Int. J Sup. Chain. Mgt Vol. 1, No. 3, December 2012

Utilizing Relay Points to Improve the Truckload Driving Job

Kerry Melton[#1], Ricki Ingalls[*2]

[#]*Department of Industrial & Manufacturing Engineering & Technology, Bradley University*
101 Morgan Hall, Peoria, IL 61625 USA
[1]kdmelton@fsmail.bradley.edu

[*]*School of Industrial Engineering and Management, Oklahoma State University*
322 Engineering North, Stillwater, OK 74078 USA
[2]ricki.ingalls@okstate.edu

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

***Keywords*—** *Relay points, Truckload driver turnover, Driver home time, Length-of-haul, Slip-seating*

1. Introduction

Freight transportation has increased dramatically over the last thirty years as freight and shipment demand has expanded resulting in driver and equipment capacity issues and infrastructure problems. Freight transport tonnage in the U.S. is predominately truck transportation consisting of 69% of all freight distribution with a growth expectation of 27% between years 2006 and 2018 [1]. Truck transportation currently represents about 5% of the U.S. Gross Domestic Product [1]. Rail freight ranks second in tonnage distributed at 13% [1]. Within the trucking industry, truckload transportation consists of 50% of all truck tonnage shipped [1]. Due to high truckload demand, truckload driver capacity issues and poor job conditions have plagued the truckload industry for years. High truckload driver turnover and poor driver retention are the result of strenuous job requirements and poor work conditions. Drivers drive long distances and are home infrequently causing turnover and retention problems.

As the U.S. economy grows, truck driver turnover and shortages will worsen causing idle equipment, poor customer service, large driver recruitment costs, etc. Truckload driver turnover is consistently above 100% and has reached 300% in extreme cases, while the overall U.S. unemployment rate averages about 8%. The driver shortage is expected to be over 110,000 drivers by year 2014 unless measures are taken to improve the truckload driving job and work conditions [1]. Although the truckload driving job has been a major concern for years, there have been limited research efforts to explore methods for making the truckload driving job more attractive. Most transportation carriers have used driver wage increases and fringe benefits as strategies for retaining drivers with little efforts made to improve driving jobs and work conditions. Min and Emam [2] explained that 80% of the top 100 carriers used driver pay increases in the 1990s to reduce driver turnover with minimal long term impact.

This paper will present a method for enhancing the truckload driving job and reducing driver turnover, while considering key performance measures related to the truck driver, transportation carrier, and customer. Four sections will be included in the paper. Section 1 includes the introduction. Section 2 concentrates on previous research endeavors dealing with truckload driver related issues. Section 3 defines the problem and a model to develop more optimal truckload driving jobs. Section 4 includes a summary and closing remarks.

2. Background Study

Several transportation modes are used in the U.S. to transport goods from a shipper to a receiver. The major transportation modes are truck, rail, water, pipeline, and

International Journal of Supply Chain Management
IJSCM, ISSN: 2050-7399 (Online), 2051-3771 (Print)

air. It is estimated in the U.S. that the dominant mode distributions consist of 69% truck (84% of freight revenue) and 13% rail (6% of freight revenue), while pipeline and water modes account for 10% and 7% of transportation moves, respectively [3]. Rail is used to move freight less expensive over long distances while truck moves freight cheaper over shorter distances. On-time service tends to be better in truck operations compared to rail operations due to the anomalies of scheduling trains and positioning rail cars on the train. Transporting freight involves timely logistical services to ensure goods are transported in the proper condition and correct quantity. The trucking industry annually hauls about $670 billion in manufactured and retail goods accounting for over 430 billion annual miles [4]. The trucking industry employs about 3.5 million truck drivers according to the U.S. Department of Labor [5]. Truck transportation is the dominant transportation mode utilized to transport goods.

2.1. Truckload and Less-Than-Truckload (LTL) Transportation

The two main segments of freight transportation in the trucking industry are truckload and LTL. LTL involves transporting small amounts of freight averaging between 150 and 20,000 pounds. LTL carriers collect freight from various shippers and consolidate the freight into trailers for line-haul delivery to warehouses or retail stores. LTL driving jobs are more regularized with shorter driving distances resulting in more driver home time and less work hours [6]. In the truckload industry, freight is moved from a shipper to a receiver over long distances with virtually no freight consolidation occurring between the origin and the final destination. Truckload drivers are home anywhere from one day per week to one day per month. Truckload drivers average 60-70 work hours per week, which is extremely high compared to other professions, resulting in low hourly driver pay. The truckload trucking industry has experienced driver turnover rates between 100% and 200% due to long work hours and long driving distances and minimal driver home time [2]. In 2007, LTL driver turnover was 15% compared to 112% for the truckload industry [7]. The Bureau of Labor and Statistics report that high turnover rates exist in the transportation and logistics industries [8].

2.2. Truckload Driver Turnover Cost and Job Satisfaction

Truckload driver turnover leads to high recruiting, hiring, and training costs. Also, transportation companies spend a large amount of dollars trying to retain drivers. Inducements have had limited long term impact on curbing driver turnover based on the fact that driver turnover is consistently high. Several studies will be outlined that have queried driver turnover costs and job satisfaction.

LeMay et al. [9] did a study on driver turnover by issuing surveys to the CEOs of 650 member firms of the Interstate Truckload Carriers Conference of the American Trucking Associations, and 175 usable responses were returned. Firms involved in the study were company drivers only. The study used the Spearman's correlation coefficient between driver turnover and selected variables to determine the statistical significance of certain factors. Results showed a statistically significant negative correlation between driver turnover and mileage pay and a statistically significant positive correlation between driver turnover and average miles driven per week. The results showed a statistically significant positive correlation between driver turnover and average driving length-of-haul.

DeWeese [10] reinforced the fact that major driver turnover and retention issues exist due to poor management communication, poor training, and lackluster hourly wages. He noted that safety is an important concern since driver turnover results in a lack of experienced drivers. DeWeese noted that the potential cost to replace a truck driver is between $10,000 and $30,000, which includes recruiting, advertising, training, exit interviews, and other miscellaneous costs. Rodriguez et al. [11] also reported the average cost of turnover per driver for all companies was $8,234 ranging from $2,243 to $20,729. Company profit margins are also eroded due to driver turnover.

McElroy et al. [12] conducted a survey of 13 truckload carriers in the U.S. where 11,390 surveys were distributed and 3,379 returned usable. Short and long road time drivers were critical in this research and defined as follows. Drivers who were away from home one weekend or less were considered short road time drivers, while drivers gone more than one weekend were considered long road time drivers. In the study, there were two independent variables associated with the driver's career stage and the amount of time a driver spent on the road. There were 14 dependent variables associated with driver attitudes including: job satisfaction, job enlargement interest, equipment satisfaction, importance of influencing management, training interest, benefit adequacy, recognition importance, supervisor description, perceived attitude of a company toward employees, standard of living, income compared to other trucking companies, income compared to other industries, advancement opportunities within a company, and advancement opportunity within an industry. The time spent on the road independent variable was considered important as it impacted nearly all 14 dependent driver attitude variables. The results indicated that long driver road time significantly impacted all driver attitudes excluding interest in job enlargement, job satisfaction, and perceived advancement opportunities within the industry, resulting in negative driver attitudes.

Stephenson et al. [13] studied drivers associated with different truckload carriers to gain an understanding of driver retention and turnover. In the research, 2,256 surveys were sent to different carriers and 1,791 usable surveys were returned completed. The results showed that driver home time was a key factor that played a role in driver retention and driver job satisfaction along with training, driver attitudes toward direct supervisors, career path advancement, company pride, compensation and benefits, and working conditions. The study indicated that 67% of drivers average 60 or more work hours per week and 22% average more than 70 work hours per week. The study showed that 29% of drivers get home less than once every two weeks, 15% once every two weeks, and 21% once a week. It was noted that driver pay as a function of hours worked was very low compared to other professions.

2.3. Modern Approaches to Improve the Truckload Driving Job

The truckload industry consists of many carriers having the same characteristics with operational characteristics, management policies, and carrier size being the main differentiators in truckload transportation companies [14]. Most truckload trucking companies experience the same daily challenges under tight profit margins and combat high driver turnover using: driver pay increases, fringe benefits, new equipment, driver route regularization, reward programs, etc. Over the years, several research endeavors have been considered to improve the truckload driving job by creating better driving routes and utilizing equipment exchange points on a small scale to shorten driving distances. These efforts have had some positive impact on driver turnover but with limited transportation carrier and customer consideration and without the inclusion of key transportation costs. Several key studies are now outlined.

Tsu and Agarwal [15] considered creating consistent and regularized transportation tours for a retailer using equipment relay points where trailers were switched between trucks to prevent drivers from traveling long distances. The goals were to get drivers home more often, develop consistent driving routes, and utilize more private fleet drivers. A transportation relay point is a physical location where trailer equipment is exchanged and a shipment is divided into two transportation legs. Key operational parameters involved incorporating out-of-route miles and empty miles to ensure operational parameters were at acceptable levels. A baseline model included an optimized solution without relay points which was compared to a solution with relay points. The results showed that relay points reduced the total transportation cost by 6% and increased private fleet utilization. Regularized tours consisted of headhaul and backhaul matched routes, inter-facility moves, and out loaded/back empty tours (see Figure 1). The study concluded that regular routes better utilized the private fleet and reduced transportation costs.

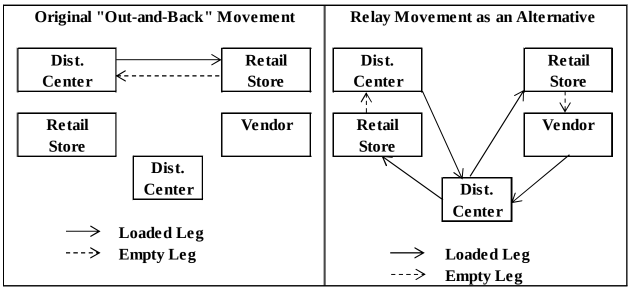

Figure 1. Freight movement example with and without relay points [15]

Taylor et al. [16] considered using freight pipelines in truckload transportation to more optimally dispatch drivers to improve driver life quality while minimizing out-of-route mileage. The study was done with J.B. Hunt Transport, Inc. Freight pipelines were established on a lane between two drop/swap points requiring three drivers and three dispatches for each truckload. One driver was required at the origin between the shipper and the pipeline begin drop/swap point, one driver was required at the destination between the pipeline drop/swap point and final destination, and one driver was required on the pipeline between the drop/swap points. A pipeline move is equivalent to a line-haul move, and moves at the origin and destination are local moves that transition loads to and from the pipeline. Figure 2 illustrates the pipeline concept showing local dray moves and a line-haul pipeline move.

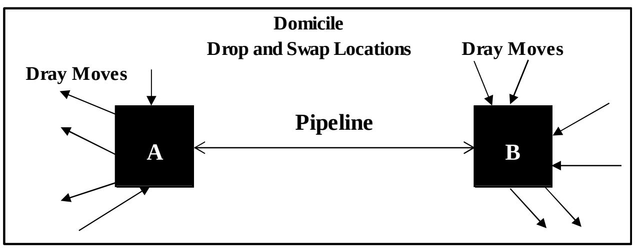

Figure 2. Pipeline illustration with pipeline and dray moves [16]

The goal was to regularize driver moves to improve driver life quality and home time. The study revealed that 22% of loads and 13% of loaded miles at J.B. Hunt Transport, Inc. were good candidates for pipeline moves.

Hunt [17] also considered truckload routing and the use of switch points. Hunt [17] focused on reducing driver tour lengths to combat driver turnover and improve driver home time. A three step method was used to solve the routing and relay point location problem assuming switch points could be located anywhere in the network without fixed charges. First, a shortest path routing problem was solved on a network without switch points while considering backhaul. Second, switch point locations were determined using an iterative spring algorithm, which considered proximity requirements at the beginning of the algorithm. Minimum, maximum, and desired distances between switch points were defined. Third, the routing problem was solved over the transportation network using the created switch points, proximity requirements, and a shortest path heuristic. The study showed that freight flows were more through switch points when fewer numbers of switch points existed. Regularized driving routes were also increased.

Ali et al. [18] considered locating equipment relay points where freight is exchanged to better optimize driver and truck operations traveling over long distances. Straight route and detour algorithms on a shortest path network were used to determine equipment relay point locations. The detour algorithms allowed drivers to deviate from the shortest path to certain degrees, but the straight route algorithm allowed no deviation. The results showed that the straight route algorithm locates a larger number of relay points compared to the detour algorithms. Both algorithms enhanced driver home time and regularized driving routes, but did not consider costs to establish relay points.

Creating more optimal driving jobs in truckload transportation is a relatively unexplored area despite triple digit driver turnover rates. The approaches discussed above considered methods to create better truckload driving jobs, but with limited degrees of implementation and with minimal to no cost consideration for establishing relay points to regularize driving routes. Most research fails to mention how the driver job would be modified when changes are made to the transportation network and fails to consider changes the transportation carrier and customer may need to make. An approach needs to consider necessary transportation network and structure changes, operational requirements, transportation and facility costs, and a more inclusive approach involving the driver, transportation carrier, and customer while incorporating key performance measures.

A model to improve driver turnover will be presented that considers the driver, transportation carrier, and customer. The model will consider transportation costs and key performance measures using a relay point methodology where both trailer and tractor equipment are exchanged at relay points. The intention is not to improve the driving job at the expense of the transportation carrier and customer.

3. Problem Definition and Model

In truckload transportation, a driver picks up a loaded trailer at a shipping facility and transports the trailer over a long distance to a final customer. The driver may be required to load or unload or monitor freight depending on operational characteristics. Federal hours-of-service rules permit drivers to only drive 11 consecutive hours before a 10 hour rest must be taken. Also, after driving 60 hours over 7 consecutive days or 70 hours over 8 consecutive days, the driver must take a 34 hour rest. Since truckload drivers drive long distances and are required to shut-down to rest along the path of their destination, drivers are away from home for a significant amount of time and are often fatigued. Also, equipment is idle when drivers are shut-down. Due to the current nature of the truckload driving job, driver turnover is very high causing excessive driver replacement costs, idle equipment, and poor customer service. Therefore, a more comprehensive approach must be taken to improve the truckload driving job while being sensitive to transportation carrier and customer needs. Costs need to be considered along with the expected impact on driver turnover. A more optimal truckload transportation network will be considered that more inclusively incorporates driver, transportation carrier, and customer needs with the inclusion of industry specific performance metrics. From a driver's perspective, the important performance measures are weekly miles per driver, route regularity, driver home time, and average length-of-haul (one-way driving distance). From a transportation carrier’s perspective, the critical performance metrics are customer service and cost. From a customer's viewpoint, the key performance measure is order cycle time (time from shipper to final destination). The study provides a more optimal transportation plan to minimize network costs and to improve the driving job while considering the transportation carrier and customer.

3.1. Model

To develop a model, a highway transportation network is required that includes nodes where freight is produced and consumed, links between nodes where freight is transported, and freight assignments where freight is routed along a shortest path network between production and consumption nodes. The four-step urban planning approach is used to establish the highway transportation network that includes: freight generation where freight production and consumption are established, freight distribution between production and consumption nodes, and freight assignments establishing routes on a shortest path network [19]. Only truckload transportation is considered. The result is a shortest path highway transportation network between production and consumption nodes. Along each shortest path, relay points will be established at locations where truckload drivers can exchange tractor and trailer equipment with other drivers, sleep in a hotel to rest, drop tractor and trailer equipment or hitch a ride home with another driver, etc. The relay points can serve as multi-functional facilities where equipment maintenance is performed, computing facilities are accessed, trucks are fueled, etc. At relay points, drivers will be dispatched on a loaded or empty trailer. Figure 3 illustrates the concept of the relay point.

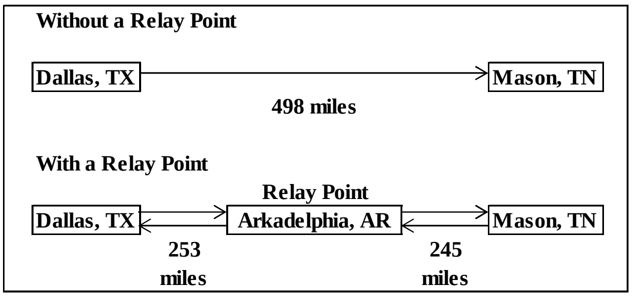

Figure 3. An example of a relay point on a driving path

In the Without a Relay Point scenario in Figure 3, a driver is required to drive the full 498 mile distance from Dallas to Mason. In the With a Relay Point scenario using a relay point in Arkadelphia, AR, a driver from Dallas would drive from Dallas to Arkadelphia and a driver would drive from Mason to Arkadelphia, and the drivers would exchange equipment in Arkadelphia and drive back home. By exchanging equipment in Arkadelphia, drivers drive shorter length-of-hauls, drivers are home more often compared to the Without a Relay Point scenario, and equipment continuously moves. The Without a Relay Point Scenario requires drivers to shut-down for 10 hours, to comply with federal hours-of-service rules, along the path after delivering in Mason. The average driving length-of-haul is 498 miles without the relay point and 249 miles using the relay point. Drivers are home daily using the relay point and only 2-3 days per week without the relay point.

In establishing relay points, fixed and variable costs will be incurred. Fixed costs include equipment depreciation costs and costs to establish "brick and mortar" relay point facilities. Variable costs include line-haul transportation costs, fuel costs, equipment maintenance costs, driver wages, and driver turnover costs. A mixed integer quadratic program (MIQP) will be used to determine optimal relay point locations by minimizing total costs. The MIQP is given below showing the model variables, objective function, and constraints.

3.1.1 Model Sets

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

3.1.2 Model Parameters

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

- t_i- driver turnover % associated with mileage band m_i
- m_i - mileage band

3.1.3 Decision Variables

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

3.1.4 Objective

Minimize

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

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

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

$$b * q \quad (4)$$

Where:

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

3.1.5 Constraints

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

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

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

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

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

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

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

$$\lambda_0 \leq \delta_1 \quad (8)$$

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

$$\lambda_r \leq \delta_r \quad (10)$$

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

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

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

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

Where:

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

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

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

An example will be shown to illustrate how the MIQP works in terms of the model decision variables and the establishment of relay points. The origin-destination path from Loomis, CA to Lowake, TX is considered with relay points established in Stockton, CA; Banning, CA; Tucson, AZ; and Sierra Blanca, TX (see Figure 4).

Figure 4. Loomis, CA to Lowake, TX path [20]

In Figure 4, origin *i* is Loomis, CA (point A) and final destination *j* is Lowake, TX (point F). A relay point z_k is located at Stockton, CA; Banning, CA; Tucson, AZ; and Sierra Blanca, TX with unique values for *k* at each relay point. Decision variable z_k equals 1 when a relay point is established at some location *k*. Truckload flow between relay points is coordinated and sequenced properly using decision variable y_{kl}^{ij}, and y_{kl}^{ij} will equal 1when truckload flow is coordinated from relay point location *k* to relay point location *l* on origin-destination path *ij*. In Figure 4, y_{kl}^{ij} equals 1 between points B and C (*k* = Stockton, CA to *l* = Banning, CA), between points C and D (*k* = Banning, CA to *l* = Tucson, AZ), and between points D and E (*k* = Tucson, AZ to *l* = Sierra Blanca, TX) on origin-destination path *ij*. A variable y_{il}^{ij} coordinates truckload flow from origin *i* to the first relay point established at *l* (*i* = Loomis, CA to *l* = Stockton, CA). A variable y_{lj}^{ij} coordinates truckload flow from the final relay point *l* to the final destination at *j* (*l* = Sierra Blanca, TX to *j* = Lowake, TX). Both y_{il}^{ij} and y_{lj}^{ij} are decision variables and equal 1 when truckload flow is coordinated between the location points. The truckload flow (f^{ij}) on the Loomis, CA to Lowake, TX origin-destination path equals 15,386 truckloads annually. Fixed costs are associated with establishing each relay point (z_k), and variable costs are established along the path in the form of equipment maintenance, equipment depreciation, fuel, line-haul market-to-market costs, driver pay, and driver turnover. The z and y decision variables ensure relay points are established and that truckload flow is coordinated and sequenced correctly between relay points, from origin points, and to the final destination points.

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

To illustrate the relay point concept, a case study is considered that establishes relay points on a path from Quantico, Maryland to Tahlequah, Oklahoma, which includes performance metrics related to the driver, transportation carrier, and customer. The transportation related data and cost information for the MIQP were obtained from the Freight Movement Model project [19], which is an Oklahoma Department of Transportation project focused on transportation and infrastructure planning at the national and Oklahoma state level, and from a large transportation company.

3.2. Case Study

The MIQP presented in section 3.1 establishes relay points on a highway transportation network, and performance measures are used to compare the relay point results with the non-relay point scenario. In this example, relay points are established on the path from Quantico, Maryland to Tahlequah, Oklahoma. The performance measures include: order cycle time (hours per order); driver, truck, and trailer quantity requirements; driving one-way length-of-haul (miles); driver home time (days/week); weekly driver work hours; driver utilization (miles/week/driver); truck utilization (miles/week/truck); equipment idle time (hours/week); and driver pay. Quantico, MD to Tahlequah, OK is a 1,333 mile path with a transit time of 25.6 hours, which requires two 10 hour shut-down periods to comply with federal hours-of-service rules for truck drivers.

For the 1,333 mile path from Quantico, MD to Tahlequah, OK, four relay points were established in: Glen Burnie, MD; Hopwood, PA; Eminence, IN; and Joplin, MO. Figure 5 shows the relay points and the mileage between each relay point with arrows depicting the driving route between relay points.

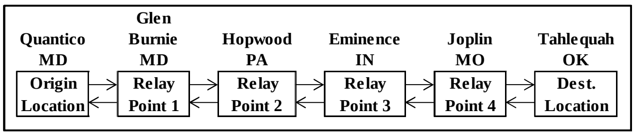

Figure 5. 1,333 mile path (Quantico, MD to Tahlequah, OK) with four relay points

The one-way transit time between Quantico, MD and Glen Burnie, MD is 1.88 hours; 3.86 hours between Glen Burnie, MD and Hopwood, PA; 7.93 hours between Hopwood, PA and Eminence, IN; 9.60 hours between Eminence, IN and Joplin, MO; and 2.34 hours between Joplin, MO and Tahlequah, OK. Figure 6 illustrates the path and the relay points on a U.S. map.

Figure 6. Quantico, MD to Tahlequah, OK path [20]

The path has an annual flow of 8,320 truckloads or 160 weekly truckloads requiring 169 total drivers for both the relay and non-relay point scenarios. For the relay point scenario, 16 drivers are based in Quantico, MD, 32 drivers are based in Glen Burnie, MD, 48 drivers are based in Hopwood, MD, 57 drivers are based in Eminence, MD, and 16 drivers are based in Joplin, MO. In the relay point scenario, drivers can be slip-seated because drivers have compatible driving schedules that can be setup in two 12 hour work shifts. Slip-seating means drivers can share the same truck on different work shifts. For example, a driver would drive a truck for the first 12 hour work shift, and a different driver would drive the same truck for the second 12 hour work shift. Using relay points, 64 drivers are slip-seated between consecutive 12 hour work shifts, but 105 drivers cannot be slip-seated because driving schedules prohibit slip-seating; therefore, 137 day cab trucks and 137 trailers are required. In the non-relay point scenario, driver schedules cannot be coordinated into shift-type work due to long driving distances, so drivers cannot be slip-seated; therefore, 169 sleeper cab trucks and 169 trailers are required. All non-relay point drivers are based in Quantico, MD. Sleeper cab trucks have a berth for sleeping while day cab trucks do not. The operational results of the relay and non-relay point scenarios are shown in Table 1.

Table 1. 1,333 mile path scenario (operational metrics- relay point/non-relay point)

Metric	Result (Relay Point)	Result (Non-Relay Point)
Cycle Time Per Order (hours)	29.0	45.8
Driver Quantity	169	169
Truck Quantity	137 day cabs	169 sleeper cabs
Trailer Quantity	137	169
Average Length-of-Haul (miles)	266.6	1,333
Driver Home Time (days/week/driver)	5.8	1
Driver Work Hours (hours/week/driver)	51.7	70
Driver Utilization (miles/week/driver)	2,524	2,524
Truck Utilization (miles/week/truck)	3,114	2,524
Equipment Idle Time (hours/week)	3,550	11,070
Annual Driver Pay (per driver)	$55,125	$55,125

The order cycle time for the relay point scenario is 16.8 hours faster compared to the non-relay point scenario. The number of drivers required for both scenarios is equivalent, while 32 less trucks and 32 less trailers are required for the relay point scenario. The average length-of-haul is 1,066.4 miles shorter using the relay point scenario. The relay point driver home time is 4.8 days per week better than the non-relay point scenario, and relay point drivers are able to earn strong pay. Relay point drivers work an average of 18.3 hours less each week compared to non-relay point drivers. The driver utilization is the same for both scenarios, but truck utilization is 590 more using the relay point scenario because equipment is slip-seated. Utilizing the relay point concept, the weekly equipment idle time decreased from 11,070 hours to 3,550 hours. Relay point drivers experience less idle time because only the Hopwood, PA and Eminence, IN based drivers reach federal hours-of-service driving threshold limits, which require enforcement of the 10 hour and 34 hour shut-down rules. Relay point drivers drive the same routes daily. Assuming drivers have a wage rate of $0.42 per mile, each relay and non-relay point driver earns $55,125 in annual wages.

In addition to operational performance, equipment costs, in terms of purchase, maintenance, and depreciation costs, are less costly using relay points versus the non-relay point scenario. Day cab and sleeper cab trucks cost $79,736 each and $95,312 each, respectively, and box trailers cost $19,936 each. Using MACRS depreciation and a 3-year property class, average annual unit depreciation costs are $19,934 and $23,828 for day cab and sleeper cab trucks, respectively. Each trailer averages $4,984 annually in depreciation costs. Table 2 shows the cost difference between the relay and non-relay point scenarios. Equipment costs were obtained from a large transportation company.

Table 2. 1,333 mile path scenario (cost metrics- relay point/non-relay point)

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

Truck and trailer purchase costs are $5,821,848 less, annual depreciation costs are $1,455,462 less, and annual maintenance costs are $604,434 less expensive using the relay point concept. Overall, the results indicate better performance measures for the driver, transportation carrier, and customer from operational and cost perspectives, and annual driver pay remains strong. Also, based on the weekly miles driven per week per driver, driver turnover was determined to be 25% by the MIQP, which is much lower than the triple digit driver turnover occurring annually in the truckload driving industry. Assuming relay point and non-relay point drivers turnover at a rate of 25% and 120%, respectively, and a driver turnover occurrence costs $3,000, the relay point scenario would be $481,650 less costly per year in terms of driver replacement costs.

4. Conclusion

The case study results indicate the relay point concept has the potential to improve the truckload driving job while improving performance measures related to the transportation carrier and customer. In addition to improving the driving job, one goal was to improve the driving job but not at the expense of the transportation carrier and customer, and that has been illustrated. As demonstrated in the case study, key performance indices related to the relay point scenario were significantly better than the non-relay point scenario from both operational and cost perspectives. Relay point drivers are home more often, drive less, and maintain solid pay and driving utilization.

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

References

[1] American Trucking Associations, Inc. "American Trucking Associations Trucking and the Economy". 2007. <www.truckline.com>.

[2] Min, H., Emam, A. "Developing the Profiles for Truck Drivers for Their Successful Recruitment and Retention: A Data Mining Approach." International Journal of Physical Distribution & Logistics Management 33 1/2 (2003): 149-62.

[3] Bureau of Transportation Statistics, “Commodity Flow Survey”, Retrieved from

[4] http://www.bts.gov/publications/commodity_flow_survey/ on July 2008.

[5] Truckinfo.net. "Trucking Statistics". <http://www.truckinfo.net/trucking/stats.htm#Size Stats>.

[6] Bureau of Labor Statistics, U.S. Department of Labor. 1999. <http://stats.bls.gov/news.release/tenure.toc.htm>

[7] Taylor, G. Don. "Development and Analysis of Efficient Delivery Lanes and Zones in Truckload Trucking." Fayetteville, AR: University of Arkansas, Mack-Blackwell National Rural Transportation Study Center, 1997.

[8] Bureau of Labor Statistics (2008), Career Guide to Industries: Overview and Outlook. Retrieved on April 26, 2008, from http://www.bls.gov/oco/cg/indchar.htm.

[9] LeMay, S., Taylor G., Turner, G. "Driver Turnover and Management Policy: A Survey of Truckload Irregular Route Motor Carriers." Transportation Journal 33.2 (1993): 15-21.

[10] DeWeese, Aaron. "Turning Around Driver Turnover." Waste Age 30.7 (1999): 10.

[11] Rodriguez, J., Kosir, M., Lantz, B., Griffen, G., Glatt, J. (2000), The Costs of Truckload Driver Turnover, Upper Great Plains Transportation Institute, North Dakota State University, Fargo, ND.

[12] McElroy, J., Rodriguez, J., Griffin, G., Morrow, P., Wilson, M. "Career Stage, Time Spent on the Road, and Truckload Driver Attitude." UGPTI Staff Paper No. 113. Iowa State University, 1993.

[13] Stephenson, F., Fox, R. "Driver Retention Solutions: Strategies for For-Hire Truckload (TL) Employee Drivers." Transportation Journal 35.4 (1996): 12-25.

[14] Taha, T., Taylor, D. "An Integrated Modeling Framework for Evaluating Hub-and- Spoke Networks in Truckload (TL) Trucking." Logistics and Transportation Review 30 2 (1994): 141-66.

[15] Tsu J., Agarwal M. "Use of Transportation Relays to Improve Private Fleet Management." Thesis. Massachusetts Institute of Technology, 2009.

[16] Taylor, G. D., Whicker, G., Ducote, W. "Design and Analysis of Delivery 'Pipelines' in Truckload Trucking." Transportation Research: Part E: Logistics and Transportation Review 45.1 (2009): 255-269.

[17] Hunt, G. W. "Transportation Relay Network Design." Dissertation. Georgia Institute of Technology, 1998.

[18] Ali, T. H., Radhakrishnan, S., Pulat, S., Gaddipati, N. C. "Relay Network Design in Freight Transportation Systems." Transportation Research Part E-Logistics and Transportation Review 38 6 (2002): 405-22.

[19] Ingalls, R. G., Kamath, M., Pulat, P., Shen G. (2009). “Freight Movement Model Development for Oklahoma.” Final Report, Oklahoma Transportation Center.

[20] MapQuest. "MapQuest Maps-Driving Directions-Map". 2012. January 7 2012. <http://www.mapquest.com/>.