of synthesis for the hierarchy and is consistent with handling networks without sinks (nodes which are not "with respect to nodes" for any comparison) correctly, which in this Freight Transport Network Selection model, it did contain sinks. The resulting limit matrix output is shown below in table 5.8.

Table 5.8 Limit Matrix

	Energy	Travel Time	Safety	Environmental	Travel Delay Costs	Quality of Life	Accessibility
Point to Point	.03797	.02854	.09843	.00333	.00784	.02551	.00416
Hub and Spoke	.03662	.02753	.09493	.00321	.00704	.02460	.00401
Distributed Multi-Segment	.04063	.03054	.10531	.00356	.00996	.02730	.00445

Based on the limit matrix output in table 5.8, the transport network of choice in all criteria categories would be the Multi-Segment Distributed network. This would be followed by Point to Point and lastly Hub & Spoke. This result is consistent with the overall preferences generated in the final report by the software which displayed the following:

Table 5.9 Alternative Rankings Output

Alternatives	Ranking
Hub & Spoke	3
Distributed Multi-Segment	1
Point to Point	2

The results from the AHP/ANP analysis will be compared with those found in the empirical study simulation to follow in Chapter 6.

CHAPTER 6

INTRODUCTION

6.1 Empirical Study: I-40 Test Corridor

This chapter describes the construction of a number of truck freight performance measures reviewed in chapter 4, and making use of prior data collected by the National Cooperative Freight Research Program (NCFRP) from various sources described in Chapter 3 of this work. Based on the location of the top 10 Logistics /Distribution/Shipping hubs in the US as ranked by the Material Handling Industry of America in 2011, Memphis, TN ranked #1. The world headquarters of FedEx, Memphis International Airport has the distinction of being the busiest cargo airport in the world and also a major passenger airline hub. Memphis is also located on the Mississippi River and Interstates 40 and 55. Due to the high percentage of truck traffic that utilizes these interstates for freight hauling and the ease of route mapping, Interstate 40 has been selected as the test corridor for empirical modeling of all three transport networks.

Interstate 40 composes a major link of the federal super highway as proposed by Frederick D. Eisenhower in 1955. This highway is a major east-west freeway that spans a length of 2,559 miles. Interstate 40 originates near I-15 in Barstow, California and then passes through Arizona, New Mexico, Texas, Oklahoma, Arkansas and Tennessee before ending at US 117/NC 132 in Wilmington, North Carolina. Its cross-country journey includes major cities such as Albuquerque, Amarillo, Oklahoma City, Little Rock, Memphis, Nashville, Knoxville, Winston-Salem, Durham and Raleigh. The journey also includes interchanges with eight of the ten primary north-south interstates.

Figure 6.1 shows the section of I-40 used in the analysis, which runs from Oklahoma City, OK to Asheville, NC. The results are not meant to be definitive. The purpose is to determine, at a high level, the impact of the performance measures on the overall viability of freight transport networks as compared one with the other using a more quantitative method. The results uncovered in this analysis will be used to support the methodology used in chapter 5.

Based on the performance measure reviews in chapter 4 and 5, the following Interstate highway based performance metrics were considered in the quantitative analysis.

A. Truck Travel Time:

1. Average truck speeds in the corridor on a typical day
2. Average travel time
3. Free flow travel time
4. Total Daily Delay
5. Travel Time Index

B. Truck Energy

6. Gallons of fuel and per mile fuel consumption in the corridor on a typical day

C. Truck Mobile Source Emissions

7. Metric tons of carbon dioxide equivalent motor fuel based emissions produced daily

D. Truck Travel Costs

8. Estimated daily costs of traffic delay
9. A corridor per mile delay cost

E. Truck Safety

10. Percent probability of corridor truck-involved accidents annually

F. Interstate Corridor Accessibility

11. Typical truck speeds on major truck route connectors.

G. Quality of Life

12. Number of days away from home

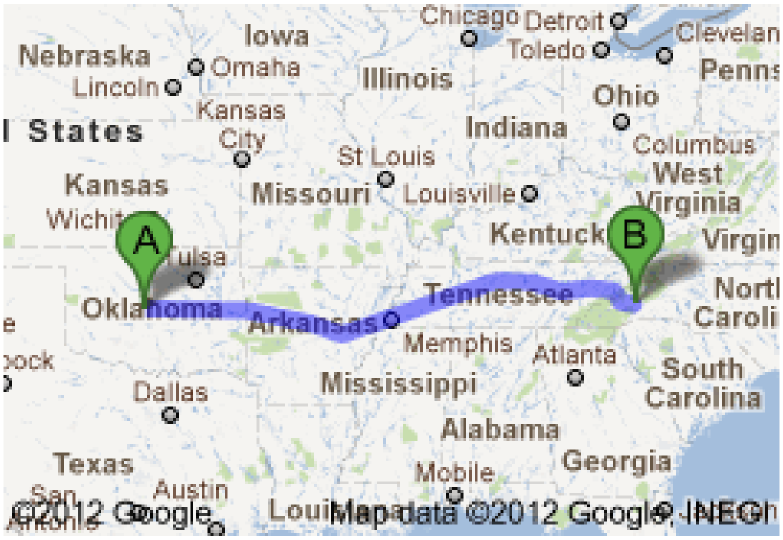


Figure 6.1 I-40 Corridor Study Route (Google Maps)

6.2. Empirical Model

For this analysis, a simple vehicle based discrete event simulation model (modified) has been created with the use of Microsoft Excel. By technical definition, *discrete event simulation* utilizes a mathematical/logical model of a physical set of chronological events that portrays state changes at precise points in simulated time. Both the nature of the state change and the time at which the change occurs mandate precise description (Albrecht, 2010).

A freight transportation model is built on a vehicle-based platform which typically models vehicle trips directly. The mode of travel and vehicle choice (usually in the unit of truck trips) is assumed to be limited to one mode. Empty trucks are not an issue with vehicle-based models because, for purposes of traffic impacts, one empty truck essentially plays the same role as a fully or partially loaded truck. Chow (2004) succinctly summarized such vehicle trip-based models, citing Jack Faucett Associates (1999). In Jack Faucett Associates' work (1999), trip-based models are described as an approach in which truck trips are generated directly, usually as a function of different land uses and trip data from trip diaries or shipper surveys. The trip rates are calculated as a function of socio-economic data (trips per employee) or land use data (trip per acre) leading to generation of trips. The generated trips are then distributed using some form of spatial interaction models, commonly known as gravity models.

6.2.1 Linear Programming Model

Although there has been no linear programming (LP) methodology applied in theory in this study thus far, there is value added to include some high level application to this problem for potential future research.

One of the most important and effective LP applications of quantitative analysis to has been in the physical distribution of products commonly referred to as the *transportation problems*. From an historical perspective, this problem was originated by Hitchcock on 1941 during World War II when a solution was needed on how to move troops located in different parts of the United States to battlegrounds in Europe and Asia (Reeb and Leavengood, 2002). Basically, the purpose is to minimize the cost of shipping goods from one location to another so that the needs of each arrival area are met and every shipping location operates within its capacity.

Applying the LP principles to this specific study scenario, the objective would be to minimize costs related to the performance measures outlined. Assigning a cost variable to each performance measure, we create the decision variables as shown below.

Decision Variables:

Time: X_dC_1 (delay time) + X_tC_2 (average travel time)

Carbon Emissions: X_cC_3

Safety (Traffic Accidents): X_sC_4 ($ loss per accident)

Diesel Fuel use: X_eC_5 ($ per gal of fuel use)

Constraints: hours of service rule (11 hours continuous driving only then 10 hr break); Weigh station stops are mandatory, driver unloads and loads freight containers at origin, destination and hub.

Objective function:

Minimize $X_dC_1 + X_tC_2 + X_cC_3 + X_sC_4 + X_eC_5$

Subject to:

$X_d + X_t \leq 11$ Hours of driver service rules for each segment

$X_d \leq 5$ Time spent at weigh station stops (minutes)

$X_d, X_t, X_c, X_s, X_e, > 0$

Using an LP model to solve, we can find the "optimal values" under these conditions that will minimize the costs to the stakeholder. These values could then be compared to the values found in an empirical model, like the one below to validate the solution.

6.2.2 Model Details

The following model components will be used in our Microsoft Excel model to compare the networks of hub and spoke, point to point and distributed multi-segment.

Route: O-D

- Origin (Shipper): Distribution Services product fulfillment warehouse located at 5525 Morton Drive Oklahoma City, OK 73128
- Destination (Customer) : Mills Manufacturing located at 22 Mills Place, Asheville, NC 28804
- Total Miles: 974 miles
- Major Highway: Interstate 40
- Average operating speed on I-40 (FHWA, 2010) : 58.6 mph
  - Peak period avg speed: 58.3
  - Non-peak avg speed: 58.8
  - Free flow speed (posted speed limit): 70 mph

Carriers:

- General Truckload long freight hauls- 5 axle tractor trailer configuration (Traditional)
- 3 Truck Classes: Heavy – 80,000lbs; Medium – 60,000lbs; Small- 40,000lbs

- Traditional engine, not hybrid.
- Commodities: Mixed (nonperishable/no cooling req)

Weigh Stations along 1-40(Coopsareopen.com)

1. OKC to Arkansas State line: 2
2. Arkansas/Tennessee State line: 5 (2 are inspection stations)
3. Tennessee State line to North Carolina State Line: 5
4. North Carolina State line to Asheville, NC: 1
5. Average time at weigh stations: 3-5 minutes assuming no waiting queue (no preclearance)*:*

Known congestion areas:

1. Exit #44, I-40, Nashville
2. Weekly hours of bottleneck congestion**: 94**
3. Worst bottleneck**: Eastbound, I 65/Exit 210**
4. Length of worst bottleneck**: .37 mi**
5. Weekly hours of congestion on worst bottleneck**: 14**
6. Speed of worst bottleneck when congested**: 12.4 mph**

Assumptions:

1. All trucks will be within weight and height restrictions. No oversized loads.
2. Vehicles of the same capacity and load factor collect and/or distribute load units in a given zone.
3. Each vehicle makes a round trip of approximately the same length at a constant average speed.
4. The collection step starts from the vehicle's initial position, which can be anywhere within the 'shipper' area and ends at the origin's intermodal terminal. The distribution step starts from the destination intermodal terminal where the vehicles may be stored in a pool and ends in the reception area at the last receiver.

5. Headways between the arrivals and departures of the successive vehicles (and thus loads) at the origin and from the destination intermodal terminal, respectively, are approximately constant and independent of each other.
6. Unless otherwise noted, the driver attaches and detaches the freight container.

6.2.3 Hub-and-Spoke

"The concept of hub-and-spoke (H&S) networks is not new to the transportation industry. For many years, the airline industry and less-than-truckload (LTL) trucking companies have made use of such networks. In general terms, a H&S network involves a series of nodes (hubs), connected by arcs (spokes) that represent viable transportation alternatives between two nodes. In the airline industry, H&S networks allow airlines to offer a greater variety for service between city-to-city pairs, permit economies of scale in terms of passenger consolidation along frequently traveled spokes, and to a certain extent allow an airline to dominate market share in a particular region. In LTL trucking, break-bulk terminals (hubs) allow load consolidation that is similar to passenger aggregation in airlines.

Typically, hub and spoke networks are not a beneficial option for truckload carriers (except in cross docking warehouses for consolidation and regional shipping) so other motivating circumstances need to be identified. This motivation comes from the desire to better serve customer needs while reducing excessive tour lengths for individual drivers. It is theorized that tour reduction would result in lower driver turnover rates, and thus drastically reduce the cost associated with hiring and training replacement drivers. This cost reduction could be passed on to customers, providing an even greater competitive edge to those companies implementing successful strategies" (Taylor, Harit and English, 1995).

Route Model: Figure 6.2 is a graphical depiction of a typical hub and spoke network configuration for a truckload freight haul.

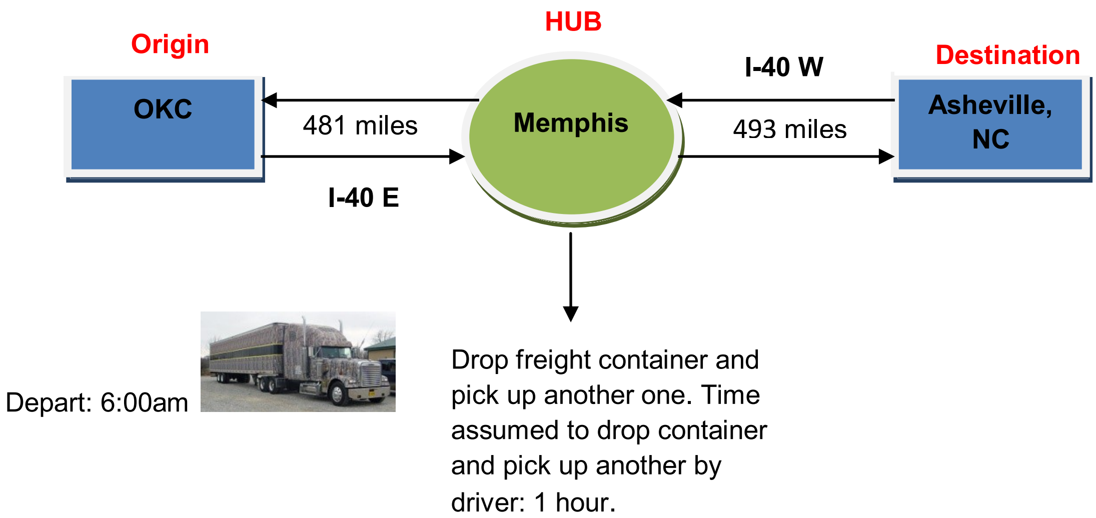


Figure 6.2 Hub-and-Spoke Network Model Configuration

<u>Quantitative Results</u>

Table 6.1 Hub-and-Spoke Performance Measures Quantitative Results (see Appendix A for additional calculations)

Travel Time PMs	**Eastbound**	**Westbound**
Avg. Speed (miles per hour)	58.6	58.6
Avg. Route Travel Time (mins)		
- Oklahoma City, OK to Memphis , TN	492	492
- Memphis, TN to Asheville, NC	505	505
Total Daily Delay (due to congestion)	162	162
Other delay factors (weigh stations, hub)	185	185
Total travel time (mins)	1344	1344
Energy PMs	**Eastbound**	**Westbound**
Avg Daily Fuel Use (Truck-Gallons)		
40,000 lbs	139	139
60,000 lbs	150	150
80,000 lbs	162	162
Avg. Daily Miles per Gallon		
40,000 lbs	7.0	7.0
60,000 lbs	6.5	6.5
80,000 lbs	6.0	6.0
Emissions PMs	**Eastbound**	**Westbound**
Avg Daily Emissions PMs (CO_2E) kilograms		

Table 6.1- *Continued*

40,000 lbs	2920.05	2920.05
60,000 lbs	3144.67	3144.67
80,000 lbs	3406.73	3406.73
Travel Cost Based PMs	**Eastbound**	**Westbound**
Avg Daily Dollar Cost of Delay ($83/hr)	$480	$480
Safety PMs	**Eastbound**	**Westbound**
Number of heavy truck involved crashes per million truck miles	2.4	
Quality of Life PM	**Eastbound**	**Westbound**
Number of days out per trip	2	1.25
Accessibility		
Number of trucks trips (segments) between O-D	2	2

6.2.4 Point-to-Point

A transportation system is where a plane, bus or train travels directly to a destination, rather than going through a central hub. This differs from the spoke-hub distribution paradigm in which the plane to reach their destination.

<u>Route Model:</u> Figure 6.3 is a graphical depiction of the a typical point to point network configuration for a truckload freight hauls.

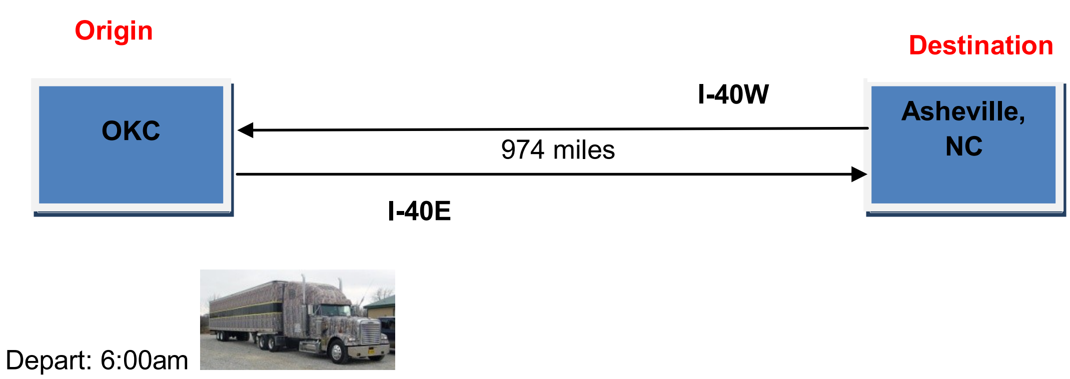


Figure 6.3 Point-to- Point Network Model Configuration

Quantitative Results:

Table 6.2 Point to Point Performance Measures Quantitative Results (see Appendix A for additional calculations)

Travel Time PMs	Eastbound	Westbound
Avg. Speed (miles per hour)	58.6	58.6
Avg. Route Travel Time (mins)		
- Oklahoma City, OK to Asheville, NC	997	997
Total Daily Delay (due to congestion)	162	162
Other delay factors (weigh stations, hub)	125	125
Total travel time (mins)	1284	1284
Energy PMs	**Eastbound**	**Westbound**
Avg Daily Fuel Use (Truck-Gallons)		
40,000 lbs	139	139
60,000 lbs	150	150
80,000 lbs	162	162
Avg. Daily Miles per Gallon		
40,000 lbs	7.0	7.0
60,000 lbs	6.5	6.5
80,000 lbs	6.0	6.0
Emissions PMs	**Eastbound**	**Westbound**
Avg Daily Emissions PMs (CO_2E) kilograms		
40,000 lbs	2920.05	2920.05
60,000 lbs	3144.67	3144.67
80,000 lbs	3406.73	3406.73
Travel Cost Based PMs	**Eastbound**	**Westbound**
Avg Daily Dollar Cost of Delay ($83/hr)	$397	$397
Safety PMs	**Eastbound**	**Westbound**
Number of heavy truck involved crashes per million truck miles (2011)	2.4	
Quality of Life PM	**Eastbound**	**Westbound**
Number of days driver away from base	2	1.04
Accessibility PMs		
Number of trucks trips between O-D	1	1

6.2.5 Distributed Multi-Segment

A distributed multi-segment transport network is a series of segments of partitioned highway covered by multiple drivers carrying containers through the physical internet with:

- Distinct carriers and/or modes taking charge of inter-node segments;

- Hubs and transit nodes enabling synchronized transfer of containers and/or carriers between segments;
- Web software platform enabling an open market of transport requesters and transport providers. (Montreuil, 2011)

Route Model: Figure 6.4 is a graphical depiction of the typical distributed multi-segment network configuration for a truckload freight haul.

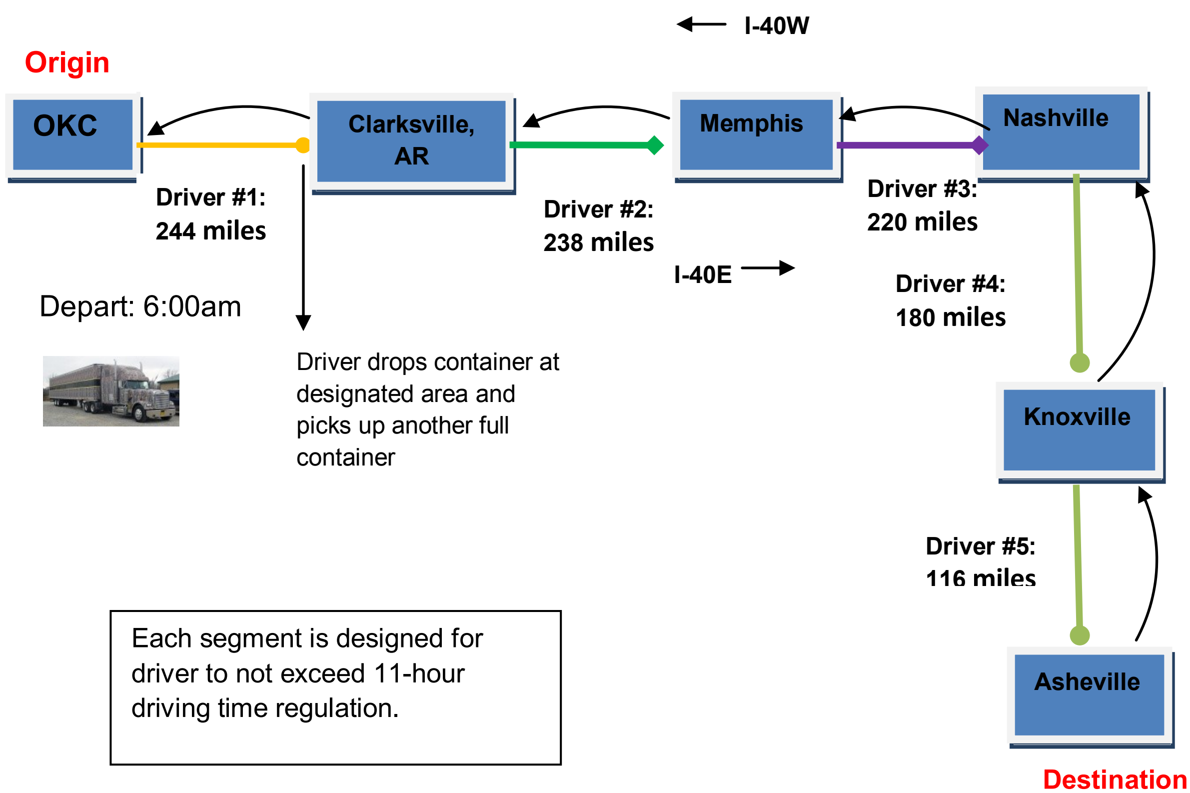


Figure 6.4 Distributed Multi-Segment Network Model Configuration

Quantitative Results

Table 6.3 Distributed Multi-Segment Performance Measures Quantitative Results-Segment #1 (see Appendix A for additional calculations)

Travel Time PMs	**Eastbound**	**Westbound**
Avg. Speed (miles per hour)	58.6	58.6
Avg. Route Travel Time (mins)		
#1 Oklahoma City, OK to Clarksville, AR	250	250
Total daily Delay	40	40
Other Delay	75	75
Total travel Time Segment # 1	365	365
Energy PMs	**Eastbound**	**Westbound**
Avg Daily Fuel Use (Truck-Gallons)		
40,000 lbs	35	35
60,000 lbs	38	38
80,000 lbs	41	41
Avg. Daily Miles per Gallon		
40,000 lbs	7.0	7.0
60,000 lbs	6.5	6.5
80,000 lbs	6.0	6.0
Emissions PMs	**Eastbound**	**Westbound**
Avg Daily Emissions PMs (CO_2E) kilograms		
40,000 lbs	365.76	365.76
60,000 lbs	393.89	393.89
80,000 lbs	426.72	426.72
Travel Cost Based PMs	**Eastbound**	**Westbound**
Avg Daily Dollar Cost of Delay ($83/hr)	$159	$159
Safety PMs	**Eastbound**	**Westbound**
Number of heavy truck involved crashes per million truck miles (2011)	2.4	
Quality of Life PM	**Eastbound**	**Westbound**
Number of days out per trip	0.50	0.50
Accessibility PMs		
Number of trucks trips between O-D	5	5

Table 6.4 Distributed Multi-Segment Performance Measures Quantitative Results-Segment #2 (see Appendix A for additional calculations)

Travel Time PMs	**Eastbound**	**Westbound**
Avg. Speed (miles per hour)	58.6	58.6
Avg. Route Travel Time (mins)		
#2 Clarksville, AR to Memphis, TN	244	244
Total daily Delay	40	40
Other Delay	80	80
Total travel Time Segment # 2	364	364
Energy PMs	**Eastbound**	**Westbound**
Avg Daily Fuel Use (Truck-Gallons)		
40,000 lbs	34	34
60,000 lbs	37	37
80,000 lbs	40	40
Avg. Daily Miles per Gallon		
40,000 lbs	7.0	7.0
60,000 lbs	6.5	6.5
80,000 lbs	6.0	6.0
Emissions PMs	**Eastbound**	**Westbound**
Avg Daily Emissions PMs (CO_2E) kilograms		
40,000 lbs	356.76	356.76
60,000 lbs	384.21	384.21
80,000 lbs	416.22	416.22
Travel Cost Based PMs Westbound	**Eastbound**	
Avg Daily Dollar Cost of Delay ($83/hr)	$166	$166
Safety PMs	**Eastbound**	**Westbound**
Number of heavy truck involved crashes per million truck miles (2011)	2.4	
Quality of Life PM	**Eastbound**	**Westbound**
Number of days out per trip	0.50	0.50
Accessibility PMs		
Number of trucks trips between O-D	5	5

Table 6.5 Distributed Multi-Segment Performance Measures Quantitative Results-Segment #3 (see Appendix A for additional calculations)

Travel Time PMs	**Eastbound**	**Westbound**
Avg. Speed (miles per hour)	58.6	58.6
Avg. Route Travel Time (mins)		
#3 Memphis, TN to Nashville, TN	225	225
Total daily Delay	37	37
Other Delay	70	70
Total travel Time Segment # 3	332	332
Energy PMs	**Eastbound**	**Westbound**
Avg Daily Fuel Use (Truck-Gallons)		
40,000 lbs	31	31
60,000 lbs	34	34
80,000 lbs	37	37
Avg. Daily Miles per Gallon		
40,000 lbs	7.0	7.0
60,000 lbs	6.5	6.5
80,000 lbs	6.0	6.0
Emissions PMs	**Eastbound**	**Westbound**
Avg Daily Emissions PMs (CO_2E) kilograms		
40,000 lbs	329.78	329.78
60,000 lbs	355.15	355.15
80,000 lbs	384.74	384.74
Travel Cost Based PMs	**Eastbound**	**Westbound**
Avg Daily Dollar Cost of Delay ($83/hr)	$148	$148
Safety PMs	**Eastbound**	**Westbound**
Number of heavy truck involved crashes per million truck miles (2011)	2.4	
Quality of Life PM	**Eastbound**	**Westbound**
Number of days out per trip	0.46	0.46
Accessibility PMs		
Number of trucks trips between O-D	5	5

Table 6.6 Distributed Multi-Segment Performance Measures Quantitative Results-Segment #4 (see Appendix A for additional calculations)

Travel Time PMs	**Eastbound**	**Westbound**
Avg. Speed (miles per hour)	58.6	58.6
Avg. Route Travel Time (mins)		
#4 Nashville, TN to Knoxville, TN	184	184
Total daily Delay	30	30
Other Delay	75	75
Total travel Time Segment # 4	289	289
Energy PMs	**Eastbound**	**Westbound**
Avg Daily Fuel Use (Truck-Gallons)		
40,000 lbs	26	26
60,000 lbs	28	28
80,000 lbs	30	30
Avg. Daily Miles per Gallon		
40,000 lbs	7.0	7.0
60,000 lbs	6.5	6.5
80,000 lbs	6.0	6.0
Emissions PMs	**Eastbound**	**Westbound**
Avg Daily Emissions PMs (CO_2E) kilograms		
40,000 lbs	269.82	269.82
60,000 lbs	290.58	290.58
80,000 lbs	314.79	314.79
Travel Cost Based PMs	**Eastbound**	**Westbound**
Avg Daily Dollar Cost of Delay($83/hr)	$145.25	$145.25
Safety PMs	**Eastbound**	**Westbound**
Number of heavy truck involved crashes per million truck miles	2.4	
Quality of Life PM	**Eastbound**	**Westbound**
Number of days out per trip	0.40	0.40
Accessibility PMs		
Number of trucks trips between O-D	5	5

Table 6.7 Distributed Multi-Segment Performance Measures Quantitative Results-Segment #5 (see Appendix A for additional calculations)

Travel Time PMs	**Eastbound**	**Westbound**
Avg. Speed (miles per hour)	58.6	58.6
Avg. Route Travel Time (mins)		
#5 Knoxville, TN to Asheville, NC	119	119
Total daily Delay	19	19
Other Delay	65	65
Total travel Time Segment # 5	203	203
Energy PMs	**Eastbound**	**Westbound**
Avg Daily Fuel Use (Truck-Gallons)		
40,000 lbs	17	17
60,000 lbs	18	18
80,000 lbs	19	19
Avg. Daily Miles per Gallon		
40,000 lbs	7.0	7.0
60,000 lbs	6.5	6.5
80,000 lbs	6.0	6.0
Emissions PMs	**Eastbound**	**Westbound**
Avg Daily Emissions PMs (CO_2E) kilograms		
40,000 lbs	173.88	173.88
60,000 lbs	187.76	187.76
80,000 lbs	202.86	202.86
Travel Cost Based PMs Westbound	**Eastbound**	
Avg Daily Dollar Cost of Delay ($83/hr)	$116.20	$116.20
Safety PMs	**Eastbound**	**Westbound**
Number of heavy truck involved crashes per million truck miles (2011)	2.4	
Quality of Life PM	**Eastbound**	**Westbound**
Number of days out per trip	0.30	0.30
Accessibility PMs		
Number of trucks trips between O-D	5	5

6.3 Summary of Results

6.3.1 Time Related Performance Measures

Performance measure results were reported in Tables 6.1, 6.2 and 6.3 (a-e) for each of the three transport networks. Moving from top to bottom of the tables average travel speeds along interstate 40 as published in the *I-40 Trucking Operations and Safety Analyses* by Stammer(2010) and total miles driven to determine the time it would take a truck to travel from origin to destination in a given direction. Initially, those times did not include any type of delay. Delay times were comprised of three different elements: weigh stations, hub stop (H&S network only), and congestion. The delay time computed for weigh stations were taken to be 5 min based on personal interviews with small trucking owner operators. There was assumed to be no waiting time and no trucks in queue upon the arrival of the truck at the weigh station. The number and location of the weigh stations were found through *coopsareopen.com* which maintains a real time listing of all weigh stations and their current status (open or closed). Hub delays were assumed to be one hour which includes 30 min for unloading a trailer and loading a new one by the driver (1 hour total-drop and hook only). It does not account for any delay at the hub in the event of a failure. Congestion accounts for the remainder of the delay time which was computed by the use of the total daily delay index.

As shown in the results, the average total time to complete the one way route from origin to destination was shortest overall for the point to point network at 21 hrs and 24 minutes as compared to 22 hours and 24 minutes for the hub and spoke network and 26 hours and 3 minutes for the distributed multi-segment network. In both the hub and spoke and distributed multi-segment networks, additional time was added due to required stops at the hub and transit points respectively.

6.3.2 Energy and Environmental Performance Measures

The motor fuel consumption performance measure was addressed due to the continuing fluctuating diesel prices the trucking industry is facing on an ongoing basis today. As Tom Sanderson of Transplace discusses in his blog (last published in May 9, 2012), weekly retail on-highway U.S. diesel prices decreased by 1.6 cents to $4.057 per gallon, see figure 5.5 below. Diesel topped $4 in November, then dropped to $3.78 by the beginning of the year, but has been above $4 since 2/27; 11 straight weeks. The recent low price point for diesel was $2.023 on March 16, 2009. A view of weekly prices over the last 3+ years shows much higher prices in each year over the preceding year (figure 6.5) until the last few weeks with fuel about equal to this time last year. Diesel prices peaked at $4.771 per gallon in July of 2008 and were above $3 per gallon from September 24, 2007 to November 3, 2008 (over 13 months). Prices have been back over $3 since October 4, 2010 (19 months). In 2008, diesel exceeded $4 per gallon for 23 straight weeks, compared with 6 straight weeks early in 2011 and now 11 weeks in 2012.

Sanderson attributed the increase of diesel over the last three years to a recovering economy and the continued growth and expansion of the middle class in China and other higher-growth countries on the demand side. On the supply side, Middle East uncertainties and opportunistic oil companies are probably the culprits.

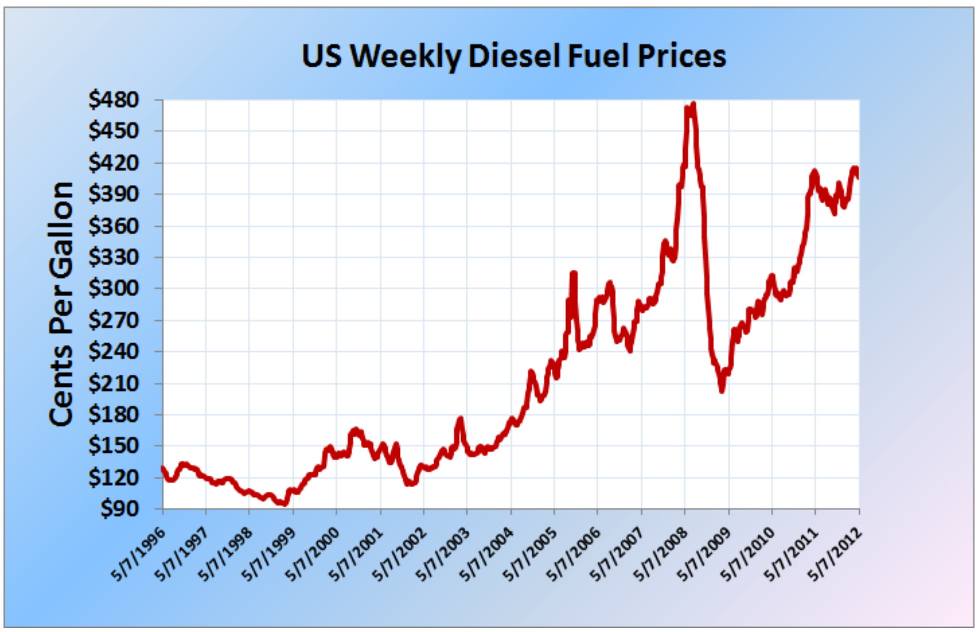


Figure 6.5 Weekly Diesel Fuel Prices (Sanderson, 2012)

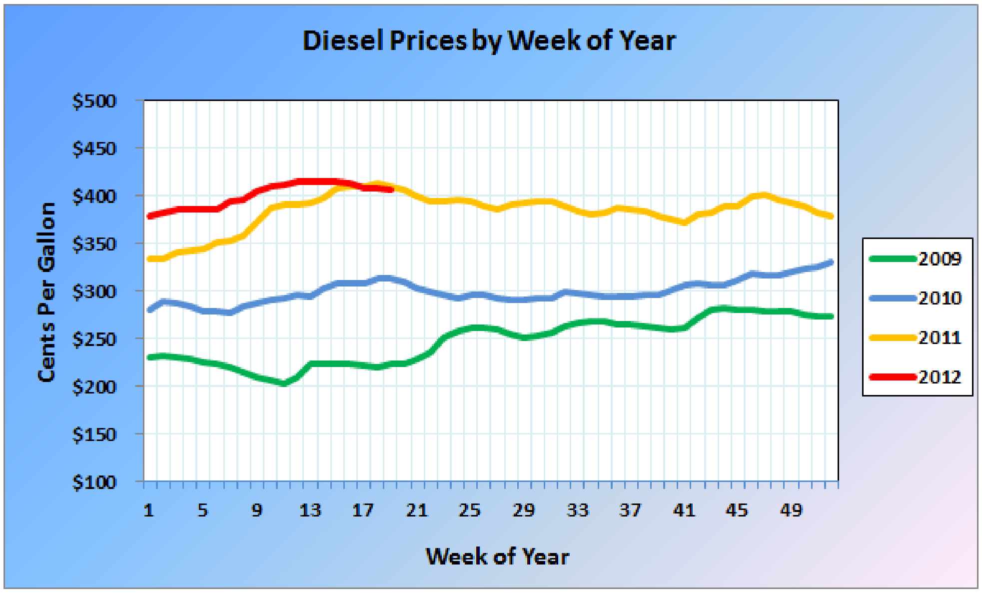


Figure 6.6 Diesel Prices Week of Year (Sanderson, 2012)

To compute the diesel fuel consumption measured in this study, gallons of fuel and per mile fuel consumption in the corridor on a typical day was assessed. To create a baseline for diesel usage, three different sizes of class 8 tractor trailers were used to show the degree at which usage is affected based in truck volume. Based on the tractor trailer performance guide produced by Caterpillar, which shows that an average tractor trailer holds 200-300 gallons of diesel fuel, for purposes of this study, we assumed a 250 gallon tank for all three truck sizes. Caterpillar also lists the average miles per gallon (mpg) grade of good conditioned tractor trailers of 80,000 lbs is 6 mpg. For less weight, the mpg increases. So for purposes of this study, trucks weighing 60,000 get 6.5 mpg and 40,000 lbs get 7.0 mpg. Using these values as a standard, the computations for this study were found to be:

- For 80,000 lbs: 250 gal * 6mpg = 1500 miles capacity

  Daily Diesel use (gallons) = (974 miles/6 mpg) * 2 = 324.667 ~ 325 gallons

- For 60,000 lbs: 250 gal *6.5mpg = 1625 miles

  Daily Diesel use (gallons) = (974 miles/6.5 mpg) * 2 = 299.692 ~ 300 gallons

- For 40,000 lbs: 250 gal * 7mpg = 1750 miles

Daily Diesel use (gallons) = (974 miles/7.0 mpg) * 2 = 278.282 ~ 278 gallons

These figures would yield a cost of diesel fuel for the round trip, using an average of $4/gal, at a minimum of $1,120 for the 40,000lbs truck to a maximum of $1,300 for the 80,000 lbs truck for both the point to point and hub and spoke networks. Performing a simple sensitivity analysis using slightly lower cost per gallon figures gives the driver minimal roundtrip savings for the 80,000 lbs truck. However, with the use of lower weighted trucks, the diesel fuel savings is higher. For the distributed multi-segment network, diesel usage would dramatically decrease per truck due to the decrease in tour length.

Table 6.8 Diesel Fuel Costs Sensitivity Analysis

Truck Size (lbs)	Daily Diesel use (gallons, roundtrip)	Cost/gal $	Diesel Fuel cost ($) (roundtrip)
80,000	325	4.00 3.80 3.50	1,300 1,235 1,137.50
60,000	300	4.00 3.80 3.50	1,200 1,140 1,050
40,000	278	4.00 3.80 3.50	1,112 1,056.40 973

The emissions of carbon dioxide equivalent, which are emissions from various greenhouse gases based upon their global warming potential (GWP), were computed by multiplying the conversion factor of a US gallon of diesel to kg of CO_2 which is published as 10.493kg (US Energy Information Administration). The resulting data in the empirical study found that both point to point and hub and spoke networks emit 3-4 times as much CO_2 when compared with the distributed multi-segment network. This can be easily attributed to the fact that due to the trucks on point to point and hub and spoke networks drive further distances and subsequently burn more fuel.

6.3.3 Safety

As shown in table 6.9, the Federal Motor Carrier Safety Administration's Safety progress report shows that over the last three years (2009-2011) large trucks have contributed to the greater percentage of crashes, fatalities and injuries when grouped with buses. There was a decline in the number of large truck related crashes, fatalities and injuries from 2010 through 2011 but the numbers are still alarming for the public. As expressed by the Advocates for Highway and Auto Safety large trucks – "including tractor-trailers, single-unit trucks, and certain heavy cargo vans with gross weight of more than 10,000 pounds - account for a disproportionate share of traffic deaths based on miles traveled. The fatal crash rate for large trucks is 2.4 deaths per 100 million vehicle miles traveled - more than 50 percent greater than the rate for all vehicles on the roads. People in passenger vehicles are especially vulnerable in collisions with large trucks because of the great difference in weight between cars and large trucks. In two-vehicle crashes involving passenger vehicles and large trucks, 98 percent of the fatalities were occupants of the passenger vehicle. 3,797 people were killed in crashes involving large trucks in 2010, representing 93 % percent of all fatalities caused by trucks and buses".

Table 6.9 Motor Carrier Safety Progress Report (as of December 31, 2011)

MCMIS SAFETY OUTCOMES*	CY 2009	CY 2010**	CY 2011** Jan. 1, 2011 - Sep. 30, 2011
CRASHES			
Large Trucks and Buses	118,428	128,747	93,976
Large Trucks	105,526	115,398	84,569
Buses	13,314	13,774	9,719
FATALITIES			
Large Trucks and Buses	3,803	4,089	2,906
Large Trucks	3,548	3,797	2,679
Buses	270	304	241
INJURIES			
Large Trucks and Buses	74,280	79,731	57,132
Large Trucks	59,586	64,338	46,639
Buses	15,469	16,327	11,311

Source: Federal Motor Carrier Safety Administration (2011)

A direct link between drivers' hours and fatigue has been researched and documented over many years. In the USA, a series of studies by the National Transportation Safety Board (NTSB) have pointed to the significance of sleepiness as a factor in accidents involving heavy vehicles.

The NTSB came to the conclusion that 52% of 107 single-vehicle accidents involving heavy trucks were fatigue-related;" in nearly 18 per cent of the cases, the driver admitted to falling asleep. Summarizing the US Department of Transportation's investigations into fatigue in the 1990s, the extent of fatigue-related fatal accidents is estimated to be around 30%. Research shows that driver fatigue is a significant factor in approximately 20% of commercial road transport crashes and over 50% of long haul drivers have fallen asleep at the wheel. Recently The National Highway Traffic Safety Administration (NHTSA) estimate that there are 56,000 sleep related road crashes annually in the USA, resulting in 40,000 injuries and 1,550 fatalities" (Smart Motorist).

In a research study conducted by Jovanis, Wu and Chen (2011) on Hours of Service and Driver Fatigue, the authors found, in truck load (TL) driving, associations between some multiday driving patterns and increased crash risk with driving times in the 7–11-hour range. TL drivers who drive during the day have increased odds of a crash with long driving hours. These longer hours mean the drivers may be on the road in the late afternoon and early evening when higher traffic levels are possible. The study also revealed that driving breaks during a trip reduced the odds of a crash for both TL and less than truckload (LTL) drivers (by 32 percent and 51 percent respectively for two breaks).

The authors performed a detailed review of the current literature found on driver fatigue that one of the challenges of conducting research in truck safety and hours of service (HOS) is that various studies have found differing effects of driving hours. Several studies using crash data from a variety of sources have found increased crash odds (or relative risk) with hours driving, particularly after about 5–6 hours. Increased crash odds were found by:

Jovanis and colleagues; Campbell and Hwang; Harris and Mackie; and Mackie and Miller. Studies by Frith (1994) and Saccomanno (1995) also found an association between driving hours and increase crash odds.

By contrast, the Wylie et al. (1996) study, using alertness tests and instrumented truck measures rather than crashes, found a stronger correlation between fatigue and time of day, and very little correlation between fatigue and driving hours. Many other researchers have also found elevated crash odds with night and early morning driving including Mackie and Miller (1978); Hertz (1988); Kaneko and Jovanis (1992); and Kecklund and Akerstedt (1995). In another study, Klauer et al. (2003) conducted an experiment with 30 solo drivers and 13 team drivers with data measured by both objective and subjective measures. They found team drivers had extreme fatigue only in the morning and night hours and solo drivers had fatigue incidents throughout the day and night, with fewer fatigue incidents in the morning and more in the evening and nighttime.

In its most recent final ruling of the hours of driver service regulations (Dec. 2011), the Federal Motor Carrier Safety Administration (FMCSA) maintains the HOS driving time from 11 hours, with the maximum consecutive on-duty time to 14 hours, and mandated that the time run continuously. FMCSA did however revise the hours of service (HOS) regulations to limit the use of the 34-hour restart provision to once every 168 hours and to require that anyone using the 34-hour restart provision have as part of the restart two periods that include 1 a.m. to 5 a.m. It also includes a provision that allows truckers to drive if they have had a break of at least 30 minutes, at a time of their choosing, sometime within the previous 8 hours.

The results of the empirical study of the three networks show based on the hours of service and fatigue study reveal that for the point to point and hub and spoke networks, drivers statistically are at a higher risk of being involved in a crash with the point to point network possessing the higher exposure due to solo drivers having to drive an extended period of time over long distances. The distributed multi-segment network provides the lowest possible chance that a driver will be involved in a crash due to fatigue since tour lengths are shorter and will be less than the 11 hour driving regulated drive time.

6.3.4 Travel Delay Costs

The average daily dollar cost due to delay measured the difference between the free-flow travel time (70 mph) and the average travel time. This "lost" time was then multiplied by a value of per hour truck operating costs. A cost of $83 per hour was used (Southworth and Gillett, 2011). Based on the quantitative results, dividing the trip into segments in the distributed multi-segment network yields lower costs values. However if assessing the trip as a whole, the point-to-point network is an overall lower alternative.

6.3.5 Quality of Life

Trucking has been classified as one of the highest-risk occupations in the United States. Occupational stress is even greater for long-haul truckers who are away from home, family, friends, and other support networks for several days or weeks at a time. Stressors faced by many long haul drivers include: pressure due to time demands, unpredictable driving conditions, fatigue, lack of sleep, loneliness, boredom, etc. Consequently these stressors lead to poor health, high divorce rates, a high incidence of fidelity among married drivers, and an increase in drug and alcohol abuse (Shattell et al, 2010). Truckers who drive short regional routes typically do not identify the same stressors as those that report being home fewer than ten days a month. The key result for this performance measure is comparing the time spent away from by each transport network. Both the point to point and hub-and-spoke networks show on average the driver is away from home 6-8 days per trip while with the distributed multi-segment transport network the driver is home every night, outside an occasional overnight stay due to unexpected delays.

6.3.6 Accessibility

The ease and ability at which the truck is able to gain access to major highways from warehouses, manufacturing facilities, and other loading/unloading locations is important in determining the amount of additional time the O-D trip may take. The Interstate Accessibility has been computed as the typical number of truck trips between origin and destination. The results from the empirical simulation show that the point-to-point and hub-and-spoke networks both provide better accessibility than the distributed multi-segment network. This is mainly due to fewer handoffs and transit points.

6.3.7 Side by Side Comparison

Table 6.5 below gives a side by side snapshot comparison of the three transport networks in regards to the amount of travel time and labor/equipment requirements for the trip from the origin (OKC) to the destination (Asheville, NC). Based on the table, it is clear that the distributed multi-segment network requires the most labor and equipment to complete the trip with five drivers and five trucks but the tradeoff is quickly seen in the average driving time per driver at only eight hours. This decrease in tour length allows the driver to complete the shipment round trip within the federal regulation hours and essentially be at home every night.

Table 6.10 Roundtrip Travel Comparison

Distance traveled one-way	**Hub & Spoke** **974 miles**	**Point to Point** **974 miles**	**Distributed Multi-Segment** **974 miles**
Drivers	1	1	5
Trucks	1	1	5
Trailers	1	1	1
One way driving time (h)	16+	16+	21
Return driving time (h)	16+	16+	21
Total time at transit points (h)	1	0	5
Total trailer trip from OKC to Asheville (h)	22+	21+	26
Total trailer trip from Asheville to OKC (h)	22+	21+	26
Total trailer round trip (h)	44+	42+	52
Avg driving time per driver(h)	32+	32+	8
Avg trip time per driver (h)	44+	42+	10

comparison summary of the performance measures computed using our Excel model is provided in table 6.7 below.

Table 6.11 Performance Measures Comparison

Sustainability Objectives	Performance Measures	Point-to Point 974 miles (one way)	Hub-and-Spoke 974 miles (one way)	Distributed Multi-segment 974 miles (one way)
Economic	Travel Time (roundtrip)	44+ hours	42+ hours	52 hours
	Travel Costs (Delay)	$794	$960	$294 (average per segment)
	Accessibility (# of trips O-D)	2	4	5
	Return trip if empty	974 miles	974/2 = 487 miles	974/5 = 195 miles
Environmental	Energy –diesel fuel usage (80,000 lb truck)	325 gal/ $1,300 ($4/gal)	325 gal/ $1,300 ($4/gal)	67 gal/ $268 ($4/gal) avg per segment
	Emissions (CO_2E) (80,000 lb truck)	6813 kg	6812 kg	698 kg (average per segment)
Social	Quality of Life (hours/driver)	44+	42+	10
Economic/Social	Safety (#of crashes per 100 million truck miles)	2.4	2.4	2.4

Discussion into the selection of the network which yields greater sustainable results will be done in Chapter 7.

CHAPTER 7

CONCLUSIONS AND DISCUSSIONS

The initial objective of this study was to answer the research question of *whether a distributed multi-segment transport network, when compared with the existing networks of point-to-point and hub-and-spoke, can provide a viable sustainable alternative for shippers to transport goods from origin to destination*. In addition, the study sought to accept the hypothesis statement of *a distributed multi-segment network is a proven viable freight transport network alternative for truckload shipping that will address the environmental, economic and social challenges faced by the supply chain industry in the 21st century*.

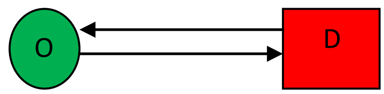
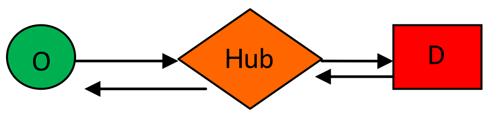
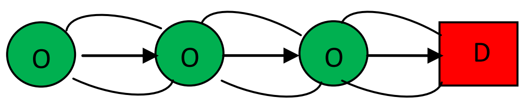
This research presented two methods by which three transportation networks, point to point, hub and spoke and distributed multi-segment, were assessed to determine which was most sustainably viable of the three based on a chosen set of performance measures used by both public and private stakeholders. In the AHP/ANP analysis done by the use of Super Decisions software created by Bill Adams and Saaty, the resulting alternatives prioritized the distributed multi-segment network as the most preferred based on the weighted influence factors given in the comparison profile. This was followed by the point to point network and lastly hub and spoke. The results of the simulated empirical study quantitatively revealed that using the primary sustainability goals of reducing diesel usage (energy), emissions, increasing safety and quality of life (less time away from home for drivers), the distributed multi-segment network is a more preferred alternative. However when stakeholders consider all three alternatives with respect to time and associated delay costs, the point-to-point and hub and spoke networks are still viable options.

While this study has introduced a third viable network for stakeholders to consider that will introduce a more sustainable option into the logistics profile for truckload operations in a more regionalized construct, the reality is, the supply chain must remain competitive by keeping costs low while continuing to maintain high service levels. This balancing act comes with many tradeoffs to consider when selecting the distributed multi-segment network.

Tradeoff 1: Improving quality of life at the cost of quality wages. Utilizing a distributed multi-segment network drastically reduces the amount of hours a trucker will spend on the road and away from his/her family which positively affects the driver's home life and ultimately peace of mind. However, this may ultimately reduce the driver's earning potential. According to The Trucker's Report (2011), a typical trucker gets paid by the mile. He/she has to make as many miles as possible to achieve a good paycheck. While that trucker is sitting in dock, traffic, and shops they get paid typically nothing. A driver can make anywhere from .19 cents a mile to around .44 cents a mile, with an average of approximately .35 cents a mile. Depending on how long they've driven and many other variables, a driver- truck duo on the distributed multi-segment network on the route from OKC to Asheville, NC, as analyzed in this study will make on average a minimum of $583/wk to a maximum of $1225/wk assuming that the duo is running the route seven days a week. These figures depend on how the route miles segment are distributed and whether each driver-truck duo as one or two drivers. In comparison, the point-to-point and hub-and-spoke networks drivers will typically make around $1200/wk depending on the number of times they are able to complete the route in accordance with federal regulations of drivers' hours.

Tradeoff 2: Distributed Multi-Segmented network equates to investment in infrastructure. In the hub-and-spoke network configuration, hubs are predetermined centralized locations that are designed for the receiving and shipping demands that high volume freight operations require but the transition to a distributed multi-segment network will require the creation of more regionalized locations that can accept and manage volumes of freight containers on an ongoing bases. The costs to build this type of infrastructure can be done through further research. However, additional transit points could yield great benefits if coordinated to reduce quantity of empty trucks on the highway. A quick comparison of the cycle time of each transport network as shown in table 7.1 below shows that use of the distributed multi-segment network presents only a 20% chance of driving empty in the event a load is unavailable versus 50% chance with hub-and-spoke and 100% with the point-to-point network.

Table 7.1 Return Trip Cycle Times Comparison

Point to Point (P2P)		1 segment = 100% return trip time
Hub and Spoke (H&S)		2 segments = 50% return trip time.
Distributed Multi-Segment (DMS)		5 segments= 20% return trip time

Tradeoff 3: Increase in transit locations could yield to increase in potential delays. Adding additional transit points for the movement of freight will increase the amount of container handoffs which could potentially lead to unwanted delays. The time truckers spend unloading and loading freight varies from 30 minutes to hours if the destination location is closed or a load is not yet available. So with new transit points where unloading and loading containers will occur the delay time could exponentially increase which will negatively impact delay costs and O-D time.

Tradeoff 4: Sustainable quest may lead to law of diminishing returns. With the primary focus of sustainability creating negative impacts to the environment and social aspects of society, economics can easily be overlooked. Economics helps show how limited and short-sighted the pursuit of eco-efficiency can be, if it is an organization's only sustainability goal. The "law of diminishing returns" means that a sustainability program trying to decrease an organization's harmful impacts can be successful early on, but at some point it will require higher and higher expenditures to obtain the same reductions in impacts and eventually it will 'hit the wall' in an asymptotic curve, shown in figure 7.2, that will never achieve zero impact (Bolton, 2010).

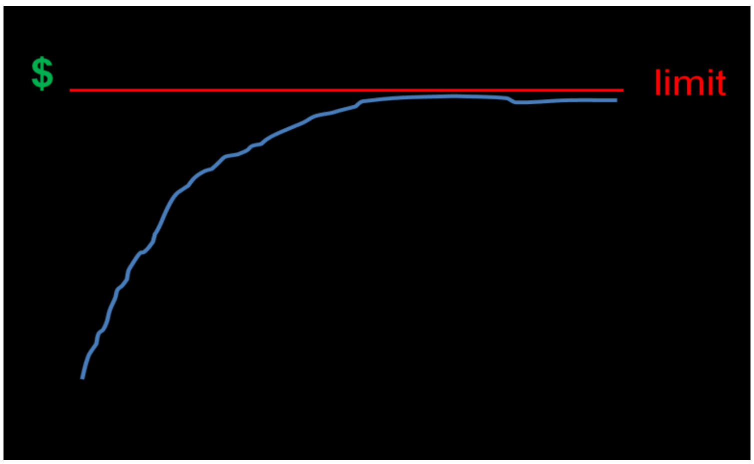


Figure 7.1 Law of Diminishing Returns

Essentially adding more elements into a configuration to make it bigger does not make it better. At some point the additional effort needed to manage all of the freight movement effectively while maintaining an adequate level of sustainability may require a more in-depth look at the entire supply chain. Stakeholders seeking to increase the level of sustainable transportation as the distributed multi-segment network offers have to also seek to reduce waste out of the entire supply chain organization to be fully successful.

7.1 Limitations and Future Research

There are some limitations related to this study that should be noted.

1. The ANP/AHP hybrid tool used to perform analysis was still in trial form (Beta) when electronically downloaded. Consequently, many programming bugs were encountered

which restricted the depth and potentially accuracy of analysis. Additional study could be completed using another commercially available tool or manually if the size of matrix is minimal in size.

2. The demographic study of the trucking industry only included truckload profiles. While the current trend from a supply chain perspective is to ship truckloads in response to the dragging economy and the financial loss that accompanies empty travel, not considering less than truckload may prove to be short sighted in the bigger picture. Including less than truckload profiles in future analysis within the empirical study will give a more in-depth comparison within the trucking industry.
3. The freight performance measures outlined within the study were obtained from recent survey studies done by federal, state and private agencies. While the study data was thorough and statistically sound in design and collection, an independent survey could have validated the findings of the published surveys specific for use in this dissertation.
4. Times relating to loading and unloading, weigh stations and other delay times used in the empirical study were based on the most optimistic scenario. This may be unrealistic and give a false sense of security. A project management approach should be utilized in further study including pessimistic and most likely values which will give management a more complex picture for planning.
5. Trucking was the only freight transport mode considered in this study. While trucks are the most used mode, future research involving the integration of the distributed multi-segment network within an intermodal framework may be more cost effective and sustainable considering the tradeoffs.

7.2 Contribution to the Body of Knowledge

The application of an AHP/ANP hybrid methodology in the use of prioritizing freight transport networks is the first of its kind. In addition, while the distributed multi-segment network has been introduced, this is one of the first studies done that capture the comparisons to existing networks. The findings from this research should help to establish a solid foundation towards addressing the sustainability issues inherent in logistics transportation.

APPENDIX A

EMPIRICAL STUDY: ADDITIONAL CALCULATIONS

Appendix: I-40 Corridor Test Computations

Carrier Route: Oklahoma City, OK (OKC) to Asheville, NC

Hub and Spoke Network

Origin: Distribution Center @ 5525 Morton Drive, Oklahoma City, OK

Hub: Memphis International Airport, 3875 Airways Blvd Memphis, TN

Destination: Manufacturing Facility, 22 Mills Place Asheville, NC

Total Distance: 974 miles

Avg Speed on I-40: 58.6

Time of Departure: 6:00am local time

Total Approx Actual Time of Trip:

1. Origin-Hub: 481 miles ;

$d = r * t$ 481 miles = 58.6 mph * t t = 8.205 hours (8 hrs. 12 min)

2. Weigh Stations from Origin to Hub: 7 X 5min avg to go through = 35 min
3. Hub: unload shipper#1 container – load shipper#2 container by driver = avg 1 hour w/o delay
4. Total daily delay (congestion): avg time – (miles/free flow speed)

   Free flow speed is posted speed limit on I-40 = 70 mph

   8.205 hrs – (481 miles/70 mph) = 8.205 – 6.871 = 1.334 hrs (1 hr. 20 min)

Total time Origin – Hub leg of trip

Avg driving time:	8 hrs 12 min
Weigh Stations	35 min
Hub unload/load	1 hr. 0 min
Congestion	1 hr 20 min

Total	10 hrs. 67 min = 11 hrs. 7 min

5. Hub to Destination: 493 miles

$d = r * t$ 493 miles = 58.6 mph * t t = 8.41 hours (8 hrs. 25 min)

6. Weigh Stations from Hub to destination: 6 X 5min avg to go through = 30 min
7. Destination unload shipper #2 container, load shipper #3 container
8. Total daily delay (congestion): avg time – (miles/free flow speed)

   Free flow speed is posted speed limit on I-40 = 70 mph

   8.41 hrs – (493 miles/70 mph) = 8.205 – 7.04 = 1.37 hrs (1 hr. 22 min)

Total time Hub– Destination leg of trip

Avg driving time:	8 hrs	25 min
Weigh Stations		30 min
Congestion	1 hr	22 min
Destination unload/load	1 hr	0 mn

Total 10 hrs. 77 min = 11 hrs. 17 min

Total time one-way = 22 hrs. 24 min

Round Trip = 44 hrs. 48 min

Number of days driver on the road: 3.25 days

Regulations: 11 hours of drive time then 10 hours rest

Day 1: Leave 6:00am

Origin to hub (unload and load included) – 11 hrs. 7 min (5:07pm)

Rest: 10 hours (include refueling truck if needed) (3:07 am)

Day 2: leave 3:07am

Hub to Destination (unload and load): 11hrs 17 min (2:24pm)

Rest: 10 hours (12:24am)

Day 3: leave 12:24am

Destination (Origin) to Hub: 11 hrs 17 min (11:41am)

Rest: 10 hours (9:41pm)

Start: 9:41pm

Hub to Origin (Destination): 11 hrs. 7 min (8:48am)

Point to Point Network

Origin: Distribution Center @ 5525 Morton Drive, Oklahoma City, OK

Destination: Manufacturing Facility, 22 Mills Place Asheville, NC

Total Distance: 974 miles

Avg Speed on I-40: 58.6

Time of Departure: 6:00am local time

Total Approx Actual Time of Trip:

1. Origin-Destination: 974 miles ;

$d = r * t$ 974 miles = 58.6 mph * t t = 16.62 hours (16 hrs. 37 min)

2. Weigh Stations from Origin to Hub: 13 X 5min avg to go through = 65 min (1 hr 5 min)
3. Total daily delay (congestion): avg time – (miles/free flow speed)

   Free flow speed is posted speed limit on I-40 = 70 mph

   16.62 hrs – (974 miles/70 mph) = 16.62 – 13.914 = 2.706 hrs (2 hr. 42 min)

Total time Origin – Destination

Avg driving time:	16 hrs 37 min
Weigh Stations	1 hr 5 min
Destination unload/load	1 hr 0 min
Congestion	2 hr 42 min

Total	20 hrs. 84 min = 21 hrs. 24 min

Total time one-way = 21 hrs. 24 min

Round Trip = 42 hrs. 48 min

Number of days driver on the road: 3.04 days

Regulations: 11 hours of drive time then 10 hours rest

Day 1: Leave 6:00am

Origin to rest stop: 11 hours (5:00pm)

Rest: 10 hours (include refueling truck if needed) (3:00 am)

Day 2: leave 3:00am

Rest stop to Destination (unload and load): 11hrs (2:00pm)

Rest: 10 hours (12:00am)

Day 3: leave 12:00am

Destination (Origin) to Rest stop: 11 hrs (11:00am)

Rest: 10 hours (9:00pm)

Start: 9:00pm

Rest stop to Origin (Destination): 11 hrs. (8:00am)

Distributed Multi-Segment Network

Segment #1 : Distribution Center @ 5525 Morton Drive, Oklahoma City, OK to Clarksville, AR

Segment # 2: Clarksville, AR to Memphis International Airport, 3875 Airways Blvd Memphis, TN

Segment #3: Memphis International Airport, 3875 Airways Blvd Memphis, TN to Nashville, TN

Segment #4: Nashville, TN to Knoxville, TN

Segment #5: Knoxville, TN to Manufacturing Facility, 22 Mills Place Asheville, NC

Total Distance (all segments combined): 998 miles (difference in mileage as compared to other networks attributed to non-interstate miles)

Avg Speed on I-40: 58.6

Time of Departure: 6:00am local time

Total Approx Actual Time of Trip:

1. Segment 1: 244 miles ;

$d = r * t$ 244 miles = 58.6 mph * t t = 4.16 hours (4 hrs. 10 min)

2. Weigh Stations on Segment #1: 3 X 5min avg to go through = 15 min
3. Truck duo drop container #1/pick up container # to return = 1 hr
4. Total daily delay (congestion): avg time – (miles/free flow speed)

   Free flow speed is posted speed limit on I-40 = 70 mph

   4.16 hrs – (244 miles/70 mph) = 4.16 – 3.49 = 0.67 hrs (40 min)

Total time Segment #1

Avg driving time:	4 hrs	10 min
Weigh Stations		15 min
Stop unload/load	1 hr.	0 min
Daily Delay		40 min
Total	5 hrs.	65 min = 6 hrs 5 min

5. Segment 2: 238 miles ;

$d = r * t$ 238 miles = 58.6 mph * t t = 4.06 hours (4 hrs. 4 min)

6. Weigh Stations on Segment #1: 4 X 5min avg to go through = 20 min
7. Truck duo pickup/drop #1/pick up container #2 to return = 1 hr
8. Total daily delay (congestion): avg time – (miles/free flow speed)

   Free flow speed is posted speed limit on I-40 = 70 mph

   4.06 hrs – (238 miles/70 mph) = 4.06 – 3.4 = 0.66 hrs (40 min)

Total time Segment #2

Avg driving time:	4 hrs	4 min
Weigh Stations		20 min

Stop unload/load	1 hr.	0 min
Daily Delay		40 min

Total 5 hrs. 64 min = 6 hrs. 4 min

9. Segment 3: 220 miles ;

$d = r * t$ 220 miles = 58.6 mph * t t = 3.75 hours (3 hrs. 45 min)

10. Weigh Stations on Segment #1: 2 X 5min avg to go through = 10 min
11. Truck duo drop container #1/pick up container #2 to return = 1 hr
12. Total daily delay (congestion): avg time – (miles/free flow speed)

    Free flow speed is posted speed limit on I-40 = 70 mph

    3.75 hrs – (220 miles/70 mph) = 3.75 – 3.14 = 0.61 hrs (37 min)

Total time Segment #3

Avg driving time:	3 hrs 45 min	
Weigh Stations	10 min	
Stop unload/load	1 hr.	0 min
Daily Delay		37 min

Total 4 hrs. 92min = 5 hrs 32 min

13. Segment 4: 180 miles ;

$d = r * t$ 180 miles = 58.6 mph * t t = 3.07 hours (3 hrs. 4 min)

14. Weigh Stations on Segment #1: 3 X 5min avg to go through = 15 min
15. Truck duo pickup/drop #1/pick up container #2 to return = 1 hr

16. Total daily delay (congestion): avg time – (miles/free flow speed)

 Free flow speed is posted speed limit on I-40 = 70 mph

 3.07 hrs – (180 miles/70 mph) = 3.07 – 2.57 = 0.50 hrs (30 min)

Total time Segment #4

Avg driving time:	3 hrs 4 min
Weigh Stations	15 min
Stop unload/load	1 hr. 0 min
Daily Delay	30 min
	--
Total	4 hrs. 49 min

17. Segment 5: 116 miles ;

$d = r * t$ 116 miles = 58.6 mph * t t = 1.98 hours (1 hrs. 59 min)

18. Weigh Stations on Segment #1: 1 X 5min avg to go through = 5 min
19. Truck duo pickup/drop #1/pick up container #2 to return = 1 hr
20. Total daily delay (congestion): avg time – (miles/free flow speed)

 Free flow speed is posted speed limit on I-40 = 70 mph

 1.98 hrs – (116 miles/70 mph) = 1.98 – 1.66 = 0.32 hrs (19 min)

Total time Segment #5

Avg driving time:	1 hrs 59 min
Weigh Stations	5 min
Stop unload/load	1 hr. 0 min
Daily Delay	19 min
	--
Total	2 hrs. 83 min = 3 hrs. 33min

Total time one-way = 26 hrs. 3 min

Distributed among 5 truck duos: Avg time per duo =5 hrs 12min

Number of days driver on the road: 1 day per segment

Number of days to deliver container: 1.167 days

Regulations: 11 hours of drive time then 10 hours rest

Day 1: Truck duo # 1 leaves 6:00am

Segment #1 (unload and load included) – 5 hrs. 55 min (12:55pm)

Truck duo leaves 12:55pm –

Segment #2 - 6 hrs 4 min (6:59pm)

Truck duo #3 leaves 6:59pm

Segment #3 - 5 hrs. 32 min (12:31am)

Truck duo #4 leaves 12:31am

Segment #4 – 4 hrs 49 min (6:20am)

Day 2: Truck duo #5 leaves 6:20am

Segment #5 – 3 hrs 33 min (9:53am) – Destination

Energy Security

Average tractor trailer holds 200-300 gallons of diesel fuel. For this simulation, a 250 gallon tank will be assumed. Based on literature, the average miles per gallon (mpg) grade of good condition tractor trailers (80,000 lbs) is 6mpg. For less weight, the mpg increases. So for purposes of this study, trucks weighing 60,000 get 6.5 mpg and 40,000 lbs get 7.0 mpg.

For 80,000 lbs: 250 gal * 6mpg = 1500 miles capacity

Daily Diesel use (gallons) = (974 miles/6 mpg) * 2 = 324.667 ~ 325 gallons

For 60,000 lbs: 250 gal *6.5mpg = 1625 miles

Daily Diesel use (gallons) = (974 miles/6.5 mpg) * 2 = 299.692 ~ 300 gallons

For 40,000 lbs: 250 gal * 7mpg = 1750 miles

Daily Diesel use (gallons) = (974 miles/7.0 mpg) * 2 = 278.282 ~ 278 gallons

Mobile Source Emissions

CO_2E (equivalent- greenhouse emissions)

US gallon diesel = 10.493kg of CO_2

		Highway Interstate	Distance (miles)	Accessibility (distance from hwy, miles)	Truck Weight (lbs)	Average Speed (MPH)	Average Travel Time (Hrs)	Free Flow Travel Time (Hrs) [Mean travel rate/free flow travel rate]	Total Daily Delay (mins)	Daily Fuel Use (gallons)	Kg per day
							d = r*t	Free Flow rate = 70 mpg		Diesel	CO_2
1. Hub and Spoke (Hub: Memphis, TN)											
Oklahoma City, OK to Memphis , TN		I-40 E	481	8		58.6	8.21	6.87	1.337		
Memphis, TN to Asheville, NC		I-40 E	493	8		58.6	8.41	7.04	1.370		
			974		80,000	58.6	16.62	13.91	2.707	324.667	3406.73
			974		60,000	58.6	16.62	13.91	2.707	299.692	3144.67
			974		40,000	58.6	16.62	13.91	2.707	278.286	2920.05
2. Point to Point											
Oklahoma City, OK to Asheville, NC		I-40E	974	8		58.6	16.62	13.91	2.707	149.846	
3. Distributed Multi-Segment											
Oklahoma City, OK to Clarksville, AR		I-40E	244	4		58.6	4.16	3.49	0.678		
			244		80,000					40.667	426.72
			244		60,000					37.538	393.89
			244		40,000					34.857	365.76
Clarksville, AR to Memphis, TN		I-40E	238	5		58.6	4.06	3.40	0.661		
			238		80,000					39.667	416.22
			238		60,000					36.615	384.21
			238		40,000					34.000	356.76
Memphis, TN to Nashville, TN		I-40E	220	5		58.6	3.75	3.14	0.611		
			220		80,000					36.667	384.74
			220		60,000					33.846	355.15
			220		40,000					31.429	329.78
Nashville, TN to K	Knoxville, TN	I-40E	180	4		58.6	3.07	2.57	0.500		
			180		80,000					30.000	314.79
			180		60,000					27.692	290.58
			180		40,000					25.714	269.82
Knoxville, TN to Asheville, TN		I-40E	116	6		58.6	1.98	1.66			
			116		80,000					19.333	202.86
			116		60,000					17.846	187.26
			116		40,000					16.571	173.88

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BIOGRAPHICAL INFORMATION

Andrea Graham received her Bachelor of Science Degree in Mechanical Engineering from Tuskegee University in 1995. She then obtained a Master of Science degree in Technology Management from Stevens Institute of Technology in 2004. Andrea was conferred the Doctor of Philosophy degree from the University of Texas at Arlington in Industrial and Manufacturing Systems Engineering in the Summer of 2012.

Andrea's research interests are in the areas of sustainability, supply chain risk management, logistics network optimization and engineering education. During her time at UTA, she has authored three (3) refereed publications that have been presented at the Institute of Industrial Engineers Annual Conferences (2011-2012) and two(2) co-authored refereed publications that she has presented at the American Society of Engineering Education conference (2012). As a part of her interest in engineering education, she assisted in the creation, development and implementation of a module to improve undergraduate student knowledge of and competency in addressing sustainability issues in engineering design and problem solving. She also participated in the UT-Arlington Engineering Summer Camps held on the campus, introducing the field of Industrial Engineering to potential future engineering students in 5th thru 10th grades. In addition, Andrea has served as a Graduate Teaching Assistant since 2008 in the Industrial and Manufacturing System Engineering Department where she has mentored several undergraduate and graduate students.

Andrea is a member of Phi Kappa Phi National Honor Society, a STEM Doctoral Fellow and UTA's first recipient of the Alfred P. Sloan Minority PhD Scholarship.

Andrea seeks to remain in academia where, as a part of the professorate, she will continue to contribute significant research to the field of Industrial Engineering and engineering education, build critical partnerships between industry and academia and teach, mentor and motivate the next generation of engineers.