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# Mack-Blackwell Transportation Center

FINDING SYNERGY IN INTERMODAL
OPERATIONS WITH TRUCK AND RAIL

MBTC FR-1101

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Intermodal transportation has become a topic of great interest in the transportation industry because of the opportunities it provides, especially financially. However, few trucking companies provide both over-the-road (OTR) trucking services and intermodal services. The reason for this may lie in the fact that there are few tools available to determine the benefits of operating both modes. Another reason may be that many companies are not large enough to be involved economically in both modes of transportation. Suspicion exists that, by integrating OTR and intermodal operations, greater operational flexibility, better balance, lower cost, and better customer service may be achieved over the use of the single modes independently. This report presents a simulation-based tool to examine this suspicion, and quantifies the benefits of operating intermodal and OTR fleets concurrently.

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16. Abstract

Intermodal transportation has become a topic of great interest in the transportation industry because of the opportunities it provides, especially financially. However, few trucking companies provide both over-the-road (OTR) trucking services and intermodal services. The reason for this may lie in the fact that there are few tools available to determine the benefits of operating both modes. Another reason may be that many companies are not large enough to be involved economically in both modes of transportation. Suspicion exists that, by integrating OTR and intermodal operations, greater operational flexibility, better balance, lower cost, and better customer service may be achieved over the use of the single modes independently. This report presents a simulation-based tool to examine this suspicion, and quantifies the benefits of operating intermodal and OTR fleets concurrently.

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# Chapter 1

# Introduction

Intermodal transportation has become a topic of great interest in the transportation industry because of the opportunities it provides, especially financially. However, few trucking companies provide both over-the-road (OTR) trucking services and intermodal services. The reason for this may lie in the fact that there are few tools available to determine the benefits of operating both modes. Another reason may be that many companies are not large enough to be involved economically in both modes of transportation. Suspicion exists that, by integrating over-the-road and intermodal operations, greater operational flexibility, better balance, lower cost, and better customer service may be achieved over the use of the single modes independently.

## 1.1 Project Objectives

This research project focuses on providing an evaluation tool to determine the possible synergies between truckload and intermodal transportation. Simulation is chosen to model the two different modes of freight transportation (OTR versus intermodal) due to its ability to model multi-criteria and stochastic situations. Simulation is also able to manipulate the large quantity of entities that need to be processed by the model.

One of the main objectives is to measure the benefits of multi-mode operations. This is performed by simulating the combined modes and comparing these results to the results obtained by running OTR and intermodal modes separately. The simulation model presented herein is capable of collecting information on driver concerns, customer service concerns and equipment utilization concerns.

This simulation model differs from other documented models because it explicitly differentiates between local, regional and over-the-road fleets. It also considers the tractor (power) as a separate entity than the trailer. Idle trailers are staged in trailer pools available for use whenever needed.

The next chapter considers a broad literature review on the published articles and documented research on the different modes of transportation, focusing especially on intermodal transportation. Chapter 3 describes the simulation model and the methodology for this research project. Chapter 4 presents the statistical analysis results. Chapter 5 provides the conclusions drawn from this research project.

# Chapter 2

# Literature Review

## 2.1 Introduction

Holcomb and Jennings (1995) offer several definitions for intermodal transportation. The first, taken from the 1987 National Council of Public Works Improvements, is "the movement of goods and/or people by two or more modes of transportation between specific origins and destinations." The authors also explain that intermodal freight transportation is often associated with only trailer-on-flatcar (TOFC) or container-on-flatcar (COFC). They feel that the definition should be expanded to include not only a transfer from one mode of transportation to another but also from one type of containing device to another. The words piggyback, COFC and TOFC are often used when the intermodal system includes a rail component. It may be useful to define these terms at this point. COFC, container-on-flatcar and TOFC, trailer-on-flatcar, describe the method of containing the freight as it is moved by rail. COFC unlike TOFC does not have a highway chassis. Piggyback is a term to define the double stacking of two containers without a chassis onto a flatcar. Holcomb and Jennings describe the most appropriate definition of intermodalism as "a logistically linked movement using two or more modes of transportation." In this way, the term intermodal transportation includes services provided to small companies who would not ordinarily use intermodal transportation due to the size of shipments.

Taylor (1993) explains that intermodal transportation will have to provide the best customer service as well as charge the lowest possible price. Intermodalism will have to appear to be 'seamless' when transferring between modes of transportation. Container standardization and infrastructure improvements are needed to make intermodalism a greater success.

Minahan (1998) suggests two changes that intermodal companies are making to improve their growth rate. The first is providing an express and time-defined service. The second is providing customers with more information on the location of their freight. Automatic Equipment Identification (AEI), Electronic Data Interchange (EDI) and the Internet are allowing this information to be passed on to the customer.

T. J. Pasqualini, director of distribution services for Sweetheart Cup, suggests that intermodal pricing should be based on performance (quoted in "Everyone needs to move equipment more efficiently," 1993). Intermodal companies should also find ways of serving the short-haul market. He believes that communication between shippers, intermodal marketing companies and railroads needs to improve. Finally, he suggests that older containers and trainers be replaced. Melbin (1995) explains why this last improvement has become so essential. For several years, as the railroad industry grew, the amount of equipment remained the same. Because of this in recent years, shortage of equipment has been a problem faced by intermodal companies.

According to Muller (1998), intermodal freight companies are having to redefine the services they offer. Several companies are forming partnerships, mergers or buyouts to increase their services, while others remain small providing services that larger companies cannot provide. He also explains that intermodal providers, whatever their size, will have to "continue to identify, implement, and manage new, innovative and efficient solutions that customers will need in order to survive and prosper in a challenging business environment."

### 2.1.1 IMCs versus Rail/Truck Partnership Companies

MacDonald (1993) in his article published in "Traffic Management" explains in detail the difference between the two types of companies that provide intermodal services. The first type is known as Intermodal Marketing Companies (IMCs). These companies schedule the move from origin to destination and handle any special requests from the customer. IMCs do not usually own the equipment used to move the freight but hire other providers. The other type is trucking companies that have formed partnerships with railroad companies to provide intermodal services. In this case, the partnership owns all the equipment needed to make the move. Macdonald describes the debate on which type of company will succeed. According to the author, the answer lies in the company who is able to provide the highest quality for the lowest cost.

Richardson (1993) explains that, in order to survive, IMCs will have to be able to provide their customers with any mode of transportation or service that might be needed. Because IMCs do not own the moving equipment, it is important for them to not only meet the needs of their customers, but also meet the needs of their service providers. This will mean that commitment to improve their assets is imperative. Yeager (1993) explains that shippers have to be willing to discuss "their distribution needs, goals, and expectations" with the IMC. IMCs, on the other hand, have to respond to shippers needs and be willing to act as consultants.

Bradley (1993) describes the advantages and disadvantages of selecting an IMC as an intermodal service provider over the rail/truck partnerships. IMCs have three problems to face: a lack of available equipment, a lack of the correct equipment size, and the inability to reach middle distance and transcontinental markets. IMCs however, have certain advantages over rail/truck partnerships, which include "nationwide access to the existing intermodal system, tailor-made products for specific customers, greater knowledge of the rail system, [and] potentially higher density drayage markets."

### 2.1.2 Intermodal versus Truck

The results of a survey taken in 1994 show that shippers preferred trucking companies to intermodal companies for haul lengths less than 2,000 miles (Thomas, 1995). It also shows that shippers expected intermodal performance to increase. This survey concluded that intermodal trends are increasing and will continue to increase. According to Candler's article "Road and Rail Connections" (1994), intermodal transportation is only cost effective if the haul length is greater than 500 miles. Costs decrease further if the length of haul increases. Costs also vary depending on drayage costs. Slack (1990) explains how these savings are achieved. In a hub and spoke situation, trucks pickup and deliver shipments (spokes) in a particular area that is a load center (hub). The trucks transport this freight to and from a railway yard. This method is effective because trucks are flexible and fast enough to accumulate freight at the hub while railways can transport a larger volume of freight over a longer distance cheaper.

Plunkett (1998) developed a cost analysis that is able to select (on a profitability basis) between intermodal and over the road (OTR) modes of transportation. The factors considered that affect profit include service level of the freight, volume of the freight through a specified lane over time, length of haul, market type, redistribution of equipment, drayage needs, purchased transportation price, price breaks per equipment type, and profit margins. The project evaluates cost breakeven points and service breakeven points for over the road (only truck used for the mode of transportation) versus intermodal transportation. The project makes use of a decision support system that determines the optimal alternative out of eight possible scenarios. The scenarios are generated due to the possibility of the two modes of transportation, truck or intermodal, two return methods, loop or next dispatch, and two different industries, truckload or less than truckload. The model calculates a threshold for the length of haul above which intermodal transportation should be used; otherwise, truck should be used.

Some shippers are skeptical that intermodal transportation provides the same level of quality as trucking in respect to avoiding damage. Companies providing intermodal services are struggling to convince shippers that rail provides the same quality service as trucks. An article published in the "Railway Age" ("The proof is in the payout", 1991) describes an experiment that was performed to determine if there was a difference in the vibrations of different intermodal transportation methods and trucking transportation method. The results showed that the environments for rail and for truck were the same.

### 2.1.3 Optimal Size of an Intermodal Terminal

Howard (1983) debates the optimal size of an intermodal terminal. He explains that many believe that large terminals achieve economies of scale. In practice however, it is noted that larger terminals have a greater initial cost and still have a greater operational cost on a per unit basis than smaller terminals. According to Howard, there are two main terminal costs: handling costs and joint costs. Handling costs consist of handling staff wages, maintenance staff wages, outside contractors, fuel and power, depreciation and rent of additional equipment. Joint costs, on the other hand, consist of salaries (administration, management, and staff), establishment costs and terminal infrastructure maintenance and depreciation. Economies of scale are not achieved mainly because larger terminals require large wide-span cranes that are more expensive to construct and operate but do not increase throughput proportionally. Small terminals have the advantage of being able to use existing rail infrastructure, roadways and rail sidings. Because they are small, they are also able to be more sensitive to customer needs, which is important in this competitive market. Howard concludes that small to medium terminals tend to be more cost efficient and provide a higher level of service.

### 2.1.4 Government Involvement in Intermodal Transportation

The Intermodal Surface Transportation Act of 1991 (ISTEA) was enacted because the government recognized the need to move from modal to intermodal systems. From the ISTEA, the National Foundation on Intermodal Transportation was founded to aid in this movement to intermodal systems (Krebs, 1994). According to authors Turnquist and List (1993), congress and congressional staff should be to educate in intermodal systems. This is because the Office of Intermodalism will need the appropriate funds supported by congress. Secondly, statistical data regarding service quality to shippers needs be to collected. Krebs suggests that "federal policy should support private sector innovations, provide maximum flexibility for state and local transportation officials and not intrude unnecessarily into private sector operations." It is also important that government officials do not impose unnecessary delays on local projects.

According to an article published in *Governing* ("Delivering the goods", 1994), the individual states will have a major role in this movement to intermodal systems. States should focus on improving road and rail connections, upgrading existing roads, and improving rail and highway crossings such that overpass clearances accommodate double-stack trains. Some states are even providing financial assistance to railroads with improvements on their property.

Luberoff (1997) suggests that projects that are partially funded by the government should be analyzed in great detail. The public sector should only provide funds in proportion to public benefits and the private sector should pay the remainder. The government should therefore be responsible to determine if the project is justified.

### 2.1.5 Intermodalism in Europe

In most of Europe (Britain is the exception), railroads are still mainly owned by the government (Stone, 1998). The European Union (EU) has attempted to open up access to the railroads. So far, open access has not worked because of the fragmented operations of the European railway. This prevents rail from providing services over a wider and integrated area and limits the choice of routes. Rail, unlike truck or barge, has not responded to deregulation. Stone explains that for intermodal operations to survive in Europe, all EU members must react to deregulation. He suggests that the EU uses stricter laws against monopoly, which in turn will promote competition. The creation of third parties or intermodal marketing companies and a significant reduction in costs will help intermodal transportation to succeed in Europe.

An article published in the Railway Gazette International claims that the intermodal growth rate in Germany has been consistently high and forecasts show that it will continue to grow (Kracke et al., 1995). However, for short hauls, trucking is more cost effective. This article points out that intermodal transportation in Germany is appropriate only for distances above 400 km, assuming the train is direct, and cost effective (only cost effective if the traffic between the two points is large and regular). This limits the routes to those connecting major industrial centers.

Muller (1997) describes the planning activities for setting up an intermodal terminal in Germany. He points out that the terminal will need to improve customer service, should be easily expandable to accommodate for growth, have low handling costs and be easily accessed by rail or road.

## 2.2 Simulation Models

Many researchers use simulation models to analyze transportation systems. These models can be used to design future systems or to analyze changes in current systems. This section will review both general simulation models for the transportation industry and models created for a particular company or mode of transportation.

Hammesfahr and Clayton (1986) describe a basic intermodal simulation model using the simulation language Queuing-Graphical Evaluation and Review Techniques (Q-GERT) that allows managers to analyze their terminals. This intermodal model can be used to simulate terminals that transfer freight between rail and truck, rail and ship, and truck and ship. Train schedules, shipping schedules, yard switching rules, siding operations and working rules, container parking-lot activities and over-the-road traffic patterns are all taken into consideration in this model. The capability of a particular terminal is given by switching times, container onloading and offloading times, parking-lot processing times and maximum capacities of sidings and parking lots, which are entered into the program as input data. The model's output includes capacities of the system's flatcars and containers, throughput of ships, flatcars, tractors, and containers through the system, average number of units in the system, operating efficiency and expected costs. This model is appropriate to determine the effects of changing schedules, capacities or service times. It is especially helpful in determining parking lot requirements, the effects of changing ship and/or rail transfer systems, equipment capacities, employee requirements, new facility evaluations, and the effects of increasing terminal traffic. An advantage of using Q-GERT is its ability to produce graphical representation of the network that can easily be understood by upper management that have no experience in simulation.

Another general-purpose simulation model, known as TRANSMODE, was developed specifically for the intermodal transportation industry (Kondratowicz, 1990). This model allows any transportation model or group of interconnected terminals to be simulated. The functions of the simulation model can be divided into five main categories: terminal resources, storage facilities, cargoes, means of transportation and rules of system functioning. Two algorithms are performed. The first simulates the arrival and departure of freight and the overall terminal operations. The second controls the simulation process as a whole. The unique element of this model is its ability to treat data and control logic as distinct parts of the system. This means that in order to analyze different scenarios, the only change necessary is the modification of the input data supplied in a specific format.

Mazzucchelli et al. (1996) describe an application model for the simulation of an interport. An interport is described as a node where freight is transferred from one mode of transportation to another. The model focuses on the Displacement and Stocking Service module (DSS) which is divided into two processes: Means Process Set (MPS) and Freight Process Set (FPS). The MPS models the transfer of freight between transportation modes using DSS resources. FPS describes the behavior of freight at the interport. The application model provides both static and dynamic information. This information is transferred to two databases, which are used to determine an event scheduler, two state (static and dynamic) transition function modules, and a resource scheduler. This new information can finally be transferred to an output interface.

There have been several papers published that use simulation models for specific terminal types. These papers will now be considered. There are also several papers that illustrate simulation models for non-intermodal operations. These projects will also be considered in this section.

### 2.2.1 Intermodal Rail-Truck Terminals

Golden and Wood (1983) describe a simulation that models an intermodal terminal. This model focuses on the transfer of trailers or containers between trucks and trains and vice versa. Trailers-on-flatcar (TOFC) are considered to be used in the rail transportation part of the intermodal move. The model is used to evaluate the productivity of different configurations of terminals. The simulation creates files that can be input into a program report generator. This generated report will provide the user with statistical information on the terminal's productivity. A highly graphic output was chosen as a suitable format to represent the statistical information. The simulation model was run on Pennsylvania Truck Lines. Once the model was tested on current train schedules, different train schedules were used to evaluate performance.

Ferreira and Signut (1993) describe a simulation that models loading and unloading of containers at an intermodal terminal. The following statistics are noted: mean loading and unloading times per container, mean and maximum container queue lengths, and handling equipment utilization. The objective of this project is to reduce costs and improve customer service. Two types of loading and unloading methods are considered: random access and the use of skeletal trailers. Random access is when customers are able to pick up or deliver containers directly at a train or storage area (method often used in Australia and Europe). Skeletal trailers are dedicated fleet trailers that are used to transport containers from a train to a storage area ready for pick-up by the customer (method often used in North America). This method avoids double handling of containers (assumed to be because customers can use the dedicated trailers, but not clearly specified in the paper), increases track productivity (faster loading and unloading), and increases customer service (customers use the dedicated trailer storage area instead of the train loading and unloading area). However, this system requires a higher capital cost of maintaining a dedicated fleet and provide the storage place for this fleet.

In another article published in "Road and Transport Research", Ferreira and Sigut (1995) describe a simulation model that considers two types of intermodal terminals. Customer service and operational efficiency are used to compare the two types of terminals. The first type of terminal is a conventional facility that transfers containers between rail and truck. The second type is a RoadRailer terminal. A RoadRailer is a trailer that can be transported as easily on rail as on the road. The main difference between this technology and the convention trailer-on-flatcar is that a RoadRailer does not need to be carried on a railway wagon. The more sophisticated models of RoadRailers use a pneumatic suspension system to switch from road to rail and vice versa. The simulation shows that RoadRailers take more time to load than containers. However, the equipment cost for RoadRailer terminals is lower than that for conventional container terminals. It is important to note that the authors do not consider the initial cost of equipment.

Boese (1983) describes a simulation model used to test new intermodal terminal designs. The simulation controls single movements and actions of the intermodal equipment. The dispatching sequence, that depend on train and truck arrivals, focuses on maximizing equipment productivity and minimize truck waiting time. The objective of the simulation model is to not only provide alternative layout and equipment configurations, but also to determine the effects on throughput, equipment productivity and service levels. The model assumes that arrivals for trucks are random, while arrivals for trains follow a Poisson distribution associated to the train schedule. Boese points out that an intermodal terminal should not be treated as a separate system, but should be analyzed with the railway network.

Weigel (1994) describes a simulation model used by Union Pacific Railroads that determines capacity estimates by considering the effects train schedules, facility design and equipment availability have on performance. The discrete event simulation model of an intermodal terminal is written in SIMAN and can be animated using CINEMA. The output provides statistics on track utilization, parking requirements and train schedule performance. Equipment utilization statistics are provided hourly and daily. The train schedule performance factors include: train arrival time versus train placement, actual load grounding versus planned grounding, and outbound cut-off time to train departure. The author explains that in order to modify the model to simulate another terminal, the following information is needed: layout of the facility, equipment quantities, processing times and local operating practices.

Conrail uses simulation to analyze different scenarios at intermodal terminals (Sarosky and Wilcox, 1994). Conrail in conjunction with Vickerman Zachary Miller consultants has developed a simulation model using SLAMSYSTEM that uses two types of information: train schedule information and operational information. The train schedule information determines the size and composition of trains, the arrival times of inbound trains, and the creation of outbound trains. The operational information determines the unloading, loading and gate processes. The gate process simulates the delivery and pick up of freight by drayage trucks. This simulation model generates output in table and graphical format and can also be animated. The statistical output that the model can produce includes loading and unloading times, the number of units in parking, capacity requirements information, bottleneck information, and utilization of workers and equipment. Conrail has used this model to determine the feasibility of consolidating two intermodal terminals in Chicago. The model results conclude that without acquiring additional land, the consolidated terminal would not have the necessary capacity. Because of this, Conrail chose to upgrade the two terminals instead of combining the terminals. It was expected that the simulation model would continue to be used in the planning of the improved terminals.

Meinert et al. (1998) developed a similar simulation model that can be used to analyze rail-truck intermodal terminals. This model takes into consideration the design and operation of the terminal, integrating both the rail facilities and truck networks. Multiple terminals can be simulated concurrently. A case study was performed to analyze the addition of an intermodal terminal in the Chicago area using data supplied by Burlington Northern/Santa Fe (BNSF). The model was used to determine a suitable location for the new terminal. The new terminal was assumed identical in design to a currently used terminal in Willow Springs because it is a state-of-the-art facility. Experimentation on historical data was performed to determine the re-routing of loads to the new facility. Sensitivity analysis was also performed by changing the distributions of the load routings. The simulation model is capable of analyzing rail yard size, intra-yard handling capacity, yard design considerations, and demand distributions.

### 2.2.2 Intermodal Rail-Ship Terminals

The demand on container intermodal terminals has increased due to the advances in technology in containerization. It would make intermodal terminals more efficient if simultaneous unloading and loading between ships and trains could be achieved (Vickerman, 1993). Vickerman Zackary Miller (VZM) performed a study to analyze this option. In the past, this option has failed due to the complexity of the loading and unloading operations. A simulation model was created to analyze a situation were a critical number of containers was to be assembled after being unloaded from a ship in such a way that they can be randomly accessed for loading onto a train. The same process is used to transfer freight from a train to a ship. The output showed that land use was more efficient, equipment utilization increased, and double handling was eliminated. Industry was consulted to determine the feasibility of operations. Representatives agreed that the process was technically feasible but would require the use of Electronic Data Interchange to ensure that there is an interface between ship and railroad operations.

Fuller et al. (1983) have developed a simulation model for an export grain port terminal. Simulation was chosen over mathematical analysis because the system was stochastic in nature and contained interactive elements. The model is divided into three categories. The rail logistics system simulates the transportation of grain by rail from inland to the port. The port elevator simulates the unloading from the train, the storage, and the loading of grain onto a ship. Finally, the ship logistics system simulates the ship movements and departure. The model was used to determine the effects of increasing freight volume through a port terminal on congestion costs and utilization of terminal capacity. It was also used to determine ways to decrease congestion.

Simulation was used extensively in the planning of a port at Roberts Bank in Delta, British Columbia (Ward, 1995). The port was being developed by the Vancouver Port Corporation. The port terminal was designed to have two berths for container ships, and an on-dock intermodal rail yard containing four tracks and having a 44 double stack rail car capacity. The simulation can be used to resolve three major issues. The first is determining throughput and storage demand. The Terminal Inventory Simulation Program was used for this analysis. The program requires the following information: ship and train schedules, storage dwell times, work sequences and the terminal operating schedule. The second issue, analyzed using the GENTRY generic gate simulation model, determines the size and layout of the gate. This model uses gate layout, truck arrival patterns, truck processing times and worker schedules. The final issue to resolve is the determination of the method of container handling. In this case, the General Marine Terminal Simulation is used to evaluate terminal operations. It was noted that by using simulation the designers for the port were able to create a well-balanced design and allocate resources efficiently.

Pope et al. (1995) describe a simulation model that was used to determine the effects that road congestion have on port terminals. The model is focused on the Hampton Roads Area in Virginia. Again, a discrete-event simulation was chosen over linear programming because the problem was stochastic in nature and was very complicated. The simulation language Q-GERT was used. The model had two main objectives. The first was to determine the effects of increasing congestion in the area. A second objective was to evaluate the consequences of adding a unit train on congestion. The authors felt that simulation modeling was more time consuming and expensive than they had originally expected. However, they believe that if simulation is used on a macroscopic level, it is an effective planning tool.

### 2.2.3 Railway Transportation Systems

Dessouky and Leachman (1995) describe a model that simulates the motion of trains. The model's objective is to determine a track configuration that minimizes congestion. Certain factors are considered in this model, including single and double track lines, merging of rail lines, passing tracks (known as sidings), and arrivals and departures from railway terminals. SLAM II was the simulation language used due to the fact that a generic model could be created that could be easily changed to evaluate different scenarios. Two separate models were simulated: a single-track network and a double-track network. Changes in the network size or in the track configuration can be modeled by changing the input files since these values are not hard wired into the system. The disadvantage of this model is the fact that to obtain a more accurate representation of the system, decomposition of the track into smaller segments is needed. The problem is that run times tend to increase without a significant difference in accuracy. Transportation engineers need to be consulted to determine the appropriate size of a track segment. The simulation model was tested on the San Pedro Bay Ports. The results show that the model is effective in comparing train delays of different scenarios.

A model was developed that simulates a marshalling yard in a railway network (Klima and Kavicka, 1996). A marshalling yard contains expensive equipment and performs involved operations. Because of this, optimal configuration and control procedures are needed. It is noted in this article that the model needs to perform certain functions: the simulation of different yard configurations, the evaluation of various procedures and control strategies, the ability to modify service resources, the ability to modify the model to reflect changes in the environment, the provision of graphical output results including animation, the ability to provide information about the state of the system, and the generation of post-simulation statistics. The model is divided into stable, mobile and control subsystems. The stable subsystem models the infrastructure of the marshalling yard, the mobile subsystem controls elements that change locations during the simulation (example trains), while the control subsystem controls dispatching decision making and technological procedures. The user of the model is given the option of planning activities before the simulation is run. These activities include interruption, termination or taking snapshots of the system's state. The unique property of this model is its ability to identify several problems and propose a solution. The simulation model output includes post-run statistics and utilization of servers.

The Association of American Railroads has developed three simulation models that can be used to analyze vehicle/track performance standards: the Train Energy model (TEM), the Train Operation and Energy Model (TOES), and NUCARS (Singh and Handal, 1995). The first model, TEM, can predict fuel consumption for trains. TEM can be used to analyze future motive power options. TOES, on the other hand, simulates "the effects of train handling, track profile, train makeup, and various rolling stock and braking equipment on longitudinal forces, safety of operation, and overall train response." The NUCARS model is capable of simulating vehicle/track systems. This model can be used to predict non-linear interaction and creep forces caused by specific wheel and rail shape combinations. These models have proven to be effective analyzing tools that reduce and focus field-testing.

## 2.3 Algorithm and Network Models Used to Evaluate Intermodal Systems

Several researchers chose to use algorithm or network models to analyze transportation systems instead of using simulation. Several of these attempt to minimize cost as a way of improving the system. Others attempt to find an optimum way of utilizing equipment.

### 2.3.1 Cost Analysis

Crainic and Rousseu (1986) developed an algorithm to be used at a medium-term planning level to design a multicommodity, multimode transportation network, establish routings and determine terminal policies. The model is an optimization tool to determine the best system having the least operating costs and delays and the highest performance. The algorithm is an iterative process, which does not guarantee obtaining an optimal solution but is able to provide significant improvements to the original system. It has been noted that when the initial model used is a good solution, the algorithm results show a notable reduction in system performance measures. On the other hand, if the initial model is not a very good solution, the results are not as significant. A large amount of data is needed to calibrate and use the model. The information needed includes operating costs, delay costs, operating characteristics of the system and the congestion function for the system. The authors have found the model to be an effective tool for improving the planning process of a freight transportation system.

One way of improving an intermodal system is to minimize costs. Barnhart and Ratliff (1993) define intermodal costs to be composed of transportation costs, including drayage costs and line haul rail costs, and inventory costs. The authors explain that the ability to determine the least cost routing enables shippers to lower their transportation cost and intermodal providers to develop more competitive pricing. Three network algorithms are described. For small shipments charged on a per trailer basis, a shortest path algorithm is an efficient tool. A network is developed by defining the origin and destination points, terminals, and method of transportation (piggyback, direct truck, drayage). Transportation and inventory costs are assigned to each feasible method of transporting the freight from origin to the destination. The least costly would be the optimum method. For larger shipments, a matching network is more suitable. In this case pairs of trailers are matched and are moved using a piggyback method of rail transportation. The network considering schedule requirements and flatcar configurations is used to determine a minimum weight matching that represents a minimum cost solution. The b-matching network goes a step further and takes into consideration that each pair of the matched trailers will have the same optimal transportation method. These algorithms can quickly solve large problems on small computers.

Nozick and Morlock (1997) also developed a model that minimizes cost. The model was designed for medium-term operations planning for the railroad part of an intermodal system. The railroad begins and ends at an intermodal terminal. Freight transported in trailers or containers are retrieved for a pool at the terminal. Once the freight has been transported to the destination terminal, either directly or stopping at terminals along the way, a drayage company delivers the freight using trucks. The model uses a mathematical program that determines the sequence of aggregate feasible moves that will result in minimize the cost. It takes into consideration the configuration of the train schedules, the level of service, and equipment, fleet size and terminal capacity constraints.

Yan et al. (1995) developed a model that takes into consideration the opportunity costs of an intermodal process. It was noted from their research that opportunity cost has an effect on the determination of pricing strategies. The opportunity cost deals with the potential value that each trailer or flatcar has at each station at a particular time due to its ability to serve other loads and produce a profit. The total cost used in this model is comprised of the cost of using the railroad lane, the opportunity cost at the original terminal, and the congestion costs. The benefit of adding a trailer to the destination terminal now needs to be subtracted from this cost. An algorithm was used to approximate the reduced costs by combining the use of Lagrangian Relaxation with a minimum cost flow algorithm and a shortest path algorithm. A risk pricing approach was used to handle the instability of the opportunity costs. The model can be used to determine the efficiency of the system operations, evaluate past and current operations, and develop tactical plans for the future by reducing costs.

### 2.3.2 Linear Programs and Network Models

Dial (1994) developed a model for United Parcel Service (UPS) that determines the minimum cost of transporting freight via railroad. The model considers the option of using the shipper's trailers or renting a trailer from the railroad. A combination of an integer linear program and a network flow problem was used. The particular requirements taken into consideration include the need to bound certain trailer flows (limit the number of rented and company owned trailers on a particular route), the determination of an optimal solution, the consideration of exogenous trailer flows, and the ability to operate in the time dimension. The model has proven to be effective and fast.

Feo and Gonzalez-Velarde (1995) developed a linear program that determines the optimal process for trailer assignments. The main objective is to maximize the percentage of loaded trailers over the total number of trailers moved. This is an important consideration because unloaded trailers can cost as much as loaded trailers but produce no profit. Three different scenarios are considered. The first assumes that unlimited switches are allowed. This means that railcars can be repositioned such that empty railcars can be removed or railcars can be reorganized in such a way that those having the same destination are grouped together (a group of railcars having the same destination is known as a block). The second and third scenario consider a system where switching is not allowed. In these cases, railcars are not repositioned and only railcars at the end can be removed. This is defined as a cut-and-pull system. The second scenario is a series cut-and-pull system. Only railcars on a single track are considered at one time. Railcars are ordered from the front of the first track to the last car on that track, before the next track is considered. The third scenario is a parallel cut-and-pull system where several tracks are considered at one time. A linear program relaxation technique was used to solve this problem because of its ability to find an optimal solution in a reasonable amount of time. The Greedy Randomized Adaptive Search Procedure (GRASP) was used as a heuristic methodology so that a good solution could be obtained very quickly. This method first assigns the most difficult to use railcar with the most difficult to assign trailers. Once less compatible equipment are used, greater options are available for later use. The experimentation with this model shows that optimal solutions are achieved.

Powell et al (1998) explain that there is one major problem with the previous model; it does not take into consideration the destination terminal. Because of the fact that there are usually different types of trailers available for use, it is important to determine the optimal selection of trailers considering both the current and destination terminal needs. The authors therefore developed a logistics queuing network that can handle such a variety of equipment and can incorporate complex operating rules. The model provides local decision-makers with the information that is needed in selecting an alternative. The model also allows the system to be updated once the decision is made. This is important in order to have a robust system. It has been noted that the model is especially useful when the railroad is having problems meeting target deliveries because it gives the local decision-makers the tools needed to solve these problems.

## 2.4 The Effect of Drayage Companies on Intermodal Transportation

The word drayage comes from the earliest movement of freight when loads were transported using wagons and dray horses (Morlock and Spasovic, 1994). Drayage is the movement of freight from the rail terminal to the receiver and from a shipper to the rail terminal. In an intermodal move involving rail and truck, a drayage company moves a load from a shipper to a rail terminal. A railroad company then transports the load to its destination terminal where a drayage company again picks up the load to deliver it to the receiver. Drayage is the part of an intermodal move that is closest to the customers.

Because of this, drayage companies unlike railway companies develop a personal relationship with their clients.

An article documented in "Transportation and Distribution" (Richardson, 1994) describes several of the problems faced by drayage companies. Many of the inefficiencies are caused by poor communications between drayage companies and the other companies involved in an intermodal system which include railway companies and intermodal marketing companies (IMCs). Drayage companies have no control over the equipment at terminals, which usually means that repositioning is necessary when delivering a load to the rail terminal. Delays at rail terminals are another problem that drayage companies encounter. Congestion is the source of this problem and is often caused by the understaffing of terminals during peak periods, the failure to remove problem trucks out of the line to keep the line moving, or the closing of gates due to breaks. Another reason for delays is that equipment is released before it is inspected for roadworthiness. When breakdowns do occur, trucks have to wait for repairs; this makes the loads late. This article suggests that drayage companies report problems more promptly. It also proposes that in order to help communications, the truck drivers may need cellular telephones to communicate breakdowns and the drayage companies may want to improve their on-board and in-the-office communication systems. Finally, it is suggested that it may be advantageous for drayage companies to merge with intermodal marketing companies.

Morlock and Spasovic (1994) describe a research project that was performed to find ways of reducing drayage cost using a mathematical model. It is noted that although drayage is only a small portion of the distance moved, it accounts for a relatively high fraction of the cost. One of the reasons for the high drayage costs is that often empty trailers have to be returned to the terminal in a certain time period. One method of reducing these empty miles is for the drayage companies to schedule deliveries at the same time that loads need to be picked up from the same area. The research shows that central planning can increase efficiency and reduce costs. The central planning should include the scheduling of delivery and pick up of loads and the repositioning of trailers from consignees to shippers. The results show that substantial cost reductions associated with drayage operations are possible.

Nierat (1997) in an article published in "Transportation Research" describe factors that have an effect on intermodal transportation. Two main performance factors have an effect on the optimization of the drayage portion of the intermodal move: the number of operations per driver per day and the distance traveled empty per driver per day. These factors impact the optimal size of the terminal market area. Analysis shows that a higher empty haul rate leads to a smaller area serviced by the drayage company. On the other hand, as the number of operations per day increases, the market area increases. Lighter loads, unbalanced traffic and longer haul lengths make intermodal transportation more cost efficient than just truck transportation.

## 2.5 Conclusions

In summary, it can be seen that there is a vast amount of research focused on intermodal terminals that uses simulation models. The different research projects cover the following areas: the modeling of activities at a terminal, determination of terminal capacities, determination of the effects of changes in operative characteristics, simulation of loading and unloading activities between truck and rail, comparisons of types of terminals, analysis of different terminal designs, feasibility of the addition of a terminal, determination of feasible future locations for terminals, and determination of throughput and storage demands. Simulation is also used to analyze railway transportation. A model was used to determine track and terminal configurations that minimized congestion. Other models used simulation to determine train fuel consumption and the effects of stress on railway equipment.

Several research projects opted for a non-simulation approach and used mathematical models, network models and algorithm procedures instead. Cost analyses were performed to determine ways to increase profitability on both intermodal services and drayage services. One project even considered opportunity costs of an intermodal process. The process of trailer assignments and the determination of a particular type of trailer to use have also been documented.

This project will focus on determining synergies between truckload and intermodal transportation. Plunkett (1998) has touched on this topic by developing a mathematical formulation of the model. However, with the help of simulation tools, this project, will analyze the problem on a larger scale and in more detail. It is also noted that none of the previous research separates the tractor from the trailer when analyzing truck or intermodal operations. Another difference in this project is the division of fleets into local, regional and over-the-road. In addition, no research was found specifically addressing intermodal/OTR synergies on a national scale, which will be the focus of this project.

# Chapter 3

# Research Methodology

SIMNET II is chosen as the modeling tool. This discrete simulation language is written in FORTRAN (Taha, 1992). The structure of the language uses four different nodes connected by branches. The four nodes are sources that create entities (objects of interest), queues that allow waiting to occur, facilities that permit a service to be completed and auxiliaries that are infinite capacity facilities. Branches can be used to make special assignments. It is possible to use read and write files with this simulation language making it easy to read in data sets and write data to an output file. The model in this research project uses the READ assignment to read in the data set on load and trailer information. SIMNET II default output includes statistical data on queue and facility nodes and global variables. User defined variables can be requested as observation based, time based, or run end outputs.

## 3.1 Description of Simulation Model

Three types of entities are considered in this model: driver/tractor, load and trailer entities. The driver and tractor are considered as one type of entity because it is assumed that a driver will always have a tractor. Each of these entities contains attributes holding the specific information that defines that entity. Table 3.1 described the attributes for each type of entity.

| Attribute | Driver/Tractor | Load | Trailer |
|---|---|---|---|
| 1 | Load # | Load # | Current pool #<br>0=Driving<br>1-11 pool numbers |
| 2 | Origin Latitude (rad) | Origin Latitude (rad) | |
| 3 | Origin Longitude (rad) | Origin Longitude (rad) | |
| 4 | Destination Lat<br>or Current Lat | Destination Lat (rad) | Current Lat (rad) |
| 5 | Destination Long<br>or Current Long | Destination Long (rad) | Current Long (rad) |
| 6 | Pick-up Date & Time | Pick-up Date & Time | |
| 7 | Delivery Date & Time | Delivery Date & Time | |
| 8 | Delay Times at Auxiliaries | | |
| 9 | Time Till Sleep | | |
| 10 | Next Load # | | |
| 11 | Driver Type<br>1=Local (0-75)<br>2=Regional (75-300)<br>3=OTR (300+) | Load Type<br>1=Local (0-75)<br>2=Regional (75-300)<br>3=OTR (300+) | Current Pool #<br>0=Driving<br>1-11 pool numbers |
| 12 | Trailer Status<br>0=Bobtail<br>1-11=Trailer & Pool #<br>88,99=Dummy | Trailer Status<br>0=Bobtail<br>1-11=Trailer & Pool #<br>88,99=Dummy | Trailer Status<br>0=unloaded<br>1=loading<br>2=loaded<br>3=unloaded<br>4=awaiting loading |
| 13 | | Load Status<br>1=Truck<br>2=Interm Pick-Up Dray<br>3=Interm Del Dray | |

Table 3.1: Description of Attributes

The simulation model considers only loads being transported inside the continental U.S. This area is divided into 11 separate regions each of which have a separate trailer pool. Each trailer pool (each coded as a queue in the simulation model) keeps up with the idle trailers in that region. Figure 3.1 shows a map that locates the 11 regions. The last region (11) includes all areas that are not included in the other 10 regions. These regions coincide with intermodal planning regions currently in use at J. B. Hunt Transportation, Inc. (JBHT).

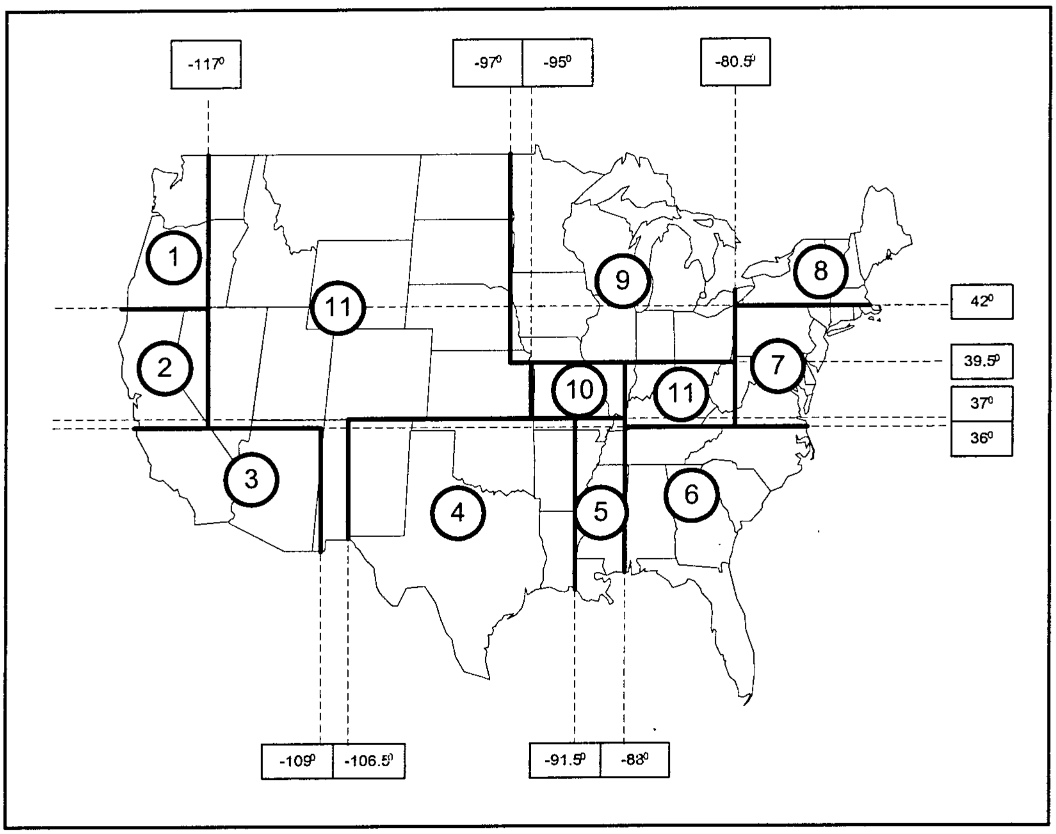


Figure 3.1: Regional Boundaries

Due to the complexity of the simulation model, the description of the model is separated into six parts. Each of these parts is discussed in the following sub-sections. A copy of the simulation model can be seen in Appendix A.

Figure 3.2 shows all the segmented queues used. The segmented queues differ from all other queues because entities do not automatically exit when a condition is met, but are manipulated out of the queue via file manipulation statements from a SIMNET II branch. The last queue in this figure (QPOOL(1-11)) is actually 11 different queues representing one trailer pool for each region.

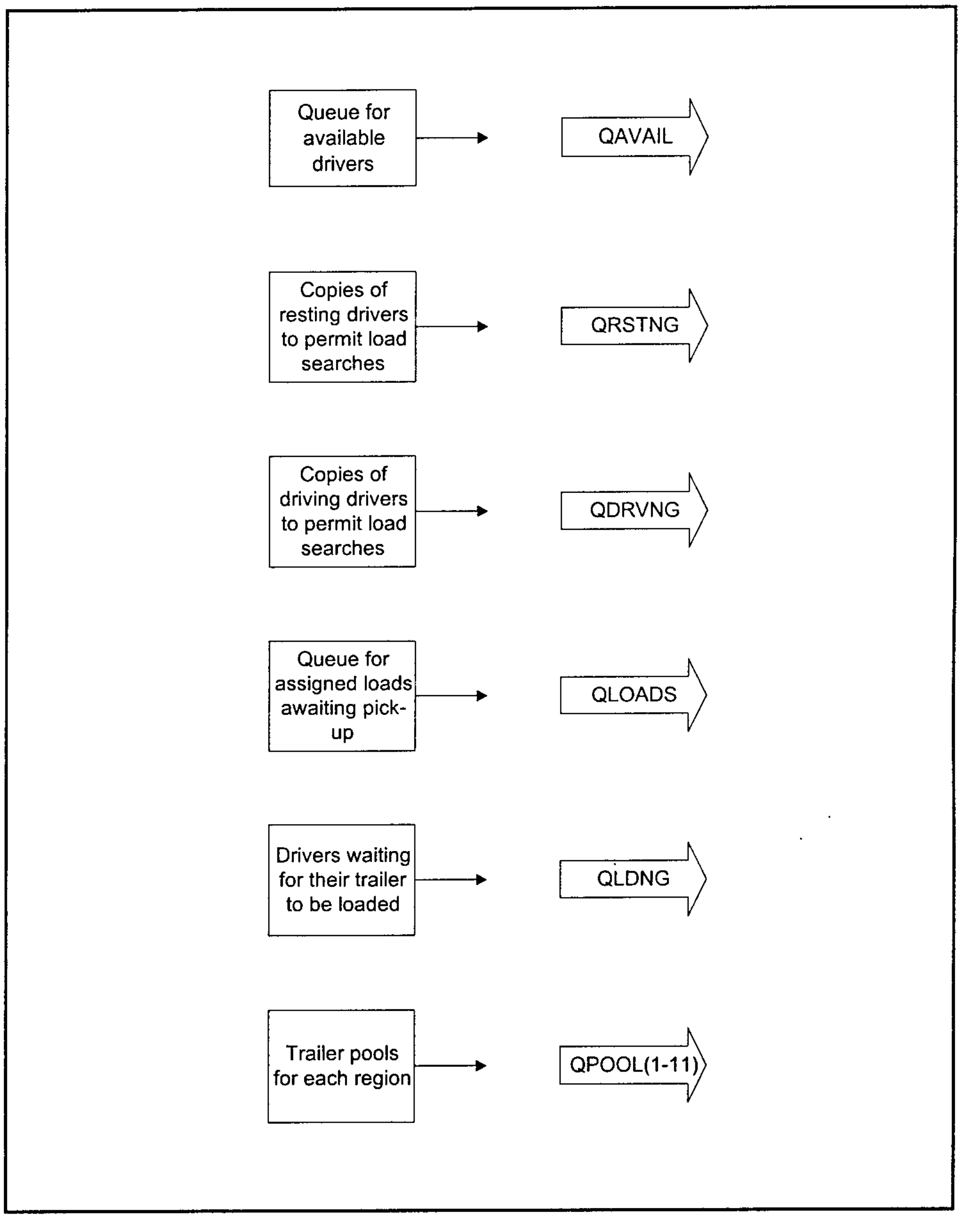


Figure 3.2: Segmented Queues

### 3.1.1 Part 1

The simulation starts by reading all the available idle trailers and placing them in the appropriate pool (refer to Figure 3.3 for the flow chart for this part). Next, loads are read in one at a time. If there are no more loads to be picked up, the simulation finishes processing any current loads already in the system and then terminates. If a load is found, the model checks to see if the pick-up time is within the next eight hours (pick-up window). If it is not, it delays the load from continuing until the pick-up time is within eight hours. Once the load is within the pick-up window, the next load is read, and the load entity continues to the next part.

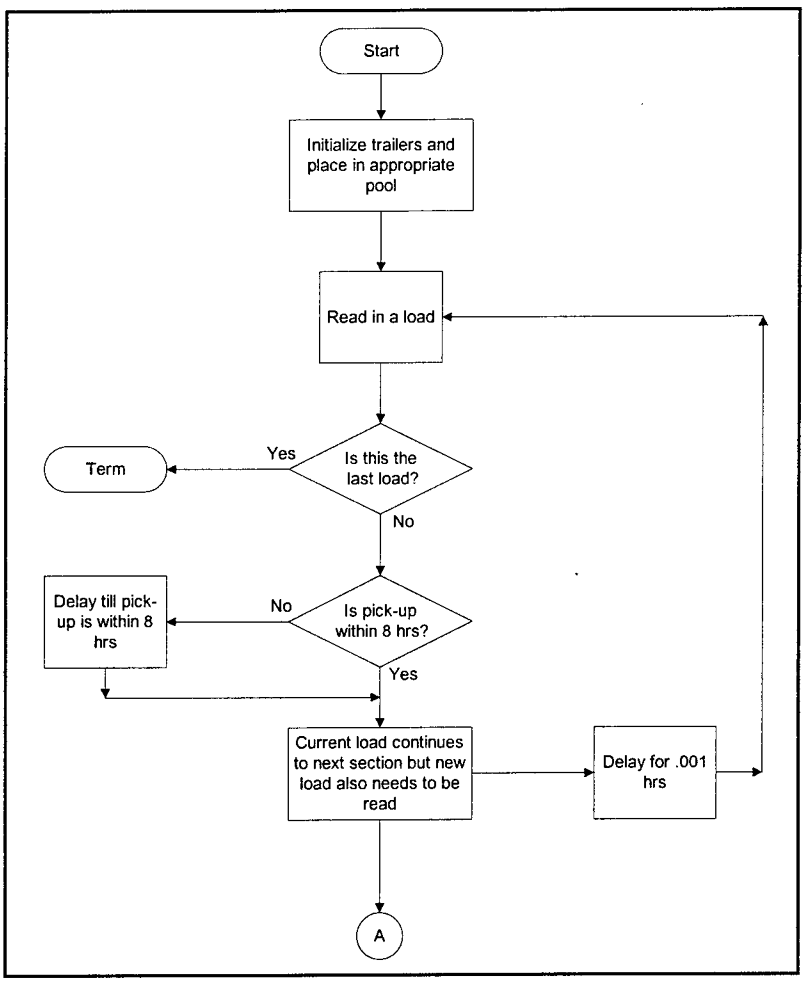


Figure 3.3: Part 1 – Initialization of trailers and loads

### 3.1.2 Part 2

The aim of Part 2 is to locate a driver to pick up this load. First, the model tries to locate a driver (available, resting or driving) that is within 50 miles of load and is of the same type (local, regional or OTR) as the load. If none is found, the allowable deadhead is increased to a larger user defined value. If still none are found and the number of drivers in the system is still below the maximum, a driver is created. If the load to be picked up is an intermodal delivery, no driver has been located, and the maximum number of drivers has reached a maximum, a driver is still created because the load has to be picked up. This is a rare event once steady state is reached. The reason for this special case is that the trucking company delivered the load to the rail yard; therefore, the same company must pick up the load at the destination rail terminal. If none of these conditions are met the load is deleted from the system because of lack of drivers. On the other hand, if a driver is located and the driver is available, the driver entity continues to the next part. If the driver found is resting or driving, the driver is notified of the next load to be picked up by placing the load number in driver attribute 10. The load entity, in the case that a driver is found, is placed in the QLOADS queue where it can wait to be picked up. Figure 3.4 show the flowchart for this part of the model.

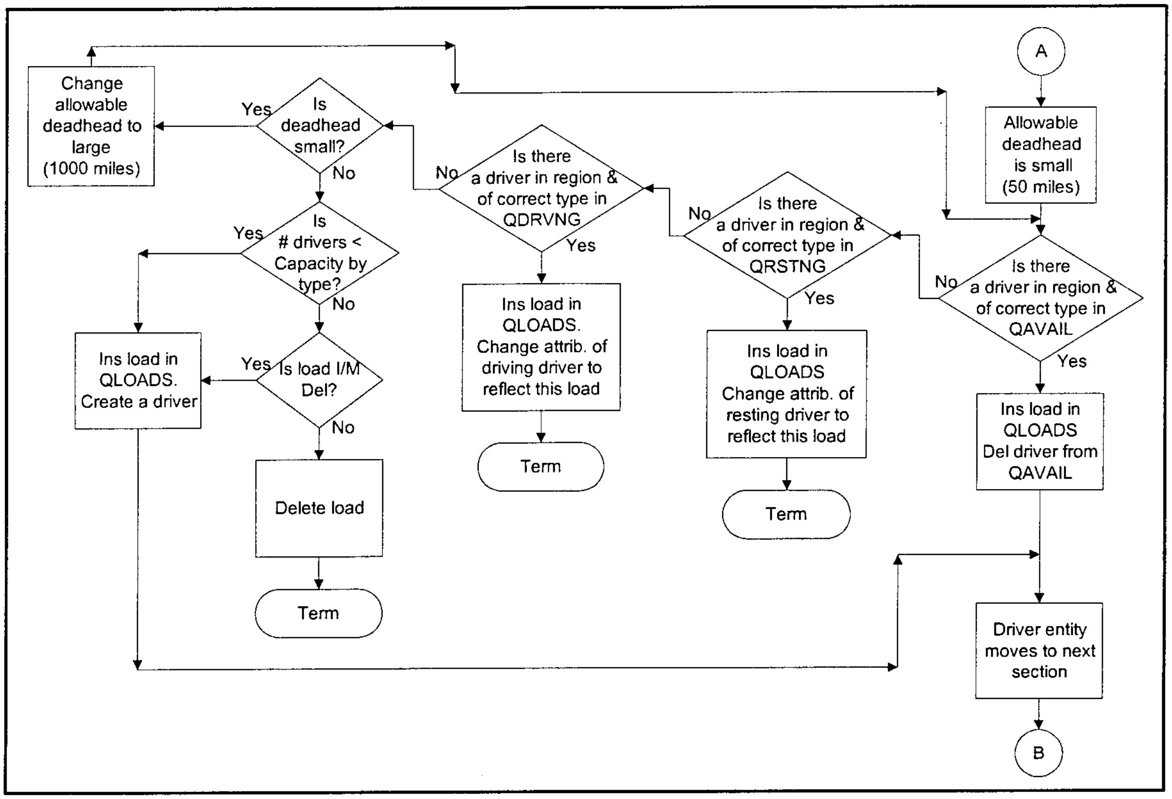


Figure 3.4: Part 2 – Locating a driver

### 3.1.3 Part 3

Once a driver has been located, the next step is to locate a trailer to carry the load (refer to Figure 3.5 for the flowchart on Part 3). If the load happens to be an intermodal delivery, the load is contained in a trailer; therefore, the driver entity skips this step and continues to the next part. If the driver has an empty trailer attached to the tractor he or she is driving, the driver entity skips the remainder of this step. If it has been determined that a trailer is needed, the closest trailer in the pool of the current region is located. In the event that the closest trailer happens to be at the load site, the model signals that the located trailer is to begin the loading process. The driver entity continues to the next section. On the other hand, if the trailer found is at a different site, the driver bobtails (travels without a trailer) to the trailer before moving to the next section. In this case, the trailer selected is deleted from the pool of idle trailers for that region. For the final instance where no trailer is found, a trailer is created at the center of the region. Again, the driver bobtails to this new trailer and continues to the next part.

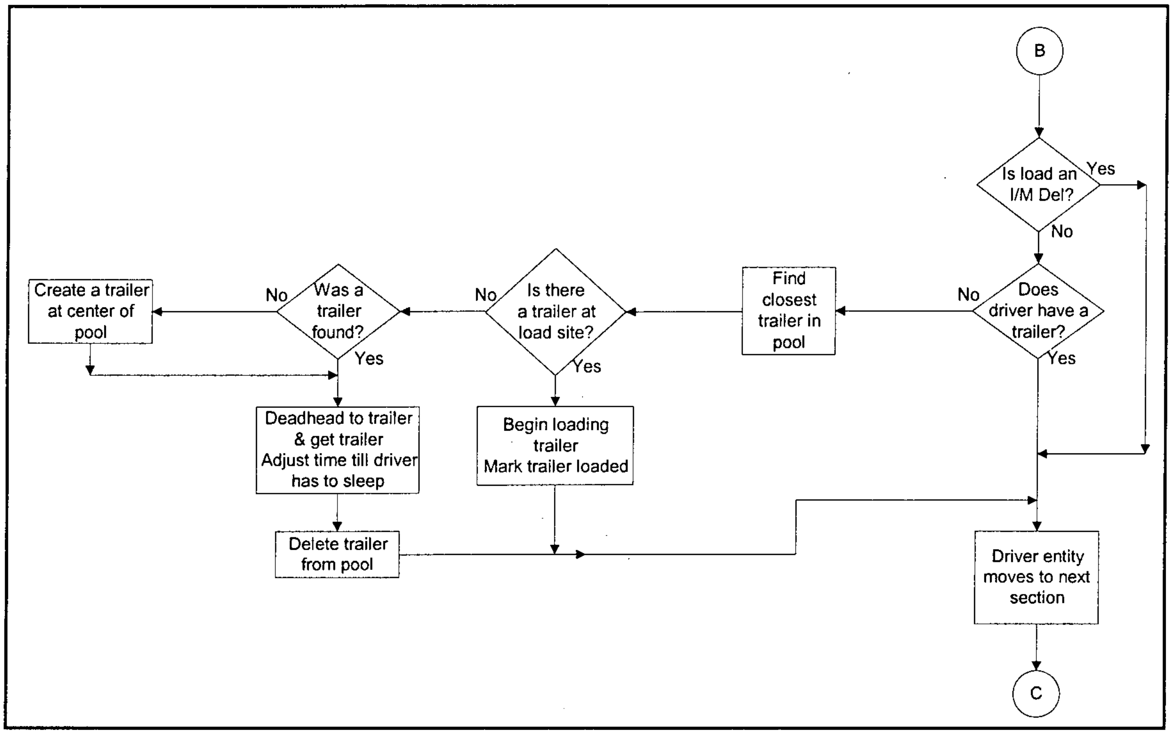


Figure 3.5: Part 3 – Locating a trailer

### 3.1.4 Part 4

The first step in Part 4 is for the driver to drive empty (deadhead) to the load. In the model driving drivers are stored in the QDRVNG queue. Figure 3.6 shows the flowchart for this section. At this point, the model needs to determine if the load to be picked up is an intermodal delivery and if the tractor is already attached to a trailer. If it is, the empty trailer is dropped off at the intermodal yard before hooking on the trailer with the load in it. If the load is not an intermodal delivery, a trailer is needed. If there is a trailer at the yard site, the driver waits until the freight has been fully loaded into the trailer before the tractor is hooked to the trailer. If the trailer is not at the yard, the loading process is now started. The trailer is deleted from the current pool of idle trailers. Once the trailer is completely loaded, it is hooked onto the tractor. The remaining time available to drive is adjusted, and the time it takes to drive the load to its destination including sleeping time is calculated. The driver/load/trailer entity progresses to the next part.

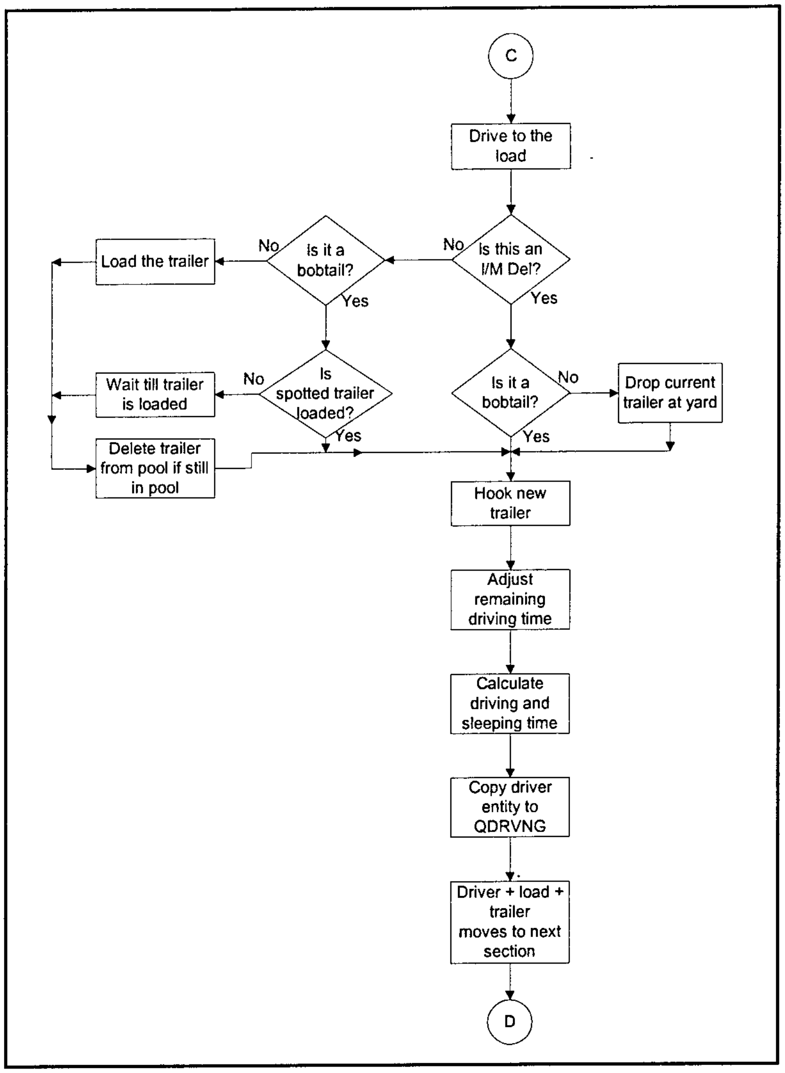


Figure 3.6: Part 4 – Dispatch driver to load and load trailer

### 3.1.5 Part 5

Once the driver has reached the destination, the model determines if the current load is an intermodal pick-up. If so, the trailer is unhooked, and the trailer is deleted from the trailer pool because the trailer is now moved by rail. If the load is not an intermodal pick-up, the model specifies a percent chance of the trailer being unloaded live. The default value for this percentage is 50%. In the case of a live unload, the trailer is unloaded as the driver waits. In the case of a non-live unload, the trailer is unhooked from the tractor. In the latter case, the trailer is unloaded later and added to the number of idle trailers in the region. The trailer retains its current position by storing these values in the trailer attributes. The driver entity at this point determines if he or she has any driving time left. If so, the next question would be whether there is another load to be picked up. If there is, the process starts over at Part 3. If the driver has no drive time remaining or there is no load to be picked up next, the driver rests (part 6). The flowchart for this section is seen in figure 3.7.

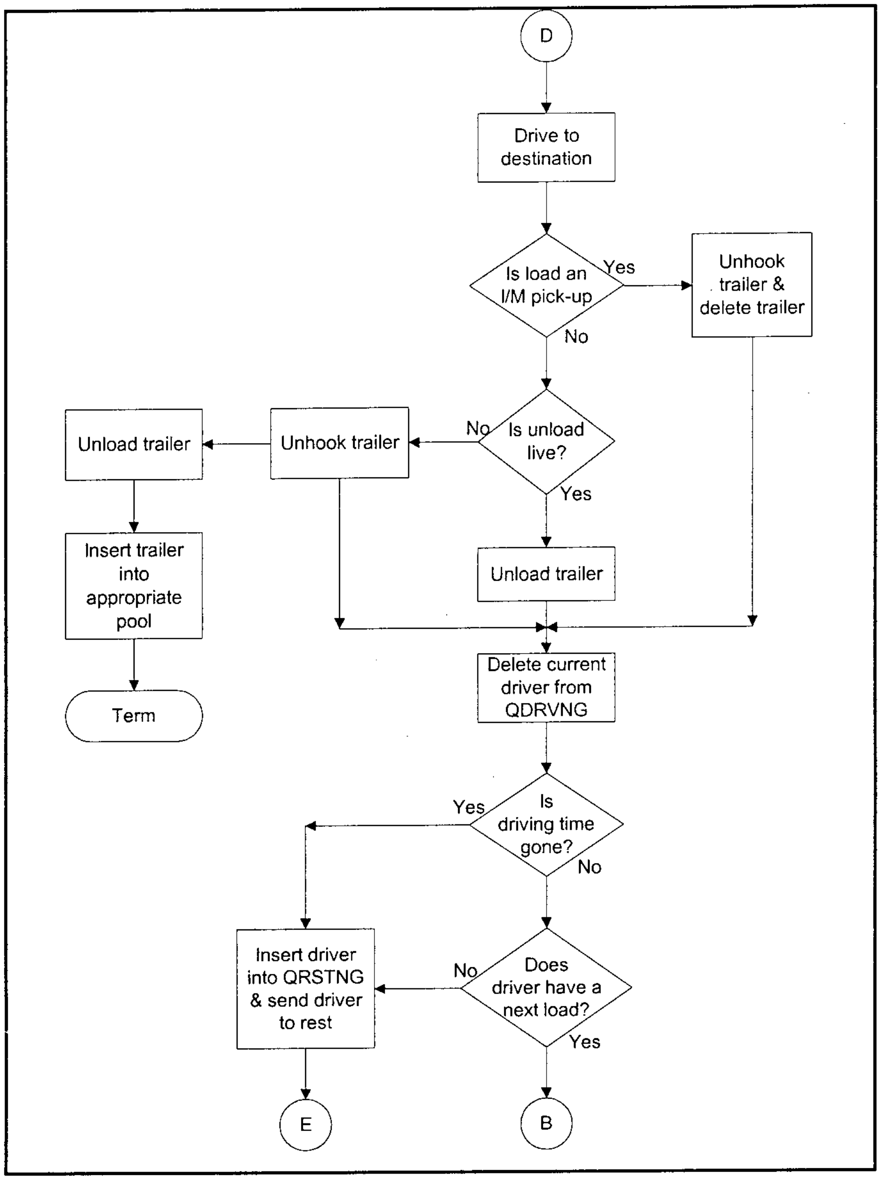


Figure 3.7: Part 5 – Drive to destination and unload trailer

### 3.1.6 Part 6

In Part 6, the driver rests for 8 hours (in the model resting drivers are stored in QRSTNG). Once this resting time is completed, the model determines whether or not there is a load to pick up. If there is, the process starts over at Part 3. If there is no load to be picked up, the driver is added to a pool of available drivers (in the model the driver entity is stored in QAVAIL). Figure 3.8 shows this last flowchart.

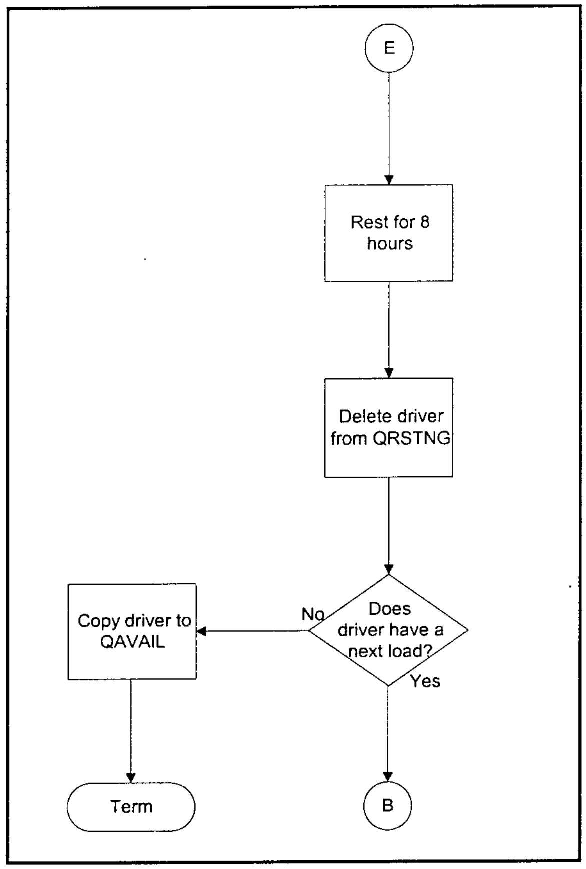


Figure 3.8: Part 6 – Driver rests

### 3.1.7 Model Assumptions

The model takes into consideration a number of assumptions throughout the simulation. The following list describes these assumptions.

- According to the Department of Transportation regulations, drivers can drive for 10 hours at a time and each 10-hour drive span should be separated by an eight-hour resting period. This regulation is taken into account in the simulation model. The 10-hour driving time includes "on duty" time while waiting for loading or unloading.

- Loads are scheduled when their pick-up time is within the next eight hours. This is included to simulate the actual notification time from customers.
- The loading time is exponentially distributed with a mean of two hours.
- The time to hook a trailer to a tractor is exponentially distributed with a mean of a quarter of an hour.
- The live unload time is exponentially distributed with a mean of two hours. On the other hand, non-live unloading has a mean of eight hours.

One of the reasons why load/unload times and the time to hook trailer to tractor is considered exponential is that interarrival and service time are usually considered exponential in queuing situations (Taha, 1997). Another reason is that J. B. Hunt Transportation, Inc. ran a study to determine the distribution for such load and unload times. This project was performed by Jeff Young (personal conference on October 1999). The results showed that the exponential distribution was a valid assumption for the load/unload times.

## 3.2 Data Required

The simulation reads data from two files. Appendix B contains a sample of these data files. The first file contains information about trailers. This data specifies the number of trailers in a specific region and their exact location. This data set includes the following attribute information for each trailer: the current latitude and longitude position, the pool number and the status of the trailer (initially the trailers will be empty and will therefore have a value of zero).

The second file contains load information. The following data is needed in this set: load ID (loads are numbered), original latitude and longitude, destination latitude and longitude, pickup and delivery times, load type (local, regional or OTR) and load status (truck, intermodal pick-up or intermodal delivery). The loads in this file are placed in order of pick-up time, with the earliest pick-up first.

The last record in each file contains zeros. This indicates that the end of the file has been reached. Drivers are initialized by the model and therefore have no file input.

Actual historical data is provided by J. B. Hunt Transportation, Inc. (JBHT). This enables the model to be tested using a real system. The JBHT data sets indicate whether the loads were originally moved via OTR or intermodal means. These data sets are modified for this project for two reasons; the first is to protect the company's information and the second is to make the simulation model tractable.

## 3.3 Scenarios

Three different scenarios are considered. The first considers all loads to be moved using OTR methods. In this case all loads are picked up and delivered to the destination point by truck. The second scenario considers the intermodal loads and the truckloads independently. In Scenario 2a, only the intermodal loads are considered. This portion of the total loads (intermodal loads) are picked up by truck and delivered to a rail yard. When the load reaches the destination rail yard terminal another truck picks up this load and transports it to its final destination. In Scenario 2b, the remaining loads that are transported solely by truck are taken into account exclusively. The results for these two parts are combined to give the final results for Scenario 2. In the last scenario, both methods will be used concurrently. This means that some of the loads will be transported using truck only and other will use both truck and rail (intermodal). Performance results should indicate any synergies that may be associated with joint use.

## 3.4 Performance Variables

Trucking companies have several concerns to consider. From the company's standpoint, it needs to be sure that the business produces a profit. However, it is also concerned about customer and driver satisfaction. Because of this a number of performance variables are considered in this model.

The output report gives the average number of miles per driver per day driven loaded and unloaded. The unloaded miles are sub-divided into miles driven to get a trailer (bobtail) and miles driven to get to the load (deadhead). The trucking company is interested in keeping the loaded miles at a maximum and the unloaded miles to a minimum, because the unloaded miles do not produce revenue. It is also important for the company to know how many drivers they need for the different driver types (local, regional and OTR). The ideal distance driven by each driver per day should be around 500 miles. Give or take a few mile, this distance is the maximum distance that a driver is able to drive in one day when conforming to the Department of Transportation's speed regulations.

From the driver's standpoint, the company needs to keep track of the average distance that drivers travel per day, because wages are based on miles driven. This information is gathered for the three different types of drivers: local, regional and OTR.

Finally, to determine how well the company is meeting customer's expectations, the average lateness per load is calculated. It is noted that this calculation includes the effect of delivering loads early. This cancels out the effect of delivering loads late. Because of this, the percentage of loads delivered late is noted. The company needs to know the loads turned down due to lack of resources. Therefore, the total number of truck loads and intermodal pick-up loads they turned down are collected. Recall that intermodal delivery loads are always picked up, so none of these types of loads will be turned down. In this project, the maximum number of drivers is specified as a large number such that the number of loads turned down is zero. The reason for this is to be able to calculate the number of drivers needed to pick up and deliver all the loads.

Table 3.2 shows the units for all these performance variables. SIMNET II output also includes other information including all queue length statistics.

| Variables | Units | Description |
| --- | --- | --- |
| MAX_OTRD | # of Drivers | The number of OTR drivers needed |
| MAX_REGN | # of Drivers | The number of regional drivers needed |
| MAX_LOCL | # of Drivers | The number of local drivers needed |
| | | |
| MI_OTRDR | Miles/Driver*Day | The average number of miles driven by OTR drivers per day |
| MI_REGDR | Miles/Driver*Day | The average number of miles driven by regional drivers per day |
| MI_LOCDR | Miles/Driver*Day | The average number of miles driven by local drivers per day |
| | | |
| BOBTAIL | Miles | The average number of miles traveled per load to get a trailer |
| DEADHEAD | Miles | The average number of miles traveled per load to get a load |
| LOADED | Miles | The average number of miles traveled loaded per load |
| | | |
| TRLD_NOT | # of Loads | The number of truck loads turned down |
| IM_NOT | # of Loads | The number of intermodal pick-up loads turned down |
| | | |
| LATE_HRS | Hours | The average number of hours that each load was delivered late |
| LATE_PCT | Percent | The percentage of loads that were delivered late |

Table 3.2: Performance Variables

## 3.5 Statistical Analysis

Before a statistical analysis can be performed, the length of the transient period needs to be calculated. This can be done by taking note of the maximum number of drivers for each type. The variable names for the three types are MAX_OTRD (maximum number of over-the-road drivers), MAX_REGN (maximum number of regional drivers), and MAX_LOCL (maximum number of local drivers). The current number of drivers for each type and the current simulation time are written to three different files every 12 hours. Steady state is reached at the time when the number of drivers reaches a maximum. Because this time might be different according to the type of driver, the largest of the three is considered as the time when steady state for the system as a whole is reached. The length of time before steady state for the system is reached is the length of the transient period.

The simulation needs to be run for several times (incorporating the transient period). Initially the model runs for 10 replications. The 95% confidence levels for the performance variables are then determined. If the confidence levels are not tight enough more runs are required.

Once the transient period and number of runs is determined, the statistical analysis can be performed. In reviewing several test that compare pairs of treatment means, Duncan's multiple range test was selected due to its ability to detect differences between means when differences really do exist (Montgomery, 1997). Duncan's multiple range test can be performed on the three different scenarios to determine if there is a statistical difference between them. This test is suitable for this experiment because it will compare all possible combinations of scenarios. This test also avoids greatly increasing the Type I error or the experimentwise error rate, which is the probability of finding that there is a significant difference when in reality there is no significant difference (Montgomery and Runger, 1994). If Scenario 3 is significantly different from Scenario 2 then, synergy exists. In order to perform the Duncan's multiple range test, the mean values of the performance variables are needed for each run. Unfortunately, the default SIMNET output provides only the mean, standard deviation, maximum, minimum and 95 percent confidence limits for all the runs. Therefore, the values for each performance variable are written to an output file at the end of each run. These output files together with the default SIMNET output enable the tests to be run.

# Chapter 4

## Analysis of Results

This chapter presents the results obtained from the simulations, the statistical analysis performed on these results, and a discussion of the difference in behavior between scenarios. Appendix C tabulates the results obtained from the output files while Appendix D shows the calculations for the Duncan's Multiple range tests. As a reminder,

Scenario 1 - Baseline (all loads moved by truck only)

Scenario 2a - Intermodal loads are run separately

Scenario 2b - Truckloads are run separately

Scenario 2 - The aggregate from Scenario 2a and 2b are observed (intermodal and truck loads are run independently)

Scenario 3 - Intermodal and truck loads are run concurrently

### 4.1 Statistical Analysis Results

The following tables summarize the results obtained from the Duncan's multiple range tests. The first scenario, which is the baseline, is used to establish a basis of comparison with the other scenarios.

Table 4.1 shows the results for the maximum number of drivers for all three driver types (local, regional and OTR). The last section in this table is the sum of these three driver types to give the total maximum number of drivers needed to transport all the loads. According to the results, there is a significant decrease from Scenario 2 to Scenario 3 in the maximum number of regional and local drivers needed to transport the loads. However, there is not a significant decrease in the maximum number of OTR drivers. When considering the total number of drivers for all three types, there is a decrease of three hundred drivers when operations are run concurrently instead of separately. This significant reduction means that synergy does exists in combining operations when considering the maximum number of drivers. Another interesting fact is that it requires the least number of drivers when all the loads are being transported by truck. However, this choice of transportation is not ideal because of the higher costs in transporting freight over large distances by truck only rather than using intermodal services. This simulation model these not consider these costs.

| **Maximum Number of OTR Drivers** | |
|---|---|
| Scenario | Average |
| 1 | 3632.20 |
| 2 | 2526.50 |
| 3 | 2374.20 |
| **Maximum Number of Regional Drivers** | |
| Scenario | Average |
| 1 | 270.00 |
| 2 | 987.10 |
| 3 | 875.00 |
| **Maximum Number of Local Drivers** | |
| Scenario | Average |
| 1 | 97.70 |
| 2 | 1062.00 |
| 3 | 1010.40 |
| **Maximum Number of Drivers (Local + Regional + OTR)** | |
| Scenario | Average |
| 1 | 3999.90 |
| 2 | 4575.60 |
| 3 | 4259.60 |

Table 4.1a: Results for the Maximum Number of Drivers

| **Duncan's Comparison Test** | |
|---|---|
| Comparison | Result |
| 1 vs. 2 | significant |
| 1 vs. 3 | significant |
| 2 vs. 3 | not significant |
| **Duncan's Comparison Test** | |
| Comparison | Result |
| 1 vs. 2 | significant |
| 1 vs. 3 | significant |
| 2 vs. 3 | significant |
| **Duncan's Comparison Test** | |
| Comparison | Result |
| 1 vs. 2 | significant |
| 1 vs. 3 | significant |
| 2 vs. 3 | significant |
| **Duncan's Comparison Test** | |
| Comparison | Result |
| 1 vs. 2 | significant |
| 1 vs. 3 | significant |
| 2 vs. 3 | significant |

Table 4.1b: Results from Duncan's Comparison Test

Table 4.2 considers the distance that each type of driver travels per day. Again, the comparison of Scenario 2 to Scenario 3 is most important to this project. The test confirms a significant difference between Scenario 2 and 3 in the daily distance traveled by both OTR and regional drivers. On the other hand, there is no significant difference between Scenario 2 and 3 in the daily distance traveled by local drivers. In all three results, the average distance traveled for each type of driver is longer when the intermodal and over-the-road operations are considered concurrently. Table 4.2 results again show that synergy exists in combining operations because at least two of the driver types (regional and OTR), comprising the vast majority of all drivers, are able to drive longer distances each day.

| **Distance Traveled per OTR Driver per Day** | |
|---|---|
| Scenario | Average |
| 1 | 467.26 |
| 2 | 393.34 |
| 3 | 434.14 |
| **Distance Traveled per Regional Driver per Day** | |
| Scenario | Average |
| 1 | 286.89 |
| 2 | 258.75 |
| 3 | 285.21 |
| **Distance Traveled per Local Driver per Day** | |
| Scenario | Average |
| 1 | 241.81 |
| 2 | 193.10 |
| 3 | 201.60 |

Table 4.2a: Daily Distances Traveled

| **Duncan's Comparison Test** | |
|---|---|
| Comparison | Result |
| 1 vs. 2 | significant |
| 1 vs. 3 | not significant |
| 2 vs. 3 | significant |
| **Duncan's Comparison Test** | |
| Comparison | Result |
| 1 vs. 2 | significant |
| 1 vs. 3 | not significant |
| 2 vs. 3 | significant |
| **Duncan's Comparison Test** | |
| Comparison | Result |
| 1 vs. 2 | significant |
| 1 vs. 3 | significant |
| 2 vs. 3 | not significant |

Table 4.2b: Results from Duncan's Comparison Test

Table 4.3 analyzes the average loaded and unloaded (partitioned into bobtail and deadhead) miles. These results show that there is a significant increase in both the loaded and unloaded miles from Scenario 2 to Scenario 3. An explanation for this is that there are fewer drivers in Scenario 3. Therefore, these drivers have to travel longer distances to obtain a trailer, pick up the load and deliver the load. According to these performance variables, synergy does not exist. Another interesting factor to note in these results is that Scenario 1 has the least empty miles. This is probably caused by the fact that the rail terminals are located at non-ideal locations. Scenario 1 has a very large average for loaded miles per load compared to the other two scenarios. This is because Scenario 1 does not use rail transportation for part of the delivery tour.

| Average Bobtail per Load | |
|---|---|
| Scenario | Average |
| 1 | 138.92 |
| 2 | 173.31 |
| 3 | 201.48 |
| **Average Deadhead per Load** | |
| Scenario | Average |
| 1 | 88.23 |
| 2 | 123.93 |
| 3 | 137.94 |
| **Average Loaded Miles per Load** | |
| Scenario | Average |
| 1 | 1000.79 |
| 2 | 390.98 |
| 3 | 420.65 |

Table 4.3a: Average Loaded and Unloaded Miles per Load

| Duncan's Comparison Test | |
|---|---|
| Comparison | Result |
| 1 vs. 2 | significant |
| 1 vs. 3 | significant |
| 2 vs. 3 | significant |
| **Duncan's Comparison Test** | |
| Comparison | Result |
| 1 vs. 2 | significant |
| 1 vs. 3 | significant |
| 2 vs. 3 | significant |
| **Duncan's Comparison Test** | |
| Comparison | Result |
| 1 vs. 2 | significant |
| 1 vs. 3 | significant |
| 2 vs. 3 | significant |

Table 4.3b: Results from Duncan's Comparison Test

The final table (Table 4.4) shows the results for the average late hours per load and the ratio of loads delivered late. The results from this table show that there is no significant difference in the average late hours between Scenario 2 and 3. However, the three-percent increase in the loads delivered late may have some practical significance. Again, this result opposes the idea that synergy exists when combining operations.

| Average Late Hours per Load | |
|---|---|
| Scenario | Average |
| 1 | -26.40 |
| 2 | -64.04 |
| 3 | -55.04 |
| **Ratio of Loads Delivered Late** | |
| Scenario | Average |
| 1 | 0.289708 |
| 2 | 0.238605 |
| 3 | 0.268222 |

Table 4.4a: Average Late Hours per Load And Ratio of Loads Delivered Late

| Duncan's Comparison Test | |
|---|---|
| Comparison | Result |
| 1 vs. 2 | significant |
| 1 vs. 3 | significant |
| 2 vs. 3 | not significant |
| **Duncan's Comparison Test** | |
| Comparison | Result |
| 1 vs. 2 | significant |
| 1 vs. 3 | not significant |
| 2 vs. 3 | significant |

Table 4.4b: Results from Duncan's Comparison Test

## 4.2 Overall results

As seen in the previous section the results for the different performance variables are conflicting. When taking into consideration the maximum number of drivers and the daily distances that each type of driver travels, results show that synergy exists. On the other hand, when considering the average loaded and unloaded miles and the lateness analysis, results show that synergy does not exist. Looking at the global aspect of the project, the results show there are trade-off factors in combining intermodal and over-the-road operations.

### 4.2.1 Company's Standpoint

As described in chapter three, this project determines three performance variables from the point of view of the company: loaded miles, unloaded miles and the maximum number of drivers. When considering the maximum number of drivers needed to transport all the loads, synergy exists in combining operations. However, when examining the unloaded miles that drivers travel both to obtain a trailer and to pickup a load, synergy no longer exists in combing operations.

### 4.2.2 Driver's Standpoint

The drivers usually want to know the average distance they will be travelling every day because wages are based on miles driven. The results show that at least for OTR and regional drivers synergy does exist in combining operations because the distance drivers travel per day increases significantly. There is not significant increase in the distance that local drivers travel each day.

### 4.2.3 Customer's Standpoint

From the customer's standpoint, loads need to be delivered on time. In this case, synergy does not exist in combining operations because there is a three-percent increase in the loads delivered late. Nonetheless, there is no change in the lateness per load (average late hours per load).

# Chapter 5

# Conclusions and Recommendations

## 5.1 Conclusions

The objective of this project has been to determine if synergy exists in combining intermodal and over-the-road operations. Simulation was used as the tool to analyze freight transportation using both operations. The simulation model collected suitable performance variables, which could then be compared between two scenarios. One of these scenarios combined over-the-road and intermodal operations, while the other separated the operations.

The results show that there is a trade-off between different performance variables when combining operations. Synergy exists when considering the driver but does not exist when considering the customer. When considering factors from the company's point of view, the factors are once again contradictory.

## 5.2 Recommendations

A detailed cost analysis should be performed because of the trade-off between performance variables. It is important for the company to determine if the cost savings associated with the decrease of three hundred drivers exceeds the cost of the increased mileage that drivers travel to deliver the load (bobtail miles, deadhead miles and loaded miles). It is also necessary to determine the financial impact resulting from the three-percent increase of loads delivered late.

Once the results from the cost analysis have been obtained, the solution will show whether synergy does exist in combining intermodal and over-the-road operations. It is the authors suspicion that a well-engineered solution will show that synergy is possible in combining operations; however the advantages might not be as great as originally expected.

## 5.3 Research Continuation with Simulation Model

This simulation model can be used for a variety of other purposes. This section will describe some of these uses.

The model can be used to determine suitable geographical locations for combined OTR and intermodal operations in terms of both freight availability and ramp (transfer from truck to rail) locations. In this case, selected regions are considered for combining intermodal and over-the-road operations. The simulation will then determine if greater synergy exists.

It is also possible to determine a suitable balance between intermodal and non-intermodal transportation for a trucking company. A sensitivity analysis can be performed by varying the ratio of loads moved by truck alone versus the loads moved using intermodal transportation.

Finally, this model can be used to analyze freight from new customers. The freight information for new customers can be added to the current freight load of the trucking company to determine if the new customers will improve profitability. It is possible that the addition of customer freight eliminates current synergies, which would mean that the trucking company should refuse the new freight. It is also possible that only a portion of the customers freight should be transported by the trucking company such that synergies remain the same or increase. This model can be used to evaluate these possibilities.

# Bibliography

Barnhart, C., and Ratliff, H. D., "Modeling intermodal routing," *Journal of Business Logistics*, Vol. 14, No. 1, pp. 205-223, (1993).

Boese, P., "Applications of computer model techniques for railroad intermodal terminal configuration, equipment and operational planning," *Transportation Research Record*, No. 907, pp. 45-52, (1983).

Bradley, P., "Know your orders for truckloads of savings," *Purchasing*, Vol. 119, No. 3, pp. 33-35, (1993).

Candler, J., "Road and rail connections," *Nation's Business*, Vol. 82, pp. 73-74, (July 1994).

Crainic, T. G., and Rousseu, J. M., "Multicommodity, multimodal freight transportation, a general modeling and algorithmic framework for the service network design problem," *Transportation Research B*, No. 20, pp. 242-255, (1986).

"Delivering the goods," *Governing*, Vol. 7, pp. 64-66, (1994).

Dessouky, M. M., and Leachman, R. C., "A simulation modeling methodology for analyzing large complex rail networks," *Simulation*, Vol. 65, No. 2, pp. 131-142, (1995).

Dial, R. B., "Minimizing trailer-on-flat-car costs: a network optimization model," *Transportation Science*, Vol. 28, No. 1, pp. 24-36, (1994).

"Everyone needs to move equipment more efficiently," *Transportation and Distribution*, Vol. 34, No. 12, pp. 13, (1993).

Feo, T. A., and Gonzalez-Velarde, J. L., "Intermodal trailer assignment problem," *Transportation Science*, Vol. 29, No. 4, pp. 330-341, (1995).

Ferreira, L., and Sigut, J., "Measuring the performance of intermodal Freight terminals," *Transportation Planning and Technology*, Vol. 31, No. 3, pp. 5-15, (1993).

Ferreira, L., and Sigut, J., "Modeling intermodal freight terminal operations," *Road and Transport Research*, Vol. 4, No. 4, pp. 91-106, (1995).

Fuller, S., Puimsomboon, P., Paggi, M., and Phillips, D., "Modeling an intermodal transfer system: The case of export grain terminals," *Logistics and Transportation Review*, Vol. 19, No. 3, pp. 195-210, (1983).

Golden, C. W., and Wood, C. F., "TOFC terminal simulation model," *Transportation Research Record*, No. 907, pp. 42-45, (1983).

Hammesfahr, R. D., and Clayton, E. R., "A computer simulation model to assist intermodal terminal managers in operational analysis," *The Transportation Journal*, Vol. 22, No. 4, pp. 55-86, (1986).

Holcomb, M. C., and Jennings, B., "Intermodal freight transportation, transload option," *Transportation Quarterly*, Vol. 49, No. 2, pp. 31-40, (1995).

Howard, S. G., "Large or small terminals in intermodal transport: what is the optimal size?" *Transportation Research Record*, No. 907, pp. 14-21, (1983).

Klima, V., and Kavicka, A., "RBSIM-simulation model of marshalling yard operation," *Proceedings of the International Conference On Computer Aided Design, Manufacture and Operation in the Railway and Other Mass Transit Systems*, Part 1 of 2, Aug 21-23, pp. 493-500, (1996).

Kondratowicz, L. J., "Simulation methodologies for intermodal freight transportation terminals," *Simulation*, Vol. 55, No. 1, pp. 49-57, (1990).

Kracke, R., Siegmann, J., and Voges, W., "Automation and the private sector hold the keys to efficiency," *Railway Gazette International*, Vol. 151, No. 2, pp. 86-88, (1995).

Krebs, R. D., "Towards a national intermodal transportation System," *Transportation Quarterly*, Vol. 48, No. 4, pp. 333-342, (1994).

Luberoff, D., " Back to freight's future," *Governing*, Vol. 10, No. 10, pp. 68, (1997).

MacDonald, M. E., "Truckload carriers climb into the intermodal ring," *Traffic Management*, Vol. 32, No. 7, pp. 49-52, (1993).

Mazzucchelli, M., Recagno, V., and Sciutto, G., "Interport modeling with state automata," *Proceedings of the International conference on Applications of Advanced Technologies in Transportation Engineering sponsored by: ASCE*, June 27-30, Capri Italy, pp. 104-108, (1996).

Meinert, T. S., Youngblood, A. D., Taylor, G. D., and Taha, H. A., "Simulation of the railway component of intermodal transportation," *Mack-Blackwell National Rural Transportation Study Center, Final Research Report MBTC-1077*, (1998).

Melbin, J., "Is this the golden age of intermodal?" *Distribution*, Vol. 94, No. 4, pp. 32-36, (1995).

Minahan, T., "Intermodal service gains go unnoticed," *Purchasing*, Vol. 124, No. 7, pp. 77-79, (1998).

Montgomery, D. C., *Design and Analysis of Experiments*, 4th edition, John Whiley and Sons, Inc., New York, (1997).

Montgomery, D. C. and Runger, G. C., *Applied Statistics and Probability for Engineers,* John Whiley and Sons, Inc., New York, (1994).

Morlock, E. K., and Spasovic, L. N., "Redesigning rail-truck intermodal drayage operations for enhancing service and cost performance," *Transportation Research Forum*, Vol. 34, No. 1, pp. 16-31, (1994).

Muller, G., "The business of intermodal freight transportation," *Transportation Quarterly*, Vol. 52, No. 3, pp. 7-11, (1998).

Muller, W., "Rail terminals: Intermodal transport hubs," *Rail International*, No. 3, pp. 21-24, (1997).

Nierat, P., "Market area of rail-truck terminals: pertinence of the spatial theory," *Transportation Research, Part A: Policy and Practice*, Vol. 31, No. 2, pp. 109-127, (1997).

Nozick, L. K., and Morlock, E. K., "A model for medium-term operations planning in an intermodal rail-truck service," *Transportation Research*, Vol. 31, No. 2, pp. 91-107, (1997).

Plunkett, W. M., "Intermodal Profitability analysis in the truckload and LTL Industries," Master's Thesis, Dept. of Industrial Engineering, University of Arkansas, Fayetteville, AR, (1998).

Pope, J. A., Rakes, T. R., Rees, L. P., and Crouch, I. W., "Network simulation of high-congestion road-traffic flows in cities with marine container terminals," *Journal of the Operational Research Society*, Vol. 46, No. 9, pp. 1090-1101, (1995).

Powell, W. B., and Carvalho, T. A., "Real-time optimization of containers and flatcars for intermodal operations," *Transportation Science*, Vol. 32, No. 2, pp. 110-126, (1998).

Richardson, H. L., "Better service draws freight to rail," *Transportation and Distribution*, Vol. 34, No. 4, pp. 30-33, (1993).

Richardson, H. L., "Remove delays, improve drayage efficiency," *Transportation and Distribution*, Vol. 35, No. 1, pp. 24, (1994).

Sarosky, T., and Wilcox, T., "Simulation of a railroad intermodal terminal," *Proceedings of the 1994 Winter Simulation Conference*, Dec 11-14, Buena Vista FL, pp. 1233-1238, (1994).

Singh, S., and Handal, N., "Tools for the 21st century", *Railway Age*, Vol. 196, No. 6, pp. 65-75, (1995).

Slack, B., "Intermodal transportation in North America and the development of inland load centers," *The Professional Geographer*, Vol. 42, No. 1, pp.72-83, (1990).

Stone, B. A., "Is intermodalism sustainable?" *Transportation Quarterly*, Vol. 52, No. 4, pp. 77-87, (1998).

Taha, H. A., "*Simulation with SIMNET II*," SimTec, Inc., Fayetteville, Arkansas (1992).

Taha, H. A., "*Operations Research an Introduction*," Sixth Edition, Prentice-Hall, Inc, New Jersey (1997).

Taylor, J. C., "Remove Barriers to Intermodal," *Transportation and Distribution*, Vol. 34, No. 4, pp. 34-36, (1993).

"The proof is in the payout," *Railway Age*, Vol. 192, No. 8, pp. 50-52, (1991).

Thomas, J., "Say cheese: An intermodal snapshot," *Distribution*, Vol. 94, No. 4, pp. 50-54, (1995).

Turnquist, M. A., and List, G. F., "Charting a course for intermodal policy and research," *Transportation Quarterly*, Vol. 47, No. 2, pp. 257-280, (1993).

Vickerman, M. J., "Innovations in the development and expansion of intermodal facilities," *Proceedings of the ASCE 3rd International Conference on Applications of Advanced Technologies in Transportation Engineering*, Jul 25-28, pp. 42-49, (1993).

Ward, T., "Simulation analysis for planning Deltaport container terminal, Vancouver B. C.," *Proceedings of the Ports' 95 Conference on Port Engineering and Development for the 21st Century*, Vol. 1, Mar 13-15, pp. 640-651, (1995).

Weigel, M. L., "A railroad intermodal capacity model," *Proceedings of the 1994 Winter Simulation Conference*, Dec 11-14, pp. 1229-1232, (1994).

Yan, S., Bernstein, D., and Sheffi, Y., "Intermodal Pricing using network flow techniques," *Transportation Research*, Vol. 29B, No. 3, pp. 171-180, (1995).

Yeager, P. C., "Third party services keep getting better," *Transportation and Distribution*, Vol. 34, No. 1, pp. 34, (1993).

# Appendix A

# Simulation Code

```
$PROJECT;INTERMODAL SIMULATOR;1/15/99;TAYLOR AND PETRE:
$DIMENSION;ENTITY(90),A(13),DUMMY(13):
$VARIABLES:MAX_OTRD;RUN.END;NO_OTR:     ! MAX # OF OTR DRIVERS
           MAX_REGN;RUN.END;NO_REG:     ! MAX # OF REG DRIVERS
           MAX_LOCL;RUN.END;NO_LOC:     ! MAX # OF LOC DRIVERS

           !DISTANCE TRAVELED PER DRIVER PER DAY FOR EACH DRIVER TYPE
           MI_OTRDR;RUN.END;OTR_MI/MAX(NO_OTR,.01)/(RUN.LEN/24):
           MI_REGDR;RUN.END;REG_MI/MAX(NO_REG,.01)/(RUN.LEN/24):
           MI_LOCDR;RUN.END;LOC_MI/MAX(NO_LOC,.01)/(RUN.LEN/24):

           BOBTAIL;;BOBTL:              ! AVG BOBTAIL/LOAD
           DEADHEAD;;DDHD:              ! AVG DEADHEAD/LOAD
           LOADED;;LDED:                ! AVG LOADED MILES/LOAD

           TRLD_NOT;RUN.END;TRK_NOT:    ! TRK LDS DENIED--NO DRVR
           IMLD_NOT;RUN.END;IM_NOT:     ! IM  LDS DENIED--NO DRVR

           LATE_HRS;;LATE:                ! AVG HOURS LATE/LOAD
           LATE_PCT;RUN.END;NO_LATE/NO_LDS:! % OF LOADS DELIVERED LATE

!          MIN/MAX/AVG/LAST TRLRS BY POOL IN QPOOL DEFAULT STATISTICS
!          ie. TRAILER STATISTICS ARE ALREADY ACCOUNTED FOR

!*********************************************************************!
!                        ATTRIBUTE DEFINITIONS                        !
! ATTRIB  DRIVER/POWER     LOAD             TRAILER                   !
!  A(1)   LOAD NUMBER      LOAD NUMBER      CURRENT POOL NO.          !
!                                             0=DRIVING               !
!                                             1-11 POOL NUMBERS       !
!  A(2)   ORIGIN LAT       ORIGIN LAT                                 !
!  A(3)   ORIGIN LONG      ORIGIN LONG                                !
!  A(4)   DEST LAT OR      DEST LAT         CURRENT LAT               !
!         CURRENT LAT                                                 !
!  A(5)   DEST LONG OR     DEST LONG        CURRENT LONG              !
!         CURRENT LONG                                                !
!  A(6)   P/U DATE/TIME    P/U DATE/TIME                              !
!  A(7)   DEL DATE/TIME    DEL DATE/TIME                              !
!  A(8)   DRV&SLEEP TIME                                              !
!         OR ENTRY TIME                                               !
!         IN QUEUE AVAIL                                              !
!  A(9)   TIME 'TIL SLEEP                                             !
!  A(10)  NEXT LOAD #      DEL DRAY LENGTH                            !
!                          FOR IM P/U'S                               !
!  A(11)  DRVR TYPE        LOAD TYPE          CURRENT POOL #          !
!           1=LOC (0-75)     1=LOC (0-75)       0=DRIVING             !
!           2=REG (75-300)   2=REG (75-300)     1-11=POOLS            !
!           3=OTR (300+)     3=OTR (300+)                             !
!  A(12)  TRAILER STATUS   TRAILER STATUS     TRAILER STATUS          !
!           0=BOBTAIL        0=BOBTAIL          0=EMPTY               !
!           1-11=TRAILER     1-11=TRAILER       1=LOADING             !
!                & POOL #         & POOL #      2=LOADED              !
!           88,99=DUMMY      88,99=DUMMY        3=UNLOADING           !
!                                               4=AWAITING LOADING    !
```

```
!  A(13)                     LOAD STATUS                                   !
!                              1=TRUCK                                     !
!                              2=I/M P/U DRAY                              !
!                              3=I/M DEL DRAY                              !
!**********************************************************************!


$BEGIN:

!**********************************************************************!
!                                PART 1                                !
!                      INITIALIZATION OF TRAILERS                      !
!                INITIALIZATION OF LOADS ONE AT A TIME                 !
!**********************************************************************!

! TRAILERS ARE READ IN AND PLACED IN APPROPRIATE POOL
INIT_TR *S;/L/LIM=1:
READ_TR *A:
       *B;LAST_TR;;
        READ(60)=(A(4),A(5),A(11),A(12)),
        A(4)=A(4)/57.3,
        A(5)=A(5)/57.3,
        IF,A(11)>0,THEN,
         INS(QPOOL(A(11)))=TRANS,
        ENDIF%:

LAST_TR *A:
        *B;READ_TR/1;A(11)>0?:
        *B;TERM/L:

START   *S;;.01;/L/LIM=1:


! READ LOADS 8 HOURS IN ADVANCE (FILE IS SORTED BY PICK-UP DATE)
READ_LD *A;.001:
        *B;LAST_LD;;
          READ(61)=(A(1),A(2),A(3),A(4),A(5),&
            A(6),A(7),A(10),A(11),A(13)),
          A(2)=A(2)/57.3,
          A(3)=A(3)/57.3,
          A(4)=A(4)/57.3,
          A(5)=A(5)/57.3%:

LAST_LD *A:
        *B;TERM/1;A(1)=0?:
        *B;ROUTER1/1;A(6)<=CUR.TIME+8?:
        *B;DLAY/L:

! DELAY UNTIL THE LOAD IS WITHIN 8 HOURS OF PICKUP
DLAY    *A;A(6)-CUR.TIME-8:
ROUTER1 *A:
        *B;READ_LD/2;A(1)>0?:
        *B;ORIG/2;A(1)>0?:
```

```
!*******************************************************************!
!                              PART 2                                !
!                          FIND A DRIVER                             !
!*******************************************************************!

! FIND A DRIVER BASED ON DEADHEAD LENGTH AND DRIVER TYPE
ORIG    *A:
        *B;TERM;;
          FOR,J=1,TO,2,DO,
            IF,J=1,THEN,     ! SMALL DEADHEAD
              RAD=50,
            ELSE,
              RAD=1000,      ! LARGE DEADHEAD
            ENDIF,
            LOAD_NMBR=A(1),
            ORIG_LAT=A(2),
            ORIG_LONG=A(3),
            PICK_UP=A(6),
            LOAD_TYPE=A(11),
            LOAD_STATUS=A(13),
            CLOSEST =1000,
            CANDIDATE=-1,

! LOOK FOR AN AVAILABLE DRIVER
            IF,LEN(QAVAIL)>0,THEN,
              FOR,I=1,TO,LEN(QAVAIL),DO,  ! LOOK FOR CLOSEST
                COPY=I(QAVAIL),
                TV1=(SIN(A(4))*SIN(ORIG_LAT))+(COS(A(4))*&
                  COS(ORIG_LAT)*COS(ABS(ORIG_LONG-A(5)))),
                TV1=MIN(1,TV1),
                DRVR_CLOSE=4632.03*(ACOS(TV1)),
                IF,DRVR_CLOSE<CLOSEST,AND,DRVR_CLOSE<RAD,AND,&
                    A(11)=LOAD_TYPE,THEN,
                  CLOSEST=DRVR_CLOSE,
                  CANDIDATE=I,
                ENDIF,
              NEXT,
              IF,CANDIDATE>0,THEN,  ! AVAILABLE DRIVER IS FOUND
                TRANS=OLD,
                LOAD_NO=A(1),
                INS(QLOADS)=TRANS,
                COPY=CANDIDATE(QAVAIL),
                CANDIDATE(QAVAIL)=DEL,
                A(1)=LOAD_NO,
                TRANS=NEW,
                INS(QDEADHD)=TRANS,
                LOOP=BREAK,
              ENDIF,
            ENDIF,

! LOOK FOR A RESTING DRIVER
            IF,CANDIDATE<0,THEN,
              CLOSEST=1000,
              IF,LEN(QRSTNG)>0,THEN,
                FOR,I=1,TO,LEN(QRSTNG),DO,  ! FIND CLOSEST DRIVER
                  COPY=I(QRSTNG),
                  IF,A(10)=0,THEN,
```

```
                TV2=(SIN(A(4))*SIN(ORIG_LAT))+(COS(A(4))*&
                  COS(ORIG_LAT)*COS(ABS(ORIG_LONG-A(5)))),
                TV2=MIN(1,TV2),
                DRVR_CLOSE=4632.03*(ACOS(TV2)),
                IF,DRVR_CLOSE<CLOSEST,AND,DRVR_CLOSE<RAD,AND,&
                  A(11)=LOAD_TYPE,THEN,
                    CLOSEST=DRVR_CLOSE,
                    CANDIDATE=I,
                ENDIF,
              ENDIF,
            NEXT,
            IF,CANDIDATE>0,THEN, ! RESTING DRIVER IS FOUND
              TRANS=OLD,
              LOAD_NO=A(1),
              INS(QLOADS)=TRANS,
              COPY=CANDIDATE(QRSTNG),
              A(10)=LOAD_NO,
              CANDIDATE(QRSTNG)=REP,
              LOOP=BREAK,
            ENDIF,
          ENDIF,
        ENDIF,

! LOOK FOR A DRIVING DRIVER
        IF,CANDIDATE<0,THEN,
          CLOSEST=1000,
          IF,LEN(QDRVNG)>0,THEN,
! FIND DRIVER WHOSE DESTINATION IS CLOSEST
            FOR,I=1,TO,LEN(QDRVNG),DO,
              COPY=I(QDRVNG),
              IF,A(10)=0,THEN,
                TV3=(SIN(A(4))*SIN(ORIG_LAT))+(COS(A(4))*&
                  COS(ORIG_LAT)*COS(ABS(ORIG_LONG-A(5)))),
                TV3=MIN(1,TV3),
                DRVR_CLOSE=4632.03*(ACOS(TV3)),
                IF,DRVR_CLOSE<CLOSEST,AND,DRVR_CLOSE<RAD,AND,
                  A(11)=LOAD_TYPE,THEN,
                    TM_REM=DRVR_CLOSE/NO(50,1.5)+2,
! .5 PROBABILITY LIVE UNLOAD * 2 HRS + 1 HR FOR TRAILER
! CAN DRIVER GET HERE WITHOUT SLEEPING
                    IF,A(9)>TM_REM,THEN,
                      CANDIDATE=I,
                      CLOSEST=DRVR_CLOSE,
                    ENDIF,
                ENDIF,
              ENDIF,
            NEXT,
            IF,CANDIDATE>0,THEN, ! DRIVING DRIVER IS FOUND
              TRANS=OLD,
              LOAD_NO=A(1),
              INS(QLOADS)=TRANS,
              COPY=CANDIDATE(QDRVNG),
              A(10)=LOAD_NO,
              CANDIDATE(QDRVNG)=REP,
              LOOP=BREAK,
            ENDIF,
          ENDIF,
```

```
            ENDIF,

! IF NO DRIVER IS FOUND....
            IF,CANDIDATE<0,THEN,
              IF,J=1,THEN,  ! GO BACK AND MAKE DEADHEAD LARGE
                TRANS=OLD,
                LOOP=CONTINUE,
              ENDIF,
              TRANS=OLD,
              LOAD_NO=A(1),
              IF,NO_OTR<MAX_OTR,OR,A(13)=3,THEN, !CREATE AN OTR DRIVER
                OTR_IM=1,
              ELSE,
                OTR_IM=0,
              ENDIF,
              IF,LOAD_TYPE=3,AND,OTR_IM=1,THEN,
                  INS(QLOADS)=TRANS,
                  NO_OTR=NO_OTR+1,
                  A(1)=LOAD_NO,
                  A(9)=10,
                  A(12)=0,
                  INS(QDEADHD)=TRANS,
              ELSE,
                IF,NO_REG<MAX_REG,OR,A(13)=3,THEN, !CREATE A REG DRIVER
                  REG_IM=1,
                ELSE,
                  REG_IM=0,
                ENDIF,
                IF,LOAD_TYPE=2,AND,REG_IM=1,THEN,
                  INS(QLOADS)=TRANS,
                  NO_REG=NO_REG+1,
                  A(1)=LOAD_NO,
                  A(9)=10,
                  A(12)=0,
                  INS(QDEADHD)=TRANS,
                ELSE,
                  IF,NO_LOC<MAX_LOC,OR,A(13)=3,THEN, !CREATE A LOC
DRIVER
                    LOC_IM=1,
                  ELSE,
                    LOC_IM=0,
                  ENDIF,
                  IF,LOAD_TYPE=1,AND,LOC_IM=1,THEN,
                    INS(QLOADS)=TRANS,
                    NO_LOC=NO_LOC+1,
                    A(1)=LOAD_NO,
                    A(9)=10,
                    A(12)=0,
                    INS(QDEADHD)=TRANS,
                  ELSE,
! NO DRIVER WAS FOUND OR CREATED
                    IF,A(13)=1,THEN,
                      TRK_NOT=TRK_NOT+1,
                    ELSE,
                      IM_NOT=IM_NOT+1,
                    ENDIF,
                  ENDIF,
```

```
              ENDIF,
            ENDIF,
          ENDIF,
        NEXT%:

!**********************************************************************!
!                              SEGMENTED QUEUES                         !
!**********************************************************************!

! QUEUE FOR AVAILABLE DRIVERS
QAVAIL   *Q:
$SEGMENT:

! COPIES OF RESTING DRIVERS TO PERMIT LOAD SEARCHES
QRSTNG   *Q:
$SEGMENT:

! COPIES OF DRIVING DRIVERS TO PERMIT LOAD SEARCHES
QDRVNG   *Q:
$SEGMENT:

! QUEUE FOR ASSIGNED LOADS AWAITING PICK-UP
QLOADS   *Q:
$SEGMENT:

!**********************************************************************!
!                               PART 3                                  !
!                         LOCATING A TRAILER                            !
!**********************************************************************!

! DEADHEAD (BOBTAIL TO TRAILER)
QDEADHD *Q:
ADEADHD *A:
        *B;TERM;;
          NEXT_LD=A(1),
          FOR,I=1,TO,LEN(QLOADS),DO,   ! LOAD ATTRIBUTES
            COPY=I(QLOADS),
            IF,A(1)=NEXT_LD,THEN,
              LOAD_NO=A(1),
              ORIG_LAT=A(2),
              ORIG_LONG=A(3),
              LD_STAT=A(13),
              LOOP=BREAK,
            ENDIF,
          NEXT,
          TRANS=OLD,   ! BACK TO DRIVER ATTRIBUTES
          IF,LD_STAT=3,OR,A(12)>0,THEN,
            INS(Q1DISP)=TRANS,
          ELSE,                              ! DETERMINE POOL NUMBER
            POOL=11,
            IF,ORIG_LAT>=(42/57.3),AND,ORIG_LONG<=(-117/57.3),THEN,
              POOL=1,ENDIF,
            IF,ORIG_LAT>=(36/57.3),AND,ORIG_LAT<(42/57.3),AND,&
              ORIG_LONG<=(-117/57.3),THEN,POOL=2,ENDIF,
            IF,ORIG_LAT<(36/57.3),AND,ORIG_LONG<=(-109/57.3),THEN,
              POOL=3,ENDIF,
            IF,ORIG_LAT<(37/57.3),AND,ORIG_LONG<=(-91.5/57.3),AND,&
```

```
          ORIG_LONG>(-106.5/57.3),THEN,POOL=4,ENDIF,
        IF,ORIG_LAT<(37/57.3),AND,ORIG_LONG<=(-88/57.3),AND,&
          ORIG_LONG>(-91.5/57.3),THEN,POOL=5,ENDIF,
        IF,ORIG_LAT<(36/57.3),AND,ORIG_LONG>(-88/57.3),THEN,
          POOL=6,ENDIF,
        IF,ORIG_LAT>=(36/57.3),AND,ORIG_LAT<(42/57.3),AND,&
          ORIG_LONG>(-80.5/57.3),THEN,POOL=7,ENDIF,
        IF,ORIG_LAT>=(42/57.3),AND,ORIG_LONG>(-80.5/57.3),THEN,
          POOL=8,ENDIF,
        IF,ORIG_LAT>=(39.5/57.3),AND,ORIG_LONG<=(-80.5/57.3),AND,&
          ORIG_LONG>(-97/57.3),THEN,POOL=9,ENDIF,
        IF,ORIG_LAT>=(37/57.3),AND,ORIG_LAT<(39.5/57.3),AND,&
          ORIG_LONG<=(-88/57.3),AND,ORIG_LONG>(-95/57.3),THEN,
          POOL=10,ENDIF,
        BEST_TR=-1,
        TR_DIST=1000,
        IF,LEN(QPOOL(POOL))>0,THEN,
          FOR,I=1,TO,LEN(QPOOL(POOL)),DO,
! FIND CLOSEST TRAILER IN POOL
            COPY=I(QPOOL(POOL)),
            IF,A(12)=0,THEN,
              TR_LAT=A(4),
              TR_LONG=A(5),
              TV4=(SIN(ORIG_LAT)*SIN(TR_LAT))+(COS(ORIG_LAT)*&
                COS(TR_LAT)*COS(ABS(TR_LONG-ORIG_LONG))),
              TV4=MIN(1,TV4),
              TR_LD=4632.03*(ACOS(TV4)),
              IF,TR_LD<TR_DIST,THEN,
                TR_DIST=TR_LD,
                BEST_TR=I,
                BEST_LAT=A(4),
                BEST_LONG=A(5),
              ENDIF,
            ENDIF,
          NEXT,
        ENDIF,
        TRANS=OLD,
        IF,TR_DIST<5,THEN,          ! IF A TRAILER IS AT P/U SITE
          TRANS=OLD,
          INS(Q1DISP)=TRANS,
          COPY=BEST_TR(QPOOL(POOL)),
          A(1)=LOAD_NO,
          A(12)=1,
          TRANS=NEW,
          INS(QLDTR)=TRANS,
          BEST_TR(QPOOL(POOL))=REP,
        ELSE,
          IF,BEST_TR<0,THEN,         ! IF NO TRAILER FOUND, CREATE
            A(1)=LOAD_NO,            ! ONE AT POOL CENTROID
            A(4)=(TL(1,POOL))/57.3,
            A(5)=(TL(2,POOL))/57.3,
            BEST_LAT=A(4),
            BEST_LONG=A(5),
            A(11)=POOL,
            A(12)=4,
            LAST(QPOOL(POOL))=TRANS,
            TV5=(SIN(ORIG_LAT)*SIN(A(4)))+(COS(ORIG_LAT)*&
```

```
              COS(A(4))*COS(ABS(A(5)-ORIG_LONG))),
            TV5=MIN(1,TV5),
            TR_DIST=4632.03*(ACOS(TV5)),
          ELSE,                       ! TRAILER FOUND IN POOL
            COPY=BEST_TR(QPOOL(POOL)),
            A(1)=LOAD_NO,
            A(12)=4,
            TRANS=NEW,
            BEST_TR(QPOOL(POOL))=REP,
          ENDIF,
          TRANS=OLD,
          A(4)=BEST_LAT,
          A(5)=BEST_LONG,
! CALCULATE DISTANCE AND TIME TO GET TO TRAILER
          TV6=(SIN(A(2))*SIN(A(4)))+(COS(A(2))*&
            COS(A(4))*COS(ABS(A(5)-A(3)))),
          TV6=MIN(1,TV6),
          BOB_DIST=4632.03*(ACOS(TV6)),
          TM_EN_RT=BOB_DIST/NO(50,1.5),
          IF,A(9)>TM_EN_RT,THEN, !ADJUST REMAINING DRIVING TIME
            A(8)=TM_EN_RT,
            A(9)=A(9)-A(8),
          ELSE,
            A(8)=A(9)+8,
            TM_EN_RT=TM_EN_RT-A(9),! = REM. TIME AFTER 1ST SLEEP
            A(8)=TM_EN_RT+(INT(TM_EN_RT/10)*8)+A(8),
            TEMP_VAR1=INT(TM_EN_RT/10),
            A(9)=((TEMP_VAR1+1)*10)-TM_EN_RT,
          ENDIF,
          INS(QBOBTL)=TRANS,
          IF,A(11)=1,THEN,LOC_MI=LOC_MI+BOB_DIST,ENDIF,  ! KEEP UP
          IF,A(11)=2,THEN,REG_MI=REG_MI+BOB_DIST,ENDIF,  ! WITH
          IF,A(11)=3,THEN,OTR_MI=OTR_MI+BOB_DIST,ENDIF,  ! DISTANCE
          BOBTL=BOB_DIST,                                ! TRAVELED
          COLLECT=BOBTAIL,                               ! & BOBTAIL
        ENDIF,                                           ! DISTANCE
      ENDIF%:

! BOBTAIL TO GET A TRAILER
QBOBTL    *Q:
ABOBTL    *A;A(8):    ! DELAY FOR DRIVER TO GET TO TRAILER
          *B;Q1DISP;;
            LOAD_NO=A(1),
            FOR,I=1,TO,LEN(QLOADS),DO,
              COPY=I(QLOADS),
              IF,A(1)=LOAD_NO,THEN,
                ORIG_LAT=A(2),
                ORIG_LONG=A(3),
                LOOP=BREAK,
              ENDIF,
            NEXT,
            TRANS=OLD,
            POOL=11,   ! LOCATE TRAILER POOL
            IF,ORIG_LAT>=(42/57.3),AND,ORIG_LONG<=(-117/57.3),THEN,
              POOL=1,ENDIF,
            IF,ORIG_LAT>=(36/57.3),AND,ORIG_LAT<(42/57.3),AND,&
              ORIG_LONG<=(-117/57.3),THEN,POOL=2,ENDIF,
```

```
        IF,ORIG_LAT<(36/57.3),AND,ORIG_LONG<=(-109/57.3),THEN,
          POOL=3,ENDIF,
        IF,ORIG_LAT<(37/57.3),AND,ORIG_LONG<=(-91.5/57.3),AND,&
          ORIG_LONG>(-106.5/57.3),THEN,POOL=4,ENDIF,
        IF,ORIG_LAT<(37/57.3),AND,ORIG_LONG<=(-88/57.3),AND,&
          ORIG_LONG>(-91.5/57.3),THEN,POOL=5,ENDIF,
        IF,ORIG_LAT<(36/57.3),AND,ORIG_LONG>(-88/57.3),THEN,
          POOL=6,ENDIF,
        IF,ORIG_LAT>=(36/57.3),AND,ORIG_LAT<(42/57.3),AND,&
          ORIG_LONG>(-80.5/57.3),THEN,POOL=7,ENDIF,
        IF,ORIG_LAT>=(42/57.3),AND,ORIG_LONG>(-80.5/57.3),THEN,
          POOL=8,ENDIF,
        IF,ORIG_LAT>=(39.5/57.3),AND,ORIG_LONG<=(-80.5/57.3),AND,&
          ORIG_LONG>(-97/57.3),THEN,POOL=9,ENDIF,
        IF,ORIG_LAT>=(37/57.3),AND,ORIG_LAT<(39.5/57.3),AND,&
          ORIG_LONG<=(-88/57.3),AND,ORIG_LONG>(-95/57.3),THEN,
          POOL=10,ENDIF,
        FOR,I=1,TO,LEN(QPOOL(POOL)),DO,
          COPY=I(QPOOL(POOL)),
          IF,A(1)=LOAD_NO,THEN,
            I(QPOOL(POOL))=DEL,
            LOOP=BREAK,
          ENDIF,
        NEXT,
        A(2)=A(4),
        A(3)=A(5),
        A(12)=POOL%:

!*********************************************************************!
!                           TRAILER POOLS                              !
!*********************************************************************!
        *PROC(1-11):
QPOOL() *Q:
        *B;TERM/1;PROCCHK=1?: !CONDITION NEVER MET - SEGMENTED QUEUE
        *ENDPROC:


!*********************************************************************!
!                        PART 3 SPECIAL CASE                           !
!                LOAD TRAILER IF TRAILER IS AT SITE                    !
!*********************************************************************!

QLDTR   *Q:
ALDTR   *A;EX(2): ! LOADING TIME
        *B;TERM;;
          LOAD_NO=A(1),
          FOR,I=1,TO,LEN(QPOOL(A(11))),DO,
            COPY=I(QPOOL(A(11))),
            IF,A(1)=LOAD_NO,THEN,
              A(12)=2,
              I(QPOOL(A(11)))=REP,
              LOOP=BREAK,
            ENDIF,
          NEXT,
          IF,LEN(QLDNG)>0,THEN,   ! SEND DRIVER TO DISPATCH
            FOR,I=1,TO,LEN(QLDNG),DO,
              COPY=I(QLDNG),
```

```
            IF,A(1)=LOAD_NO,THEN,
              I(QLDNG)=DEL,
              TRANS=NEW,
              INS(Q1DISP)=TRANS,
              LOOP=BREAK,
            ENDIF,
          NEXT,
        ENDIF%:

!*********************************************************************!
!                              PART 4                                 !
!                     DISPATCH DRIVER TO LOAD                         !
!                           LOAD TRAILER                              !
!*********************************************************************!

Q1DISP   *Q:
A1DISP   *A;.001:
         *B;NODRV/1;A(12)=88?:  ! DRIVER IS WAITING AT SITE
         *B;DRVLD/L;;
           LOAD_NO=A(1),
           ORIG_LAT=A(2),
           ORIG_LONG=A(3),
! CALCULATE DISTANCE AND TIME TO GET TO LOAD
           FOR,I=1,TO,LEN(QLOADS),DO,
             COPY=I(QLOADS),
             IF,A(1)=LOAD_NO,THEN,
               TV7=(SIN(ORIG_LAT)*SIN(A(2)))+(COS(ORIG_LAT)*&
                 COS(A(2))*COS(ABS(A(3)-ORIG_LONG))),
               TV7=MIN(1,TV7),
               1ST_DIST=4632.03*(ACOS(TV7)),
               IF,A(11)=1,THEN,LOC_MI=LOC_MI+1ST_DIST,ENDIF,
               IF,A(11)=2,THEN,REG_MI=REG_MI+1ST_DIST,ENDIF,
               IF,A(11)=3,THEN,OTR_MI=OTR_MI+1ST_DIST,ENDIF,
               DDHD=1ST_DIST,
               COLLECT=DEADHEAD,
               LOOP=BREAK,
             ENDIF,
           NEXT,
           TRANS=OLD,
           A(2)=A(4),
           A(3)=A(5),
           TM_EN_RT=1ST_DIST/NO(50,1.5),
           IF,A(9)>TM_EN_RT,THEN, ! NO SLEEP REQUIRED
             A(8)=TM_EN_RT,
             A(9)=A(9)-A(8),
           ELSE,                  ! SLEEP REQUIRED
             A(8)=A(9)+8,
             TM_EN_RT=TM_EN_RT-A(9),! = REM. TIME AFTER 1ST SLEEP
             A(8)=TM_EN_RT+(INT(TM_EN_RT/10)*8)+A(8),
             TEMP_VAR1=INT(TM_EN_RT/10),
             A(9)=((TEMP_VAR1+1)*10)-TM_EN_RT,
           ENDIF%:

DRVLD    *A;A(8):  !DELAY TO DRIVE TO LOAD
NODRV    *A:

!        PICK UP LOAD
```

```
*B;LOAD;;
  LOAD_NO=A(1),
  SLEEP=A(9),
  IF,A(12)=88,THEN,
    TR_STAT=0,
  ELSE,
    TR_STAT=A(12),
  ENDIF,
  IF,LEN(QLOADS)>0,THEN,
    FOR,I=1,TO,LEN(QLOADS),DO,   ! GET LOAD ATTRIBS TO DRIVER
      COPY=I(QLOADS),
      IF,A(1)=LOAD_NO,THEN,
        TRANS=NEW,
        A(9)=SLEEP,
        I(QLOADS)=DEL,
        LOOP=BREAK,
      ENDIF,
    NEXT,
  ENDIF,
  ORIG_LAT=A(2),   ! DETERMINE TRAILER POOL AT PICK UP
  ORIG_LONG=A(3),
  POOL=11,
  IF,ORIG_LAT>=(42/57.3),AND,ORIG_LONG<=(-117/57.3),THEN,
    POOL=1,ENDIF,
  IF,ORIG_LAT>=(36/57.3),AND,ORIG_LAT<(42/57.3),AND,&
    ORIG_LONG<=(-117/57.3),THEN,POOL=2,ENDIF,
  IF,ORIG_LAT<(36/57.3),AND,ORIG_LONG<=(-109/57.3),THEN,
    POOL=3,ENDIF,
  IF,ORIG_LAT<(37/57.3),AND,ORIG_LONG<=(-91.5/57.3),AND,&
    ORIG_LONG>(-106.5/57.3),THEN,POOL=4,ENDIF,
  IF,ORIG_LAT<(37/57.3),AND,ORIG_LONG<=(-88/57.3),AND,&
    ORIG_LONG>(-91.5/57.3),THEN,POOL=5,ENDIF,
  IF,ORIG_LAT<(36/57.3),AND,ORIG_LONG>(-88/57.3),THEN,
    POOL=6,ENDIF,
  IF,ORIG_LAT>=(36/57.3),AND,ORIG_LAT<(42/57.3),AND,&
    ORIG_LONG>(-80.5/57.3),THEN,POOL=7,ENDIF,
  IF,ORIG_LAT>=(42/57.3),AND,ORIG_LONG>(-80.5/57.3),THEN,
    POOL=8,ENDIF,
  IF,ORIG_LAT>=(39.5/57.3),AND,ORIG_LONG<=(-80.5/57.3),AND,&
    ORIG_LONG>(-97/57.3),THEN,POOL=9,ENDIF,
  IF,ORIG_LAT>=(37/57.3),AND,ORIG_LAT<(39.5/57.3),AND,&
    ORIG_LONG<=(-88/57.3),AND,ORIG_LONG>(-95/57.3),THEN,
    POOL=10,ENDIF,
  A(12)=POOL,
  TRANS=NEW,
  IF,A(13)=3,THEN,
    IF,TR_STAT=0,THEN,       ! IF DEL DRAY & BOBTAIL
      A(8)=EX(.25),          ! HOOK ONLY
      A(9)=A(9)-A(8),
    ELSE,                    ! IF DEL DRAY & TRAILER
      DST_LAT=A(4),          ! DROP & HOOK
      DST_LONG=A(5),
      DR_TYPE=A(11),
      LD_STAT=A(12),
      A(4)=A(2),
      A(5)=A(3),
      A(11)=POOL,
```

```
      A(12)=0,
      INS(QPOOL(POOL))=TRANS,
      A(4)=DST_LAT,
      A(5)=DST_LONG,
      A(8)=EX(.25)+EX(.25),
      A(9)=A(9)-A(8),
      A(11)=DR_TYPE,
      A(12)=LD_STAT,
    ENDIF,
  ELSE,
    IF,TR_STAT>0,THEN,        ! IF NOT DEL DRAY & TRAILER
      A(8)=EX(2)+EX(.25),
      A(9)=A(9)-A(8),
    ELSE,                     ! IF NOT DEL DRAY & BOBTAIL
      FOR,J=1,TO,13,DO,
        DUMMY(J)=A(J),
      NEXT,
      FOR,I=1,TO,LEN(QPOOL(POOL)),DO,
        COPY=I(QPOOL(POOL)),
        IF,A(1)=LOAD_NO,THEN,
          IF,A(12)=2,THEN,    ! IF SPOTTED TRAILER LOADED
            A(1)=DUMMY(1),
            A(2)=DUMMY(2),
            A(3)=DUMMY(3),
            A(4)=DUMMY(4),
            A(5)=DUMMY(5),
            A(6)=DUMMY(6),
            A(7)=DUMMY(7),
            A(8)=EX(.25),
            A(9)=DUMMY(9)-A(8),
            A(10)=DUMMY(10),
            A(11)=DUMMY(11),
            A(12)=DUMMY(12),
            A(13)=DUMMY(13),
          ELSE,               ! IF SPOTTED TRAILER NOT LOADED
            A(1)=DUMMY(1),
            A(2)=DUMMY(2),
            A(3)=DUMMY(3),
            A(4)=DUMMY(4),
            A(5)=DUMMY(5),
            A(6)=DUMMY(6),
            A(7)=DUMMY(7),
            A(8)=DUMMY(8),
            A(9)=DUMMY(9),
            A(10)=DUMMY(10),
            A(11)=DUMMY(11),
            A(12)=0,
            A(13)=DUMMY(13),
            INS(QLOADS)=TRANS,
            A(12)=88,
            INS(QLDNG)=TRANS,
            A(12)=99,
          ENDIF,
          LOOP=BREAK,
        ENDIF,
      NEXT,
    ENDIF,
```

```
         ENDIF%:
!*******************************************************************!
!                           SEGMENTED QUEUE                         !
!*******************************************************************!

! DRIVERS WAITING FOR THEIR TRAILER TO LOAD
QLDNG    *Q:
$SEGMENT:

!*******************************************************************!
!                             PART 4 CONT.                          !
!*******************************************************************!
LOAD      *A:
          *B;TERM/1;A(12)=99?: ! LOAD IS ALREADY LOADED
          *B;LOAD1/L:

LOAD1     *A;A(8): !DELAY TO LOAD
          *B;DRV;;
            A(8)=0,
            IF,A(9)<=0,THEN,
              A(8)=8,           ! IF LOAD TIME USES DRIVE TIME, SLEEP
              A(9)=10,
            ENDIF,
! CALCULATE DISTANCE THAT WILL BE TRAVELED LOADED
            TV8=(SIN(A(2))*SIN(A(4)))+(COS(A(2))*&
              COS(A(4))*COS(ABS(A(5)-A(3)))),
            TV8=MIN(1,TV8),
            DIST=4632.03*(ACOS(TV8)),
            LDED=DIST,
            COLLECT=LOADED,
            IF,A(11)=1,THEN,LOC_MI=LOC_MI+DIST,ENDIF,
            IF,A(11)=2,THEN,REG_MI=REG_MI+DIST,ENDIF,
            IF,A(11)=3,THEN,OTR_MI=OTR_MI+DIST,ENDIF,
            TM_EN_RT=DIST/NO(50,1.5),
            IF,A(9)>TM_EN_RT,THEN, ! NO SLEEP REQUIRED
              A(8)=A(8)+TM_EN_RT,
              A(9)=A(9)-A(8),
            ELSE,                   ! SLEEP REQUIRED
              A(8)=A(8)+A(9)+8,
              TM_EN_RT=TM_EN_RT-A(9),! = REM. TIME AFTER 1ST SLEEP
              A(8)=TM_EN_RT+(INT(TM_EN_RT/10)*8)+A(8),
              TEMP_VAR1=INT(TM_EN_RT/10),
              A(9)=((TEMP_VAR1+1)*10)-TM_EN_RT,
            ENDIF,
            INS(QDRVNG)=TRANS,     ! SEND A COPY TO QDRVNG
            LOAD_NO=A(1),
            POOL=A(12),
! DELETE TRAILER FROM POOL IF NOT PREVIOUSLY DELETED
            IF,LEN(QPOOL(POOL))>0,THEN,
              FOR,I=1,TO,LEN(QPOOL(POOL)),DO,
                COPY=I(QPOOL(POOL)),
                IF,A(1)=LOAD_NO,THEN,
                  I(QPOOL(POOL))=DEL,
                  LOOP=BREAK,
                ENDIF,
              NEXT,
            ENDIF%:
```

```
!*********************************************************************!
!                              PART 5                                 !
!                  DRIVE TO DESTINATION AND UNLOAD                    !
!*********************************************************************!

DRV       *A;A(8): ! DELAY TO DRIVE TO DESTINATION
          *B;UNLOAD;;
            NO_LDS=NO_LDS+1,
            LATE=CUR.TIME-A(7),
            IF,LATE>0,THEN,NO_LATE=NO_LATE+1,ENDIF,
            COLLECT=LATE_HRS,
            IF,A(13)=2,THEN,        ! IF IM PICK-UP DRAY
              A(8)=EX(.25),
              A(12)=0,
            ELSE,
              POOL=11, ! LOOK FOR POOL AT DESTINATION
              IF,A(4)>=(42/57.3),AND,A(5)<=(-117/57.3),THEN,
                POOL=1,ENDIF,
              IF,A(4)>=(36/57.3),AND,A(4)<(42/57.3),AND,&
                A(5)<=(-117/57.3),THEN,POOL=2,ENDIF,
              IF,A(4)<(36/57.3),AND,A(5)<=(-109/57.3),THEN,
                POOL=3,ENDIF,
              IF,A(4)<(37/57.3),AND,A(5)<=(-91.5/57.3),AND,&
                A(5)>(-106.5/57.3),THEN,POOL=4,ENDIF,
              IF,A(4)<(37/57.3),AND,A(5)<=(-88/57.3),AND,&
                A(5)>(-91.5/57.3),THEN,POOL=5,ENDIF,
              IF,A(4)<(36/57.3),AND,A(5)>(-88/57.3),THEN,
                POOL=6,ENDIF,
              IF,A(4)>=(36/57.3),AND,A(4)<(42/57.3),AND,&
                A(5)>(-80.5/57.3),THEN,POOL=7,ENDIF,
              IF,A(4)>=(42/57.3),AND,A(5)>(-80.5/57.3),THEN,
                POOL=8,ENDIF,
              IF,A(4)>=(39.5/57.3),AND,A(5)<=(-80.5/57.3),AND,&
                A(5)>(-97/57.3),THEN,POOL=9,ENDIF,
              IF,A(4)>=(37/57.3),AND,A(4)<(39.5/57.3),AND,&
                A(5)<=(-88/57.3),AND,A(5)>(-95/57.3),THEN,
                POOL=10,ENDIF,
              RAND=RND,
              IF,RAND<=.5,THEN,        ! IF NOT LIVE UNLOAD 50% PROB.
                DRV_TYPE=A(11),
                A(11)=POOL,
                A(12)=3,
                INS(QUNLD)=TRANS,
                A(8)=EX(.25), ! UNHOOK TIME
                A(9)=A(9)-A(8),
                A(11)=DRV_TYPE,
                A(12)=0,
              ELSE,                     ! IF LIVE UNLOAD
                A(8)=EX(2),    ! UNLOAD TIME - NOT UNHOOKED
                A(9)=A(9)-A(8),
                A(12)=POOL,
              ENDIF,
            ENDIF%:

! QUEUE FOR UNLOADING TRAILERS NOT CONNECTED TO TRACTOR
QUNLD     *Q:
AUNLD     *A;EX(8): !UNLOAD TIME FOR NOT-LIVE-UNLOAD TRAILERS
```

```
          *B;TERM;;
            A(12)=0,
            INS(QPOOL(A(11)))=TRANS%:

UNLOAD    *A;A(8): ! DELAY TIME TO UNHOOK OR UNLOAD
          *B;TERM;;                ! FIND & DELETE COPY IN QDRVING
              LOAD_NMBR=A(1),
              FOR,I=1,TO,LEN(QDRVNG),DO,
                COPY=I(QDRVNG),
                IF,A(1)=LOAD_NMBR,THEN,
                  I(QDRVNG)=DEL,    ! DELETE DRIVER FROM DRIVING QUEUE
                  NXT_LD=A(10),     ! IF THERE IS A NEXT LOAD
                  TRANS=OLD,
                  A(10)=NXT_LD,
                  LOOP=BREAK,
                ENDIF,
              NEXT,
              A(2)=A(4),
              A(3)=A(5),
              IF,A(9)<=0,THEN,      ! SLEEP IF UNLOAD TOO LONG
                INS(QRSTNG)=TRANS,
                INS(QREST)=TRANS,
              ELSE,
                IF,A(10)>0,THEN,    ! IF NEXT LOAD ASSIGNED
                  A(1)=A(10),
                  A(10)=0,
                  INS(QDEADHD)=TRANS,
                ELSE,       ! IF NO NEXT LOAD ASSIGNED
                  A(10)=0,
                  INS(QRSTNG)=TRANS,
                  INS(QREST)=TRANS,
                ENDIF,
              ENDIF%:

!*********************************************************************!
!                              PART 6                                 !
!                           DRIVER RESTS                              !
!*********************************************************************!

QREST     *Q:  ! QUEUE FOR RESTING DRIVERS
AREST     *A;8: !REST FOR 8 HRS
          *B;TERM;;
            LOAD_NMBR=A(1),
            FOR,I=1,TO,LEN(QRSTNG),DO,
              COPY=I(QRSTNG),
              IF,A(1)=LOAD_NMBR,THEN,
                I(QRSTNG)=DEL, ! DELETE DRIVER FROM RESTING QUEUE
                TRANS=NEW,
                A(9)=10,
                A(1)=A(10),
                LOOP=BREAK,
              ENDIF,
            NEXT,
            IF,A(10)>0,THEN, ! IF THERE IS A NEXT LOAD TO BE PICKED UP
              A(10)=0,
              INS(QDEADHD)=TRANS,
            ELSE, ! IF NO NEXT LOAD DRIVER WAITS IN QAVAIL
```

```
      INS(QAVAIL)=TRANS,
    ENDIF%:
!**********************************************************************!
!                              END                                     !
!**********************************************************************!

$END:
! MAXIMUM NUMBER OF DRIVERS FOR EACH TYPE
$CONSTANTS:1-10/MAX_OTR=100,MAX_REG=100,MAX_LOC=100:
! TRAILER POOL CENTROIDS
$TABLE-LOOKUPS:1-10/11/1,46;2,39;3,34;4,32;5,34;6,34;7,39;8,43;
                       9,43;10,38;11,38: !POOL LAT CENTRIODS
                    11/1,-120;2,-120;3,-114;4,-97;5,-90;6,-83;
                       7,-78;8,-72;9,-89;10,-92,11,-98: !LONG CENT
!$TRACE=0-1000: ! FOR DEBUGGING PURPOSES
$RUN-LENGTH=1000:
!$TRANSIENT-PERIOD= : ! NEEDS TO BE DETERMINED
!$RUNS= :             ! NEEDS TO BE DETERMINED
$STOP:
```

# Appendix B

# Sample of Input Data

**Input Data for Load Information (February):**

(Load Number [reference number starting with 1], Original Latitude, Original Longitude, Destination Latitude, Destination Long, Pickup Time, Delivery Time, Next Load Number [equal to zero], Load Type, Load Status)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 34.73 | -79.31 | 43.04 | -76.15 | 1.00 | 81.00 | 0 | 3 | 1 |
| 2 | 33.94 | -118.20 | 36.06 | -119.03 | 1.14 | 48.01 | 0 | 2 | 1 |
| 3 | 34.73 | -79.31 | 40.53 | -74.33 | 2.02 | 55.02 | 0 | 3 | 1 |
| 4 | 40.30 | -76.88 | 39.14 | -75.51 | 4.00 | 72.00 | 0 | 2 | 3 |
| 5 | 40.30 | -76.88 | 39.14 | -75.51 | 4.01 | 72.01 | 0 | 2 | 3 |
| 6 | 40.30 | -76.88 | 39.43 | -76.77 | 4.02 | 83.02 | 0 | 1 | 3 |
| 7 | 34.73 | -79.31 | 41.39 | -84.14 | 4.03 | 62.03 | 0 | 3 | 1 |
| 8 | 34.73 | -79.31 | 39.98 | -75.22 | 4.04 | 33.04 | 0 | 3 | 1 |
| 9 | 34.73 | -79.31 | 36.85 | -76.21 | 4.04 | 56.04 | 0 | 3 | 1 |
| . | . | . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . | . | . |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Input Data for Trailer Information:**

(Destination Latitude, Destination Longitude, Trailer Pool, Trailer Status)

| | | | |
|---|---|---|---|
| 31.0000 | -103.700 | 4 | 0 |
| 37.0630 | -120.852 | 2 | 0 |
| 43.7121 | -73.8895 | 8 | 0 |
| 33.2083 | -92.6633 | 4 | 0 |
| 36.7650 | -90.4167 | 5 | 0 |
| 37.7566 | -100.022 | 11 | 0 |
| 28.7624 | -96.4759 | 4 | 0 |
| 45.7234 | -87.6304 | 9 | 0 |
| 33.0417 | -89.5713 | 5 | 0 |
| . | . | . | . |
| . | . | . | . |
| . | . | . | . |
| 0 | 0 | 0 | 0 |

# Appendix C

## Simulation Results

| Maximum Number of OTR Drivers | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Observations | | | | | | | | | |
| Scen | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 3425 | 4641 | 3528 | 3655 | 3498 | 3406 | 3505 | 3700 | 3355 | 3609 |
| 2a | 585 | 720 | 504 | 522 | 678 | 686 | 659 | 531 | 488 | 450 |
| 2b | 1900 | 1880 | 1975 | 2006 | 1935 | 1971 | 1935 | 2020 | 1838 | 1982 |
| 2 | 2485 | 2600 | 2479 | 2528 | 2613 | 2657 | 2594 | 2551 | 2326 | 2432 |
| 3 | 2329 | 2467 | 2459 | 2395 | 2328 | 2522 | 2432 | 2221 | 2221 | 2368 |
| **Maximum Number of Regional Drivers** | | | | | | | | | | |
| | Observations | | | | | | | | | |
| Scen | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 293 | 365 | 256 | 264 | 286 | 236 | 232 | 265 | 228 | 275 |
| 2a | 632 | 741 | 653 | 608 | 675 | 668 | 656 | 684 | 713 | 719 |
| 2b | 325 | 371 | 300 | 312 | 363 | 271 | 280 | 299 | 275 | 326 |
| 2 | 957 | 1112 | 953 | 920 | 1038 | 939 | 936 | 983 | 988 | 1045 |
| 3 | 866 | 995 | 778 | 834 | 885 | 823 | 856 | 866 | 916 | 931 |
| **Maximum Number of Local Drivers** | | | | | | | | | | |
| | Observations | | | | | | | | | |
| Scen | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 87 | 85 | 79 | 74 | 75 | 109 | 113 | 122 | 121 | 112 |
| 2a | 913 | 1089 | 918 | 916 | 939 | 928 | 939 | 959 | 1004 | 923 |
| 2b | 106 | 90 | 89 | 92 | 87 | 101 | 128 | 141 | 133 | 125 |
| 2 | 1019 | 1179 | 1007 | 1008 | 1026 | 1029 | 1067 | 1100 | 1137 | 1048 |
| 3 | 953 | 1171 | 987 | 993 | 960 | 1014 | 971 | 1005 | 1078 | 972 |
| **Maximum Number of Drivers (Local + Regional + OTR)** | | | | | | | | | | |
| | Observations | | | | | | | | | |
| Scen | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 3805 | 5091 | 3863 | 3993 | 3859 | 3751 | 3850 | 4087 | 3704 | 3996 |
| 2a | 2130 | 2550 | 2075 | 2046 | 2292 | 2282 | 2254 | 2174 | 2205 | 2092 |
| 2b | 2331 | 2341 | 2364 | 2410 | 2385 | 2343 | 2343 | 2460 | 2246 | 2433 |
| 2 | 4461 | 4891 | 4439 | 4456 | 4677 | 4625 | 4597 | 4634 | 4451 | 4525 |
| 3 | 4148 | 4633 | 4224 | 4222 | 4173 | 4359 | 4259 | 4092 | 4215 | 4271 |
| **Distance Traveled per OTR Driver per Day** | | | | | | | | | | |
| | Observations | | | | | | | | | |
| Scen | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 469.87 | 323.71 | 470.38 | 464.53 | 479.61 | 483.65 | 493.71 | 456.62 | 525.28 | 505.25 |
| 2a | 209.44 | 164.40 | 234.77 | 213.40 | 183.48 | 185.95 | 195.30 | 225.12 | 248.43 | 256.34 |
| 2b | 439.35 | 450.80 | 433.32 | 436.86 | 458.42 | 432.88 | 447.80 | 428.94 | 501.25 | 455.21 |
| 2 | 385.22 | 371.49 | 392.96 | 390.72 | 387.08 | 369.13 | 383.65 | 386.51 | 448.21 | 418.41 |
| 3 | 429.79 | 396.26 | 408.60 | 427.92 | 449.18 | 403.67 | 429.84 | 464.63 | 479.20 | 452.33 |

| Distance Traveled per Regional Driver per Day | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Observations | | | | | | | | | |
| Scen | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 284.15 | 243.87 | 289.03 | 312.43 | 282.83 | 277.33 | 320.16 | 286.75 | 312.45 | 259.94 |
| 2a | 258.98 | 244.60 | 243.48 | 250.24 | 238.76 | 226.24 | 250.07 | 232.10 | 245.11 | 240.10 |
| 2b | 315.22 | 268.12 | 295.00 | 302.90 | 271.72 | 289.57 | 314.43 | 310.56 | 305.05 | 263.28 |
| 2 | 278.08 | 252.44 | 259.70 | 268.10 | 250.29 | 244.52 | 269.32 | 255.96 | 261.79 | 247.33 |
| 3 | 304.10 | 273.38 | 301.01 | 296.82 | 288.63 | 271.28 | 289.39 | 282.05 | 277.49 | 267.94 |
| Distance Traveled per Local Driver per Day | | | | | | | | | | |
| | Observations | | | | | | | | | |
| Scen | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 255.98 | 227.76 | 227.76 | 227.07 | 278.47 | 217.50 | 223.77 | 252.14 | 252.30 | 255.39 |
| 2a | 178.35 | 174.53 | 175.90 | 175.75 | 191.42 | 167.60 | 189.25 | 202.54 | 184.38 | 213.22 |
| 2b | 254.15 | 237.60 | 239.51 | 233.36 | 290.65 | 283.23 | 232.41 | 276.33 | 291.86 | 276.22 |
| 2 | 186.23 | 179.34 | 181.52 | 181.00 | 199.83 | 178.95 | 194.43 | 212.00 | 196.95 | 220.73 |
| 3 | 197.93 | 177.97 | 177.45 | 181.79 | 212.29 | 178.48 | 213.35 | 225.34 | 209.07 | 242.31 |
| Average Bobtail per Load | | | | | | | | | | |
| | Observations | | | | | | | | | |
| Scen | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 131.03 | 168.10 | 109.31 | 154.56 | 138.91 | 153.96 | 133.34 | 113.50 | 137.67 | 148.84 |
| 2a | 205.70 | 230.38 | 195.53 | 190.84 | 193.36 | 199.13 | 204.50 | 201.34 | 202.75 | 201.11 |
| 2b | 140.28 | 134.72 | 147.08 | 154.06 | 145.20 | 162.68 | 134.86 | 126.95 | 174.52 | 138.64 |
| 2 | 171.52 | 184.59 | 169.73 | 170.95 | 168.80 | 180.67 | 169.00 | 161.85 | 188.51 | 167.52 |
| 3 | 205.35 | 202.72 | 194.49 | 198.32 | 200.86 | 202.56 | 199.94 | 200.72 | 205.63 | 204.25 |
| Average Deadhead per load | | | | | | | | | | |
| | Observations | | | | | | | | | |
| Scen | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 83.42 | 108.21 | 72.53 | 97.82 | 86.52 | 96.51 | 85.24 | 73.02 | 87.00 | 91.99 |
| 2a | 174.25 | 174.99 | 157.57 | 155.12 | 151.05 | 149.68 | 161.16 | 152.94 | 154.49 | 157.49 |
| 2b | 87.18 | 84.38 | 93.20 | 98.51 | 90.53 | 102.32 | 83.26 | 78.98 | 106.13 | 87.86 |
| 2 | 128.75 | 131.62 | 123.29 | 124.50 | 120.19 | 125.69 | 121.45 | 113.68 | 130.08 | 120.05 |
| 3 | 144.77 | 133.74 | 133.91 | 137.43 | 135.90 | 139.15 | 142.34 | 133.14 | 139.42 | 139.55 |
| Average Loaded Miles per Load | | | | | | | | | | |
| | Observations | | | | | | | | | |
| Scen | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 1004.2 | 982.0 | 999.6 | 980.2 | 984.6 | 1019.0 | 1022.4 | 991.1 | 1014.2 | 1010.8 |
| 2a | 150.4 | 142.6 | 134.6 | 132.7 | 143.4 | 151.9 | 144.6 | 131.0 | 130.6 | 125.3 |
| 2b | 628.9 | 630.0 | 623.5 | 626.6 | 611.5 | 645.3 | 633.0 | 617.9 | 628.2 | 617.7 |
| 2 | 400.4 | 375.9 | 395.0 | 399.8 | 382.1 | 401.8 | 393.6 | 389.5 | 381.7 | 390.0 |
| 3 | 436.6 | 428.7 | 419.2 | 424.4 | 413.0 | 443.3 | 425.6 | 407.3 | 406.1 | 402.2 |

| Average Late Hours per Load | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Observations | | | | | | | | | |
| Scen | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | -26.8 | -19.5 | -32.0 | -24.6 | -22.7 | -26.9 | -29.0 | -33.4 | -25.9 | -23.2 |
| 2a | -37.4 | -97.9 | -117.0 | -129.8 | -103.1 | -121.6 | -132.2 | -135.1 | -165.1 | -127.8 |
| 2b | -14.9 | -15.7 | -16.5 | -15.0 | -16.3 | -13.5 | -14.9 | -18.3 | -10.7 | -14.1 |
| 2 | -25.6 | -58.6 | -63.5 | -67.7 | -58.8 | -66.8 | -72.4 | -73.1 | -87.2 | -66.6 |
| 3 | -20.5 | -48.0 | -53.6 | -59.9 | -49.8 | -53.4 | -61.6 | -64.2 | -78.2 | -61.1 |
| **Ratio of Loads Delivered Late** | | | | | | | | | | |
| | Observations | | | | | | | | | |
| Scen | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 0.278 | 0.357 | 0.232 | 0.307 | 0.316 | 0.278 | 0.289 | 0.246 | 0.278 | 0.315 |
| 2a | 0.150 | 0.155 | 0.132 | 0.125 | 0.214 | 0.128 | 0.120 | 0.122 | 0.130 | 0.123 |
| 2b | 0.330 | 0.326 | 0.302 | 0.345 | 0.333 | 0.320 | 0.332 | 0.299 | 0.370 | 0.347 |
| 2 | 0.244 | 0.237 | 0.223 | 0.244 | 0.275 | 0.225 | 0.228 | 0.216 | 0.251 | 0.243 |
| 3 | 0.283 | 0.258 | 0.250 | 0.265 | 0.308 | 0.261 | 0.268 | 0.252 | 0.263 | 0.275 |

# Appendix D

# Duncan's Multiple Range Test Calculations

| Maximum Number of OTR Drivers | | | | |
|---|---|---|---|---|
| Comparisons | Diff in Means | | Least Sign Ranges | Results |
| 1 vs. 3 | 1258.00 | > | 221.77 | sign diff |
| 1 vs. 2 | 1105.70 | > | 210.90 | sign diff |
| 2 vs. 3 | 152.30 | < | 210.90 | not sign diff |
| **Maximum Number of Regional Drivers** | | | | |
| Comparisons | Diff in Means | | Least Sign Ranges | Results |
| 2 vs. 1 | 717.10 | > | 53.01 | sign diff |
| 2 vs. 3 | 112.10 | > | 50.41 | sign diff |
| 3 vs. 1 | 605.00 | > | 50.41 | sign diff |
| **Maximum Number of Local Drivers** | | | | |
| Comparisons | Diff in Means | | Least Sign Ranges | Results |
| 2 vs. 1 | 964.30 | > | 50.86 | sign diff |
| 2 vs. 3 | 51.60 | > | 48.36 | sign diff |
| 3 vs. 1 | 912.70 | > | 48.36 | sign diff |
| **Maximum Number of Drivers (Local + Regional + OTR)** | | | | |
| Comparisons | Diff in Means | | Least Sign Ranges | Results |
| 2 vs. 3 | 575.70 | > | 251.70 | sign diff |
| 2 vs. 1 | 316.00 | > | 239.35 | sign diff |
| 1 vs. 3 | 259.70 | > | 239.35 | sign diff |
| **Distance Traveled per OTR Driver per Day** | | | | |
| Comparisons | Diff in Means | | Least Sign Ranges | Results |
| 1 vs. 2 | 73.92 | > | 36.39 | sign diff |
| 1 vs. 3 | 33.12 | < | 34.61 | not sign diff |
| 3 vs. 2 | 40.80 | > | 34.61 | sign diff |
| **Distance Traveled per Regional Driver per Day** | | | | |
| Comparisons | Diff in Means | | Least Sign Ranges | Results |
| 1 vs. 2 | 28.14 | > | 16.24 | sign diff |
| 1 vs. 3 | 1.68 | < | 15.45 | not sign diff |
| 3 vs. 2 | 26.45 | > | 15.45 | sign diff |
| **Distance Traveled per Local Driver per Day** | | | | |
| Comparisons | Diff in Means | | Least Sign Ranges | Results |
| 1 vs. 2 | 48.71 | > | 18.60 | sign diff |
| 1 vs. 3 | 40.22 | > | 17.68 | sign diff |
| 3 vs. 2 | 8.50 | < | 17.68 | not sign diff |
| **Average Bobtail per Load** | | | | |
| Comparisons | Diff in Means | | Least Sign Ranges | Results |
| 3 vs. 1 | 62.56 | > | 11.44 | sign diff |
| 3 vs. 2 | 28.17 | > | 10.88 | sign diff |
| 2 vs. 1 | 34.39 | > | 10.88 | sign diff |

| **Average Deadhead per Load** | | | | |
|---|---|---|---|---|
| Comparisons | Diff in Means | | Least Sign Ranges | Results |
| 3 vs. 1 | 49.71 | > | 7.17 | sign diff |
| 3 vs. 2 | 14.01 | > | 6.82 | sign diff |
| 2 vs. 1 | 35.70 | > | 6.82 | sign diff |
| **Average Loaded Miles per Load** | | | | |
| Comparisons | Diff in Means | | Least Sign Ranges | Results |
| 1 vs. 2 | 609.81 | > | 12.60 | sign diff |
| 1 vs. 3 | 580.15 | > | 11.99 | sign diff |
| 3 vs. 2 | 29.67 | > | 11.99 | sign diff |
| **Average Late Hours per Load** | | | | |
| Comparisons | Diff in Means | | Least Sign Ranges | Results |
| 1 vs. 2 | 37.64 | > | 12.35 | sign diff |
| 1 vs. 3 | 28.64 | > | 11.75 | sign diff |
| 3 vs. 2 | 9.00 | < | 11.75 | not sign diff |
| **Ratio of Loads Delivered Late** | | | | |
| Comparisons | Diff in Means | | Least Sign Ranges | Results |
| 1 vs. 2 | 0.051103 | > | 0.024303 | sign diff |
| 1 vs. 3 | 0.021487 | < | 0.023111 | not sign diff |
| 3 vs. 2 | 0.029617 | > | 0.023111 | sign diff |