AN ABSTRACT OF THE THESIS OF

Kyler S. Kokenge for the degree of Master of Science in Forest Engineering and Civil Engineering presented on June 8, 2011.

Title: Opportunities and Challenges for Decision Support Systems in Log Truck Scheduling and Dispatching

Abstract approved:

John Sessions   Katharine M. Hunter-Zaworski

The transportation of logs from the forest to the mill accounts for 25-50% of the delivered cost of wood, depending mostly on haul distance. Decision support systems (DSS) for log truck scheduling and dispatching have the potential to reduce transportation costs by optimally constructing routes, also known as schedules for each truck in the fleet. The benefits that are typically achieved from DSS for log truck scheduling and dispatching include increases in capacity through reductions in the total vehicle miles traveled and the number of trucks needed to service all customer loads. Research has shown that the cost reductions expected from implementation could be five percent or more depending on the efficiency of the existing transportation system and the spatial arrangement of log sources and destinations.

There have been implementations of DSS for log truck scheduling and dispatching in the United States and elsewhere in the past, but the adoption of these systems has been slow. Most of the research involving DSS for log truck scheduling and dispatching focuses on the development of better solution methods for the log truck scheduling problem (LTSP); however, less attention has been paid to identifying the challenges that are slowing the adoption of DSS. This project aims to identify the unique characteristics of the forest industry related to log transportation and management, evaluate the existing technologies for log truck scheduling and dispatching, assess the availability of DSS for log truck scheduling and dispatching, and determine the challenges and opportunities of implementing DSS for log truck scheduling and dispatching in the Pacific Northwest.

Opportunities and Challenges for

Decision Support Systems in Log Truck Scheduling and Dispatching

by

Kyler S. Kokenge

A THESIS

submitted to

Oregon State University

in partial fulfillment of

the requirements for the

degree of

Master of Science

Presented June 8, 2011

Commencement June 2012

Master of Science thesis of <u>Kyler S. Kokenge</u> presented on <u>June 8, 2011</u>.

APPROVED:

_____

Co-Major Professor, representing Forest Engineering

_____

Co-Major Professor, representing Civil Engineering

_____

Head of the Department of Forest Engineering, Resources and Management

_____

Head of the School of Civil and Construction Engineering

_____

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

_____

Kyler S. Kokenge, Author

ACKNOWLEDGEMENTS

CONTRIBUTION OF AUTHORS

I would like to recognize Dr. John Sessions for his contributions to the content of this thesis.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

Opportunities and Challenges for

Decision Support Systems in Log Truck Scheduling and Dispatching

Chapter 1 – Introduction

Forests are highly valued in the Pacific Northwest and throughout the world for a variety of reasons. They provide beautiful and aesthetic landscapes for recreation, pristine rivers for fishing and rafting, and resources that sustain regional and local economies. In today's society, sustainable forest management is relied upon to ensure that wood products will be available to meet current societal demand and ensure that forests will be there to provide the same opportunities and resources for future generations.

In Oregon alone, approximately 27.5 million acres of forest land covers 45% of the state. Nearly 11 million acres of these lands are privately owned, comprising about 39% of Oregon's total forest land. Federal lands in Oregon, which make up 57% of the total forest land, are increasingly being managed to provide environmental services; placing more reliance on private lands to produce logs for the state's resource based industries (Oregon Department of Forestry, 2001).

The transportation of logs from the forest to the mill is the single largest cost for the majority of landowners. In fact, it has been estimated to represent as much as 25-50% of the total cost of delivered wood, depending on the distance traveled

(McDonald et al., 2001a). Therefore, even small increases in transportation efficiency can amount to significant savings.

A variety of methods are currently used for log truck scheduling and dispatching. In some organizations drivers are able to decide on their own schedules whereas others are provided with schedules by a central dispatch. Often in the forest industry, the truck scheduling and dispatching is done manually by a dispatcher back at the office. These dispatchers rely heavily on past experience and logic to generate truck schedules.

There is evidence that decision support systems (DSS) have the capability to reduce the cost of log transportation from the forest to the mill. Decision support systems are computer-based information systems that support organizations or businesses in making decisions about certain activities. Truck scheduling and truck dispatching are two activities that can be supported by DSS for log transportation.

Decision support systems can reduce transportation costs by generating efficient truck routes. If a time component is considered in the route construction, then the route is referred to as the truck schedule. Time is often important in real world applications; therefore, improved schedules can help trucking contractors pick up more loads with fewer trucks by traveling more efficient truck routes. Despite implementations of these systems in other countries and by other industries, parties involved in log transportation in the United States have been slow to adopt decision support systems for log truck scheduling and dispatching.

1.1   Project Objectives

This project is part of a larger effort to help improve supply chain efficiency in the forest products industry. Currently, most of the literature is focused on developing improved solution techniques for decision support systems (DSS) in log truck scheduling and dispatching. Less attention has been geared towards identifying the challenges that are slowing the adoption of DSS for log truck scheduling and dispatching. The goal of this project is to contribute to a vibrant forest products industry by performing a synthesis of these challenges and identifying opportunities for implementation in the Pacific Northwest. The objectives of this project are to:

- Identify the unique characteristics of the forest industry related to transportation and management.

- Examine different log truck scheduling and dispatching solution techniques.

- Evaluate the current state of technologies for decision support systems.

- Assess the availability of decision support systems for log transportation.

- Determine the challenges and opportunities of implementing decision support systems in the Pacific Northwest.

- Determine how other industries and countries overcame some of the challenges identified in the Pacific Northwest.

- Identify under which conditions the benefits will outweigh the costs of purchasing and implementing these systems.

1.2   Project Scope

Due to the time and resources available for this project, the goal was to gather as much information as possible from interviews with professionals involved in log transportation and professionals who are developing products to improve the supply chain. We interviewed a variety of industry professionals including:

- Timberland owners

- Trucking contractors

- Truck drivers

- Logging contractors

- Software developers and marketers

To supplement what was learned through talks with these individuals, a literature review was performed to learn about the nature of the problem, solution techniques, and how other industries and countries overcame the challenges identified in the Pacific Northwest.

Chapter 2 – Freight Movement and the Parties Involved in Log Transportation

The importance of freight movement to global, regional, and local economies is difficult to overstate. In order to remain competitive in all markets, it is important for businesses to efficiently use equipment, fuel, and human resources. Poor planning, congestion, and unexpected events such as bad weather and breakdowns commonly lead to inefficiencies in freight movement.

Different modes are used to move freight in the United States including ships, trains, and airplanes; however, trucks carry over 75% of America's freight when measured by tons and over 90% of America's freight when measured by value (AASHTO, 2009). This can likely be attributed to trucks being used as a direct link between all the other modes of freight movement. For example, trucks often transport export loads to ports and transport import loads inland to distribution centers. Similarly, trucks are responsible for transporting goods to and from rail yards and airports.

The state of Oregon ranked 10th in the nation in tonnage exported in 2001. By the year 2030, the tonnage exported is predicted to increase by 80% from 57 million tons to 122 million tons and it is predicted that Oregonians will rely even more heavily on trucks to transport freight in the future (Figure 1). Over 25% of the total tonnage shipped in Oregon is products that come from forest; thus, an estimated 115 million tons of logs, lumber, and wood products are transported annually by log trucks

(Figure2). This is also expected to increase by approximately 60% by 2030 (Global

Insight, Inc., 2005).
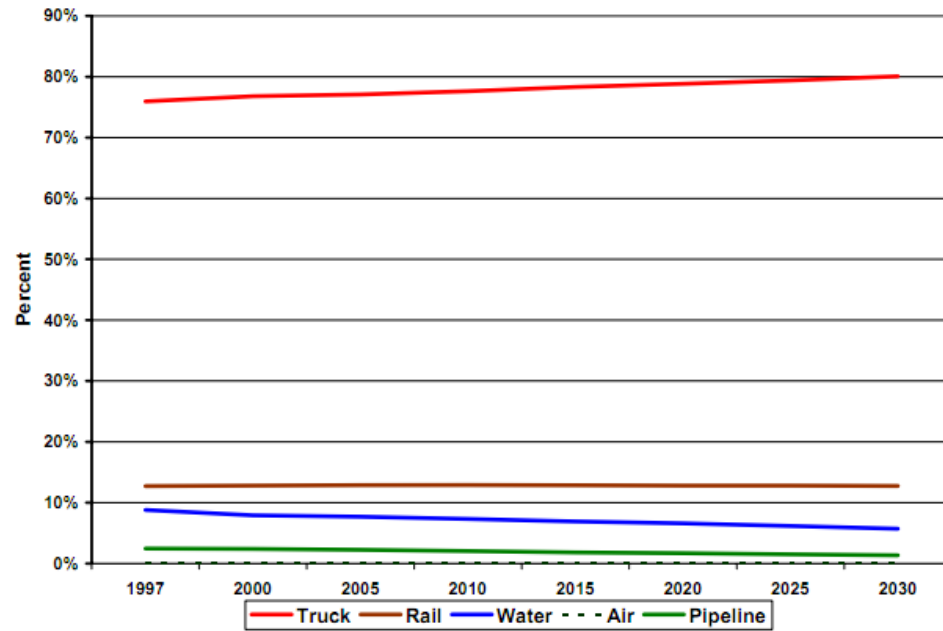
Figure 1: Mode share of tonnage (Global Insight, Inc., 2005)
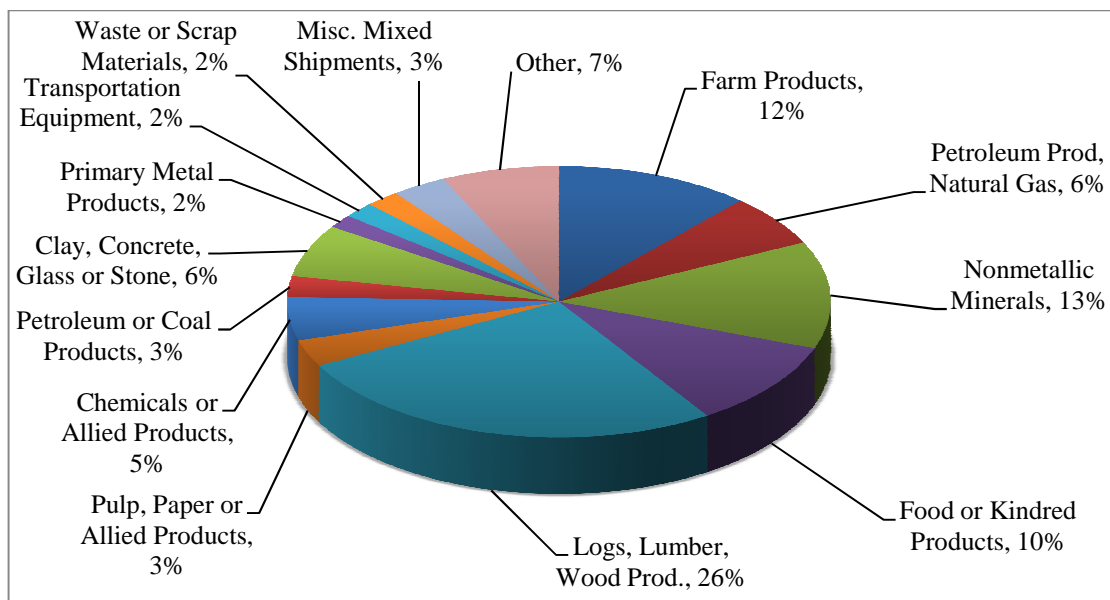
Figure 2: Percentage of total tons shipped by commodity in Oregon in 2000 (Global

Insight, Inc., 2005)

In 2004 loaded trucks traveled 164 billion miles on the US roadways and

experts are predicting that number will double in the next 30 years. Currently, only 30

miles of Interstate highways carry more than 50,000 trucks in a day, but by 2035 it is

predicted to increase to 2,500 miles carrying more than 50,000 trucks daily. In other

words, the average Interstate highway carries 10,500 trucks per day, but that is

expected to increase to 22,700 by 2035 (AASHTO, 2009). Unless things change,

congestion and the costs related to congestion will increase, e.g. fuel consumption and

poor utilization of equipment and human resources.

Congestion already slows the delivery of commodities throughout Oregon. Naturally, the number of vehicle miles traveled in Oregon has increased with population growth; however, the capacity added to the state infrastructure has not matched the increase in traffic. In fact, population has grown about four times faster than the number of roadway lane-miles. Although the number of vehicle miles statewide has increased since 1982, the number of vehicle miles per capita has remained nearly level since 1990 due to compacted land use and increases in public transit use especially in the Portland metropolitan area (Figure 3).
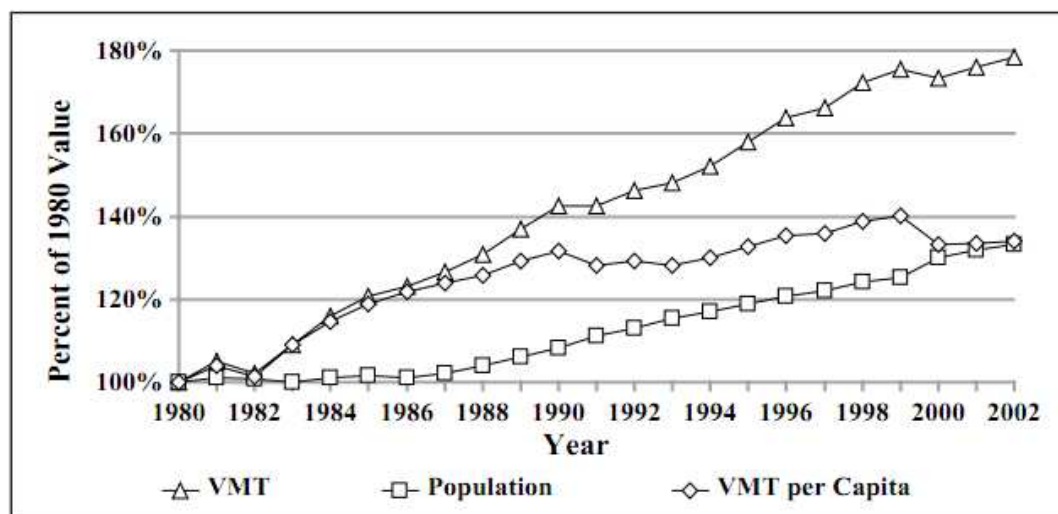
Figure 3: Statewide vehicle miles traveled, population, and vehicle miles traveled per capita in Oregon 1980-2002 (Oregon Department of Transportation, 2007)

If the infrastructure is not able to handle current traffic volumes, the situation will deteriorate in the future as congestion threatens Oregon's aspirations for a just-in-time economy. There are three solutions that can immediately reduce congestion:

(1) Add more infrastructure capacity

(2) Use intelligent transportation systems

(3) Reduce the number of vehicles on the road

Adding infrastructure capacity is expensive. Before capital is invested in constructing more roadway miles, planners often seek ways to alleviate pressure on the current system by encouraging other modes of transportation and by maximizing the capacity of the existing infrastructure using intelligent transportation systems (ITS). Intelligent transportation systems encompass a broad range of communications and wireless technologies that help improve the safety, mobility, efficiency, and sustainability of transportation systems. Examples of ITS applications include vehicle collision avoidance technologies, electronic tolling, real-time traffic and transit information, GPS-equipped navigational devices, "smart" traffic signals, congestion pricing systems, weigh-in-motion truck inspection, variable speed limits, and transit signal priority.

While ITS can help agencies maximize the capacity of existing public roads, advancements in integrated technologies have led to the development of decision support systems (DSS) that can help carriers improve customer service while reducing the number of trucks needed through more efficient truck scheduling and dispatching. Before discussing decision support systems for truck scheduling and dispatching, it is useful to understand the goals and problems of all stakeholders involved.

Regardless of the mode of freight transport, three parties are generally involved: a shipper, a carrier, and a customer. Furthermore, the shipper, carrier, and customer are all integral parts of what is commonly referred to as the supply chain. In economic terms, the shipper is the supplier of a product who would like to transport their product to one or more points of demand, also known as customers. The carrier is therefore the middle agent who transports the products between the parties for a fee.

The problem that the shipper and customer are trying to solve is a classic logistics problem of how to ensure that products are where they need to be, when they need to be, and in a cost efficient manner. Meanwhile, the most crucial challenge that carriers face is trying to reduce costs while improving service; creating a highly competitive business environment. Additionally, carriers with a large number of vehicles have to make complex scheduling and dispatching decisions in order to maximize their utilization of equipment and human resources (Institute of Transportation Engineers, 2000).

For all intents and purposes, the shipper in the log transportation scenario is the landowner or organization who owns the logs on the landing. In forestry, a landing is defined as a central area in the forest that felled logs are skidded or yarded to for loading onto a truck. The customer is the organization that demands the logs, most likely sawmills, veneer and plywood mills, pulp and paper mills, or sort yards. It is possible that the shipper and the customer could be different branches of the same company, i.e., the landowner could also own the mill.

The carrier, also referred to as the trucking contractor, is the company that owns and operates the log trucks. The trucks can be owned by the log supplier, the mills, the logging contractor, or a third party trucking contractor. A third party trucking contractor may own a fleet of log trucks or own a single truck. If the contractor owns a single truck, they are referred to as an owner-operator.

2.1   Log Transportation

While log transportation operations may differ between companies, many of the major players approach the problem in a similar fashion in the Pacific Northwest. In other countries around the world, the approach to the problem is fundamentally different. In the United States, it is typically the responsibility of the landowner to determine how their logs will be transported to the appropriate mills to achieve the most profit. Some landowners are free to send their logs to whichever mills they please while others are contracted to deliver only to specific mills. In other countries, it is the responsibility of the mills to determine where to acquire the logs from and how to transport them to their facilities in order to satisfy their own demand at the lowest cost.

This fundamental difference is important to consider when determining the appropriate mathematical formulations, constraints, and solution procedures for log truck transportation problems. Despite this difference, the goal in either case is to determine how to transport logs between destinations in a least cost fashion. Since the

goal of this project is to contribute to a vibrant forest products industry in the Pacific Northwest, the problem is looked at from that viewpoint.

The three major problems in log truck fleet management are routing, scheduling, and dispatching. Generally speaking, a route is the path that a vehicle travels between two points. In common freight movement and log transportation, the term "route" is often synonymous with "the sequence of pickups and deliveries a truck performs" because the sequence ultimately helps define the truck's travel path. A pickup and delivery are referred to as a trip within the truck's route. Since pickups and deliveries are paired as trips, the problem is then to determine the sequence in which trips are to be performed to achieve the lowest cost possible.

When a time component is incorporated into the development of a truck route, it is then referred to as the truck's schedule. The truck scheduling problem is then to determine the sequence of pickups and deliveries as well as the associated arrival times at each location for each truck subject to some constraints. In forestry, log truck schedules are usually developed the day before; however, some operations do not use truck schedules at all and rely on dispatching to inform drivers of new trip sequences as the day goes on.

Dispatching is a procedure for assigning log trucks to customers in real-time. If a schedule is developed for a truck to begin the day, dispatching is used to adapt or repair the schedule when conditions change including customer orders, equipment breakdowns, weather, and congestion. This means updating drivers on the fly with

new trip sequences or routes to destinations. If schedules are not developed in

advance, dispatching is used to inform the driver of their next trip sequence as soon as

they complete a delivery.

To fully understand the problem, it is helpful to describe the roles, operations,

and concerns for each party involved in log transportation in the Pacific Northwest.

2.1.1   The Landowner

First, the landowner makes the decision to harvest trees from a tract of land on

their property. The landowner then hires a logging contractor who agrees to perform

the harvest for a price. The landowner decides how the wood will be transported from

the landings to the destinations. In some cases, the landowner hires both the logging

contractor and the trucking contractor and pays them separately; other times the

landowner allows the logging contractor to hire the trucking contractor and it is then

the contractor's responsibility to pay for the transportation; however, the logging

contractor will include the cost of transportation in their agreement with the

landowner.

Once the harvest operation is in progress, the landowner is constantly trying to

find the best destinations for their wood to make the most profit. Some landowners

have agreements to send their logs to only certain mills while others are free to send

their logs where they please. In addition to keeping the logger informed on the

destinations for each sort, the landowner also makes sure that the logger and the

trucking contractor are in compliance with their contracts. In forestry, the log species,

grade, end use (pulp, paper, structural, flooring, etc.) or combination thereof determines the assortment; often called "sort" for short. The sort is usually the deciding factor in determining where the logs are sent to achieve the most profit.

2.1.2   The Logging Contractor

The logging contractor is hired by the landowner to harvest a tract of land for a price. In harvest operations, logs are often transported to a central area called a landing to be placed into sorts. At the landing, a loader is used to place the logs onto trucks for secondary transportation to the mills.

Often in harvest operations, it is the responsibility of the loader operator to contact the trucking contractor in the afternoon and make transportation requests for the next day. The request usually includes the number of trucks needed for the day, the spacing between each truck in the morning for first loads, and sometimes the destination of the loads.

When a truck arrives, the loader operator tells the driver the destination of the load and if they are to return for another, acting as the pseudo-dispatcher. The roundtrip time to the mill is usually known by the loader operator who uses that knowledge to plan how to use the loader in the meantime to maximize productivity and equipment utilization. As the day continues, the time windows for subsequent loads become wider; however, the logger's productivity remains constant as long as they are not waiting on trucks. The logging contractor's main concern is maintaining or increasing their productivity. It is advantageous for them to have control of the

truck dispatching because productivity can decrease if excess logs on the landing are creating bottlenecks due to trucks arriving late. In addition, the logging contractor is more likely to get all their log loads serviced if they have control of the trucks throughout the day.

A common problem for many operations is queuing times at the landings for log trucks waiting to be loaded. This is looked at differently by the logging contractor and the trucking contractor. It is seen as a problem for the trucking contractor, but not necessarily the logging contractor. Since the trucks are being paid either by weight, by the mile, or by the load, it becomes a disadvantage to the carrier when trucks are waiting to be loaded. The carrier would prefer to run operations similar to just-in-time manufacturing, where the trucks show up at the exact moment needed to continue operations. Meanwhile, the logger can afford for the trucks to wait because it is not affecting their bottom line or productivity; unless the trucks are owned by the logger.

2.1.3   The Trucking Contractor

Trucking contractors usually start receiving calls in the afternoon from logging contractors requesting transportation services for the next day. The logging contractors usually request a fixed number of trucks for the next day. It is usually assumed that the logging contractor will have enough work to keep each truck busy for the entire day. It is then the dispatcher's job to determine which trucks to assign to each logging contractor for the next day.

The role the dispatcher plays once the trucks have left the garage depends on the operation. If schedules are used, which is often not the case in the Pacific Northwest, it is the dispatcher's responsibility to update truck trip sequences as unexpected events happen throughout the day such as breakdowns, customer order changes, bad weather, and congestion. If schedules are not used, it is the dispatcher's responsibility to determine each truck's next trip sequence immediately after it completes a delivery.

The dispatcher must be able to route and reroute trucks quickly and efficiently in order to minimize the cost of transporting customer loads. In addition, they must keep track of daily and weekly driver hours for safety and to be in compliance with company policy and state laws. This becomes more complex as trucks travel interstate because state laws can differ.

The trucking contractor's goal is to maximize profit by increasing the loaded efficiency of their trucks. The loaded efficiency is a measure of the truck's utilization and is represented by the percentage of the miles that the truck travels loaded. If the loaded efficiency of a truck increases, it usually results in the truck being able to service more loads in the same amount of time, i.e. the truck is more productive for the trucking contractor.

Loaded Efficiency = (Loaded Miles Traveled / Total Miles Traveled) * 100

In order to increase the loaded efficiency of their vehicles and service more loads, dispatchers are always trying to find backhaul. Backhaul is the loaded return

trip of a truck after it has delivered a load. Often in forestry the return trips are unloaded. The time the truck travels unloaded back to a supply point is referred to as empty travel time or unloaded travel time. Backhaul can be achieved by finding another supply point near the delivery location that has wood that needs to be delivered to a location in the vicinity of the original supply point.

Aside from trying to increase the loaded miles traveled by finding backhaul, the trucking contractor also aims to minimize the deadhead miles traveled. Deadhead miles are the miles that a truck incurs at the beginning of the day traveling from the garage to the first supply point and at the end of the day traveling back to the garage after delivering the last load. If the truck is paid by the hour, a long deadhead can get expensive to the party paying the driver. If paid by the load, it becomes a non-cost to the party paying the driver except the driver loses productive time and the deadhead decreases the loaded efficiency of the truck. To decrease the deadhead travel, dispatchers try to assign trucks to pick up loads that are close to the garage at the beginning of the day. In addition, dispatchers try to assign loads to trucks that will be delivered to mills close to the garage at the end of the day.

2.1.4 The Dispatcher

Dispatchers would like to know, with certainty, specific information in order to construct optimized schedules and trip sequences for their vehicle fleets. Dispatchers would like to know the following:

- The number of loads to be picked up from each landing

- The service time windows for each load, landing, and mill

- The destination for each load

- The average loaded and unloaded haul times between landings and mills

- The approximate loading and unloading time at each location

- The maximum number of hours each driver can drive daily and weekly

- The maximum distance each truck can travel daily

- Cost per unit time for each truck

- Cost per unit distance

- Fixed costs

- The truck and trailer configuration for each load

- Road restrictions (Max vehicle weight, length, or height)

- Breakdowns

- Queues related to traffic congestion on the road or at the mill throughout the day

The reality is that some of this information can't be predicted. If it can be predicted, it is usually not known with great certainty. The number of loads at each landing is difficult to predict a day in advance because of a number of variables that factor into the harvest production rate including the terrain, tree size, species, harvesting system, crew experience, and weather. Moreover, even if the number of loads and their destinations are known, it is common for sorts to change in the middle of the day. This means that the log species, size, quality, or end use has changed. When sorts change, it often results in a change of destination for each load.

Assuming that the number of loads, time windows, and destinations of each load are known the day before, the transportation managers could, in theory, create optimized schedules using advanced solution methods that would increase transportation efficiency. However, the unpredictable nature of the industry makes it difficult for transportation managers to create schedules with certainty. Therefore, dispatchers must be able to make decisions that will place the company in the best position to succeed for the rest of the day in a time sensitive manner.

Chapter 3 – Problems Related to the Log Truck Scheduling Problem

3.1   The Traveling Salesman Problem

The Traveling Salesman Problem (TSP) is a well known combinatorial optimization problem in Operations Research. Given a collection of cities and the distances between each, the goal of the TSP is to find the minimum path or cost of visiting all of the cities exactly once and returning to the same starting point. While the concept seems deceptively simple, it is actually one of the most studied problems in Operations Research. The reason the TSP has been the attention of considerable study is because it is an NP-hard problem and currently no algorithms have been developed that can solve it in polynomial time.

As problems grow larger in terms of size and complexity, they can become what are referred to as NP-hard (non-deterministic polynomial-time hard), which essentially refers to the time an algorithm takes to reach an exact solution. The problem becomes NP-hard when the number of variables, especially binary or integer variables, increases to the point where solution time increases exponentially. Many practical vehicle routing problems are NP-hard and; therefore, are often solved using heuristics which do not guarantee an optimal answer, but can achieve good solutions in a short amount of time.

3.2   Vehicle Routing Problems

An extension to the traveling salesman problem is the vehicle routing problem (VRP). The VRP is a problem that was first proposed by Dantzig and Ramser (1959)

and is a classic problem in the fields of logistics, distribution, and transportation that has many variations. The basic premise of the VRP is to determine the optimal set of routes for a fleet of vehicles in order to satisfy the demand of each customer. If a single vehicle that has unlimited capacity is considered, the problem then becomes the TSP.

Typical constraints included in the VRP are:

- Each vehicle must begin and end the day at a depot.

- Each customer must be visited exactly once.

- Customer demand must not exceed a vehicle's capacity.

There are a number of variations of the vehicle routing problem. One of the most common variations of the VRP for solving real life problems includes the use of time windows constraints. These problems are referred to as vehicle routing problems with time windows (VRPTW). As the name implies, time windows represent the windows of time that trucks may arrive at locations to service customers. The opening and closing times of businesses are usually considered and in some cases driver breaks are also considered. In VRPTW's, all the constraints of the standard VRP still apply with the addition of the time windows.

The pickup and delivery problem with time windows (PDPTW) is another variation of the VRP except pickups are now also included. In the previous variations discussed, vehicles are typically loaded to start the day at a depot, e.g. a warehouse, and continually make deliveries until the truck is empty. In the PDPTW, however, the

driver leaves from the depot unloaded and must make pickups before any deliveries can be completed. The goal is to minimize the cost of transporting the goods by optimally constructing truck routes subject to the same constraints except pickups must always precede deliveries.

In many real-life problems, the goods coming from a certain supply point are often paired with a specific customer, called a paired order. A paired order is used when the good being transported is not homogenous and thus is not able to satisfy the demand of every customer. Therefore, each transportation request has a specific origin and destination that are paired together. Most log transportation scenarios in the Pacific Northwest fall into this category because the log sort usually determines the mill destination. In addition to the sort, some landowners are contractually obligated to deliver their wood to certain mills. Therefore, the driver is always informed of the destination for each load and does not have the freedom to choose the mill destination; therefore, the load (origin) is paired with a mill (destination).

3.3   *Solution Methods for Vehicle Routing Problems*

There are a number of Operations Research methods to solve vehicle routing problems. They are generally split into two main categories:

- Exact and Approximate Algorithms
- Heuristic/Metaheuristic Methods

3.3.1　Algorithms

An algorithm is a procedure for solving a mathematical problem in a finite number of steps that frequently requires repetition of an operation. The premise is that a problem is started in an initial state and a well-defined solution procedure is followed through a finite number of states until the final output is reached. There are generally two types of algorithms: exact and approximate. Exact algorithms guarantee an optimal solution while approximate algorithms provide suboptimal solutions.

Exact algorithms are preferable in comparison to approximate algorithms because their final solutions guarantee optimality; however, their application is limited because of the time it takes to solve large combinatorial problems. Instead of enumerating all possible combinations to be certain of an optimal solution, exact algorithms were developed to solve problems to optimality more efficiently.

Branch-and-bound is the most general exact algorithm for solving various optimization problems. The method consists of computing all candidate solutions, but discards fruitless solutions en masse by estimating upper and lower bounds of the solution. Branch-and-bound may also be used as the foundation for some heuristics. For example, one may wish to stop branching when the difference between the upper and lower bounds becomes smaller than a certain threshold. This reduces the number of computations in exchange for a slight reduction solution quality. There are other versions of this algorithm including branch-and-price and branch-and-cut.

Column generation is another popular exact method. The basic premise of the method is that many linear programming problems are too large to consider all the variables explicitly. Since most of the variables will be non-basic and assume a value of zero in the optimal solution, only a subset of variables need to be considered in theory when solving the problem. Column generation builds off this theory by determining only the variables which have the potential to improve the objective function.

If an exact algorithm can only find the optimal solution to a problem in exponential time, an approximate algorithm can be used to identify sub-optimal, but quality solutions in polynomial time. Some approximation algorithms can provide a solution within a certain percentage of the optimal solution, i.e. 5%. While approximate algorithms are superior to exact algorithms in some problems due to solution time, they are often inferior to heuristics/metaheuristics which can provide quality solutions much faster.

3.3.2   Heuristic/Metaheuristic Methods

Heuristics and metaheuristics are used when exact algorithms are not able to deliver quality solutions in a reasonable amount of time. While heuristics and metaheuristics are not able to guarantee optimal solutions, they can find quality solutions quickly. Heuristics achieve this by performing relatively limited explorations of the search using different algorithmic rules. Examples of route construction heuristics for the TSP are the Nearest Neighbor algorithm, Greedy algorithm, Clark-

Wright Savings heuristic, and Christofides algorithm. See Johnson and McGeoch (1997) for a more complete description of these heuristics.

The nearest neighbor algorithm is a classic example of a heuristic that performs a relatively limited exploration of the search space. For the TSP, the nearest neighbor algorithm determines the path of the salesman by continually choosing the nearest unvisited city from the last visited city. This quickly generates a short route; however, the heuristic on average yields a path 25% longer than the shortest possible path (Johnson and McGeoch, 1997).

While metaheuristics are similar to classical heuristics, the quality of solutions obtained by metaheuristics is typically much better than those obtained by classical heuristics. This is because they place more emphasis on deeply exploring the most promising regions of the solution space using a number of analogies to describe the methodology to the search. Popular metaheuristics include Tabu Search, Simulated Annealing, Genetic Algorithms, and Ant Colony Optimization.

The basic structure of a metaheuristic is that an initial solution is generated and is iteratively improved by trying different candidate solution combinations. The quality of each candidate solution is usually evaluated by how well it satisfies the goals of the problem through an objective function. The objective function may represent cost, unloaded travel time, net revenue, or any number of measurable characteristics that need to be minimized or maximized. The stopping criteria for the heuristic can differ depending on the user preferences or the analogy of the heuristic.

For example, the heuristic may stop after the maximum number of iterations is reached, the maximum number of iterations without an improvement is reached, or a satisfactory fitness level has been reached for the population (genetic algorithm).

3.3.3 Fuzzy Logic Models

Optimization problems in their most general form involve finding an optimal solution to a problem subject to certain constraints and criteria. In practice, however, many situations lack the information that is needed to solve the problem exactly. For example, there may be a lack of information regarding constraints or information to help clearly define an objective function. In these situations it is advantageous to model the problem using fuzzy logic. Contrary to traditional logic where binary sets are valued as true or false, i.e. 0 or 1, fuzzy logic is based on the concept that there is a range of truth values between 0 and 1.

Consider the most general formulation of the LP problem:

$$\max \quad z = cx$$

$$\text{subject to} \quad Ax \leq b$$

$$x \geq 0$$

Vehicle routing problems are often modeled using linear programming or mixed-integer programming formulations. In many real situations, however, not all the constraints and objective functions can be valued in a precise way. In these situations the general problem form is called Fuzzy Linear Programming (FLP). FLP is

characterized where a_{ij}, b_j and c_i can be expressed as fuzzy numbers, x_i as variables whose states are fuzzy numbers, addition and multiplication can operate with fuzzy numbers, and the inequalities are among fuzzy numbers. Models can therefore have fuzzy constraints, fuzzy goals, fuzzy costs as objective function coefficients, and models with fuzzy coefficients in the technological matrix. We refer the reader to Brito et al. (2009) for a more complete description of these models.

While Fuzzy Logic has not been considered for modeling the log truck scheduling problem, it has been used to model vehicle routing problems where supply at locations is uncertain (Teodorović and Pavković, 1996). Since supply at landings in the forest cannot always be predicted with great certainty, modeling the log truck scheduling problem using an FLP formulation may be an interesting area for future research.

Chapter 4 – Forest Transportation Planning

Forest transportation planning involves the transportation of logs from forests to mills. There are typically three levels of forest transportation planning: strategic, tactical, and operational. Decisions on the strategic level often determine the harvesting, road building, and road maintenance plans for several years in advance. Decisions at the tactical level may concern the transportation planning from one week to one or two years in advance. These decisions may include which roads to build as well as determining which mills to send logs to for upcoming sales. Lastly, the operational planning involves daily decision making on the actual routes and schedules for individual trucks. Operational planning is the focus of this project.

4.1   The Log Truck Scheduling Problem

In forest harvest operations, trees are felled and transported to landings where the logs are processed and stacked near the roadside until they are loaded on log trucks for transportation to the mill. The logs are usually stacked by the assortment or "sort" (grade, species, and end use) to make the loading process more efficient. The sorts are delivered to customers at sawmills, veneer and plywood mills, pulp and paper mills, and transfer yards via log trucks (Figure 4). The cost of transporting logs from the forest to the mill represents a considerable amount of the total cost of forest operations, as much as 50%. Therefore, even small gains in transportation efficiency can result in significant cost reductions. Gains in transportation efficiency can be achieved through the construction of optimal truck schedules by computer-aided

decision support systems (DSS) that solve what is known as the log truck scheduling problem (LTSP).
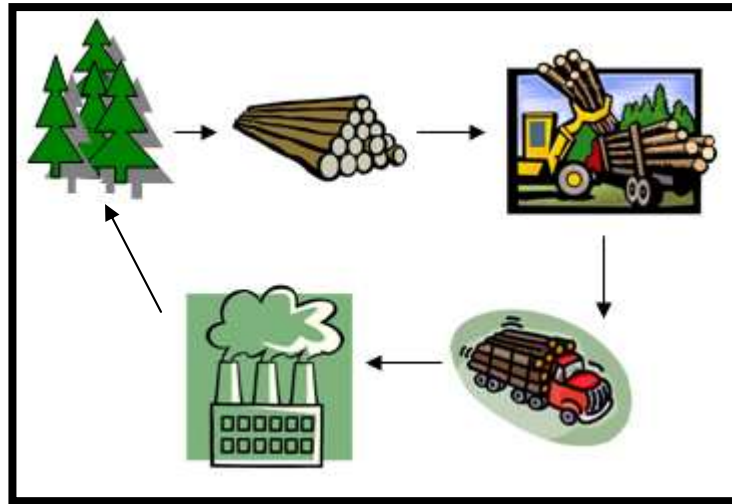
Figure 4: Wood transportation from the forest to the mill

In the Pacific Northwest, truck schedules are not often constructed in many operations. Typically, the loader operator at the landing acts as a pseudo-dispatcher that repeatedly sends trucks back and forth between the mills and their landing. Audy et al. (2007a) refer to these as 'simple' trips (Figure 5). Simple trips result in a truck traveling half of its total miles unloaded, i.e. a loaded efficiency of 50%. Often the loaded efficiency is in the range of 30-45% once the deadhead miles to and from the truck garage is added to the total. In order to increase the loaded efficiency of a truck, trips need to be constructed that involve backhaul. Backhaul is achieved when a truck is loaded for all or part of the distance back to the original supply location after completing a delivery.
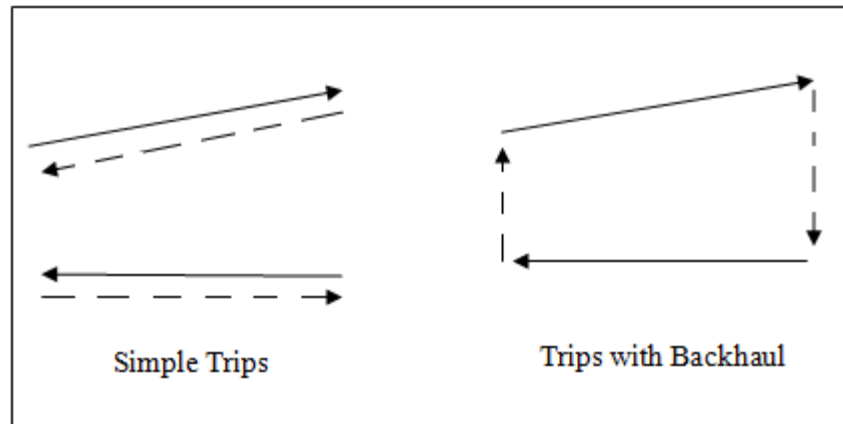
Figure 5: Reducing unloaded travel distance with backhaul (Audy et al., 2007a)

The LTSP is a special case of the vehicle routing problem known as the pickup and delivery problem with time windows (PDPTW) for log transportation. The goal is to determine what loads each truck should pick up and deliver and in what sequence. It is assumed that several landings and mills are considered otherwise simple trips would be the only logical choice.

The sort of logs is usually the deciding factor in where landowners send logs in the Pacific Northwest. Since certain sorts are often destined for specific mills, pickups and deliveries are paired together and are referred to as trips. A trip is the act of a truck completing one pickup and one delivery. The sequence in which trips are performed and the associated arrival times at each destination is referred to as the truck's schedule. In practice, a schedule is created nightly for the following work day, but can be extended further depending on the ability to accurately forecast the supply and demand for logs at each landing and mill location.

Computer-aided DSS for truck scheduling can help dispatchers choose the best truck schedules possible for their fleet when there are a large number of route combinations available. For example, there are nearly 14,000 route combinations for a single truck performing at least three trips between four forests and six mills (Figure 6). If the number of trucks is increased to three and the number of trips is increased to five per day, the number of possible route combinations exceeds 24 million. The number of possible route combinations can be reduced if the destinations of each sort are known ahead of time; however, the dispatcher still has to determine the sequence of pickups and deliveries for each truck in the fleet that will result in the lowest possible cost.
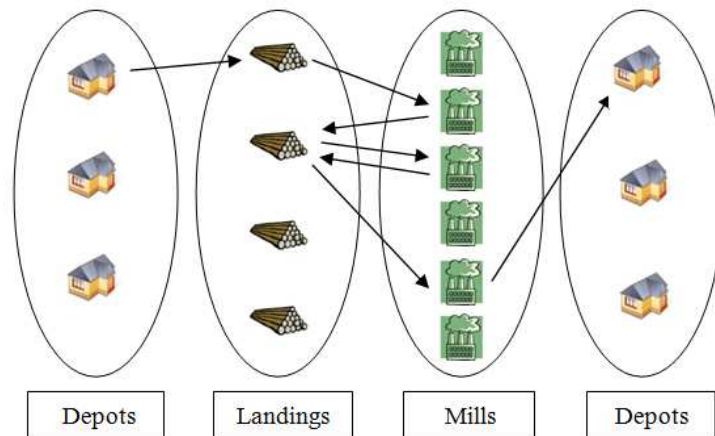
Figure 6: Example of a typical three trip sequence for a log truck schedule (Murphy, 2003)

Each truck schedule is feasible only if it satisfies all the required constraints of the problem. Time is an important aspect to consider when formulating the constraints for any practical model. Time windows are one of the most important requirements for the LTSP and are implemented to make sure that trucks are only scheduled to arrive at landings and mills during regular business hours. Furthermore, time windows can also imply a specific time when a load needs to be picked up for delivery. Load time windows may be important to prevent late truck arrivals to landings for loading. If trucks are consistently late, logs can accumulate on the landing and create bottlenecks for the logging contractor, slowing productivity. In addition, the logging contractor may not be able to get all of their loads serviced.

Constraints are also implemented to prevent drivers from operating beyond their maximum available hours. Due to differences in state laws, time constraints could be potentially more complex if a schedule requires the driver to travel interstate.

In most operations, it is up to the driver to choose the physical travel path between pickup and delivery points. A good driver knows the best path if they are familiar with the area and the localized traffic; however, the dispatcher needs to know the mean travel time so it can be used as an input in DSS.

There may be situations where the transportation manager may need to provide turn-by-turn directions for a driver. In this case, there may be additional constraints for route feasibility that address the physical path the driver travels. For example, certain road segments may be restricted to avoid school zones, congested arterials, bridges with weight limitations, or overpasses with vehicle height limitations. To determine turn-by-turn directions, a decision support system needs to be integrated with a geographic information system (GIS) that contains the road network and the associated travel speed or speed limit for each road segment.

Another requirement of the LTSP that may be desirable is the ability to assign priority to certain service requests. For example, blue stain can occur in some wood species that remain on the landing for long periods of time. Priority should be given to these loads to ensure that quality products are delivered to the mill before blue stain develops. Priority can also be given to landings where the harvesting is finished since

it is usually in the logging contractor's best interest to move to the next job as soon as possible.

The LTSP can be formulated for two different assumptions. In the United States, it is typically assumed that the goal is to generate truck schedules that satisfy the demand of each logging contractor in the least cost manner. In other words, the goal is to service all the loads requested by each logging contractor regardless of mill demands because it is commonly assumed that the mills will accept all loads. In other countries, however, it is assumed that the goal is to determine the schedules that satisfy the demand of each mill in the least cost manner. In this scenario, the supply of each sort at each landing must be considered as well as the demand at each mill.

4.2   Model Structure

Typically, the number of loads requested for service is known for each landing a day in advance. In addition to knowing the number of loads, the pickup locations and destinations are known as well, thus, creating paired orders. Since the transportation requests are predetermined, each load can be considered as an order that needs to be fulfilled.

The model formulation can be as simple or complicated as the user deems necessary. The strength of each schedule is usually measured by an objective function in the model. If a homogenous fleet is considered, the objective function may be to minimize the duration of unloaded travel time. Often drivers are paid different wages

and trucks have varied operational costs; therefore, the objective may shift from minimizing unloaded travel time to minimizing total cost.

The objective function for the formulation in this project is to minimize the total transportation costs for the fleet. Since only the hourly cost of the truck is considered, the objective is to service all customer loads in as little time as possible. To satisfy this objective we adopt Gronalt and Hirsch's (2005) mixed-integer programming model formulation of the log truck scheduling problem with some modifications. The model has been modified to consider a non-homogenous fleet since trucks often cost differently per hour. A variable, D_r, is introduced that represents the total generated route time of truck r. The generated route time must be less than the maximum time available, Tr, for each truck. The definitions and notation used are as follows:

- W = The set of all loaded and unloaded transportation arcs
- u_i = Loaded travel time to the customer receiving load i
- y_{ir} = 1 if load i is picked up by truck r, otherwise 0
- t_{ij} = Unloaded travel time from the customer of load i to the pickup location of load j
- x_{ijr} = 1 if truck r travels from the customer of load i to the pickup location of load j
- c_r = Cost of truck r per unit time
- Q_r = Maximum capacity of truck r
- T_r = Maximum route duration for truck r
- D_r = The total generated route time for truck r
- a_i = The loading time at landing i

- s_i = The loading time at the industrial site for load i
- e_i = The beginning of the time window for load i at the mill
- l_i = The ending of the time window for load i at the mill
- f_i = The beginning of the time window for load i at the landing
- k_i = The ending of the time window for load i at the landing
- e_r = The earliest time a truck r can begin the day
- l_r = The latest time a truck r can end the day
- b_i = The actual arrival time for load i at the mill
- w_i = The waiting time necessary at the mill for load i if the truck shows up earlier than the time window allows
- q_i = The quantity of load i,

The objective function is to minimize the sum of transportation costs.

$$\sum_{r \in R} D_r \cdot c_r$$

Subject to the following constraints:

1 Guarantees that a truck begins and ends at home.

$$\sum_{i \in W} x_{ihr} - \sum_{j \in W} x_{hjr} = 0 \ \dots \forall h \in W, r \in R$$

2 Guarantees that a load is only serviced by one truck.

$$\sum_{r \in R} \sum_{j \in W} x_{ijr} = 1 \ \dots \forall i \in W$$

3 Prevents trucks from traveling landing to landing, i.e. no split pickups allowed. Requires that each truck makes a pickup at the beginning of the day and delivers a load after each pickup.

$$\sum_{j \in W} x_{ijr} + x_{iir} = 1 \ ... \ \forall i \in V, r \in R \ (i = r)$$

4 Prevents trucks from being able to travel customer to customer, i.e. no split deliveries are allowed. Requires that the truck returns to the forest for a pickup after delivering a load or returns to the truck garage at the end of the day.

$$\sum_{j \in W} x_{ijr} + x_{jjr} = 1 \ ... \ \forall i \in V, r \in R \ (j = r)$$

5 Prevents load i from being serviced by truck r more than one time.

$$y_{ir} = \sum_{j \in W} x_{ijr} \ ... \forall i \in W, r \in R$$

6 Load i can't exceed the capacity of truck r.

$$q_i \cdot y_{ir} \leq Q_r \ ... \forall i \in W, r \in R$$

7 The total travel time of truck r.

$$\sum_{i \in W} \sum_{j \in W} t_{ij} \cdot x_{ijr} + \sum_{i \in W} u_i \cdot y_{ir} = D_r \ ... \forall r \in R$$

8 The duration of the travel time for truck r must be less than the max travel time allowed for that truck.

$$D_r \leq T_r \quad ... \forall r \in R$$

9 If the truck makes a pickup of load i after delivering load j, it must arrive at the customer at a time later than the time of the last delivery.

$$b_i + w_i + s_i + t_{ij} + a_j + u_j - M \cdot (1 - x_{ijr}) \leq b_j \quad ... \forall i \in W, j \in W, r \in R$$

10 The truck's arrival time for pickup at a landing has to be later than the opening time for the logging contractor's time window.

$$b_i + w_i \geq f_i \quad ... \forall i \in W$$

11 The truck's arrival time for pickup has to be earlier than the closing time for the logging contractor's time window.

$$b_i \leq k_i \quad ... \forall i \in W$$

12 The truck's arrival time for delivery has to be later than the opening time for the customer's time window.

$$b_i + w_i \geq e_i \quad ... \forall i \in W$$

13 The truck's arrival time for delivery has to be earlier than the closing time for the customer's time window.

$$b_i \leq l_i \quad ... \forall i \in W$$

14 If a truck decides to pick up a load *i* after delivering a load *j*, it must arrive at the
customer before the driver's maximum availability time is exceeded.

$$b_i + w_i + s_i + t_{ij} - M \cdot (1 - x_{ijr}) \leq l_r \quad ... \forall i \in W, j \in V, r \in R \ (j = r)$$

15 Binary variable defined.

$$x_{ijr} \in \{0,1\} \ ... \forall i \in W, j \in W, r \in R$$

16 Binary variable defined.

$$y_{ir} \in \{0,1\} \ ... \forall i \in W, r \in R$$

17 Non-negativity constraint.

$$w_i \geq 0 \quad ... \forall i \in W$$

18 Non-negativity constraint.

$$b_i \geq 0 \quad ... \forall i \in W$$

4.3   Example

The following example displays how heuristics can be used to develop truck
schedules. In this simple example, the problem is illustrated through a network of arcs
and nodes. The nodes represent the landings, mills, and truck garages. The arcs
represent the travel time between a pair of nodes (Figure 7).
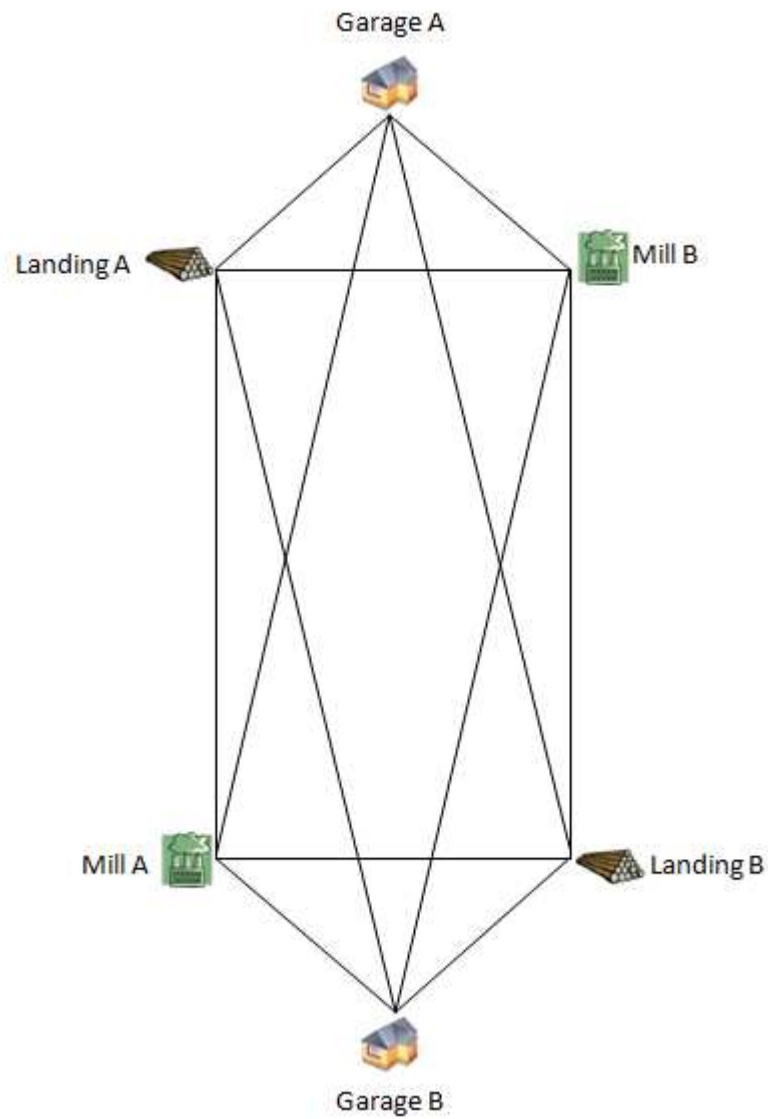
Figure 7: Graphical depiction of the network considered for the example problem

Each landing has 12 loads that need to be picked up and delivered to the corresponding mill. For example, the loads from Landing A need to be delivered to Mill A and the loads from Landing B need to be delivered to Mill B. To demonstrate

the importance of backhaul, the problem is solved twice with a different requirement for each instance.

In the first instance, it is required that the trucks from each truck garage only service their corresponding landings and mills. Garage A can only pick up loads from Landing A and deliver to Mill A. Conversely, Mill B can only pick up loads from Landing B and deliver to Mill B. In the second instance, this constraint is relaxed and the trucks are allowed to service loads from either landing, but still have to deliver the load to the appropriate mill. For example, a truck from Garage A can pick up a load from Landing B, but the load still must be delivered to Mill B. This is often the case in the Pacific Northwest since logging contractors or landowners pair the loads to mill destinations by the sort of logs.

The objective of this example problem is to minimize the cost of performing all transportation services subject to the constraints outlined in the previously stated model. A Tabu Search heuristic is used to solve the model. Short term memory is used to prevent cycling and being trapped in local optima. 1-opt and 2-opt moves are used to search the solution space and construct better candidate truck schedules.

1-opt moves reduce the number of trucks needed by taking one trip and adding it to another truck's schedule. If the truck has room for the extra trip and it reduces the objective function cost then the solution is saved as a candidate schedule. This procedure enables the heuristic to reduce the number of trucks needed by taking trips

one at a time from a single truck and adding them to other trucks until the truck is no longer needed in the schedule.

2-opt moves help create more efficient schedules by taking a trip from one truck and swapping it with a trip from another truck. If the swap creates an improvement in the objective function, the solution is saved as a candidate schedule. The basic solution procedure is outlined in a flow chart (Figure 8). See Glover (1989 and 1990) for a more complete description of the Tabu Search heuristic.
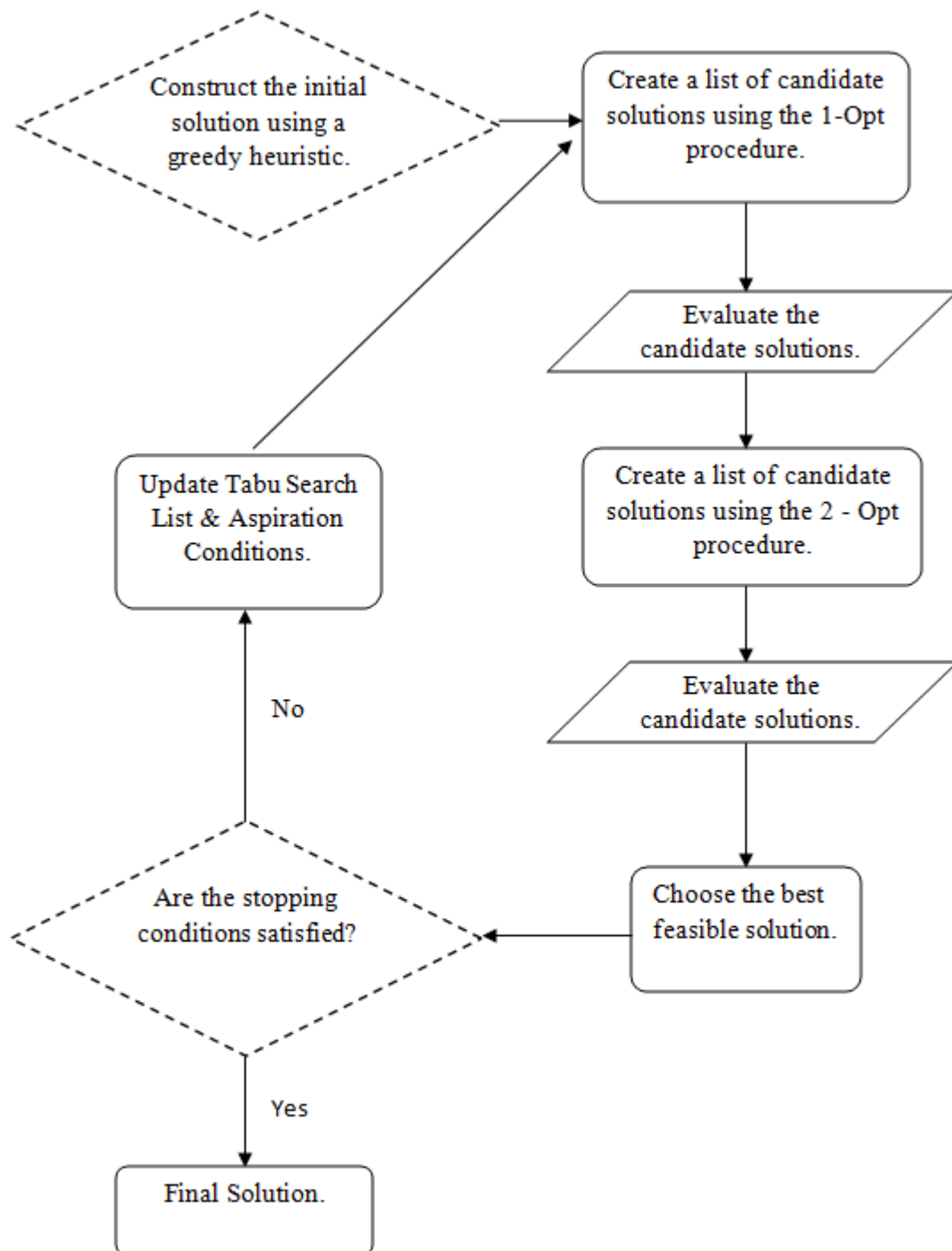
Figure 8: Flow chart for the Tabu Search heuristic used to solve the example problem

The times shown in the origin-destination matrix represent the travel times between locations (Table 1). For simplicity, it is assumed the trucks travel a speed of 60 mph; therefore, the travel time in minutes is equivalent to the miles between locations for this problem. In practice the average travel time and the distance would not usually be equivalent.

Table 1: Origin-Destination matrix for the example problem

Origin	Destination	Travel Time (Min)
Mill A	Garage B	15
Mill B	Garage A	15
Garage A	Landing A	30
Garage B	Landing B	30
Landing A	Mill B	45
Landing B	Mill A	45
Landing A	Mill A	120
Landing B	Mill B	120
Garage A	Landing B	135
Garage A	Mill A	135
Garage B	Landing A	135
Garage B	Mill B	135

The time windows at each landing and mill location are implemented to ensure that trucks are scheduled to service loads only during the regular business hours (Table 2). Each driver has a maximum work time of 12 hours for the day.

Table 2: Time windows at each location in military time

Location	Time Window Open	Time Window Close
Landing A	4.5	14
Landing B	4.5	14
Mill A	6	18
Mill B	6	18

In the first instance only simple trips are constructed for each truck in the fleet. The travel times between nodes are the same for both groups A and B; therefore, each truck in the fleet is only able to service two loads per day with a loaded efficiency of 45.71% as shown in the sample schedule for a truck from Garage A (Table 3). Since all trucks are performing simple trips, the schedules are the same for trucks from Garage A and Garage B because of symmetry in the road network.

Table 3: Schedule for each driver from Fleet A using simple trips

Sequence	Time (Military)	Action
Leave Garage A	4	
Arrive at Landing A	4.5	Pickup Load
Depart from Landing A	4.75	
Arrive at Mill A	6.75	Deliver Load
Depart from Mill A	7	
Arrive at Landing A	9	Pickup Load
Depart from Landing A	9.25	
Arrive at Mill A	11.25	Deliver Load
Depart from Mill A	11.5	
Finish at Garage A	13.75	
Total Route Time (hours)	9.75	
Total Distance (miles)	525	
Total Loads Serviced	2	
Loaded Efficiency	45.71%	

In the second instance the trucks from each garage are pooled as well as the loads from each logging contractor. Table 4 and Table 5 display the new schedules for a truck in Garage A and Garage B. The schedule generated by the heuristic is superior in many ways. Trucks pick up loads from their respective landings for the first load of the day which minimizes deadhead miles since these landings are closest to their respective garages. For the last load of the day, trucks pick up loads from the other logging contractors because the mill destinations for those loads are closer to the garage; thus, reducing deadhead miles to end the day as well. The last load of the day can be thought of as backhaul as well since the truck is returning part of the way back to the original supply point loaded.

Table 4: Schedule for each driver from Fleet A in pooled scenario

Sequence	Time (Military)	Action
Leave Garage A	4	
Arrive at Landing A	4.5	Pickup Load
Depart from Landing A	4.75	
Arrive at Mill B	6.75	Deliver Load
Depart from Mill B	7	
Arrive at Landing B	7.75	Pickup Load
Depart from Landing B	8	
Arrive at Mill B	10	Deliver Load
Depart from Mill B	10.25	
Arrive at Landing B	12.25	Pickup Load
Depart from Landing B	12.5	
Arrive at Mill B	14.5	Deliver Load
Depart from Mill B	14.75	
Finish at Garage A	15	
Total Route Time (hours)	11	
Total Distance (miles)	570	
Total Loads Serviced	3	
Loaded Efficiency	63.16%	

Table 5: Schedule for each driver from Fleet B in pooled scenario

Sequence	Time (Military)	Action
Leave Garage B	4	
Arrive at Landing B	4.5	Pickup Load
Depart from Landing B	4.75	
Arrive at Mill A	6.75	Deliver Load
Depart from Mill A	7	
Arrive at Landing A	7.75	Pickup Load
Depart from Landing A	8	
Arrive at Mill A	10	Deliver Load
Depart from Mill A	10.25	
Arrive at Landing A	12.25	Pickup Load
Depart from Landing A	12.5	
Arrive at Mill A	14.5	Deliver Load
Depart from Mill A	14.75	
Finish at Garage B	15	
Total Route Time (hours)	11	
Total Distance (miles)	570	
Total Loads Serviced	3	
Loaded Efficiency	63.16%	

By constructing intelligent truck schedules through the use of pooled trucks and logging contractor loads, a number of benefits are achieved including:

- The number of trucks needed to service all 24 loads is reduced by four.

- The average loaded efficiency of the trucks increased 17.5%.

- The total distance traveled by the trucks is reduced by 2,790 miles.

- The time needed to service all 24 loads is reduced by 29 hours.

- The total cost is reduced by nearly 25% (compare Table 6 and Table 7).

While these results may not be typical, this simple example demonstrates how truck capacity can be increased through the construction of intelligent truck schedules that minimize deadhead miles and incorporate backhaul. It also demonstrates how collaboration between other stakeholders (landowners, trucking contractors, and logging contractors) can increase opportunities for better scheduling. Collaboration for shared transportation services is discussed in Chapter 7.

Table 6: Results from the first scenario with simple trips

	Fleet A	Fleet B	Total
Number of Trucks Needed	6	6	12
Total Time (hrs)	58.5	58.5	117
Total Distance (miles)	3,675	3,675	7,350
Total Loads Serviced	12	12	24
Truck Operating Costs ($120/hr)	$7,020	$7,020	$14,040
Average Fleet Loaded Efficiency	45.71%	45.71%	45.71%

Table 7: Results from the second scenario with pooled loads and trucks

	Fleet A	Fleet B	Total
Number of Trucks Needed	4	4	8
Total Time (hrs)	44	44	88
Total Distance (miles)	2,280	2,280	4,560
Total Loads Serviced	12	12	24
Truck Operating Costs ($120/hr)	$5,280	$5,280	$10,560
Average Fleet Loaded Efficiency	63.16%	63.16%	63.16%

4.4   Literature Review

There are few decision support systems (DSS) designed specifically for the log truck scheduling problem; however, many have solved different variations of the problem using a variety of methods that range from the development of their own DSS solution techniques (similar to the one shown in the previous example) to modifying the inputs of off-the-shelf DSS to meet their needs.

There are many different methods that have been used to solve log transportation problems in the literature. While most of the attention has been focused on solving a variation of the LTSP, solution methods for real-time dispatching have also been demonstrated.

A Network Programming Approach to the LTSP

An early solution method for log truck scheduling is a network programming approach demonstrated by Shen and Sessions (1989). The goal is to minimize the cost of transporting logs from landings in the forest to the mill, while achieving a desired mill delivery schedule.

Two different types of nodes are used in the formulation. The first node type represents geographical locations and the second node type represents arrival and departure times. The set of arcs between the nodes specifies the geographical relationships between the landings, the mills, and the truck garage. In addition, the arcs specify the possible relations between the locations and time.

The inputs needed for the network programming formulation are:

- the minimum and maximum number of log truck trips needed by each landing in a day,

- mean round trip travel time associated with each landing,

- total cost per round trip for each landing,

- the average loading time at each landing,

- and the minimum and maximum number of trucks permitted to arrive at the mill during a time interval.

The capacitated network is generated mechanically using the arc and node definitions and solved using the out-of-kilter algorithm. The solution to the network is translated into a timetable displaying the recommended log truck schedule.

It is likely that this procedure would only be useful for small problems. As the number of trucks and loads in the system increases, it is better to use heuristic methods because of their ability to generate quality solutions in less computing time. In addition, a mill delivery schedule is not necessary for all operations. In the Pacific Northwest, mill delivery schedules are not generally considered, but the concept could prove useful in reducing queue times at mills and providing mills with a steady flow of logs throughout the day.

EPO in Finland

In the early 1990's Enzo-Gutzeit, a Finnish company in the pulp and paper industry, implemented a log truck scheduling system called EPO. Linnainmaa et al. (1995) describe EPO as a knowledge-based system for wood procurement management that covers strategic planning and the operational planning of truck scheduling.

The core of the system is the software component called EPO2 that generates weekly optimal schedules for log trucks based on truck and log availability as well as mill demand. The main objective is to minimize the duration of empty truck movements and truck driving as a whole. A combination of exact methods and heuristic methods is used to generate the scheduling solution. A variety of constraints are implemented; one of the most important being priority. In Finland, there is a maximum amount of time that loads are allowed to stay in the forest. Therefore, a constraint is implemented to make sure that trucks pick up loads before the maximum time in the forest is reached. EPO2 also aims to satisfy time windows for business hours and maximum driver working hours.

The inputs for EPO2 consist of information about the loads (location, type of sort, quantity), demand at the mills, time windows, information about available trucks (location, configuration), parameters to assist the heuristic, and a digitized road network for the graphical map interface.

Data about the wood supply is collected on-line from computing equipment held by the forest foreman and customers. The computing equipment is also installed in the harvesting machinery and log trucks. Data is transmitted through telecommunication cables and mobile data transmission. The foremen upload data concerning the location of future loads on electronic maps. The drivers can see these locations relative to their real-time locations via GPS satellite navigation on electronic maps installed in the cabs of the trucks.

The scheduling is performed in three phases. Loads are assigned to a customer in the first phase. With the destinations of each load determined, schedules are generated for each truck in the fleet in the second phase. The third phase is a post-processing procedure where the dispatcher and forest foreman can manually change the schedule to mitigate any errors in the solution.

The assignment of loads to different customers in the first phase is done using an attraction model. Linnainmaa et al. (1995) describe this using a wave propagation analogy where a virtual wave representing each sort leaves each customer through all road possibilities. The speed of the wave is relative to the amount of demand required by each customer. Therefore, as soon as a virtual wave reaches a load in the forest, the load is claimed by that customer. When two wave fronts searching for the same wood sort collide, the wave propagation is stopped.

The scheduling in the second phase begins with the system finding the current locations of trucks. Next, trucks are scheduled based on the assignment of loads to

customers in the first phase. A traveling salesman type of heuristic is used to generate the schedule. The user is able to make inputs into the system that relate to the driver's familiarity with certain regions or tree farms as well as the driver's skill level. This is a novel approach to avoid scheduling drivers with no familiarity with an area or ensuring that difficult loads are serviced by experienced drivers. This can also be a great way to prevent drivers and contractors with poor working relationships from being scheduled together.

The third phase of EPO2 is the post-processing phase where the dispatcher can correct errors in the solution. Manual changes may also be necessary to repair the schedule for equipment breakdowns, flat tires, bad weather, etc. The system has the capability to rerun the second phase with a subset of the original solution to make dispatching decisions if something has changed within the scheduling period. After the schedules are generated and approved by the dispatcher, they are sent to the computers in the cabs of the trucks via mobile phones.

The dispatcher usually creates a schedule for a week, but the system has the ability to change the scheduling time horizon. The digitized road network in the map interface is used by the dispatcher to view the locations of customers the customers and the landings. This helps to determine the optimal route by either vehicle miles or travel time. In addition, the dispatcher can use the map interface to click on piles of wood and view detailed information about the sort. EPO can also produce reports

displaying the wood assignment to customers generated in the first phase and the daily schedule for each truck generated in the second phase.

Linnainmaa et al. (1995) estimate the savings for Enso-Gutzeit to be at least several million US dollars per year, but because EPO significantly changed the organizational structure of the company, it is hard to determine exactly what portion of the savings can be directly attributed to the new system. Additionally, the reliability of information about wood supply became significantly more reliable to facilitate the transition to using EPO. Thus, the new information about supply changed the way commercial negotiations were performed.

EPO is an early version of a real-time dispatching system. One distinct difference between the problem solved here and the problem in the United States is the need to satisfy mill demand. In the Pacific Northwest, the mills do not provide information on demand rather they offer a price per unit volume for certain sorts. It is then up to the landowners or logging contractors to determine where the logs will be delivered. If the mill is receiving an excess of a certain sort then the price of the sort may decrease. This feeds back into the lack of collaboration and trust seen in the industry between stakeholders. Parties try to remain private about the destination of their logs to hold a competitive advantage and prevent others from sending their sorts to the same mill; thus increasing supply and driving down the price offered for the sort.

ASICAM in Chile

ASICAM is a computer-aided DSS for truck scheduling that was first implemented around 1990 by eight of the largest forest companies in Chile (Weintraub et al., 1996). The benefits from its implementation were reduced operational costs and improved overall efficiency of log transportation in Chile.

The log transportation problem in Chile is similar to the LTSP elsewhere. Logs are felled in the forest and transported to landings. After a truck is loaded by a log loader, the logs are transported to a pulp mill, saw mill, or port. The problem is then to satisfy the demand for different products at each destination, while minimizing transportation costs subject to different constraints. Their problem is unique because most Chilean firms are vertically integrated, meaning they also own and control the mills and ports. Therefore, it is necessary to coordinate the log deliveries with downstream operations at the destinations to make sure that the equipment at the destinations are not overloaded such as the log loaders and mill machinery (Weintraub et al., 1996).

Prior to ASICAM, the log transportation system in Chile was poorly organized. The lack of organized schedules for drivers resulted in long queue times at mills and poor utilization of equipment and human resources. To improve the efficiency of the log transportation system in Chile, a complete administrative change was required.

Traditionally, Chilean companies scheduled trucks manually using simple dispatch rules. Drivers were given landings and destinations to service, but were essentially free to decide on their schedules. The new administrative system required a centralized dispatch that would generate daily schedules to control operations. This new administration significantly improved the system even while using manual scheduling methods before the computerized system was developed and implemented.

Due to the combinatorial nature of the problem, Weintraub et al. (1996) developed a simulation process with heuristic rules to support the daily log truck scheduling decisions. The simulation replicates how and where the logs move during the day according to the heuristic rules. Some of the inputs and constraints considered are:

- The demands and supply for each product,
- the availability and type of trucks and log loaders,
- costs for each truck,
- trip times,
- demand for each product must be satisfied with regularity,
- driver working hours including lunch breaks,
- the first truck to arrive at a landing will drive the loader operator to the site,
- a landing is determined for each loader,
- trucks should start and end near the driver's home town,
- and an income-balancing priority system.

The heuristic builds the schedule by determining the first landing for pickup and mill delivery for a truck. After the truck has completed the load, the heuristic optimally assigns the truck a subsequent load based on three main heuristic elements. To avoid near sighted decisions, the scheduling looks ahead an hour and then firmly schedules decisions of the simulation for the first 15 to 30 minutes. This is carried on through a moving horizon to the end of the workday (Cossens, 1993).

The first element of the heuristic ensures that the mill destinations receive supply with regularity throughout the day. In doing so, this prohibits schedules that have peaks with high delivery rates during certain hours and low rates during others. The second element of the heuristic is to create a desirability index for each possible trip. The index lists the desirability of each feasible trip based on the actual cost of the trip plus a congestion penalty. The congestion is estimated by the simulation process as it analyzes possible future trips. The third element of the heuristic is where the next trips are selected based on the desirability index, but landing priority is taken into consideration (Weintraub et al., 1996).

Each afternoon the central dispatch runs ASICAM to design the schedules for the next day. The transportation manager may make a few manual adjustments or run the program additional times to improve the schedule. Printouts of the schedules are given to drivers and loader operators for the next day. To make sure that the schedule is correctly implemented, strict operating rules are in place for the loader operators and destinations. For example, loaders are not allowed to service a truck if the truck

arrives late unless there is slack time. At the time of this publication, updates and repairs to the schedule were done manually as breakdown or changes in the schedule occurred, but ASICAM was planned to allow for automated adjustments in the future.

At first there was considerable pushback from fleet owners and truck drivers to be managed by a central dispatch, but the two sides were eventually able to come to an agreement after discussing the advantages and benefits of the new system in the long run (Weintraub et al., 1996). Although the number of trucks used would decline, utilization and revenue to contractors would increase. Different policies were developed among the companies to determine how the cost savings would be shared between the company and trucking contractors (Cossens, 1993).

The implementation of ASICAM in Chile helped eight forest companies realize significant benefits through reductions in the number of trucks and loaders needed, operational costs, and total transportation costs (Table 8). Depending on the company's initial situation, each was able to reduce their total costs by 18 to 26%.

Table 8: Percent reduction in trucks needed after ASICAM (Weintraub et al., 1996)

Forest Firms	Before ASICAM	After ASICAM	Percent Reduction
Bosques Arauco	156	120	23%
Forestal Millalemu	80	50	38%
Forestal Bio Bio	118	76	36%
Forestal Bio Vergara	120	80	33%

While the reductions in trucks needed were significant, it appears that much of this success can be attributed to preventing large queues by staggering the arrival times at destinations. Because some loader operators and dispatchers in the Pacific Northwest often make an effort to stagger arrival times, results of this magnitude may not be able to be achieved for some operations. Similar to EPO in Finland, ASICAM also requires that mill demands be implemented as constraints; therefore, this software may not lend itself to the business structure in the Pacific Northwest.

ASICAM in New Zealand

After the implementation of ASICAM in Chile in the early 1990's, there was interest from potential users in New Zealand in the suitability of the system for their operations. Cossens (1993) discussed the suitability concluding that ASICAM could work in New Zealand with a few modifications.

While ASICAM provided an optimized schedule for the following day, some New Zealand companies with large fleets were seeking a system that could provide real-time dispatching. In other words, they were looking for a system that could optimize and repair the schedule on the fly as conditions in the scheduling period changed. At this time, ASICAM did not provide the capability to update the schedule and dispatchers had to use their experience to make manual changes to the schedule as breakdowns or deviations to the schedule occurred. Transportation managers wanted a real-time dispatch system because they preferred to keep wood supply low in order to

minimize inventory costs and reduce the risk of holding unwanted sorts if demand or sorts changed (Cossens, 1993).

Cossens also discusses functionalities and technologies that need to be part of the DSS of the future. He discusses the need for the dispatch to be linked to a geographic information system (GIS) so that the real-time positions of trucks, wood supply locations, and mills can be seen at all times on an electronic map interface. In addition, he predicts that future management systems will use electronic data transfer for communications and that trucks will have on-board computers with digital displays to send and receive instructions from the dispatch. Potential users in New Zealand also expressed interest in systems that can be integrated with weighbridges or scaling records, accounting systems for payment of contractors and loggers, and the ability to link to production reports (Cossens, 1993).

Because ASICAM uses an income-balancing priority system to ensure that each truck gets an even distribution of work, Cossens is wary that this may decrease the ability for subcontracted owner-operators to compete with others and is suspicious that this lack of competition may result in an increase in transportation costs. Owner-operators in the Pacific-Northwest may also have similar feelings about an income-balancing system.

Tour Generation for Log Truck Scheduling

T.F. Robinson (1994) discusses methods of tour generation, i.e. route generation, for log truck scheduling. A tour is defined as the sequence of pickups and deliveries for a single truck and a schedule is the set of tours performed by the truck fleet. The problem described is to create an optimal schedule that performs all the required pickups and deliveries at the least possible cost.

Three approaches to creating a schedule are described: explicit tree search enumeration, network programming, and a pruned tree search. Explicit tree search enumeration is a practical option for small problems since each possible log truck tour is enumerated. In this procedure, each node in the tree has an associated location (landing, truck garage, or mill), an elapsed time, and a cost. The arcs between the nodes represent the loaded and unloaded trips. The cost at each node is equal to the cost incurred at the preceding node plus the cost of the trip minus any profit made from the load. This is referred to as the "cost-so-far". Similarly, the elapsed time at each node is equal to the elapsed time from the preceding node plus the trip duration.

In explicit tree search enumeration, nodes are expanded by depth-first search (Figure 9) from the root node, i.e. the truck garage. From this node, new nodes are produced for each unloaded trip into the forest. From the forest, new nodes are produced for each loaded trip to a mill, only if the tour meets time window restrictions and is the best possible move available. The process of producing nodes for loaded and unloaded trips is repeated until a final node is created representing the truck

garage and the end of the tour. The sequence in which nodes are visited is the truck's tour.
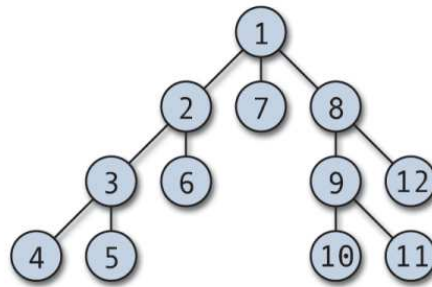
Figure 9: Order in which nodes are visited in a depth-first search tree

(http://en.wikipedia.org/wiki/Depth-first_search, Last Accessed 5/1/2011)

The network programming approach to log truck scheduling is described similarly by Shen and Sessions (1989). Nodes are created at every landing at every possible time interval throughout the day. The cost on each arc is the cost of the loaded or unloaded trip, minus the revenue from the load. The problem is then to find the shortest path through the network from the truck garage at time zero and back to the truck garage later in the day. A disadvantage to this approach is that it is necessary to use discrete time intervals to break up the day. The smaller the interval the more nodes are needed. Therefore, it is more practical to use intervals of perhaps 15 or 30 minutes rather than every minute in the scheduling period.

Since both tree search enumeration and network programming involve numerous nodes, Robinson suggests a hybrid method called pruned tree search. The solution method is essentially a variation of branch-and-bound. The advantage of this

method is that there are few nodes at the beginning of the procedure similar to tree

search enumeration and relatively few nodes towards the end similar to network

programming (Robinson, 1994).

The prune tree search procedure is similar to that of explicit tree search

enumeration except that the tree must be built breadth-first, meaning that nodes must

be created in order of increasing time (Figure 10). In addition, a record is kept of the

cheapest tour so far. Therefore, a node is only expanded if it's "cost-so-far" is

considerably less than the cheapest cost recorded for that location node; thus, the

analogy to a pruned tree.
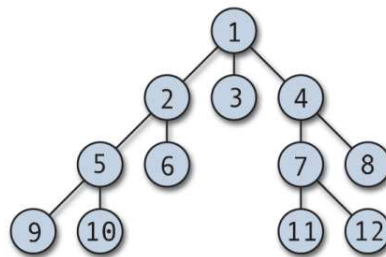
Figure 10: Order in which nodes are visited in a breadth-first search tree

(http://en.wikipedia.org/wiki/Breadth-first_search, Last Accessed 5/1/2011)

Part of the procedure is deciding how much of an improvement needs to be

made to accept the new tour. At the time of this publication, software memory was a

concern and the idea of only saving the best tours was a novel approach to efficiently

using memory space. Therefore, memory space ran out quickly if small improvements

were accepted; however, optimality would potentially suffer if only large

improvements were accepted. This was remedied by incorporating a function where the program accepted small improvements at first and then gradually increased the required improvements as memory filled up.

With the development of technology in the past two decades, prune tree search would not be disadvantaged by limitations in memory capacity; however, this procedure would still only be viable for relatively small problems due to the combinatorial NP-hard nature of the LTSP.

Real-time Truck Dispatching

Recognizing the forest industry's desire to support dispatcher's with real-time optimization, Rönnqvist and Ryan (1995) discuss a model and solution approach to ensure real-time responses with high quality solutions. The real-time dispatching problem is different than the scheduling problem where trip sequences are generated perhaps a day ahead of time or longer. In the dispatching problem, only limited look-ahead is considered, perhaps only a few hours. Therefore, only estimates of the log supply for that look-ahead period are necessary. Unlike the scheduling problem where solution time is not as important as the quality of the solution, dispatching solutions need to be made quickly which can affect solution quality. In real-time dispatching, drivers do not have a set schedule for the day. Rather, after each load is delivered drivers call into dispatch for further instructions pertaining to their next trip.

Rönnqvist and Ryan use a model similar to a set partitioning formulation where the variables in the model correspond to the alternative trip sequences for each

truck. The model considers the number of landings, mills, products, trucks, supply of each product at each landing, and demand of each product for each mill.

The majority of the constraints considered in the model are similar to previous research. Some of the constraints considered are the capacities of different truck and trailer configurations, types of vehicles able to travel on certain road networks, types of vehicles able to service certain loads or landing areas, and the need to deliver loads within time windows. Additionally, the goals are to maximize the loaded efficiency of the fleet, meet load and customer priorities, evenly distribute work between truck drivers and landing sites, and end the truck's trip sequence near home at the end of the day.

Their solution approach involves the use of two heuristic phases and then an optimization phase. The first heuristic finds the best single trip for each truck in the order that each truck is expected to need instructions for the next load. The second heuristic is applied similarly, but involves finding the set of trip sequences for each truck to finish the rest of the day. The trip sequences constructed in the second heuristic phase are the initial basis for the optimization phase in which alternative trip sequences are generated via column generation until the convergence of the LP relaxation is achieved. Finally, branch-and-bound is applied to produce integer solutions for each truck in the order which trucks need to receive further instruction.

An advantage of this solution procedure is that at any time throughout the execution process, information in the database pertaining to supply, demand, or

priority can be updated. Updates are checked for regularly at the end of each heuristic phase and during the optimization process. If an update is critical, it invalidates solutions that would be infeasible and starts over at the first heuristic phase. Another advantage of this system is that there are always potential solutions available for each truck located in the lookup table. Therefore, dispatchers can make decisions in real-time with the best solution currently available. During down periods when no dispatching is necessary, there is time for improvement of all trip sequences for the fleet. These improved solutions are then stored in the lookup table for the next dispatching decision.

An Integer Programming Approach to the LTSP

Murphy (2003) solved the log truck scheduling problem for two forest companies in New Zealand using an integer programming formulation. The goal of the problem was to minimize transportation costs subject to different constraints including supply, demand, driving time, and routes. Only full loads were considered for pickups and deliveries. The models were developed between 1989 and 1993 for two companies in New Zealand, but due to commercial reasons were not published until years later. When these models were applied, company owners reported that reductions in fleet size of 25 to 50% were achievable. In addition, costs savings as high as 47% were reported by one of the companies.

While the integer programming models described are suitable for small to medium-sized operations only, this marks another real-world implementation of

advanced scheduling where the numbers of trucks needed and operational costs were reduced.

Murphy suggests that costs may be able to be reduced even further through shared transportation services by different forest companies. In doing so, all forestry companies involved could see reductions in their transportation costs and truck owners would realize increases in utilization and loaded efficiency. This concept is investigated further in Chapter 7.

A Near-Exact Approach to the LTSP

Palmgren et al. (2003) developed another solution method for the LTSP that is near-exact. Again, the problem solved is to generate a set of truck routes that minimizes the cost to transport logs from the forest to the mills. The constraints considered are similar to those used in previous models including time windows, routes beginning and ending in the same location, and truck capacities. One major distinction in their problem formulation is that split pickups are allowed; therefore, log sorts should not be mixed on a truck and sorts need to be delivered to the correct mills.

The problem is modeled in a column-based fashion where each column represents a feasible route for a truck. Slack and surplus variables are used as penalties to ensure feasible solutions are chosen. For example, penalties are used to make sure time window constraints are met and that loads are picked up from the landings.

The solution approach is divided into two phases. In the first phase, the LP relaxation of the main problem is solved by column generation. In the second phase, integer solutions within the set of columns generated in the first phase are found by applying a branch-and-price algorithm. See Palmgren et al. (2003) for a more complete description of the solution method.

This approach was used in a case study with data provided by Sydved, a company that coordinates transportation in southern Sweden. Two case studies were presented involving one with six trucks and 39 transport tasks and the other with 28 trucks and approximately 85 transport tasks. The advantage of using exact column generation is that the computed lower bounds can give the user a measure of the solution quality. In addition, producing a set of feasible routes to choose from allows the heuristic to search more efficiently for the optimal solution.

A Tabu Search Approach to the LTSP

Gronalt and Hirsch (2007) solve the LTSP using a Tabu Search heuristic. Since a homogenous fleet is considered in this formulation, the goal is to minimize the total unloaded travel time. By reducing the unloaded time, the loaded efficiency of the trucks is increased; enabling the trucks to be more productive and service more loads. The constraints considered are:

- Time windows, i.e. driver working hours and business hours,
- a route must begin and end at the driver's home,
- route length must not exceed a maximum distance,

- and truck capacity must be equal to or larger than the capacity of the load at the landing.

In this model, the transportation orders are predefined and all orders need to be picked up and delivered to obtain a feasible solution. Arcs are used to represent the unloaded trips and loaded trips between landings and mills. Since only full truckloads are considered, a truck must deliver a load before it can pick up another. After the delivery is complete, the truck must return to a landing or to the driver's home.

See Gronalt and Hirsch (2007) for a more complete description of the Tabu Search heuristic. Gronalt and Hirsch test the Tabu Search procedures using a random problem generator for two sets of problems. Both sets involve ten trucks, 30 transport tasks, and 560 possible landings; however, the first set considers three mills, while the second set considers four. Twenty different instances are randomly generated for each set. The Tabu Search solutions are compared versus the standard solver software solutions.

A Hybrid Constraint Programming and Integer Programming Approach

El Hachemi et al. (2011) introduce another method for solving the LTSP using a hybrid constraint programming approach. In this problem formulation the authors only consider full truckloads. It is assumed that a single loader is available at each landing and mill for the loading and unloading of trucks. If the loader is busy, then the truck must wait until it becomes available.

To reduce the delay times caused by the lack of coordination between loaders and trucks, the authors address the issue through a constraint programming (CP) approach in conjunction with integer programming (IP). The objective is to minimize the non-productive time for trucks and loaders, specifically the deadhead trips and waiting times.

Using a decomposition approach, the authors decompose the solution by modeling the circulation of trucks between landings and mills as a network problem. This approach yields an optimal value for the minimization of deadhead times.

The authors observed that the optimal value is completely determined by minimizing the arcs that represent empty trips. Since the IP model can't coordinate the schedule for the trucks and loaders, the number are extracted from the IP optimal solution and are imposed in the CP model as global constraints. This constrains the CP model to use the correct number of deadhead trips for each landing and mill pair; reducing the search space considerably and speeding up the solution process.

El Hachemi et al. compare using the CP approach against the hybrid approach, where CP is used in conjunction with the IP process, on two case studies provided by the Forest Engineering Research Institute of Canada (FERIC). The hybrid approach proved superior in all instances. The log loader waiting time increased considerably in the larger instances for the hybrid approach, but this wait increase was countered by a significant reduction in deadhead costs that can be attributed to the introduction of the IP process.

A Hybrid Method Based on Linear Programming and Tabu Search for the LTSP

Flisberg et al. (2010) propose a two-phase hybrid solution approach to solve the LTSP. Similar to El Hachemi et al. (2011), the problem is decomposed. In the first phase, transport nodes are constructed by solving the flow of wood via linear programming (LP). Given the flow, the transport nodes are constructed in two steps. The first nodes are constructed after identifying which loads represent full truckloads. In the second step, the remaining flow at all supply points is combined with other supply points to form full truckloads.

A transport node is not generally one geographical point, but at least two geographical points: the supply point and the delivery point. Therefore, the node consists of the time it takes to load a vehicle at the supply point, the time it takes to drive loaded between points, the time it takes to unload a vehicle at the demand point, and the time a vehicle has to wait before loading or unloading capacity is available (Flisberg et al., 2010).

The second phase uses a Tabu Search heuristic to combine the transport nodes into routes by solving the problem as a vehicle routing problem with time windows (VRPTW). Several constraints are introduced including:

- Node restrictions for certain types of vehicles,
- time windows,
- different vehicles can have different starting and ending nodes,
- demand over several periods,

- different vehicle capacities,

- and different working times for different vehicles.

The system RuttOpt was used for all experiments with this approach. RuttOpt uses the Swedish national road database, a GIS interface, and a database with the case information. The system can generate Gantt scheme reports and has an external route planning interface.

Two case studies were used to test the system's performance. The first case study involved 12 trucks, 24 demand points, 410 supply points, 33,331 tons of supply available, and 7,511 tons of demand over three time periods. The second case study was larger and involved 110 vehicles, 113 demand points, 2,531 supply points, 261,260 tons of supply available, and 101,018 tons of demand over five time periods.

Since the tons of supply available in each case study are greater than the demand, it is not a requirement to visit each transport node; it is only desirable to fulfill the customer tons demanded. To ensure that the customer orders are filled, a penalty is introduced per ton of each order unfulfilled. In order to deal with the transport nodes not used, the concept of a virtual vehicle is introduced. The virtual vehicle visits all unused transport nodes, but does not incur any transport costs. In addition, the virtual vehicle does not have to abide by time windows or service times.

Chapter 5 – Integrated Technologies for Decision Support Systems

A number of technologies are integrated to create computer-aided decision support systems (DSS) for truck scheduling and dispatching, especially real-time dispatching systems. These technologies can be broken up into four main groups:

- Wireless telecommunications

- Positioning systems

- Geographic information systems (GIS)

- Scheduling and routing software

The integration of all this technology creates what are referred to as off-the-shelf software packages. These packages, as they pertain to freight transportation, are in the form of advanced scheduling, routing, and dispatching systems that are commonly used to support just-in-time (JIT) manufacturing. JIT manufacturing is the process of reducing inventories and fuel waste by having raw material and components arrive at a manufacturing site directly from the source at exactly the time required to support continuing manufacturing operations (Institute of Transportation Engineers, 2000).

As trucking contractors struggle to remain competitive, more are turning to DSS to optimize their schedules for the best use of resources and to reduce costs. Many carriers with large fleets are using DSS to facilitate better decision making through optimized routing and scheduling of their vehicles.

5.1 Wireless Telecommunication Technologies

Reliable communications are pivotal in enabling forestry companies to run business efficiently and communicate effectively for dispatching. Often times, log truck drivers and foresters are in remote locations and use a variety of wireless technologies to communicate with each other. Each type of technology has advantages and disadvantages and may play a number of roles in every day forest operations.

Wireless telecommunication is the transmission of messages over significant distances for communication purposes that often use radio waves. For the purpose of this research, it is not necessary to get technical about the specific frequencies each technology is allocated, rather it is more useful to have a general concept of what each technology is capable of and it's applicability to fleet management. It should be noted, however, that the Wireless Telecommunications Bureau of the Federal Communications Commission (FCC) regulates the use of the radio spectrum to fulfill the communications needs of businesses, aircraft and ship operators, and individuals in the United States. Private companies and governments are responsible for satellite communications and broadcasting.

5.1.1 Citizens' Band Radio (CB)

Citizens' band radio (CB) is a short-distance, two-way communications system that is often used by truck drivers and the public to communicate traffic problems, directions, weather alerts, or other important information. In forestry, CB radio is often used as truckers enter private forest road networks to communicate to with other

drivers coming up or down the haul road. Because turnarounds on forest roads are not always readily available and roads are often one lane, it is helpful to communicate with other drivers to coordinate passing.

In addition to log trucks using this conventional radio method, equipment operators (loader, feller-buncher, forwarder, skidder, etc.) also use it to communicate with each other and with the truck drivers to help streamline harvest operations.

5.1.2 Trunked Radio Systems

Trunked radio systems are a more advanced form of communications system than CB radio. They are computer controlled systems that allow several people to talk to each other over a few frequencies in what are referred to as talkgroups. In CB, users need to be on the same frequency to communicate with each other; however, trunked radio systems coordinate the system so several users can talk seamlessly over various frequencies. This increases the system's bandwidth and allows for more efficient utilization of limited frequencies because each talkgroup does not require a dedicated frequency (Goel, 2008).

These systems are not widely used in forestry fleets, but are used in some commercial trucking fleets. Generally, government fleets use trunked radio systems because different talkgroups can be assigned separately to individual government entities or to a combination of entities such as the police, emergency medical services, fire departments, or other municipal services.

5.1.3   Cellular Communication

Cellular phones are perhaps now the most widely used method of wireless communication worldwide. In fact, the number of cell phone subscriptions worldwide is projected to increase from 4.6 billion at the end of 2009 to 5 billion by the end of 2010 according to the U.N. Telecommunications Agency (CBS Interactive Inc., 2010).

Cellular communication is based on a growing system of geographic cells that provide transmission and reception using a set of radio frequency channels between phones and tower infrastructure. The channels are full duplex, meaning that communication can go either way, and the diameter of each cell site can be as large as 20 miles. The cells are interconnected to each other, to the local exchange provider, and to the interexchange provider. Furthermore, cellular communications can be either digital or analog (Institute of Transportation Engineers, 2000).

In forestry operations in the Pacific Northwest, cellular phones are often used secondary to CB radio because of unreliable reception in forested and rural areas. They are used, however, as a last resort if owner-operators are hired by a fleet for a short period of time and are not outfitted with the same communications equipment as the rest of the fleet.

5.1.4   Satellite Communication

If voice and/or data communication is of high importance between dispatch and drivers or loader operators, an alternative to the cellular phone, citizens band, and trunked radio is satellite communication. A satellite phone is a type of mobile phone that provides transmission and reception by connecting to orbiting satellites rather than terrestrial cell sites. Their coverage may include the entire Earth or only specific regions, depending on the system design.

There are two types of satellites, which are classified by the distance that they orbit the earth and the different spatial relationships with respect to the earth. The first type, geo-stationary satellites (GEO), orbit at an altitude of 22,300 miles above the earth. At this height, the satellite is in synchronization with the rotation of Earth's surface (Institute of Transportation Engineers, 2000). Thus, they are stationary relative to a point on Earth and provide a very wide coverage area from this high altitude.

Low-Earth orbit (LEO) satellite communications systems use satellite orbits that are much lower in altitude than geo-stationary satellites. These satellites take 1.5 to 10 hours to orbit the Earth depending on the height (Goel, 2008). Most of these satellites orbit Earth between 500 to 7,000 miles. Because they are at a lower altitude, they provide less coverage than a geo-stationary satellite and are therefore arrayed in a constellation of satellites to provide more continuous coverage (Institute of Transportation Engineers, 2000).

One limitation of satellite communication is that the satellites need a clear line of sight. Therefore, trees, obstacles, or poor weather conditions can be problematic. Additionally, reception is not available if the user is indoors. While there are limitations to satellite communication, there are benefits. A benefit to satellite phones, like cellular phones, is that they can access the internet but with limited bandwidth capabilities. In other words, the size of data and the rate at which it can be transferred is not likely to be competitive with a cellular phone in good reception.

5.1.5   Dedicated Short-Range Communications (DSRC)

Dedicated short-range communications (DSRC) devices are devices that are capable of transferring high rates of data over an interface between mobile or stationary vehicles. This technology is not specific to forestry, but is helpful in facilitating commercial fleet tracking and identification by attaching DSRC transponders to trucks, trailers, and containers. The transponders communicate with a receiver to identify a piece of equipment at a stationary roadside point such as a toll station, weigh station, or terminal gate (Institute of Transportation Engineers 2000).

5.2   *Positioning Systems*

Technological improvements have helped a key concept in freight movement to emerge called total asset visibility. This concept was initially developed by the military so that military leaders can know what weapons and supplies are available at all times and their geographical locations. Not surprisingly, the commercial freight industry saw an opportunity to adopt this concept by applying the same methodology

to track the locations of their freight and trucks in real-time (Institute of Transportation Engineers, 2000)

It is fundamental for many commercial trucking contractors to be able to track the position of each vehicle in the fleet. This enables the dispatcher to make informed dispatching decisions throughout the day as well as monitor the productivity and behaviors of each driver. Most log truck carriers have yet to equip their fleets with this technology because their current scheduling and dispatching scheme doesn't require it or may not benefit from it. Additionally, some drivers are wary of their employers monitoring their movements throughout the day.

5.2.1 The Global Positioning System

While the identification of vehicles and freight can be accomplished by DSRC transponders or satellites, the tracking of vehicles is typically done via satellites from the Global Positioning System (GPS). The Global Positioning System is a government-owned system of 24 earth-orbiting satellites that were originally put into orbit by the US Department of Defense. As with many technologies, it was originally intended for military use.

The GPS works by having a constellation of satellites in known orbits; each of which broadcasts a timing signal. A receiver on the ground accepts each timing signal with a delay proportional to the distance from the satellite to the receiver. By comparing the time delays from four satellites, the receiver is able to solve for four unknowns: the three position variables (x, y, and z) and one variable for absolute time

(Institute of Transportation Engineers, 2000). GPS is typically accurate within 10-20 meters.

Similar to satellite communications systems, the GPS also uses either LEO satellites or GEO satellites, depending on the system architecture. Therefore, positioning systems also have the same limitations as satellite communications systems in terms of coverage availability.

In some situations, dispatchers may simply monitor the locations of vehicle throughout the day using GPS technology and make dispatching decisions based on their own experience. More advanced systems of dispatching, called real-time dispatching systems, require fleets to be equipped with GPS technology so that optimization engines can make quick and optimal dispatching decisions based on the real-time locations of each truck.

5.2.2   Global Navigation Satellite Systems

Aside from being able to track vehicles, GPS can also be used in conjunction with a mapping system to help aid driver navigation. These systems are known as global navigation satellite systems (GNSS). GNSS are systems that use GPS technology to guide vehicles from one point to another, sometimes referred to as turn-by-turn navigation systems. These systems usually have an electronic map interface that provides visual and auditory directions for the driver. The driver can enter a target location and the computer will optimize a route and display it momentarily. However, the positional accuracy is decreased the longer the receiver goes without

communication with the satellite. Therefore, in some situations it is advantageous to equip the vehicle with a GNSS that is integrated with a dead reckoning system.

5.2.3   Dead Reckoning Systems

Dead reckoning is the process of determining ones position from a previous position based upon one's speed over an elapsed time and direction of travel. While previously used for air and marine navigation, it is being used more widely in automobiles to overcome the limitations of GPS/GNSS technology. In a dead reckoning navigation system, the vehicle is outfitted with sensors that document the wheel rotation and steering direction. The navigation system then uses a Kalman filter algorithm in order to combine the reliability and short-term accuracy of the sensor data with the long-term accuracy of the satellite data into a best estimate position fix. The disadvantage of dead reckoning is that new positions are calculated based on previous positions; therefore, errors are cumulative and grow larger as time without satellite availability increases.

5.3   *Geographic Information Systems*

Routing or positioning would not be possible without a map of the earth and its features. Geographic information systems (GIS) provide a means of mapping the earth in an electronic format. GIS is a computerized data management system designed to capture, store, retrieve, analyze and report geographic and demographic information. GIS integrates hardware, software, and data, which enable agencies to inventory and geographically locate roads, intersections, addresses, buildings and other landmarks.

The most common methods of creating GIS databases are manual map digitizing, scanning, remote sensing, and photogrammetry (Bettinger and Wing, 2004).

5.4   *Enterprise Resource Planning Systems*

The advantage of using off-the-shelf DSS over using a personally developed DSS is that they usually have easily navigable interfaces and can often be integrated with enterprise resource planning systems (ERP). ERP systems refer to a group of closely integrated information systems that support business functions such as materials management, production planning, sales, distribution, accounting, controlling, finance, and human resources (Institute of Transportation Engineers, 2000). Enterprise resource planning systems are useful because they allow the different departments within a company to communicate through a standard interface. This communication enables the departments to make better decisions more quickly based on the information they receive from other departments.

Chapter 6 – Decision Support Systems Available for Log Transportation

At the beginning of this project, a web search was performed to determine what decision support systems (DSS) were currently available to fleet owners. The search results yielded more than 40 different systems promising increases in efficiency and cost savings. Not surprisingly, almost none of these systems were designed for log truck fleet management. Most were designed for common freight delivery problems, instead of pickup and delivery problems.

The software discussed here is not an exhaustive list, but each has been used and tested for its potential to schedule and/or dispatch log trucks. It is unclear, however, how many commercial DSS can be tailored to meet the requirements of the log truck scheduling problem (LTSP).

6.1   ORTEC

To the best of the author's knowledge, Longview Timber implemented one of the first computer-aided DSS for log truck scheduling in the Pacific Northwest in 2005. After noticing inefficiencies in log transportation from the forest to the mill for many years, management sought outside consultation to improve their logistics. Longview enlisted the help of ORTEC, one of the largest providers of resource planning and optimization software in the world, to implement an advanced planning system with the hope of increasing their fleet's loaded miles.

Longview was using a manual planning/dispatch approach prior to ORTEC's DSS, which yielded a loaded efficiency of around 40% for all of their trucks. In this system, the loader operator from each landing would call the dispatch at the end of the day and request a number of trucks for the following morning. The next day the loader operators then served as pseudo-dispatchers. For example, the loader operator would look at the sort, determine the appropriate destination, and then instruct the drivers on which mill to deliver the load. The driver would then proceed to drive back and forth between this landing and the mill trying to get as many loads as possible that day.

To break the cycle of trucks continuously servicing the same landings, ORTEC's plan was to intelligently create a schedule for the fleet by using their software to choose each truck's next landing based on the proximity of the truck to other landings after a completed delivery.

The new system called for a substantial change in operations. Trucks were no longer dispatched by the fleet owner or loader operator, but rather the landowner, i.e. Longview Timber. Therefore, Longview Timber hired a dispatcher and requested that all of the trucks working for them purchase radios so that dispatch could maintain communications. Previously, the loggers contracted by Longview Timber were responsible for hiring trucks to service their loads.

The trucks Longview Timber was using, which ranged from 50 to more than 100 depending on harvest production, were comprised of owner-operators and trucks that were part of a fleet owned by large carriers. At the peak of operations, the

dispatcher was directing more than 100 trucks to approximately 20 different harvest sites and 50 destinations.

ORTEC's DSS used a heuristic that took approximately 5-10 minutes to construct an optimized schedule, depending on the number of trucks. There were two layers of optimization. The first optimization layer tried to minimize cost by increasing the loaded miles of the trucks while striving to keep all the drivers working approximately ten hours per day. The second optimization layer was a revenue optimization model that could choose mill destinations for loads based on the sort prices.

Every day at about 3:00 P.M. the loggers would call the dispatcher and make their orders for the next day. The orders would include the total number of loads they expected to have on the landing, the sort and destination of each load, load time windows, and mill/destination time windows. The loggers could not always forecast loads with certainty, but did their best to predict. The transportation manager then entered these requests into ORTEC's software interface and by approximately 5:00 P.M., the dispatcher would have the plan created for the next day and available for viewing by each driver.

The planning software staggered the arrival times of trucks to eliminate queuing at the landings. The transportation manager knew from empirical results the time it took to load each trailer type and programmed these service times into the description of each load. While staggering the arrival times is a more efficient way of

scheduling, it didn't appeal to all of the drivers because some were required to start earlier or later in the mornings than they were used to, and/or the start times were inconsistent throughout the week. This is an issue that the dispatch presumably could have remedied to appease the drivers.

For the most part, the schedule was adhered to throughout the day barring unforeseeable events such as bad weather, flat tires, or the occasional driver who failed to mention an appointment. While the solver could be re-run to update the schedule or suggest alternatives, the dispatcher would usually react, make decisions manually, and dispatch accordingly based on their experience.

Longview Timber consistently used ORTEC's DSS for the next two years from 2005-2007. Over this time period, the loaded efficiency of their vehicles increased from approximately 40% to 60-65%. Despite the success, Longview Timber opted not to continue with the DSS after the company was restructured in 2007.

The decision to discontinue the use of ORTEC's DSS was partly due to considerable resistance from the drivers. In the system prior to ORTEC, loader operators were responsible for hiring trucking contractors, thus, drivers often worked with the same loader operators daily. Many drivers and loader operators had developed strong working relationships and were resistant to being managed by a central dispatch.

ORTEC tried to provide incentives for the drivers to support the DSS by changing the pay system to reflect driver performance and share some of the increases

in efficiency. For example, instead of paying by the hour, drivers were paid by the loaded mile. In the end, drivers shared 5% of the 20% savings in costs.

Aside from drivers disliking being managed by a new dispatch, some drivers had trouble finding the new landings. Many drivers had served the same tree farms continually and the new schedules required them to venture to the company's other tree farms. The drivers were supposed to be provided with paper maps for each tree farm, but there were times when the drivers never got them or lost them and consequently had difficulties finding their way.

At the time, GPS vehicle navigation systems weren't commonplace in ORTEC's DSS; however, they are considered standard in all of their current ones. ORTEC recently partnered with TomTom, which uses NAVTEC's road databases. These road databases cover public road networks, but would have to be updated to include a private landowner's forest road network if requested.

Although the forest roads were not in ORTEC's system during the implementation, it did not affect the scheduling. The dispatch used the average travel times between the public roads and the landing and entered them into the system manually to simulate realistic loaded and unloaded travel times.

While the implementation of ORTEC's DSS increased the efficiency of Longview Timber's transportation, changing the culture of the parties involved, especially the drivers, proved to be more of a difficult task than the company was willing to handle while restructuring.

This implementation showed that these systems clearly have a place in Pacific Northwest forestry while at the same time affirmed that the culture is not something that can change overnight. Looking forward, it is evident that the drivers need some type of incentive to encourage them to adapt more rapidly to these new systems; perhaps in the form of a higher share in the cost savings or switching to performance-based job security.

Plum Creek Timber Company, Inc. has also used an ORTEC DSS for their log truck scheduling and dispatching in the past with at least three logging contractors. Using several logging contractors who employ other subcontractors for hauling essentially creates a collaborative truck scheduling effort by pooling fleets and wood supply locations. The new real-time dispatching DSS calculates optimal truck routes from the landowner's landings to the mill destinations (McCary, 2009). The system uses an onboard Genesis site navigation system to route drivers (Figure 11).

Figure 11: A photo of the Genesis site navigation system that has helped boost production and reduce fuel consumption (McCary, 2009)

Bunch Logging, Inc., (Waynesboro, MS) was one of the logging contractors employed by Plum Creek participating in the implementation. Bunch Logging, Inc. runs two crews that operate eight trucks, including five contract haulers and three company trucks. Bunch Logging, Inc. stated that they preferred to have the truck dispatching done internally rather than hiring a third party to handle the truck scheduling and dispatching. The contractor optimistically stated that the system has the potential of delivering up to 85% loaded efficiency (McCary, 2009).

6.2   Trimble Blue Ox

Trimble MCS' Forestry Automation business unit launched Blue Ox in the first quarter of 2010. The Blue Ox system aims to increase the utilization of trucks, enabling forest companies to move more logs with fewer trucks and reduce transportation costs. In one pilot test of the Blue Ox system, the DSS increased the loaded miles per day by 31%. In a second test, the number of trucks used was reduced by 45% and total miles were reduced by 22%. Each of the trucks in the second test traveled fewer miles and delivered more loads per truck.

According to Matt Linderman, area manager for Trimble Forestry Automation Business, "Many of the inefficiencies along the supply chain are caused by a lack of information. The Blue Ox system collects and processes that information in real time, recommending actions that can reduce or eliminate the bottlenecks that waste time and fuel. The result is more efficient use of capital assets, accomplished by reducing the amount of time trucks spend traveling empty and waiting to be loaded or unloaded.

For truck owners, this can mean savings in fuel, maintenance, and truck replacement costs, which could allow them to lower their price to landowners for their services. Loggers also benefit from a more efficient distribution of trucks to all cut sites, reducing the potential for disruption in the flow of wood to the mills."

Hancock Timber Resource Group is one of the first companies to implement the Blue Ox system. "Transporting logs from the harvest site to the mill can represent nearly half of the total cost of forest products processing," said Hugh McManus, general manager for Hancock Timber's South Central Division. "With the implementation of these innovative transportation technologies across our forestry operations in Western Louisiana, East Texas and Arkansas, Hancock Timber expects to increase supply chain efficiencies and reduce costs-to the benefit of our clients."

Blue Ox is a computerized real-time central dispatch system that combines GPS and wireless communications using simple dispatch rules with limited look ahead. It is being marketed in both the western and southern United States. Trimble's business model offers a range of services from stand-alone software and hardware sales to third party logistics management.

The Blue Ox system is completely integrated. Loader operators are equipped with onboard computers called the Trimble Nomad® (Figure 12). The computers are used to enter information about each load including the sort, the time window for arrival, and the mill destination. Using this information the optimization engine

matches available loads to available trucks based on real-time locations and other information.

Figure 12: The Trimble Nomad® used to enter information about each load by the

loader operator

At the harvest site, the Blue Ox system assigns trucks to loads according to availability. Truck arrival times are staggered to minimize queue times on the landing. The system tells the loader operator what loads to put on each truck and updates the system when the truck departs for the mill. Transportation instructions and other information are dispatched to individual drivers via Trimble's Yuma® rugged tablet computer, which is mounted in the cab of each truck in the fleet (Figure 13).

Figure 13: The Trimble Yuma® used to dispatch driver assignments and route drivers to supply points and destinations

At the office, the transportation manager or dispatcher can manage by exception with active alerts and messages for events such as mill shutdowns, road hazards, detours, or breakdowns. The software allows the dispatch to monitor the locations of the trucks in real-time, check productivity reports, watch for excessive truck idling and speeding, and check the planned schedule against what is actually happening in real-time.

An advantage of Blue Ox is that it uses real-time information, making the system less rigid. Blue Ox splits the data entering workload by having each loader operator input data about their supply rather than relying solely on the dispatcher to update data each night and throughout the day. Another clear advantage of Blue Ox is that it can be applied to common Pacific Northwest transportation scenarios where several contract haulers are used by a landowner.

6.3   ArcLogistics

Interested in off-the-shelf DSS, Marshall and Boston (2003) tested the suitability of ArcLogistics 3 Route to solve log truck scheduling problems. They tested three scenarios and found that ArcLogistics Route 3 was able to: (1) allocate the orders to trucks in a manner that minimized the trucks required when there was a surplus of trucks, (2) investigate the effects that just-in-time (JIT) management at sawmills had on transportation costs and logistics, and (3) schedule orders on a priority basis when there was a shortage of trucks. The package could also be integrated with automatic vehicle location (AVL), enterprise resource planning systems (ERP), accounting systems, and other enterprise technologies.

A major limitation for ArcLogistics in terms of its applicability to log truck scheduling and dispatching is that only public street data is included. In reality, most road networks used in the forest industry are privately owned; however, roads could be added to the database with some advanced GIS skills. Another limitation is that the solver only computed schedules with the objective to minimize cost and the heuristic cannot be altered manually.

ArcLogistics 9.3 continues to use public street data (Navteq and Tele Atlas); however, in this version the user is not allowed to edit the transportation layer for adding private forest road networks. In addition, the user must specify the pickup locations by entering an address. Unfortunately, many of the forest roads and harvest

sites do not have addresses. Moreover, forest roads are constantly being built and abandoned as old timber sales close and new timber sales become active.

6.4   *ArcGIS Desktop Network Analyst Extension*

An alternative to using ArcLogistics Route for truck scheduling is ArcGIS Desktop. ArcGIS Desktop is an off-the-shelf package used by many forest companies in the Pacific Northwest for map making as well as to record data on forest and road network inventories. ArcGIS offers an extension called Network Analyst, which can be used to perform spatial and network analysis on a road network using a network dataset.

The network dataset is created from a roads shapefile in ArcCatalog and is then added to the map layer within ArcGIS Desktop. Within Network Analyst, the user can create applications that build multimodal routes, provide travel directions, look for closest facilities, schedule and route fleets, and create service areas and origin-destination cost matrices.

To create schedules and routes for a fleet of log trucks, the user creates a vehicle routing problem within Network Analyst. In Network Analyst, each pickup and delivery is called an order. The user selects the locations of each order and enters delivery information. In this case, the pickup location will be where a log truck will receive a load of logs in the forest and the delivery location will typically be a mill. The information the user can enter about each order includes the pickup and delivery quantities (which should be set to 1 to indicate a full truckload), time windows for

service, service time (i.e., loading and unloading time plus wait time), revenue (dictates the priority through which orders will be serviced), and specialties needed.

Specialties can be created to indicate if an order needs a special type of vehicle or trailer configuration. For example, a load of logs is typically carried with a stinger-steered trailer while chipped wood for biomass is transported in a chip van. Therefore, the user can create a specialty to indicate what type of truck is needed from the fleet to service the order.

After entering information about each pickup and delivery, the orders can be paired using the "paired order" function. This allows the user to specify where the pickup order needs to be delivered. Next, the user creates the fleet by editing the routes feature layer. A route specifies the vehicle and driver characteristics as well as represents the traversal between orders.

In Network Analyst, vehicles, routes, and drivers are synonymous, and the term "route" is used to encompass all three entities. The user can enter information about where and when the driver will start and end the day, truck capacity, fixed cost to pull a truck out of the garage, cost per unit time, cost per unit distance, overtime start time, cost per overtime, maximum number of orders, maximum total travel time, maximum total distance traveled, specialties, and assignment rules.

After simulating several wood transportation scenarios, I observed that the solver is not always able to find the lowest cost solution. For example, assuming all other components are held equal, the truck with the lowest hourly cost should be

assigned the schedule with most hours. This solution was not always found by the solver; however, an experienced dispatcher could see this and assign the appropriate schedule to the appropriate driver if needed. The solutions might improve if the user was able to manually change the stopping criteria or other heuristic components. More information could not be learned about the heuristic as it is deemed proprietary. The Network Analyst extension in ArcGIS would be ideal for smaller operations, maybe 5-30 trucks, but the interface can become cluttered quickly and entering the required data for each truck and paired order is time consuming.

6.5   ASICAM

As discussed previously in Chapter 4, ASICAM was developed in the early 1990s for use in the Chilean forest industry. Since then, ASICAM has also been evaluated for its potential in New Zealand (Cossens, 1993) and South Africa. In 1995 ASICAM was implemented by Mondi in South Africa, a leading international paper and packaging group, for truck scheduling. It was used to schedule Mondi's supplying fleet and assist in forecasting for expected mill deliveries and departures from plantations in the KwaZulu-Natal midlands. Mondi won the South African Logistics Achiever awards for implementing ASICAM.

While ASICAM showed potential in both New Zealand and South Africa, it was eventually abandoned for various reasons, mainly because it lacked the ability to be tailored to the specific forestry requirements of each operation. It is still used, however, by various forest companies in Chile.

ASICAM has also been assessed for its potential in the sugar cane industry (Giles et al., 2005). Results from this implementation suggested that the number of trucks needed for sugar cane transportation could be reduced by at least 60%, provided that a central dispatch is in control of scheduling.

6.6 RuttOpt

There are four major decision support systems that are currently used to manage about 50% of the log trucks in Sweden: KOLA, SMART, TROMB, and Åkarweb. The systems are used to "administer and communicate transport orders between company central systems, home offices and trucks (Anderrson et al., 2008)". Each system uses on-board computers equipped with GPS based navigation; however there is little to no support for generating truck schedules. See Anderrson (2008) for a description of each system.

The decision support system RuttOpt was developed out of the need for decision support systems to be able to provide truck scheduling services in Sweden. It was developed specifically for the Swedish forest industry by the Forestry Research Institute of Sweden (Skogforsk) during 2003-2007, but has the potential to be used in other industries. RuttOpt is a system that uses a number of components including the Swedish road database, an optimization engine, and a database to store all relevant information to the transportation system such as supply, demand, home bases, trucks, and costs. The system includes a graphical interface where information and results can be seen on GIS maps, Gantt schedules, and reports. The optimization routine uses a

two-phase algorithm that combines linear programming and a Tabu Search heuristic (see Flisberg et al., 2010).

The Swedish forest industry is different than the forest industry in the Pacific Northwest in that there is generally no pairing of logs to destinations. Typically, logs can be sent to satisfy the demand of any mill as long as the sorts are correct. The demand of each mill may vary over several days, but there are minimum and maximum limits that can be delivered daily, making it a multi-period problem (Anderrson et al., 2008). The objective in these operations is to develop the minimum cost schedule for all trucks in a given planning horizon subject to satisfying the mill demands.

RuttOpt has four main phases for use (Anderrson et al., 2008):

1. Data collection.
2. Pre-processing and set up of data for the optimization engine.
3. Running the optimization routine to generate schedules.
4. Processing and interpreting the results and generating reports.

RuttOpt has been tested on a number of case studies with forest companies and hauling companies. The cases range from ten trucks to 110 trucks using a planning horizon between one and five days. The results suggest that the system can be used to solve large problems and that the potential savings are in the range of 5-30% (Anderrson et al., 2008).

6.7   Joint Planning Tool

The Joint Planning Tool (JPT) is a real-time, web-based scheduling system that was developed in South Africa to eliminate the uneven flow of logs into mills and to reduce queue times at the mills (NCT, 2003). The system was designed specifically to meet the operational needs of NCT's new chipping plant, Durban Woodchips (DWC).

The system requires suppliers to go online and book slots for their arrival times based on the number of anticipated loads. The slots must match daily mill requirements. DWC designed the available slots based on their maintenance schedules, peak traffic times, and other factors.

The JPT booking system benefited DWC in a number of ways (NCT, 2003):

- Reduced standing times at mills.
- Reduced excessive queuing at mills.
- Efficient capacity utilization throughout the month due to a balanced flow of log deliveries.
- Lower tariffs.
- Reduced stop/start situations at the mill.

DWC eventually discontinued use the JPT system when the company moved to 24-hour shifts. The shift towards longer operational hours resulted in less excessive queues at the mills and it was deemed that the system was no longer necessary. Since

the JPT system was developed specifically for NCT's supply-chain constraints and

requirements, it may only be useful for certain industries.

Chapter 7 – Challenges and Opportunities for Implementation

The literature suggests that decision support systems (DSS) for log truck scheduling and dispatching have the potential to reduce transportation costs by minimizing the number of trucks needed and vehicle miles traveled to service customers. Despite previous implementations and technological advances in DSS, dispatchers still largely schedule by hand using manual methods in the Pacific Northwest forest industry; relying heavily on experience. In many operations, dispatchers assign trucks to logging contractors who serve as the truck's pseudo-dispatcher for the day. Professionals agree that there are efficiency and savings to be gained if landowners, loggers and carriers adopt computer-aided DSS administered by a central dispatch.

In the literature and in interviews with industry professionals, it appears that savings of 5% or more in total transportation costs can be achieved by using DSS for log truck scheduling and dispatching. Most of this analysis was done by comparing DSS generated schedules against historical schedules that were developed using manual methods. Although the transportation of logs from the forest to the mill accounts for up to 50% of the delivered cost of wood, it appears that companies are not yet willing to implement DSS to reduce transportation costs.

There may be a number of reasons why the industry is slow to adopt DSS for log truck scheduling and dispatching, but less attention has been paid in the literature on identifying these challenges. Most of the research has been dedicated to developing

different solution techniques for solving the log truck scheduling problem, but it appears that one of the more challenging problems is how to encourage the adoption of DSS by the industry. It appears that sufficient solution techniques have been developed for DSS, but many companies are still resistant to adopting them to reduce transportation costs. There are many challenges to implementing DSS for log truck scheduling and dispatching including the culture of the industry, the organizational and business structure of the log transportation system, technology, economies of scale, arrangements of sources and destinations, trust between participants, and inertia.

7.1 Challenges Associated with the Industry's Culture

In meetings with forest landowners, transportation professionals, and software developers, a characteristic that was unanimously labeled as being the major obstacle to successfully implementing a decision support system (DSS) was the culture of the forest industry. Current transportation methods have been used for years with "success"; therefore, some owners, in a sense, fear change or are resistant to change because they have a system in place that has worked in the past. The literature suggests, however, that success doesn't necessarily translate into efficiency.

Trucking contractors may be serving all the loads requested by loggers, but not in the most efficient fashion possible. In order for trucking contractors, loggers, or landowners to feel confident about changing the organizational structure of their log transportation system, the DSS must demonstrate significant savings to make up for the time and money invested as well as provide benefits for all parties involved.

7.2   The Organizational Structure of the Log Transportation System

The majority of previous decision support system (DSS) implementations for log truck scheduling and dispatching outside of the United States have had one common goal: to satisfy the mill's demand for logs at the lowest possible transportation cost. If log trucks are managed by the mill to satisfy their own demands, less change is needed in the organizational structure when implementing a DSS. Management will likely remain the same in terms of who performs the scheduling and dispatching.

However, the organizational structure of the forest industry is different in the Pacific Northwest and may not lend itself as easily to the implementation of a DSS for log truck scheduling and dispatching. Here, the goal is to pickup and deliver all the loads demanded by a logging contractor at the lowest cost possible. Mills do not explicitly state their demands for log sorts; rather they offer a price per unit volume for a given sort. Therefore, many logging contractors send each sort to the mill that offers the best price while other logging contractors may be contractually obligated to serve certain mills. If mills receive an excess supply of a sort, the price per unit volume for that sort will likely decrease.

It may be more difficult to implement a DSS in the Pacific Northwest because it is not clear who would be responsible for making the investment in the DSS and administering it. Since mills do not typically own trucks in the Pacific Northwest, the interested parties for implementing a DSS may be the landowner, the logging

contractor, the trucking contractor, or a combination thereof. In order for a DSS to be successful, a central dispatch needs to be created to assign schedules to trucks or dispatch trucks to service individual loads in real-time.

Currently, few schedules are actually developed by a central dispatch in the Pacific Northwest. A fleet dispatcher usually assigns a fixed number of trucks to a logging contractor each day. After the truck reaches the landing, the loader operator serves as the pseudo-dispatcher and informs the driver of the destination for each load and if they are to return for another. It is often assumed that the loader operator will have enough loads to keep the driver busy for the day. If the driver is instructed not to come back for another load, the fleet dispatcher is then in charge of finding the driver work for the rest of the day and dispatches accordingly.

The logging contractor prefers to have control of the truck movements to ensure that their harvesting productivity remains constant; therefore, it may be difficult for them to relinquish control of the trucks if a DSS is implemented. In order for logging contractors to feel more comfortable about allowing a central dispatch to control truck movements, the DSS needs to be able to schedule or dispatch trucks in such a way that each loader operator receives the same level of service as before or better. This can be achieved by assigning time windows for each load. Time windows that are regularly met through proper scheduling and dispatching can help loader operators plan the best use of their time while trucks are en route.

7.3   Obtaining Accurate Information about Supply in the Forest

The success of a decision support system (DSS) for log truck scheduling and dispatching depends heavily on the accuracy of information related to the supply at each landing. This information is best known by the logging contractor and/or the landowner. Currently the loader operator requests a fixed number of trucks from the trucking contractor for the following day based on how many loads they predict to need serviced.

Since it is in the logging contractor's best interest to control the truck movements, the DSS needs to generate schedules that abide by the logging contractor's time windows. The cost savings from the system could be shared with the logging contractor as an incentive to do their best to accurately predict supply.

Even if the loader operator is willing to relinquish control of the trucks to a central dispatch, it is still difficult to accurately predict supply with certainty, especially if the supply must be predicted the night before to create the following day's schedule. Based on the supply, the loader operator also needs to decide where the sort is to be delivered. Two things make it difficult to predict the supply and the load destinations: (1) the variability in the harvest production rate and (2) the type of logs being harvested.

If the production rate is faster than anticipated, more loads may need to be serviced by the trucks than were previously included in the schedule. If the production rate is slower, fewer loads will need to be serviced by the trucks. In addition to

predicting the number of loads, the destination of each load also needs to be known with certainty in order to create a useable schedule. The log sort (species, grade, and planned use) is one of the major deciding factors in determining the load destination. Log sorts can change throughout the day as the logging crew moves to different areas within the harvest unit, depending on stand variability.

If the log sorts coming to the landing change, the loader operators may have overestimated or underestimated supply for certain log sorts which in turn may affect the destinations they had predicted for the initial schedule. Moreover, the owner of the wood is always trying to get the most for their product. Therefore, if a mill changes their prices for sorts the following day, the landowner may require the logging contractor to send the sorts to different destinations.

The inability to accurately predict the number of loads and associated destinations makes it difficult to generate schedules that can be used for the entire day. Therefore, the forest industry in the Pacific Northwest may benefit more from dispatching systems that use the real-time locations of trucks and supply information at landings to assign available trucks to available loads.

7.4   Demonstrating Benefits to Drivers

Interviews with industry professionals made it clear that the changing the organizational structure of the log transportation system would not be well received by many truck drivers. It is important that drivers are agreeable to the new administration if the decision support system (DSS) is going to be successful; largely because there is

strength in numbers. In discussions with Longview Timber, the resistance from truck drivers prompted the landowner to discontinue use of the log truck scheduling DSS after the company restructured, despite increases in the fleet's loaded efficiency from 40% to 60%.

If control of the truck movements is relinquished by the loader operators, drivers must transition from being scheduled by certain loader operators, whom they become comfortable with over time, to being scheduled by a central dispatch. Aside from new management, the system may also schedule drivers to service landings with new loader operators or with loader operators that have poor working relationships with the drivers. A system should have the capability to implement constraints that prevent schedules pairing these drivers and loader operators if necessary.

Perhaps the most difficult subset of drivers to persuade to use these systems is the individual truck contractor, i.e. owner-operator. From the owner-operator's perspective, it is not advantageous to work under a centralized dispatch because it hinders their ability to compete. Owner-operators remain competitive by working longer hours and picking up more loads. This is especially true in operations where owner-operators bid on hauling contracts. Some DSS have a work-balancing system that tries to evenly distribute loads or hours to all drivers in the system, thus, decreasing the competitive advantage of the owner-operator. It is presumed that this could be remedied by allowing an exception in the system for these drivers to work more hours, but this may be seen as unfair to drivers that are part of a fleet. In Chile,

ASICAM incorporated a balancing scheme where all drivers were privileged to the same opportunities to ensure fairness and to keep drivers from fostering an overly competitive environment (Weintraub et al., 1996).

In the Pacific Northwest, it is important for log truck drivers to remain competitive because of the recent difficulties in making a decent living, especially owner-operators. A publication of survey responses by the University of Washington and Washington State University (2008) indicated that 28% of log trucking companies lost money, 50% broke even, and 21% made profit. The majority of these companies, 64%, are independent owner-operators.

The demographics suggest that the industry is going to have a hard time finding new drivers in the future. The average age of a Washington State log truck driver is 55 years old and the average experience of a driver spans 27 years. If this trend continues, there could be a serious shortage of drivers in the near future as the survey showed that 51% of the drivers were looking to retire or leave the industry. This appears to be happening already and is supported by the fact that 87% of survey takers reported that it is very difficult to find and keep skilled truck drivers and 99% reported that skilled drivers are harder to find today than 10 years ago (2008). The pending shortage of drivers may be one factor that encourages adoption of DSS in the log trucking industry.

Decision support systems may be able to help log truck drivers by increasing their loaded miles and the number of loads they can service. While fewer drivers may

be needed in a system using DSS, the drivers that remain will realize the benefits of more efficient scheduling and dispatching. In addition, the timing for implementing this new technology may never be better as older drivers retire and younger generations of drivers, more comfortable with technology, begin entering the industry.

7.5   *Finding Backhaul Opportunities*

Another challenge to the success of decision support systems (DSS) in the Pacific Northwest forest industry is the ability to find backhaul. As demonstrated in the example in Chapter 4, it is imperative to reduce the unloaded miles traveled in order to increase the loaded efficiency of trucks. Backhaul opportunities are often limited in forestry for two reasons: (1) truck and trailer configurations and (2) the arrangement of sources and destinations.

The most popular log hauling configuration in the Pacific Northwest is a truck with a stinger-steered trailer (Figure 14). This means the trailer is articulated and is guided by an extension of the truck frame called the stinger. The stinger-steered trailer develops less off-tracking around curves than a conventional 5th wheel trailer. Conventional 5th wheel trailers can be considered as a special case of the stinger-steered trailer; however, stinger-steered trailers in forestry do not have flat-bed decks like conventional semi-trailer combinations. The absence of a flat-bed deck limits the types of loads that can be handled and reduces opportunities for backhaul of other commodities besides logs.

Figure 14: Stinger-steered log truck trailer mounted on truck tractor for return to the

forest

In addition to reduced off-tracking, the stinger-steered trailer can be mounted on the truck tractor for return to the forest. This configuration allows trucks to climb steeper grades and to turn around more easily. These trailers have lower unloaded travel costs than standard trailers and weigh less.

Aside from the truck and trailer configurations, backhaul is often limited in log transportation because of the spatial arrangements of sources and destinations. In common freight movement, trucks are regularly able to pick up freight from other supply points on the way back to their point of origin, increasing their loaded efficiency. Due to the spatial arrangements of landings and mills in forestry, it may be difficult for dispatchers to construct routes that have backhaul. Some landowners may not have ownership in different regions with wood flow traveling in both directions. Collaboration between landowners, which is seldom seen in this industry, would

significantly increase the number of opportunities for backhaul through more promising spatial arrangements of sources and destinations.

7.5.1 Opportunities in Collaborative Logistics and Shared Log Transportation Services

Collaboration between landowners via sharing transportation services is one way to increase the loaded efficiency of trucks. If a DSS serves several landowners, better routes can be created because the DSS has more landings and mills to choose from when creating schedules. In shared transportation services, landowners, trucking contractors, and logging contractors would pool trucks and information regarding logistics. The problem being solved is still the log truck scheduling problem, but the loads and trucks from each stakeholder are considered in the scheduling. By pooling loads and trucks, more efficient trip sequences can be scheduled and deadhead travel times for the first and last loads of the day can be reduced.

In order to see significant increases in savings industry-wide, it is thought that a network of private landowners and carriers need to be involved. A single company with a consolidated ownership has less to gain than operating across several ownerships. Ideally, the network of private landowners would have overlapping land areas. With a large network of trucks and overlapping land ownership, there would be more opportunities to increase the loaded efficiency of the trucks through backhaul. Carlsson and Ronnqvist (2007) propose a tactical planning model that indicates the supply and demand points between which backhauling is optimal. Using this

methodology, managers may be able to identify other companies in the area that would be interested in collaborating to increase backhaul opportunities.

In discussions with Forest Capital Partners LLC, it was estimated that transportation costs could be reduced by approximately 6% using DSS for log truck scheduling (not including the cost of buying and implementing the DSS). This estimate was based on simulation using historical data for their company only. It is likely that a larger percentage of the total transportation costs could be reduced if this company were to share transportation services with another landowner.

McDonald et al. (2001) describe operations in the southern United States where a fixed number of logging trucks are assigned to a logging contractor regardless of the transportation distance. This can lead to excess trucking capacity when haul distances are short and insufficient capacity when haul distances are long. If there is excess capacity, there is more likely to be delay introduced into the system as queues form at the landings and mills. When there is insufficient capacity, a logger's productivity may suffer as wood accumulates on the landing; creating bottlenecks. In some cases, logging contractors may not be able to get all of their loads serviced if there is insufficient capacity. It is thought that transportation needs can be balanced by sharing trucking capacity; resulting in less trucks being needed and fewer unloaded miles traveled.

For the non-collaborative situation in Figure 15, the logger on the left has insufficient trucking capacity because of the long haul distance and the logger on the

right has excess capacity because of the short haul distance. If the loggers were to collaborate, the transportation needs could be balanced; reducing queue times and increasing equipment utilization.
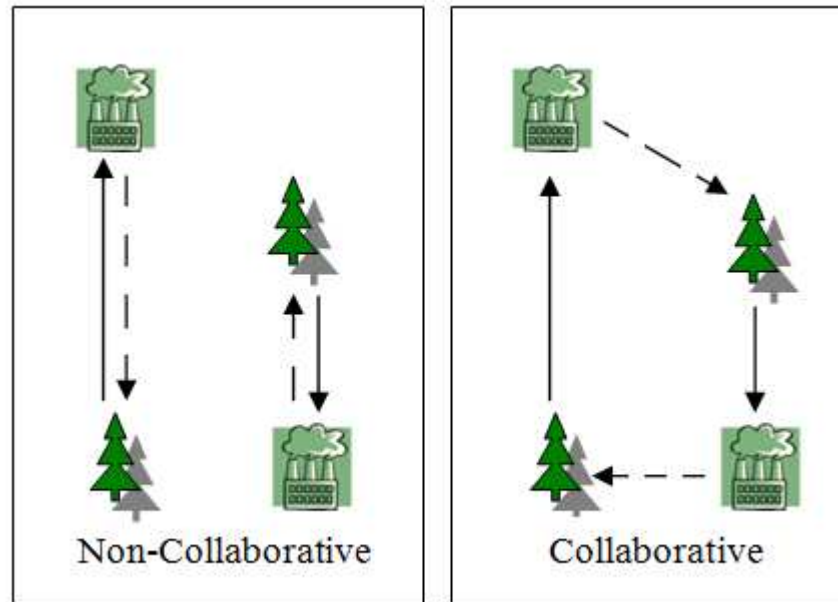

Figure 15: Collaboration between stakeholders with different haul distances

While balancing capacity needs between logging contractors with different haul distances can lead to gains in efficiency, similar results can also be achieved by collaboration from loggers with equal haul distances. Trucks often pass each other unloaded on major highways in the Pacific Northwest because they are only serving single logging contractors. If different logging contractors on opposite sides of a region were to collaborate, there would presumably be more opportunities for loaded return trips.

Consider Figure 16 where the logger on the left and the logger on the right have similar haul distances. As shown by the dashed lines, trucks often pass each other empty on their return trips to their respective logger. Long unloaded trips decrease the loaded efficiency of the vehicle for the day. In the collaborative situation, the trucks serve both loggers; creating backhaul and reducing the unloaded miles traveled by each truck.
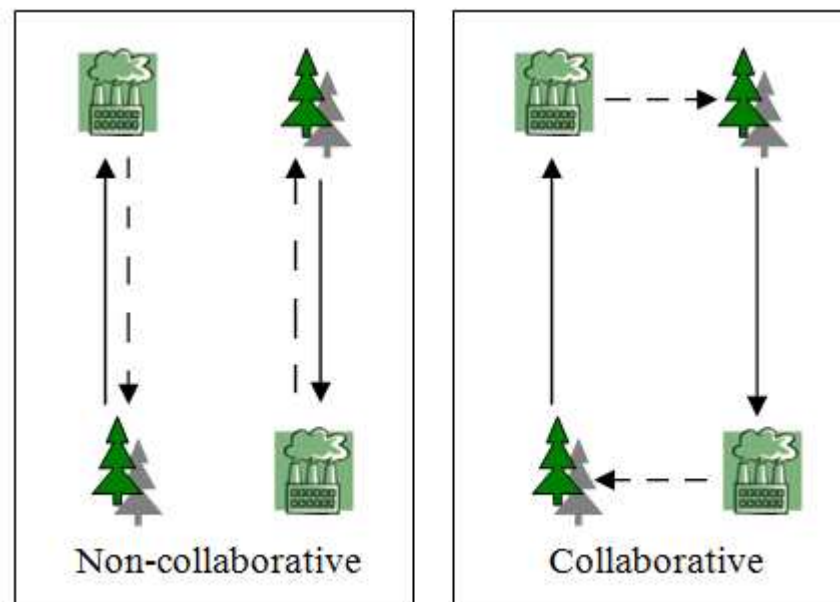
Figure 16: Collaboration between stakeholders with similar haul distances

Several collaborative efforts using shared transportation services in the forest industry have been documented. McDonald et al. (2001) performed simulations where 20-30% more wood was hauled with the same number of trucks by sharing transportation services. Murphy (2003) used a 0/1 integer programming formulation to optimize log truck schedules for two case studies in New Zealand and found that it

was possible to deliver the same number of loads using fewer trucks. In the two efforts

documented, the number of trucks needed was reduced by 25-50% and costs were

reduced by as much as 47%.

Mendell et al. (2006) evaluated the potential for a DSS administered by a

central dispatch to improve the loaded efficiency of trucks in a pooled log

transportation network. In comparing the actual results from the field study to the

simulated results by the DSS, the simulated results increased the loaded miles per day

by 4.27%, reduced the loaded miles per day by 655 miles, and reduced the hours

worked per day by 0.92 hours. Most importantly, the DSS was able to dispatch trucks

to service all of the loads requested by the logging contractors.

Audy et al. (2007a) explored the benefits of collaborative logistics through a

case study using a scheduling DSS called Virtual Transportation Manager (VTM)

developed in a joint effort by FPInnovations and the FORAC Research Consortium.

VTM is designed to be managed by a third party to help consolidate and manage

transportation data from several companies to improve the efficiency of scheduling.

The trip sequences are built by heuristics in two phases. In the first phase, an

optimized set of routes is developed and the second phase constructs an itinerary

consisting of the phase one routes. A dispatcher manually implements the planning

solution. The average cost savings through collaboration was 4.55% and the average

reduction in traveling distances was 7.25%.

Collaboration between companies regarding logistics is seldom witnessed in the Pacific Northwest. By nature, the forest industry is competitive and secretive. Many stakeholders are uncomfortable sharing sensitive information about their businesses (profits, costs, log origins/destinations) for other reasons beyond antitrust issues. Some companies do not want competitors to know where their logs are being sent, in fear that other companies will send logs to the same destination and drive down the price being offered for sorts.

Due to the general lack of trust between competitors, the best solution in the Pacific Northwest may be to hire a third party to perform the scheduling and dispatching for collaborative scenarios. A third party would help dispel any notions of unfair scheduling or cost sharing as well as alleviate concerns related to the sharing of sensitive business information with competitors.

7.6   *Paying For the System and Sharing the Savings*

The cost of a decision support system (DSS) will likely differ depending on its function. A scheduling system is cheaper in comparison to a real-time dispatching system because it requires fewer components. Scheduling systems typically only require the DSS software and a computer while a real-time dispatching DSS requires these components plus other hardware.

Real-time dispatching DSS require GPS tracking devices in each truck so that the optimization engine can use real-time locations and other information to assign available trucks to available loads. In addition, the trucks need to be equipped with

reliable wireless communications devices so that drivers can receive instructions from the dispatch at a moment's notice. This may come in the form of a mobile phone or an electronic interface installed in the cab of the truck. If real-time information concerning supply is necessary, the log loader on the landing will require computing equipment to relay this information.

Large timberland owners, especially real estate investment trusts (REITs) and timberland investment management organizations (TIMOs), would be more likely to purchase these systems because they have the capital to absorb the cost of investing in a DSS as long as the benefits are satisfactory in the long run. In addition, large landowners often own a fleet of trucks and/or employ trucking subcontractors. Depending on the price of purchasing and administering the DSS, however, it may be more cost effective to hire a third party that uses a DSS to schedule and dispatch their fleet.

It is unlikely that smaller forest landowners would be willing to pay for one of these systems, unless returns were guaranteed quickly. Additionally, the size of their operation may not even warrant a DSS. Mendell et al. (2006) suggest that specialized software is not necessary for systems with less than 40-50 trucks based on their Excel-based solver and visits with different dispatching companies. They spoke with one logging contractor who participated in an operation with a dispatching firm to manage 24 trucks at a cost of approximately $200 per day. Sun Chasers, a dispatching service for owner-operators located in Creswell, Oregon, charges 3-5% of trucking revenue

for their administrative costs (Mendell et al., 2006). According to information obtained in their research, the cost of administrating a DSS for truck scheduling and dispatching could vary from $200-450 per day.

Assuming DSS are able to schedule trucks in a fashion that ensures a steady rate of production for each logging contractor, the party most affected by this transition would be the drivers. Naturally, the drivers will want to see a share of the profits as an incentive to participate in the new log transportation system. This may come in the form of higher wages. If paid by the load, the drivers may see the benefits immediately from the ability to service more loads through increased backhaul.

Collaboration between multiple stakeholders using a DSS for shared transportation services complicates how the system can be paid for and how the benefits can be shared. It is easier to quantify what the savings could be if collaboration were to occur, but more difficult to determine how to share the savings and pay for the system. Paying for the system can be looked at from a number of business perspectives. Audy et al. (2007b) propose six different business models for implementing a DSS for log truck scheduling and dispatching in a collaborative effort. In this work, the different stakeholders involved in the purchase and use of the DSS form a coalition. The business models, as they pertain to the Pacific Northwest, may include:

1. A landowner led coalition. Example: a forest landowner aims to lower their log transportation costs by taking using DSS to dispatch backhaul loads provided by other landowners.

2. A trucking contractor leads the coalition. Example: a trucking contractor aims to maximize their profits and reduce costs by using a DSS for transportation management.

3. A third party leads the coalition. Example: a company solely interested in transportation management provides scheduling and dispatching services for all the other stakeholders by using a DSS for transportation management.

4. All the landowners share the leadership of the coalition. Example: several landowners team up to minimize transportation costs by pooling resources and using a DSS for transportation management.

5. All the trucking contractors share leadership of the coalition. Example: several contract haulers team up to increase their profits by pooling resources and using a DSS for transportation management.

6. The trucking contractors and the landowners share the leadership of the coalition. Example: trucking contractors and landowners aim to minimize the transportation costs by pooling resources and using a DSS for transportation management.

Each of these business models is investigated using four different sharing methods to allocate costs and allocate savings between stakeholders. Audy et al. (2007b) express the need for more research on the different coalition building processes and business models in order to further study the effects that each model has on the incentive for the leader of the coalition and the savings that could be achieved.

7.7 Technological Challenges

Many truck scheduling and dispatching solution methods have been developed for decision support systems (DSS) that have the potential to achieve quality results using little computing time. While there will always be a need to continually improve the quality and timeliness of solutions, there are other technological challenges that need to be addressed to ensure the success of a DSS. Many of these challenges pertain to real-time dispatching systems because of the additional software and hardware components needed.

7.7.1 Communication Availability

Due to the unpredictable nature of the forest industry with equipment breakdowns, changes in production rates, weather, and traffic congestion it is necessary for the dispatch to be able to communicate with drivers. Furthermore, if a company expects to gain maximum benefits through the use of real-time dispatching, the dispatcher needs to be able to communicate with the drivers quickly.

If operating under a central dispatch, it is assumed that there is a single fleet being scheduled. In the Pacific Northwest, several contract haulers may be needed to service a single landowner. For some systems, these contract haulers would be required to outfit their trucks with the same communications equipment required by the DSS to act as a coordinated single fleet, as was the case with Longview Timber's implementation of ORTEC's DSS.

A major difference between longhaul trucking in other industries and the forest industry is the ability to communicate with trucks at all times. In common freight transportation it is generally a simple task for dispatch to communicate with drivers via CB or cellular phones. Unfortunately, communication is not as reliable by these methods in the forest industry. It is common for drivers to be out of cellular reception for extended periods of time. CB radio is another option; however, range is limited so this would only be viable for short distance operations. The most reliable option would be satellite phones, but they are expensive compared to cellular phones.

A possible solution to this problem is if vehicles are equipped with tracking technology so that their locations can be seen in real-time by the dispatch. Once the driver has reached the landing and received a load, it is often too late to reroute the driver until the load has been delivered to the proper mill destination. Therefore, dispatch can inform drivers of new instructions as soon as the driver has entered a known reliable communications range for their next load.

7.7.2   Geographic Information Systems

In order for dispatchers to make the best decisions possible, they need tools to assist them. A geographic information system (GIS) is a tool that allows dispatchers to see an electronic map of the regions in which their company operates. The most important feature that should be included in the GIS is the road network. This allows the dispatcher to see the location of landings, mills, and drivers (assuming integration with GPS) to aid in better decision making.

An important feature in GIS is the ability to apply attributes to features. For example, it may be beneficial for dispatchers to click on a landing and view attributes such as the number of loads available, the sort of each load, the average loading time for a log truck at that landing, and the destination for each load. As supply at the landing changes, the GIS should have the ability to update in real-time. Rönnqvist and Ryan (1995) emphasize this concept in their real-time dispatching approach. This capability has been demonstrated in Finland with EPO where the loaders, harvesters, and forest foreman are equipped with computers and transmit information about wood piles back to the central dispatch (Linnainmaa, 1995). In the Trimble Blue Ox system, each loader is equipped with an onboard computer where the operator can enter information about available loads. The optimization engine on the server then assigns trucks to loads, which the loader operator can see on their GIS interface.

7.7.3   Personal Navigation Systems

Another challenge to implementing DSS for log truck scheduling and dispatching is having the ability to provide drivers with directions to reach their destinations if they are needed. Schedules generated by DSS may require drivers to travel to new forested areas that they may not be familiar with. Therefore, it may be important for drivers to have turn-by-turn directions. Even more importantly, the directions provided must be tailored for log trucks since some roads do not allow log truck travel. Personal navigations systems have become widely available in the last decade; however, most of these personal navigation systems only include public road networks.

Private forest road networks are not included in any road databases provided by commercial personal navigation systems. Even if these private networks were included, they are subject to change as new timber sales are put up for harvest. In some operations, roads are constantly being built, rebuilt, decommissioned, maintained, and/or abandoned. This presents a challenge for transportation managers to constantly update road databases in order for personal navigation systems to provide accurate directions on private forest road networks.

Paper maps could be useful for drivers to assist them in navigating to the harvest sites and are much cheaper; however, they lack the ability to get fixed locations of vehicles in real-time or give voice directions to guide the driver. Some dispute the efficiency and safety of electronic maps versus paper maps. Lee and Cheng

(2007) carried out a study with the purpose of assessing the effects of using a personal navigation system compared to a paper map in two different driving environments. The results indicated that drivers using a paper map required longer time and covered greater distance to reach a given destination. Furthermore, the results showed that car stability and control were improved when a navigation system provided visual and voice guidance information during the driving task.

One clear advantage to voice guidance systems is that the driver is not required to take their eyes off of the road and studies have found that the addition of voice messages reduces the time spent glancing towards an in-vehicle display (see Kishi, H., & Siguira, S. 1993, Burnett, G.E., & Parkes, A.M. 1993, Lansdown, T. 1997). These systems may be advantageous to a log truck driver whose attention needs to be on the forest road, which often do not have the same construction standards as public roads.

Private forest road networks also need to be included in the navigation system to estimate travel times for the DSS to optimize scheduling and dispatching. For example, if the navigation system is only able to track the vehicle up to the point where the truck exits on to the private network, the system needs to know how long it will take the driver to reach the landing or the public road if coming out loaded.

The average travel time from the public road to the landing can be empirically derived; however, the effectiveness of the optimization engine may depend on an accurate approximation of the location of the vehicle in the network. Using the average travel time is similar to using dead reckoning when satellites are unable to get

position fixes on vehicles for extended periods of time. In dead reckoning systems, the last know position of the vehicle and the travel speed is used to estimate the current location of the vehicle on the road network until the satellites are able to re-establish position fixes.

7.7.4   Updating and Repairing the Schedule

While efficiencies can be gained by creating optimal schedules to begin the day, schedules are only optimal until the first deviation in the scheduling period occurs. Each deviation creates a ripple effect that propagates throughout the scheduling period. Therefore, it is essential that DSS have a solution method that achieves quality solutions in a time sensitive manner.

Currently, most dispatching is performed manually by an experienced dispatcher. Often dispatchers have few tools to assist in decision making; let alone tools to help them evaluate the quality of their decisions. Some of the efficiencies lost by human error can be recaptured with real-time dispatching systems.

A real-time dispatching system needs to have the capability to quickly identify the locations of all trucks, the current supply at each landing, and the destinations for each load so that an optimization routine can generate the next solution for dispatching. Unlike the scheduling problem where time is not as important as the quality of the solution, the dispatching problem requires that a solution be generated in a matter of seconds or minutes. Because of the need to generate solutions quickly there will likely be a slight decrease in solution quality. Researchers have been working on

developing new hybrid methods that incorporate heuristics and exact methods to improve the solution quality of dispatching methods.

7.7.5 Software Interoperability

Another challenge for software developers is creating DSS that are interoperable with other software. Interoperability refers to the ability of two or more systems to work together to accomplish a common function, usually through some type of electronic data interchange (EDI). When systems are interoperable, it allows the different parties to exchange information using the same file formats and protocols. Professionals in the forest industry have expressed the need for interoperable DSS that can link to weighbridge and scaling systems, accounting systems, and office software for the production of various reports for managers (see Cossens, 1993).

7.8   *Inertia*

A major factor that determines how quickly a new system will be adopted is inertia, the tendency of an object to resist any change in its velocity. In the case of decision support systems (DSS), the velocity is the rate at which new systems are being implemented in an industry or in a company. As the number of DSS used in the industry increases there is less of a tendency to resist this motion.

Currently, there are few DSS for log truck scheduling and dispatching in the United States. The lack of widespread adoption has made some interested parties

skeptical; however, each successful implementation should decrease the tendency to resist adoption if it has been proven to produce benefits.

The fact that there has been continued research around the world over the last two decades on log truck scheduling and dispatching is evidence that there is interest in these advanced systems. Furthermore, as technology and solution methods become more effective over time, these systems will become more efficient and capable of meeting the forest industry's needs. Each implementation will help shape the policies for cost sharing and savings allocation as well as provide guidance on how to construct the proper business model for all stakeholders.

Chapter 8 – Conclusions and Future Research

Decision support systems (DSS) for log truck scheduling and dispatching have the potential to reduce transportation costs by reducing the number of trucks needed and the total vehicle miles traveled to service customer loads. Research has shown that the cost reductions expected from implementing DSS could be 5% or more for some companies. Additional savings can be achieved if stakeholders collaborate and use shared transportation systems. Despite potential cost reductions, there have been few implementations of DSS in the United States for log truck scheduling and dispatching. Many companies continue to schedule and dispatch trucks manually, relying heavily on experienced dispatchers.

This project identified the opportunities and challenges for implementing DSS, evaluated existing technologies for log truck scheduling and dispatching, explored the unique characteristics of the forest industry related to freight transportation and management, and assessed the current availability of DSS for log transportation.

Currently, there are only a handful of off-the-shelf DSS available for the forest industry; however, they have shown promise in each implementation documented. There are a number of factors that have slowed the adoption of DSS in the Pacific Northwest including the culture of the industry, the organizational structure of the log transportation system, technological challenges, economies of scale, arrangements of sources and destinations, trust between participants, and inertia. In discussions with industry professionals, changing the culture of the industry appears to be the largest

challenge facing adoption. For decades, companies have used the same transportation models and business structures with success and are uncomfortable with the idea of changing the business structure unless benefits are guaranteed quickly.

While it may take time for DSS to become part of the industry culture, there are still technological challenges that can be addressed by software developers in the mean time. Transportation models differ across harvest operations; therefore, a DSS that works for some stakeholders (landowners, logging contractors, trucking contractors) may not work for another if its parameters are too rigid.

There is a need for systems that can be tailored to meet the requirements of different business arrangements and add constraints specific to the supply-chain characteristics of a particular operation. Depending on the system, there may be a need for technological capabilities to ensure reliable communications, data transmission, accurate positioning, driver navigation, and software interoperability. In addition, there is a need for systems that are able to update or repair the schedule and dispatch quality solutions quickly.

The lack of favorable spatial arrangements of sources and destinations for some landowners may also be preventing implementation in some instances. The arrangement can significantly affect the quality of routes that can be generated by DSS. If arrangements are not favorable, opportunities are limited for reducing unloaded miles and the total miles traveled by the fleet. Collaboration between several stakeholders through shared transportation services may increase these opportunities.

Depending on the relationship between stakeholders, different business models may need to be used. It appears that a promising business model for companies in the Pacific Northwest may be to hire a third party for truck scheduling and dispatching. Since collaboration is rarely seen in this industry, this business model may help alleviate concerns about sharing sensitive business information and represent the fairest form of business structure to distribute the system benefits.

More research needs to be done to understand what type of business models and organizational structures would best benefit the stakeholders as a whole and individually. In addition, more research needs to be done to identify what opportunities for collaboration are available in specific regions of the Pacific Northwest to help build trust between stakeholders. Lastly, there also may be an overall misunderstanding of these systems. Future research needs to be focused on investigating what different stakeholders actually know about DSS for log truck scheduling and dispatching and if education about these systems can help dispel any apprehensions and promote adoption.

Chapter 9 – Bibliography

American Association of State Highway and Transportation Officials. 2009. *Transportation invest in our future – America's freight challenge.* Available online at http://www.transportation1.org/tif3report/freight.html; last accessed Sep. 10, 2010.

Anderrson, G., P. Flisberg, B. Lidén, and M. Rönnqvist. 2008. RuttOpt – a decision suport system for routing of logging trucks. *Can. J. For. Res.* 38: 1784-1796.

Audy, J-F., S. D'Amours, L-M. Rosseau, J. Favreau, and P. Marier. 2007a. Virtual Transportation Manger: a web-based system for transportation optimization in a network of business units. In *3rd Forest Engineering Conference*, Gingras, J.F. (ed), October 1-4, 2007, Mont-Tremblant, Canada. 8 p.

Audy, J-F., S. D'Amours, and L-M. Rousseau. 2007b. Collaborative planning in a log pickup and delivery problem. In *TRISTAN VI - 6th Triennial Symposium on Transportation Analysis*, M. Bierlaire, P. Michandani, O. Nielsen, and M. Savelsbergh (eds), June 10-15, 2007, Phuket Island, Thailand. 6p.

Audy, J-F., S. D'Amours, and M. Rönnqvist. 2007c. Business models for collaborative planning in transportation: an application to wood products. In: Camarinha_Matos LM, Afsarmanesh H, Novais P, Analide C (eds) Establishing the foundation of collaborative networks. Springer, Boston, pp 667–676.

Bettinger, P., M.G. Wing. 2004. Geographic information systems: Applications in forestry and resources management. McGraw Hill, New York, NY.

Brito, J., Moreno, J.A., and J.L. Verdegay. 2009. Fuzzy Optimization in Vehicle Routing Problems. *ISFA EUSFLAT*.

Burnett, G.E., A.M. Parkes. 1993. The benefits of "pre-information" in route guidance systems design for vehicles. P. 397-402 in *Contemporary ergonomics*, Lovesy, E.J. (ed). Taylor and Francis, London.

Carlsson, D. and M. Rönnqvist. 2007. Backhauling in forest transportation: models, methods, and practical usage. *Can. J. For. Res.* 37: 2612-2623.

CBS Interactive Inc. 2010. Number of Cell Phones Worldwide Hits 4.6B. Available online at http://www.cbsnews.com/stories/2010/02/15/business/main6209772.shtml?tag=dsGoogleModule; last accessed Sep. 13, 2010.

Cossens, P. 1993. Evaluation of ASICAM for truck scheduling in New Zealand. *Logging Industry Research Organisation*. Vol. 18., No. 7.

Crainic, T.G., G. Laporte. 1997. Planning models for freight transportation. *European Journal of Operational Research*. 97(3):409-438.

Crainic, T.G. 2002. Long haul freight transportation. P. 451-516 in *Handbook of Transportation Science*. Hall, R.W. (ed), 2nd Edition, Kluwer.

Dantzig, G. and J. Ramser. 1959. The truck dispatching problem. *Management Science*. 6, 80-91.

El Hachemi, N., M. Gendreau, and L-M. Rousseau. 2011. A Hybrid Constraint Programming Approach to the Log-Truck Scheduling Problem. *Annals of Operations Research.* 184(1): 163-178.

Flisberg, P., B. Lidén, and M. Rönnqvist. 2010, in press. A hybrid method based on linear programming and Tabu Search for routing of logging trucks. *Computers and Operations Research*.

Goel, A. 2008. *Fleet Telematics*. Springer Science+Business Media, LLC. Berlin, Germany.

Giles, RC, C.N. Bezuidenhout, and P.W.L. Lyne. 2005. A simulation study on cane transport system improvements in the Sezela Mill area. *Proc S Afr Sug Technol Ass 79. P. 408*

Global Insight, Inc. 2005. Oregon commodity flow forecast. Final report for the Oregon Department of Transportation.

Glover, F. 1989. Tabu Search—part I. *ORSA J. Comput.* 1: 190–206.

Glover, F. 1990. Tabu Search—part II. *ORSA J. Comput.* 2: 4–32

Gronalt, M. and P. Hirsch. 2007. Log-Truck Scheduling with a Tabu Search strategy. P. 65-88 in *Metaheuristics – Progress in complex systems optimization*, Doerner, K.F., M. Gendreau, P. Greistorfer, W.J. Gutjahr, R.F. Hartl, M. Reimann (eds.). Springer, New York.

Institute of Transportation Engineers. 2000. *Intelligent Transportation Primer*. Library of Congress Catloging-in-Publication data. ISBN 0-935403-45-0.

Johnson, D.S. and L.A. McGeoch. 1997. The traveling salesman problem: A case study in local optimization. P. 215-230 in *Local search in combinatorial optimization*.

Kishi, H., S. Siguira. 1993. *Human factors considerations for voice route guidance*. SAE Tech. Paper Series 930533. Warrendale, PA: Society of Automobile Engineers.

Lansdown, T. 1997. *Visual demand and the introduction of advanced driver information systems into road vehicles*. Unpublished PhD dissertation, Loughborough University, UK.

Lee, W-C., B-W. Cheng. 2008. Effects of using a portable navigation system and paper map in real driving. *Accident Analysis and Prevention*. 40(1):303-308.

Linnainmaa, S., J. Savola, and O. Jokinen. 1995. EPO: A knowledge based system for wood procurement management. *Paper presented at the 7th Annual Conference, Montreal.*

Marshall, H., K. Boston. 2003. The potential of ArcLogistics 3 Route for solving forestry transportation problems. P. 351-355 in *Proceedings of 2003 Symp. of Systems Analysis in Forest Resources*.

Mendell, B., J. Haber, and T. Sydor. 2006. Evaluating the potential for shared log truck resources in middle Georgia. *South. J. Appl. For*. 30(2):86-91.

McCary, J. 2009. Coaching Strategies – An always-thinking contractor teams up with his wood source to boost efficiency and profitability. *Southern Loggin' Times*. August 2009.

McDonald, T., S. Taylor, R. Rummer, and J. Valenzuela. 2001a. Information needs for increasing log transport efficiency. *Proceedings of the First International Forestry Cooperative Symposium*, June 17-20, 2001, Seattle, WA.

McDonald, T., B. Rummer, S. Taylor, and J. Valenzuela. 2001b. Potential for shared log transport services. P. 115–120 in *Proc. of the 24th Annual Council on Forest Engineering Meeting*. Wang, J., et al. (eds.). Counc. on For. Eng.,Corvallis, OR.

Murphy, G. 2003. Reducing trucks on the road through optimal route scheduling and shared log transport services. *South. J. Appl. For.* 27(3):198-203.

NCT Forestry Co-Operative Limited. 2003. *News and Views – Joint Planning Tool*. Available online at http://www.nctforest.com/showpage.asp?id=45&contentid=203&catid=44; last accessed May 24, 2011.

Oregon Department of Forestry. 2001. *Oregon Forest Legacy Program – Assessment of Need.*

Oregon Department of Transportation. 2007. The *Oregon Transportation Plan*. Volume 1.

Palmgren, M. 2001. *Optimization Methods for Log Truck Scheduling.* Linkoping Studies in Sci. and Tech. Theses No. 880. Linkoping Inst. of Tech., Sweden.

Palmgren, M. 2003. A near-exact method for solving the log-truck scheduling problem. *Intl. Trans. In Op. Res.* 11(2004):447-464

Parragh, S., K. Doerner, and R. Hartl. 2008. A survey on pickup and delivery problems. *Journal für Betriebswirtschaft* 58(2): 81-117.

Robinson, T.F. 1994. Tour generation for log truck scheduling. *Proceedings of the 30th Conference of the Operational Research Society of New Zealand,* Palmerston-North.

Rönnqvist, M., D. Ryan. 1995. Solving truck dispatch problems in real time. *Proceedings of the 31st Annual Conference of the Operational Research Society of New Zealand*, August 31- September 1, Wellington, NZ.

Rönnqvist, M., H. Sahlin, and D. Carlsson. 1998. P. 31 in *Operative Planning and Dispatching of Forestry Transportation.* Linkoping Inst. of Tech., Sweden. Rep. LiTH-MAT-R-1998-18. 1998.

Shen, Z., and J. Sessions. 1989. Log truck scheduling by network programming. *Forest Products Journal.* 39(10):47-50.

Teodorović, D and G. Pavković. 1996. *The fuzzy set theory approach to the vehicle routing problem when demand at nodes is uncertain.* Fuzzy Sets and systems. 82 pp. 307-317.

Trimble. 2008. *Trimble BLUE OX Transportation Management System in Forestry.* Accessed March 24, 2009 at http://www.trimbleforestryautomation.com/docs/Blue-Ox-Presentation-October-2008.pdf.

Weintraub A., R. Epstein, R. Morales, J. Serón and P. Traverso. 1996. *A Truck Scheduling System Improves Efficiency in the Forest Industries.* Interfaces. Vol. 26., No. 24.