Whole Tree Transportation Method for Timber Processing Depots

by

John Ross Lancaster

A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science in Forestry

Auburn, Alabama
May 6, 2017

Approved by

Thomas V. Gallagher, Chair, Professor, AU School of Forestry and Wildlife Sciences
Dana Mitchell, Project Leader, U.S. Forest Service
Timothy McDonald, Professor, AU Department of Biosystems Engineering

Abstract

The growing demand for alternative energy has led those interested in producing sustainable energy from renewable biomass such as timber to devise new concepts to satisfy those demands. The concept of timber processing depots, where whole stem trees will be delivered for future processing into wood products and high quality energy fuel, has led to the re-evaluation of current timber transportation methods and whether they can feasibly transport unprocessed trees in an efficient, legal, and safe manner. Modifications for standard double bunk log trailers were developed to accommodate tree length, unprocessed southern yellow pine. The first design was a swinging gate design, and the second was an extendable bolster design. These modification designs ensured that tree crowns were contained within the trailer to prevent contact with and damage to other vehicles while in transport. Consideration of criteria including modification weight, load force analysis, ease of attachment and detachment, and overall feasibility determined which of the two trailer modification designs was chosen for trial load testing. The selected design was fabricated and attached to a standard two bunk log trailer which was loaded to its maximum volume capacity with chip and saw size *Pinus taeda*. Axle weights were recorded three times for each load of timber: unprocessed, trimmed, and delimbed and processed to a merchantable top. Net load weights, axle weights, and anecdotal observations were used to determine that transporting whole tree chip and saw sized loblolly pine on the modified trailer was unfeasible.

Acknowledgments

I would like to thank my wife Morgan for her support, words of encouragement, and invaluable edits to my thesis. I thank my parents for instilling in me determination, perseverance, and a strong work ethic which has been of the utmost importance in completing this thesis. I thank my committee members Dr. Tom Gallagher, Dr. Dana Mitchell, and Dr. Tim McDonald for their continual guidance throughout this process, without which I would have been lost. I thank Caterpillar Inc. and the Auburn University Agricultural Land and Resource Management group for providing the equipment needed to conduct this research. I thank Mr. David Crouch and Mr. Robert Sanders for their time and highly skilled ability to run the equipment and load the modified trailer. I thank Rafael Santiago and Marissa Jo Daniel for all of the hard work and time sacrificed to assist in this research. I thank Auburn University, the School of Forestry and Wildlife sciences, and the Department of Energy for making my time in graduate school possible and for funding my research. Finally, and most importantly, I thank God for giving me the opportunity to attend graduate school and continue my education, and to him I give all the credit.

Table of Contents

List of Tables

List of Figures

Appendix

I. Introduction

1.1 Project Background

For decades, discussions regarding the United States' energy production from the consumption of fossil fuels and whether we should pursue alternative forms of energy production via renewable resources have become more prominent. Therefore, scientists and engineers are exploring the capabilities of producing energy from renewable resources in order to supplement the consumption of fossil fuels so that their dwindling reserves will last longer into the future.

One alternative form of renewable energy production that is available through the use of biomass materials is wood (McKendry, 2002; Scott and Tiarks, 2008). The United States has an abundance of forested land that is well stocked with timber capable of producing biomass for energy as well as a surplus of land that is available for conversion into timber stands for energy production (Haberl et al., 2010). Using wood from timber for energy production has caught the attention of the energy sector because of timber's ability to renew itself within a relatively short period of time due to modern intensive silvicultural practices such as genetic breeding for improved planting stock, irrigation, competition control, and fertilization (Tuskan 1998; Dickmann, 2006). Unlike fossil fuels, which take a great amount of time to form and are non-renewable and irreplaceable (Daniels and Duffie, 1955), timber produced using short rotation intensive culture can be grown into a usable biomass fuel material for energy production in 1 to 15 years depending on the species (Drew et al., 1987). Another advantage in using timber as a renewable energy source is the already-established systems of cultivation, harvesting, and delivery.

One system that is currently being designed to increase the availability of renewable biomass for energy production is a timber processing depot. This facility will optimize the amount of biomass fuel material yielded from timber by moving the processing of limbs and crowns of trees from the logging site in the woods to the location of this facility. By processing all of the timber at one location, researchers believe they can optimize the amount of biomass fuel material yielded from each tree by reducing the amount of usable biomass fuel material that is left behind at the harvest site and by reducing the ash content of the biomass fuel material, thus producing a higher quality fuel product. For this facility to operate, it relies on having timber delivered in an unprocessed form with all limbs still attached to the bole of a full-length tree.

This delivery method raises concerns for those within the forest operations and harvesting industry because the current system of delivery entails complete processing and size reduction of each tree before it is transported to market (Tuskan, 1998). Those designing the timber processing depot envision its greatest utilization will be achieved when processing southern yellow pine yielded from second thinnings. Attempting to haul southern yellow pine of that size on a traditional double bunk log trailer will leave much, if not all, of the crowns uncontained and unsupported by the trailer. This could lead to the crowns coming in contact with other vehicles while in transport as well as damage to other vehicles and roads. To mitigate this risk, those who haul unprocessed timber on traditional log trailers trim the crowns with pole saws once the trailer is loaded to remove any limbs that could cause damage during transportation. However, this reduces the payload and leaves behind much of the valuable material that can be processed into biomass fuel material. We plan to address this transportation issue by designing a modification that can be attached to standard double bunk log trailers to accommodate the transportation of unprocessed trees in a legal manner.

1.2 Project Objectives

The project goal is to develop an alternative method for feasibly delivering full-length trees to a timber processing depot through completion of the following objectives:

1. Design, develop, and build a modification for a standard double bunk log trailer that will allow unprocessed chip and saw sized southern yellow pine trees to be transported.
2. Determine if axle weights are in accordance with state laws when the modified trailer is loaded with unprocessed timber.
3. Estimate the potential biomass weight gain from hauling unprocessed trees.

II. Literature Review

2.1 Fossil Fuel Energy

Energy is the driving force behind human life, and fossil fuels such as coal, oil, and natural gas provide the world with the energy needed to sustain it (Asif and Muneer, 2007). The progress and accomplishments of humankind have been possible because of the ability to harness energy and power the technologies that aid in human existence. Coal was the earliest of these fuels to be used and was the driving force behind the industrial revolution of the western world. The anthropologic use of coal dates back to second century Romans in Britain (Smith, 1997) and is still the United States' third largest domestically produced energy fuel source, accounting for about one-third of the nation's electricity generation (U.S. Energy Information Administration, 2016b).

Crude oil is another invaluable fuel as it has been heavily depended on to power the world's mechanized methods of transportation since the start of the 20th century (U.S. Energy Information Administration, 2016b). Natural gas, a more recently utilized fuel source, is often used as a substitute for coal in energy production facilities because it emits about 50 percent less carbon dioxide for every one kilowatt hour of electricity generated (U.S. Energy Information Administration, 2016a).

Fossil fuels are formed from organic materials under the Earth's surface and take several thousand years to transform into a usable energy fuel source (Sato, 1990). As carbon from the organic material undergoes a chemical transformation, it decomposes resulting in fossil fuels (Sato, 1990). The type of fossil fuel that develops from the decomposing organic matter is determined by the type of matter. For example, coal is formed from the decay of land vegetation whereas oil and natural gas are formed from the remains of marine microorganisms deposited on the sea floor (U.S. Department of Energy, 2016).

Fossil fuels are the most consumed source of fuel for energy production in the United States (U.S. Energy Information Administration, 2016b). In 2015, the United States consumed approximately 35.4 quadrillion British thermal units (Btu) of energy produced by petroleum, 28.3 quadrillion Btu from natural gas, and 15.7 quadrillion Btu from coal (U.S. Energy Information Administration, 2016b). Humans are highly dependent on these fuel sources for nearly all energy demands including electricity, transportation, heating, and cooling.

Given the current human population and its increasing trend, the dependency on fossil fuels to sustain life means that an ever larger amount of fossil fuels must be consumed to provide the energy needed by Earth’s human inhabitants. World energy consumption rates are expected to increase 48 percent from 2012 to 2040 (U.S. Energy Information Administration, 2016c). However, Earth’s fossil fuels are a finite resource and inevitably will become exhausted. Current estimates for crude oil reserves are 1.7 trillion barrels (270.3 billion tonnes), coal reserves are 891.531 billion tonnes, and natural gas reserves are 187 trillion cubic meters (150 billion tonnes) (British Petroleum, 2016). Shafiee and Topal (2009) estimate that there are 165 billion tonnes of oil, 607 billion tonnes of coal,and 162 billion tonnes of natural gas remaining. Realistically, the precise quantity of fossil fuels left in the earth is unknown, and these figures only serve as an estimate to help researchers and scientists predict the time until these resources are exhausted based on current consumption rates.

The continued consumption of fossil fuels could lead to a supply and demand situation where reserves become exhausted and the demand will drive up the price to a potentially unattainable point for the average consumer. The consequences of exhausted fossil fuel reserves could be catastrophic and lead to situations such as international war, famine, and economic depression. In efforts to avoid these situations, the world's scientists, engineers, and researchers are developing, designing, and testing new technology in order to find new sources of sustainable and renewable fuel to supplement fossil fuels so that the energy needs of humankind can continue to be satisfied.

2.2 Alternative Renewable Energy Fuels

With fossil fuel reserves continually declining, the demand for new sources of sustainable energy is growing. The human race wants to ensure that its energy needs will continue to be met by a sustainable and renewable fuel source that can be renewed in a quicker time span than fossil fuels. Renewable fuel technology is already being utilized in the United States. In 2015 approximately 11 percent of the total amount of energy produced was generated from renewable fuels and approximately 10 percent of the total amount of energy consumed was generated from renewable fuels (U.S. Energy Information Administration, 2016b). In 2012, approximately 5 trillion kilowatthours of the world's 22 trillion kilowatthours of net electricity generation was generated by renewable fuel sources (U.S. Energy Information Administration, 2016c). Currently, there are five major types of renewable energy that show promising potential for sustainable energy generation: geothermal energy, solar energy, wind energy, bioenergy, and hydropower.

Bioenergy is the oldest of the five renewable energy types and the most consumed renewable energy source in the United States (U.S. Energy Information Administration, 2016b). Humans have utilized the heat produced from burning organic material (i.e. biomass) such as wood to cook food, heat water, and warm houses for several thousand years (Guo et al., 2015). Biomass is largely utilized in power plants to heat water into steam to turn turbine-generators, but recently, biomass materials high in carbohydrates like corn and switchgrass have been converted directly into liquid fuels such as ethanol and biodiesel (Guo et al., 2015).

Hydropower is the second most consumed renewable energy resource in the United States (U.S. Energy Information Administration, 2016b). Hydropower technology captures energy from flowing water and converts it into electricity by diverting the flow to turn a turbine-generator.

Geothermal energy utilizes natural heat, hot water, and steam from subsurface Earth to produce electricity and provide indoor heating and cooling (Fridleifsson, 2001). Huttrer (2001) reported that a capacity of 7,974 megawatts of electricity (MWe) was available from facilities that generate geothermal electricity around the world in 2000. That amount increased 43 percent to 11,414 MWe by 2005.

Solar energy (i.e. energy from sunlight) generation can be split into two categories: photovoltaic and concentrated solar power. Photovoltaic solar energy utilizes solar cells to convert sunlight into electricity via the photovoltaic effect, whereas concentrated solar power utilizes the sun’s thermal energy to heat water into steam, which then powers a turbine-generator (Barlev et al., 2011).

Wind has been harnessed to generate sustainable energy to pump water and grind grain for several hundred years (Kaldellis and Zafirakis, 2011). Modern wind turbines harness the wind's power to produce electricity by turning propellers connected to a generator.

There are many benefits to generating energy from renewable fuels rather than fossil fuels such as the reduction of greenhouse gas emissions, less air and water pollution, and decreased exposure to radioactive emissions (Dincer, 2000). The most beneficial is the sustainability of clean fuel sources. Since fossil fuels are a finite resource, virtually unrenewable because of the length of time required for them to form, renewable fuels such as sunlight, wind, and geothermal heat offer an alternative because they are potentially infinite sources of energy and are completely sustainable (Rathore and Panwar, 2007). An additional benefit to renewable fuels is the reduction in carbon, a primary greenhouse gas, emitted when energy is produced. Renewable fuels such as sunlight, wind, geothermal heat, and hydropower emit little to no carbon (Sims et al., 2003).

Biomass energy fuels emit carbon when burned, but they do not add to the accumulating amount of carbon dioxide in the atmosphere when the entire carbon cycle is considered. Bioenergy fuels are carbon neutral, so the net amount of carbon added to the atmosphere is zero because of the photosynthetic process of plants (Schlamadinger and Marland, 1996; Peterson and Hustrulid, 1998). When atmospheric carbon is consumed by plants, it is stored within the plant until the plant dies (or is burned for energy in this case). The carbon is then released and reabsorbed by other plants. The net zero accumulation of carbon in the atmosphere can have a significant impact on atmospheric pollution over time. While the carbon stored in plants only lasts for the life of the plant, or the life of the product made from the plant, the carbon emissions avoided by forgoing fossil fuels lasts forever (Schlamadinger and Marland, 1996). Therefore, these renewable fuel sources are vastly cleaner than fossil fuels in terms of air and water pollution and pose less risk to environmental degradation while ensuring future energy demands are met (Dincer, 2000, Panwar et al., 2011).

While there are several benefits to renewable fuels, there are also cons associated with each renewable energy type. Hydropower has been known to have environmental and anthropologic/social impacts on the surrounding ecosystems, living organisms, and local hydrology (Rosenberg et al., 1995; Dauble et al., 2003). Additionally, water must be present in an area for hydropower energy to be produced limiting its effectiveness and feasibility in drier climates. Solar energy is dependent on the quantity of sunlight available, which varies geographically and seasonally (Fthenakis et al., 2009). While consumer scale geothermal energy can be captured just about anywhere (e.g. geothermal heat pumps), large scale electricity production from geothermal energy is limited to certain areas on Earth where access to magmatic activity is feasible (Kestin et al., 1980). There are also some environmental concerns associated with geothermal energy such as surface disturbances, thermal pollution, and the release of offensive chemicals (Abbasi and Abbasi, 2000). Wind energy requires a constant flow of wind limiting its feasibility geographically. Additionally, the development of new wind energy projects and facilities have been hindered by the lack of reliable and accurate wind resource data necessary to identify potential areas suitable for development (Radics and Bartholy, 2008). Large scale wind energy farms also require a large amount of land and can have a negative visual impact on the landscape. Noise pollution from wind turbines also poses a threat to various avian species (Stewart et al., 2005; Abbasi and Abbasi, 2008). Bioenergy can result in air pollution when biomass is burned for energy, and large scale production of crop plants for bioenergy can have a negative impact on the local environment due to intense farming, cultivation, and harvesting practices (Abbasi and Abbasi, 2008). Despite negative impacts associated with renewable energy sources, the growing world population and increasing demand for energy combined with the potential to reduce the dependency on fossil fuel energy through generating sustainable electricity and liquid fuels outweigh the cons.

2.3 Timber Biomass as a Bioenergy Fuel Source

Renewable energy generated from biomass has the potential to supply the United States and the world with clean, sustainable energy in the form of electricity and liquid biofuels. Sources of biomass can be organic materials such as corn, switchgrass, algae, manure, food waste, agriculture residues, industrial wood waste, and timber (Demirbaş, 2001; McKendry, 2002a; Perlack et al., 2005). It can be argued that wood from timber is easily the most desirable biomass material for energy production. In 2014, 146 million bioenergy equivalent dry tons of wood were consumed for heat and power production of which approximately 10 percent was utilized directly by electricity generation facilities to generate 13.7 billion kilowatthours (BkWh) of electricity (Langholtz et al., 2016). Almost 60 percent of the 146 million dry tons of wood was used by industrial facilities to generate 15.4 BkWh of electricity and 539 trillion Btu of thermal power (Langholtz et al., 2016). The remaining 30 percent was utilized by the residential sector to generate 349.5 trillion Btu of thermal power for home heating and cooking (Langholtz et al., 2016). All in all, more electricity and thermal power was generated from forestry and wood products than any other biomass resource (Langholtz et al., 2016).

Essentially, there are five biomass conversion processes that can transform biomass from timber and forest residues (i.e. timber biomass) into energy (McKendry, 2002b, Caputo et al., 2005): combustion, gasification, pyrolysis, anaerobic digestion, and fermentation. Combustion is the burning of flammable biomass in the presence of oxygen to release heat. The heat produced from combustion can be used to cook food, heat spaces, and boil water into steam to power a turbine-generator for electricity production (Demirbaş, 2001; McKendry, 2002b). Gasification is a process that creates a product called syngas, which is combustible and is commonly used in the place of natural gas as fuel for gas engines and gas turbines. The gasification process extracts the usable syngas from biomass by subjecting it to heat, pressure, and partial combustion (Demirbaş, 2001; McKendry, 2002b). Pyrolysis is the thermal decomposition of biomass in a controlled environment without oxygen. Pyrolysis creates three products: a combustible liquid, syngas, and a solid called biochar (Demirbaş, 2001; McKendry, 2002b). Anaerobic digestion involves the breakdown of biomass by bacteria in a controlled environment where oxygen is absent and produces a biogas that contains methane (Demirbaş, 2001; McKendry, 2002b). The methane can be utilized to produce energy through combustion. Fermentation is a process where the glucose in plants (biomass) high in sugars and starches is converted into ethanol by adding yeast. The ethanol is then distilled to obtain higher concentrations of alcohol that can be used as transportation fuel (Demirbaş, 2001; McKendry, 2002b). The different processes for extracting energy from biomass provide us with a range of usable energy from direct use such as heat to more complex types such as gases and liquid fuels. Timber biomass is a prime candidate for feedstock (i.e. a raw material supplied for the purpose of processing it into a finished product) in any of these processes because of its abundance and ability to produce energy in many different conversion processes.

The key aspect that makes these biomass feedstock materials sustainable is the ability of the principle material from which the feedstock was produced to replace itself in a short period of time. Timber is an outstanding biomass feedstock because of a trees natural ability to renew itself. In addition, improvements in areas such as seedling genetics and reforestation techniques have increased the number of acres of forestland that can be successfully reforested and have also increased overall seedling survival and growth while decreasing the length of time until reproductive maturity is reached (Nyland, 1996; Tuskan, 1998). These factors mean that trees are suitable for use as a biomass feedstock at earlier ages, therefore decreasing rotation ages. Furthermore, timber makes a great biomass feedstock because of the proven system of production on an industrial scale. A reliable system of establishing, tending, and harvesting stands of species such as loblolly pine (*Pinus taeda*) are economically feasible for pulp and lumber production. Species such as loblolly pine found in the southeast United States are well suited to be a biomass feedstock because of advanced genetic stock and efficient, effective silvicultural and harvesting operations. If biomass energy facilities had competitive prices with competing timber companies, minimal changes would be needed to convert harvesting operations to biomass feedstock production.

In order for energy to be produced from timber biomass, there needs to be a well-stocked and accessible source of timber available. The United States has 514 million acres of timberland that is well stocked with timber capable of producing energy as well as a potential 106.253 – 313.817 million acres of marginal agriculture land that could be converted into biofuel production stands (which include timber as a biofuel feedstock) (Langholtz et al., 2016; Cai et al., 2011). The four forested regions of the United States include the North, South, Rocky Mountain, and Pacific coast (Oswalt et al., 2014).

Within these regions, the main timber-producing areas where timber biomass could be produced in quantities large enough to sustain industrial scale biomass energy production are the Southeast, Northeast, Pacific Northwest, and the Lake States (Tuskan, 1998). Each region has a variety of species (native, introduced, and hybrid) that are adapted to growing in the environmental conditions found there and suited for use as timber biomass (Wright, 1994). Oswalt et al., (2014) estimate that the United States has 818.8 million acres of forestland and woodland with a net amount of approximately 1.102 trillion cubic feet of timber. Recent trends indicate an increase in timber volume with only 12.854 billion of the approximate 26.413 billion cubic feet of annual net growth harvested each year (Oswalt et al., 2014). Since only 48 percent of the annual net growth is harvested annually, the remaining 52 percent of annual net growth could potentially be utilized to increase the amount of timber available for future bioenergy production.

2.4 Timber Biomass Harvesting, Transportation, and Processing

If timber is to be used to produce energy, it must first be harvested and processed into a usable form suitable for conversion to energy. During traditional harvesting operations, loggers process the timber at the harvesting site by removing the limbs and tops with a delimber, processing head, or chainsaw and then deliver the timber to a chipmill. The downside to this method is that removing the tree tops, limbs, and foliage significantly reduces the amount of timber biomass that is available for energy production.

In Alabama alone, approximately 2.6 million dry tons of woody biomass and forest residues are generated annually from forest harvesting operations (Muehlenfeld, 2003). An additional 2.8 million, 1.8 million, and 1.3 million dry tons of woody biomass and forest residue are generated each year in North Carolina, South Carolina, and Virginia, respectively (Galik et al., 2009). Secondary operations are often taken after the initial harvesting operation to recover these forest residues (i.e. limbs and top) (Fridley and Burkhardt, 1984; Klepac and Rummer, 2010; do Canto et al., 2011; Mitchell 2009). However, recovery operations are not able to fully recover all of the biomass material that would have been available if they had not been processed and removed from the tree in the first place (Nurmi, 2007). Also, inorganic material such as dirt often gets mixed in with recovered timber biomass material reducing its quality and energy production potential. Timber bound to be chipped and used as biomass fuel for boilers or as a feedstock for conversion into liquid biofuels is currently transported no differently than timber bound for a pulp mill that is destined to be converted into some type of paper or fiber product. A key difference between the two is that pulp and paper mills do not want limbs, tops, and foliage, whereas that material is considered valuable and desirable at bioenergy production facilities.

However, few loggers are transporting unprocessed timber because of issues surrounding safety, legality, and transportation efficiency. The concern over transportation efficiency stems from the fact that a load of low bulk density unprocessed raw material like timber is limited by the volume capacity of the trailer rather than by its mass capacity (Ranta and Rinne, 2006). Since loggers are often paid according to the weight of material they deliver to the mill from the woods, they must ensure that they are achieving the maximum legal weight allowed for each truck load or else they are incurring opportunity cost (Angus-Hankin et al., 1995). Readily available log trailers on the market are not designed to safely and effectively transport unprocessed timber with a mass of limbs projecting from the rear of the trailer. If log trailers were designed or modified to safely and efficiently accommodate unprocessed timber, more timber biomass could potentially be available for energy production. In addition to increased biomass availability, Watson and Stokes (1987) estimate that production could increase 20 – 40 percent over conventional logging with inwoods processing if processing were eliminated and trees were transported unprocessed. This increase in production could potentially equate to decreased logging costs as well as reduced costs for timber and biomass material.

Recently, research conducted by the United States Forest Service looked into the feasibility of transporting unprocessed southern yellow pine in the Florida panhandle. These studies explored the advantages and disadvantages of whole tree harvesting and transportation as well as the productivity of logging systems transporting whole tree slash pine (*Pinus elliottii*) pulpwood (PWD). Logging crews in the region have modified their log trailers with “basket” structures between the standards of the rear bunk to contain the tree crowns within the width dimensions of the trailer. The containment of limbs and crowns by these baskets mean that less material has to be trimmed from the loads of unprocessed timber to meet local transportation regulations. Thompson et al. (2015) found that loading untrimmed pulpwood achieved similar productivity to loading trimmed pulpwood indicating that hauling untrimmed trees is a viable alternative in terms of system productivity. Thompson et al. (2014) further proposed that an advantage of this method included the removal of more gross tonnage from the stand with a single operation. This potentially equates to a larger profit for loggers and landowners as well as the elimination of subsequent biomass recovery operations and their associated costs.

III. Methods

3.1 Design Process

3.1.1 Research and Brainstorming

The goals and objectives of this project are aimed at designing and testing a method for transporting unprocessed chip and saw sized southern yellow pine timber. An additional goal was created to ensure that the method would seek to modify existing log trailers to maintain their versatility and to prevent loggers from having to purchase a specific purpose built trailer that could potentially tie up limited funds in underutilized equipment. Upon researching the topic and reaching out to contacts familiar with this concept, it was discovered that a successful method of transporting unprocessed pulpwood was being utilized to deliver timber to Georgia Pacific's Foley Cellulose mill in Perry, Florida. It was decided that a first-hand observation of this system would be a logical and practical place to begin the design process for a transportation method to haul the unprocessed chip and saw sized timber required by the timber processing depot. The Foley Cellulose mill currently purchases unprocessed southern yellow pine pulpwood (typically 5" – 9" diameter at breast height) to use the biomass material that is removed from the crown portion of the trees to generate supplemental energy for the facility.

Over the course of one and a half hours, more than 20 log trucks with trailers modified to haul unprocessed pulpwood were observed entering and exiting the Foley Cellulose mill. Each trailer was documented via photograph for a later comparison of the varying styles and designs of modifications. Upon comparing the photographs of the modified trailers, brainstorming began to identify ways in which to remedy some of the problems observed with the transportation method (i.e. identify how the method could be altered to better suit the transportation of timber larger than pulpwood). The brainstorming process resulted in the formulation of two log trailer modifications which proved promising solutions to the issues and problems identified.

To begin the design process of the two modifications, research was conducted on the regulations and laws of 11 states in the southeast United States where loblolly pine (*Pinus taeda*) naturally grows. This research concerned the dimension of semi-trucks and trailers, allowable load overhang, state and federal gross vehicle weights, and allowable axle weights. A set of design criteria was created to guide the design of the two modifications based on these dimensions.

3.1.2 Load Force Analysis

Engineering drawings for each design were produced to further illustrate the concept of the design and to provide an understanding of the functionalities and dimensions of the design. The modifications designed were selected to fit onto a Pitts LT40-8L double bunk log trailer. This model was chosen because of its relatively similar design with existing log trailers already in use. American Society of Testing Materials (ASTM) A36 mild low-carbon steel was selected for the construction of the modifications because of its common availability and low cost compared to other materials. Locations on the modifications subject to failure under a weight load were then analyzed to determine the load forces acting at those locations as well as the maximum load forces capable of resisting yielding at those locations. This analysis was conducted by applying known static load weights to the appropriate locations on the modification and solving for the maximum force at which a particular component of the modification would fail under the applied weight load using the sum of the forces method.

Upon completion of the static load weight analysis for critical locations of the two designs, a summary of information on the density and per unit cost of the material utilized was created and used to calculate estimated weights and costs. Since the design modification utilized existing log trailers rather than a specific purpose built trailer, the criteria of lowest cost and lowest weight as well as the design that best upheld its structural integrity without fear of failure under a weight load was selected to determine which modification design would be chosen for trial testing. This criteria ensured that the options available to loggers would cost them the least amount in additional capital and would add the least amount of additional weight to their log trailers. Once the modification design selected for trial testing had been identified, the engineering drawings were delivered to a local machinist for construction.

3.1.3 Design Fabrication and Implementation

A used eight bolster Union-Camp pulpwood trailer was donated to attach the chosen modification and use for trial load testing. The trailer was delivered to a machinist along with the engineering drawings and was heavily altered to achieve a similar configuration to modern double bunk log trailers with four bolsters and 8-foot tall standards. Once the trailer was converted to the more modern configuration, the selected modification was built according to the engineering drawings and materials list recommended from the design process and installed on the trailer. Adaptions to the design regarding modification length had to be made for the modification to fit the log trailer to be used for trial load testing. This was due to slight inconsistencies between the configurations and dimensions of the modern log trailer used during the modification design process and the donated trailer. Due to these inconsistencies the load force calculations were recalculated and analyzed on the actual trailer and constructed modification to ensure that there were no major changes in the load forces acting on the modification and trailer.

3.2 Modified Trailer Load Trial Testing

3.2.1 Testing Location

After receiving the modified log trailer from the machinist, trial load testing began to gain an understanding about the loading capability and overall feasibility of a modified trailer as a solution to transporting unprocessed chip and saw timber to a timber processing depot. Auburn University’s Mary Olive Thomas Demonstration Forest located five miles southeast of Auburn, Alabama, was selected as the site for trial load testing. The property is managed by the School of Forestry and Wildlife Sciences, who through implementing the property’s management plan had already began a harvesting operating on a stand that contained timber of the appropriate size needed for this research project. The modified trailer and necessary equipment was set up alongside of the loading deck, and the trial load testing was completed in conjunction with the timber harvest.

3.2.2 CNS Loads

Before any trees were felled for a single loading test, 50 loblolly pine trees that fell in the chip and saw (CNS) size class diameter range were identified, numbered, measured, and marked. Measurements included recording the diameter at breast height (DBH) and total height, and markings included flagging tied around the tree as well as painting of the corresponding tree number on multiple sides of the bole. The diameter range chosen to identify chip and saw trees for this project was a 10-inch minimum DBH and a 14-inch maximum DBH (9.5 inches – 14.5 inches based on a 1-inch diameter classification). All measurements were input into an Excel spreadsheet where the DBH and total height were used to calculate the predicted total tree green weight and the predicted stem, wood, and bark to a 6-inch outside bark top diameter green weight. The equations for these weight calculations were gathered from a Georgia Forest Research Paper (Clark and Saucier, 1990). A 6-inch outside bark top diameter was selected for this project because it is a common minimum top diameter specification for southern yellow pine chip and saw mills in the Southeast. The individual tree measurements and weights were then organized into a table and summarized to predict the net trailer load weight (Appendix 1).

Selected trees were then felled and corresponding tree numbers were painted on the butts of the trees. They were then skidded to the loading deck and loaded onto the modified trailer without undergoing any intentional processing or removal of the limbs and crown. Each individual tree loaded onto the trailer was recorded by visual identification of the number painted on the butt. Unprocessed trees were loaded onto the trailer until the height of the stack of loaded trees, measured at the front standards of the trailer, reached the height of the standards. This ensured the trailer's volume capacity was filled to its maximum amount without risking the stack of trees being overloaded and unsecure during transport.

Once the trailer was fully loaded with unprocessed timber, all five axles of the truck and modified log trailer were weighed. All weights were collected using a set of four Intercomp PT300 portable truck scales with ±1 percent accuracy. Variability in weight measurements from unknown factors over the duration of the loading tests were accounted for by using the net load weights. Therefore, if any variability existed in the weight of the scales when measuring the loaded truck, it was assumed that same variability would exist in the scales when measuring the unloaded truck. Subtracting the unloaded weight from the loaded weight provides a net load weight with the variability removed. Scheuter (2008) states that gross vehicle weight is unaffected if the vehicle is weighed on level ground with less than a five percent lengthwise slope. Therefore, we ensured that all weight measurements were taken on level ground with less than a five percent slope to eliminate any possible errors or variability.

Next, the crown material and limbs not contained by the modification were trimmed from the truck to adhere with transportation regulations, and the five axles were weighed again. The trees were then unloaded and processed to a merchantable top by a knuckleboom loader and trailer mounted delimber. After processing, the trees were loaded back onto the trailer and all five axles were weighed again. The trees were again unloaded and a final weight measurement was taken of the truck and empty modified trailer.

3.2.3 PWD Loads

The same procedure was used for measuring the load weights of the pulpwood (PWD) size class timber. However, no trees were measured and marked before felling; therefore no preselected (with respect to DBH) trees were used during this portion of the project. Rather, harvested trees were selected based on a randomly chosen azimuth line that was flagged into the stand of PWD timber starting at the loading deck located on the upper portion of the slope and ending at the riparian area located on the lower portion of the slope. The feller buncher operation harvested the trees along the flagged azimuth line to a width approximately similar to the width of the machine itself. The felled trees were then skidded to the landing and the loading, weighing, and processing procedures from that point on followed those of the CNS loads.

3.3 Data Analysis

3.3.1 Net Load Weights

Recorded measurements of the axle weights (taken from portable truck scales) for each loading test were input into an Excel spreadsheet and summarized to produce a net load weight for the untrimmed (i.e. unprocessed) load, trimmed load, and merchantable top processed load. Subtraction of the trimmed load weight and processed load weight from the untrimmed load weight provided the net weight of material trimmed from the load for legal transportation and the net weight of biomass gained from hauling unprocessed timber (compared to hauling processed chip and saw timber), respectively. These differences were calculated for each trial load test, and descriptive statistics were calculated to further analyze the feasibility of this transportation method. Right tailed t-tests were performed on the differences between untrimmed and trimmed loads, trimmed and processed loads, and untrimmed and processed loads to determine any significance. A two tailed t-test was also preformed between the CNS load weight differences and the PWD load weight differences to determine if there was any significant difference between the two product classes.

3.3.2 Axle Grouping Weights

Axle weights were summarized for the tandem drive axles of the log truck and the tandem axles of the modified trailer. The averages were taken and analyzed against the legal tandem axle weight limits for the states of Alabama and Georgia. Analysis was also conducted on these weights and compared to the legal tridem axle weight limit to determine if the weight limit increase in gross vehicle weight and axle group weight from an additional axle added to the modified trailer would have an effect on the feasibility of the transportation method. This analysis was based on a distribution of the load weights measured and their averages. The axle grouping weight limits for Alabama and Georgia were designated on the distribution, and the percentage of the distribution that fell below those limits was calculated.

3.3.3 Anecdotal Observations

Visual observations from the trial load testing were enumerated. Discussion on these observations detailed how varying unquantifiable circumstances affected the loading and feasibility of the modified trailer. The discussion also included potential solutions to observed problems and potential areas of interest for future research on modified trailers transporting unprocessed timber to the timber processing depot.

IV. Results & Discussion

4.1 Transportation Laws and Regulations Research

Research on the transportation laws and regulations of 11 southeastern states where loblolly pine grows naturally was conducted to set constraints for the design of the modification and to further understand the feasibility of this method as it applies to individual states. The data collected from the research can be divided into two main groups of information: that concerning physical dimensions of semi-truck trailer combinations such as length, width, height, and allowable overhang (Table 1) and that concerning vehicle and payload weight of semi-truck trailer combinations such as allowable gross vehicle weight, axle weight, weight tolerances, and weight exemptions (Table 2).

Table 1. Semi-truck trailer transportation regulations regarding dimensions.

The information listed below is the best understanding of the ratified laws based on the Codes of Law for each of the individual states.

State	Length	Height	Width	Trailer Length and Overhang Exemptions for Timber
Alabama	53'	13'6"	102"	Exempt from Length Limitations
Arkansas	53'	13'6"	102"	25' Overhang Beyond Center of Rear Tandem Axle, Trailer Length < 53'
Florida	53'	13"6"	102"	75' Total Length, Trailer Length < 53'
Georgia	53'	13'6"	102"	100' Total Length, Trailer Length < 53'
Louisiana	59'6"	13'6"	102"	66' Total Length, 20' Overhang Beyond Center of Rear Tandem Axle
Mississippi	53'	13'6"	102"	28' Overhang Beyond Center of Rear Tandem Axle
North Carolina	53'	13'6"	102"	14' Overhang Beyond Rear of Trailer
South Carolina	53'	13'6"	102"	Exempt from Length of Vehicle and Load Limitations
Tennessee	53'	13'6"	102"	75' Total Length
Texas	59'	14'	102"	90' Total Length
Virginia	53'	13'6"	102"	65' Total Length, Trailer Length < 53'

Maximum trailer lengths were found to be fairly consistent across the Southeast at 53 feet, with the exception of Texas and Louisiana with maximum trailer lengths of 59 feet and 59 feet 6 inches, respectively. Maximum allowable heights were also consistent at 13 feet 6 inches with the exception of Texas having a maximum allowable height of 14 feet. The maximum allowable width was consistent across all 11 states at 102 inches (8 feet 6 inches). The dimension with the greatest variability from state to state is the allowable overhang and total semi-truck trailer combination lengths. These results fit into three broad groups: those with no overhang or total length limitations, those with limitations on the total vehicle, trailer, and load combination length, and those with limitations on the distance a load could protrude past the center of the rear tandem axle or the rear of the trailer.

The length, height, and width restrictions on semi-truck trailers had little effect on the modification design and how it affected the transportation of unprocessed timber from state to state. Since nearly all states considered adhered to the 102-inch width, 13-foot 6-inch height, and 53-foot length dimensions for trailers, the constraints that must be applied to the trailer in order for the modification to be acceptable according to size regulations are fairly straightforward. However, the variability of the trailer length plus overhang dimensions from state to state will have an effect on the implementation of a modified trailer. States such as Alabama and South Carolina, which are exempt from the laws concerning overhang and overall trailer and load length when hauling timber, could prove to be locations where this method of transportation is more feasible. The method may be less feasible in states such as North Carolina and Louisiana, which have stricter overhang and overall length regulations. However, combined trailer length, load length, and overhang dimensions alone will not be enough to determine the feasibility of this method. The individual states gross vehicle weights and tandem axle weights must also be considered in conjunction with these dimensions to fully understand where the method of transporting unprocessed chip and saw timber on a modified trailer will be most feasible.

Table 2. Semi-truck trailer transportation regulations regarding weight.

The information listed below is the best understanding of the ratified laws based on the Codes of Law for each of the individual states.

State	GVW	Tolerance	Total GVW for Timber	Axle Limits	
				Tandem	Tridem
Alabama	80,000	10%	88,000	40,000	42,000
Arkansas [1]	80,000	-	85,000	34,000	50,000
Florida [2]	80,000	-	80,000	44,000	66,000
Georgia	80,000	5%	84,000	40,680	61,020
Louisiana [3]	80,000	-	80,000	37,000	45,000
Mississippi [4]	80,000	2%	81,600	34,000	-
North Carolina [5]	80,000	-	90,000	38,000	-
South Carolina	73,280	15%	84,272	39,600	-
Tennessee	80,000	10%	88,000	34,000	42,000
Texas [6]	80,000	5%	84,000	34,000	42,000
Virginia [7]	80,000	10%	88,000	34,000	-

[1] 85,000 lbs. allowed for forest products
[2] 10% tolerance included in GVW of 80,000 lbs. max (72,727 lbs. + 10% = 80,000 lbs.)
[3] 40,000 lbs. tandem axle weight limit for forest products (3,000 lbs. tol. included) (2000 lbs. tol. for single axle weight)
[4] 5% tolerance on tandem axle weight and 2% tolerance on GVW
[5] 90,000 lbs. allowed for forest products
[6] Must purchase Annual Timber Permit
[7] Must purchase 1-year 5% weight extension permit. Additional 5% weight extension permit for Virginia grown forest products issuable by DOT. (10% total)

The allowable gross vehicle weight across the Southeast was also consistent at 80,000 pounds with the exception of South Carolina at 73,280 pounds. Allowable gross vehicle weight tolerance varied from state to state and ranged from a low of 2 percent in the state of Mississippi to a high of 15 percent in South Carolina. There were four states where no tolerance on gross vehicle weight was found. The state of Florida had a special situation where their allowable gross vehicle weight already included a 10 percent tolerance. In other words, the state's true allowable gross vehicle weight is 72,727 pounds, and the stated 80,000-pound allowable gross vehicle weight is achieved when the 10 percent tolerance is applied to the 72,727 pounds. Due to the variability in tolerances and the differences in laws and regulations regarding the transportation of timber, the gross vehicle weight for a semi-truck transporting a load of timber varied greatly from state to state.

Most states only granted the tolerance under the stipulation that the product being transported was timber or a raw natural material such as timber. Others such as Arkansas and North Carolina granted no tolerance for timber but stated that the allowable gross vehicle weight for a truck transporting timber was increased from 80,000 pounds to 85,000 pounds and 90,000 pounds, respectively. The law in Louisiana did not prescribe a tolerance to the gross vehicle weight but rather included a 3,000-pound tolerance to the tandem axle weight of vehicles transporting forest products. Still, others such as the states of Alabama, Tennessee, Texas, and Virginia simply applied a percentage to the gross vehicle weight, although permits might be required.

States such as North Carolina, Alabama, Tennessee, and Virginia that have gross vehicle weights of 88,000 to 90,000 pounds show the most promise when considering locations where this method will be most feasible. These higher gross vehicle weight limits are needed to accommodate the additional weight of the unprocessed biomass left on the stems while ensuring that the trailer's volume capacity as much as possible is filled with timber. In states with smaller gross vehicle weight limits, such as Mississippi, loggers risk having to remove stems from the load to adhere to weight limits because the additional weight of the biomass material might place a normally loaded trailer above the legal weight limit. The incentive for loggers to haul unprocessed timber is diminished if their trailers are only loaded to less than all of the available volume capacity to meet legal weight requirements because they are incurring opportunity costs with each load.

4.2 Modification Design

4.2.1 Design Constraints

Using the results found from the transportation laws and regulations research, a set of constraints for physical dimensions was developed to guide the design of the trailer modification (Table 3). A Pitts LT40-8L log trailer was selected for the modification design process since the log trailer that was used in the trial load testing had yet to be acquired and therefore could not be used in designing the modification on paper. Brainstorming sessions resulted in two design concepts: the swinging gate design and the extendable bolster design.

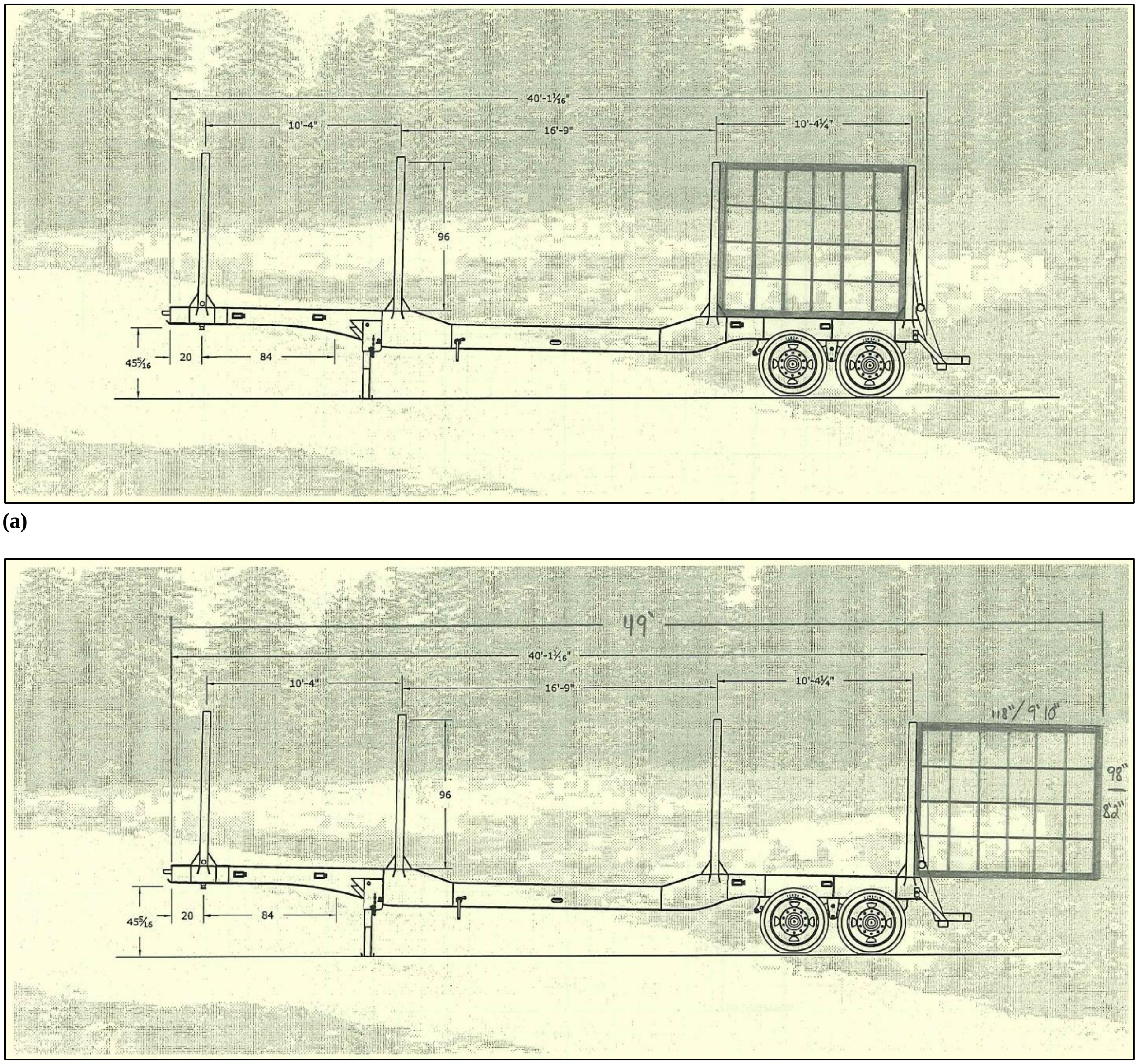
Table 3. Modification Design Criteria.

Modification Design Criteria	
Trailer + Modification Maximum Length	< 53'
Trailer + Modification Maximum Height	< 13'6"
Trailer + Modification Maximum Width	< 102"
Modification Weight Goal	< 1,200 lbs.
Modification Materials Cost Goal	Lowest Cost

An important part of this project was the fact that the method created to haul unprocessed timber involved a modification that could be easily attached to standard double bunk log trailers already in use by loggers and not a purpose-built trailer specifically designed for transporting unprocessed timber. A method involving a simple modification would mean that less capital would need to be invested for loggers to transport timber to the timber processing depot. Furthermore, since the modification is designed to be easily attached and detached, loggers can remove the modification when they are harvesting tracts where the timber is not being hauled to the timber processing depot. This ensures that they are not incurring any opportunity cost by allowing the weight of the modification to reduce their payload weight. A purpose-built specialty trailer would most likely cost more than a new standard double bunk log trailer and modification combined. This means that a logger runs the risk of having a large amount of their available capital tied up in a piece of equipment that could be underutilized if, for instance, the depot shut down, the logger was harvesting a non-biomass product tract, or if the depot could not match competitor prices. A modification that can be added to existing log trailers makes more sense because it allows loggers to be versatile in what they harvest and transport (i.e. unprocessed timber versus processed timber) with only a small amount of capital invested.

4.2.2 Swinging Gate Design

The swinging gate design (Figure 1) places two large cross-hatched gates at the back of the trailer with one mounted to the rearmost left standard and the other to the rearmost right standard. These gates revolve 180 degrees around a vertical axis (i.e. the standards of the trailer) from a closed position where the gates are situated between the standards of the rear bunk (Figure 1a) to an open position where the gates are projecting from the rear of the trailer (Figure 1b). The gates, when placed in the open position, are chained together across the bottom of the gates toward their ends. A chain binder can then be used to pull the gates in to the 102-inch width limit, thereby squeezing in the crown material and containing it for transportation.



(a)

(b)

Figure 1. Swinging gate design.

Swinging gate design for the modified trailer method of unprocessed timber transportation: (a) closed position for unloaded transportation and (b) open position for loaded transportation.

The concept of this design is that the crowns of trees loaded onto the trailer are contained once the gates are swung to the open position. The gates squeeze in the limbs that protrude beyond the allowable 102-inch width limit, thereby allowing the load to adhere to the transportation laws on legal widths without having to cut, trim, or remove those limbs from the load. By retaining those limbs and not removing them to adhere to legal width limits, biomass material can be transported to the timber processing depot, while still attached to the stems that will be used for other products, in a safe and legal manner.

The 5-inch width of the material selected for the frame of the gates was chosen to match the 5-inch width of the standards on the Pitts LT40-8L trailer. It is important for the frame material to be tubing rather than a solid material to reduce the weight of the modification as much as possible. The cross-hatch material was selected to be a solid 1 inch square material so that the cross-hatch portion of the gate when welded together is two inches thick and will lie flush within the 2-inch depth of the frame material. Solid material was chosen to increase the strength of the crosshatch portion and ensure that it would be able to withstand the pressure exerted by the crown material pushing against it once bound shut with chains.

An important part of the design process entailed calculating the forces acting on the standards at the location where they are most likely to yield. The yield strength is defined as the stress level at which a material begins to deform plastically (i.e. permanently bend). This location for the swinging gate design is found on the standards just below the point where the collar that attaches the gate to the standard rests and is indicated by the red arrow on Figure 2a. The estimated 577 pounds of material used to construct one gate (Table 4) create a resulting moment force of 2,867 foot pounds of force (ft lbf) (Figure2b) at that location. The material used in the construction of the Pitts LT40-8L log trailer states that the standards are five inches wide, five inches deep, and 5/16 inch thick and has a yield strength of 70,000 pounds per square inch (psi). The standards would therefore need to be subjected to a 50,283 ft lbf moment before they would yield (Figure 2b). The 2,867 ft lbf moment generated by the gate acting on the standard accounts for only 6 percent of what the material is capable of withstanding. Therefore, the gates in the swinging gate design are in no way compromising the structural integrity of the standards.

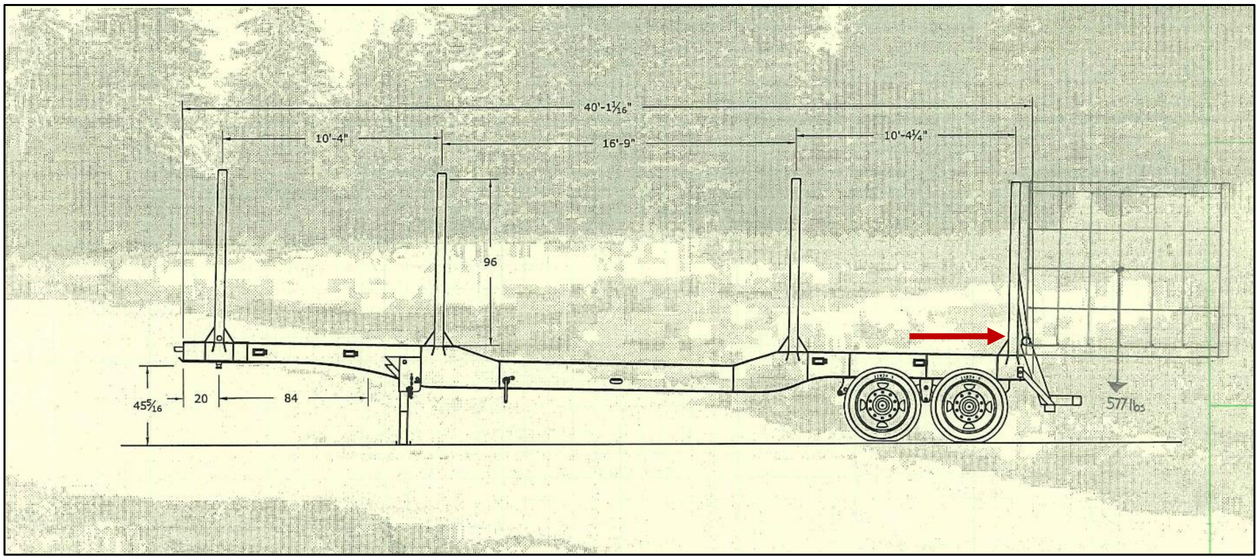
Table 4. Swinging gate design materials list and estimated modification weight.

Item	Quantity	Depth (in)	Width (in)	Length (ft)	Thickness (in)	Density (lbs/ft)	Weight (lbs)
Frame (Top & Bottom)	4	5.0	2.0	9.10	0.25	10.41	379
Frame (Front & Back)	4	5.0	2.0	8.26	0.25	10.41	344
Crosshatch Material	2	1.0	1.0	63.50	0	3.4	432
Total Modification Weight (lbs)							1154
Weight of Single Gate (lbs)							577

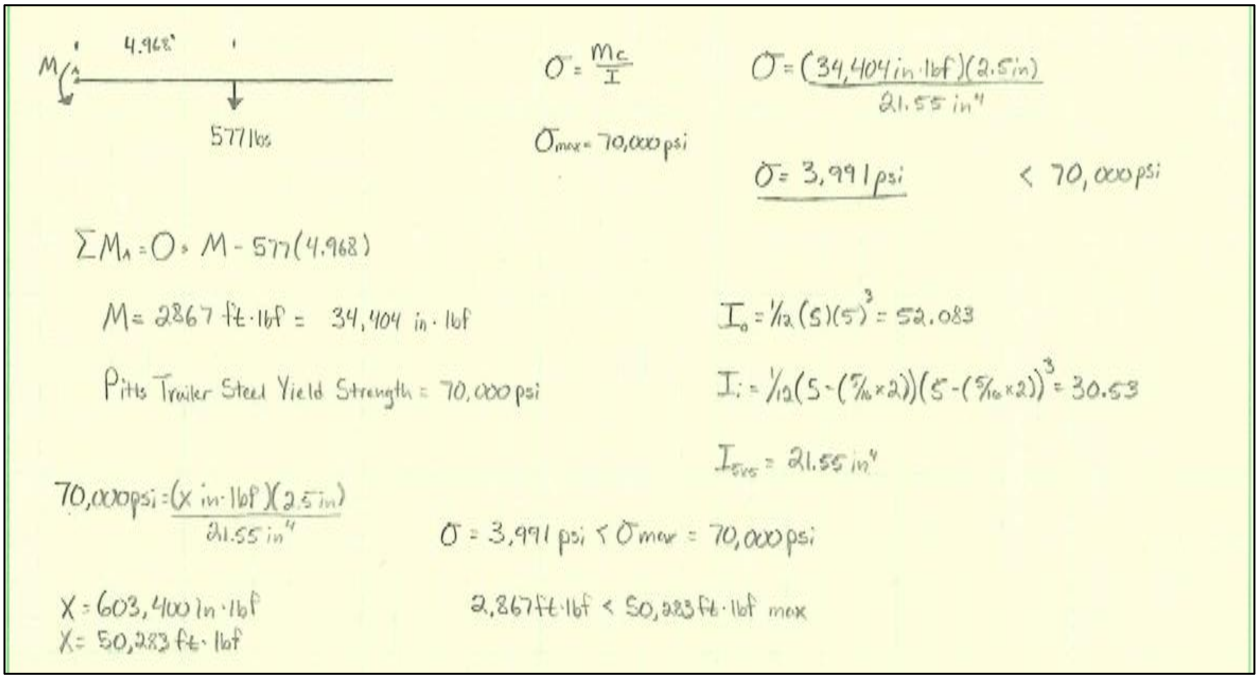
The estimated cost of the modification is $1,397.48 (Table 5). The swinging gate design comes in under budget and underweight of the goals of 1,200 pounds and $1,500. In addition, the design of this modification does not compromise the structural integrity of the standards on the log trailer. The estimated overall length of the design mounted on the Pitts LT40-8L trailer is under the 53-foot maximum length and maintains the trailer width and height of 102 inches and 13 feet six inches, respectively. This design is highly feasible for implementation due to all of the above factors.

Table 5. Swinging gate design estimated cost.

Item	Unit Cost ($/ft)	Cost
Frame (Top & Bottom)	$ 14.99	$ 545.64
Frame (Front & Back)	$ 14.99	$ 494.97
Crosshatch Material	$ 2.81	$ 356.87
Modification Cost (USD)		$ 1,397.48



(a)



$\sigma = \frac{Mc}{I}$

$\sigma_{max} = 70{,}000 \text{ psi}$

$\sigma = \frac{(34{,}404 \text{ in}\cdot\text{lbf})(2.5 \text{ in})}{21.55 \text{ in}^4}$

$\underline{\sigma = 3{,}991 \text{ psi}} \quad < 70{,}000 \text{ psi}$

$\Sigma M_A = 0 = M - 577(4.968)$

$M = 2867 \text{ ft}\cdot\text{lbf} = 34{,}404 \text{ in}\cdot\text{lbf}$

Pitts Trailer Steel Yield Strength = 70,000 psi

$I_o = 1/12(5)(5)^3 = 52.083$

$I_i = 1/12(5-(5/16 \times 2))(5-(5/16 \times 2))^3 = 30.53$

$I_{5x5} = 21.55 \text{ in}^4$

$70{,}000 \text{ psi} = \frac{(x \text{ in}\cdot\text{lbf})(2.5 \text{ in})}{21.55 \text{ in}^4}$

$\sigma = 3{,}991 \text{ psi} < \sigma_{max} = 70{,}000 \text{ psi}$

$X = 603{,}400 \text{ in}\cdot\text{lbf}$

$X = 50{,}283 \text{ ft}\cdot\text{lbf}$

$2{,}867 \text{ ft}\cdot\text{lbf} < 50{,}283 \text{ ft}\cdot\text{lbf max}$

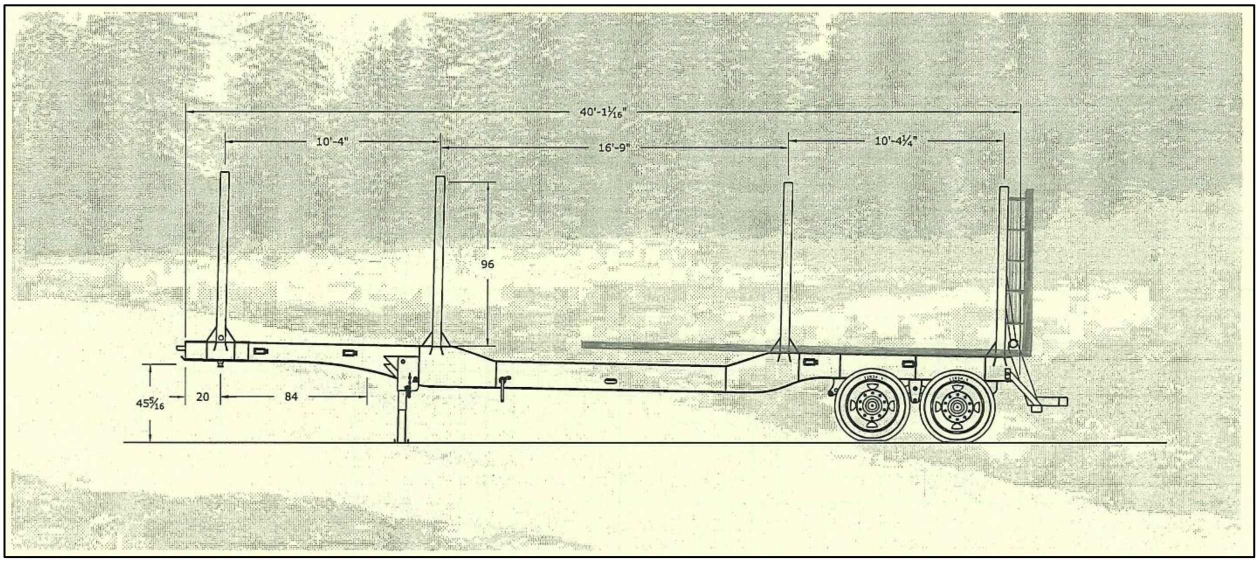
(b)

Figure 2. Swinging gate design load force analysis.

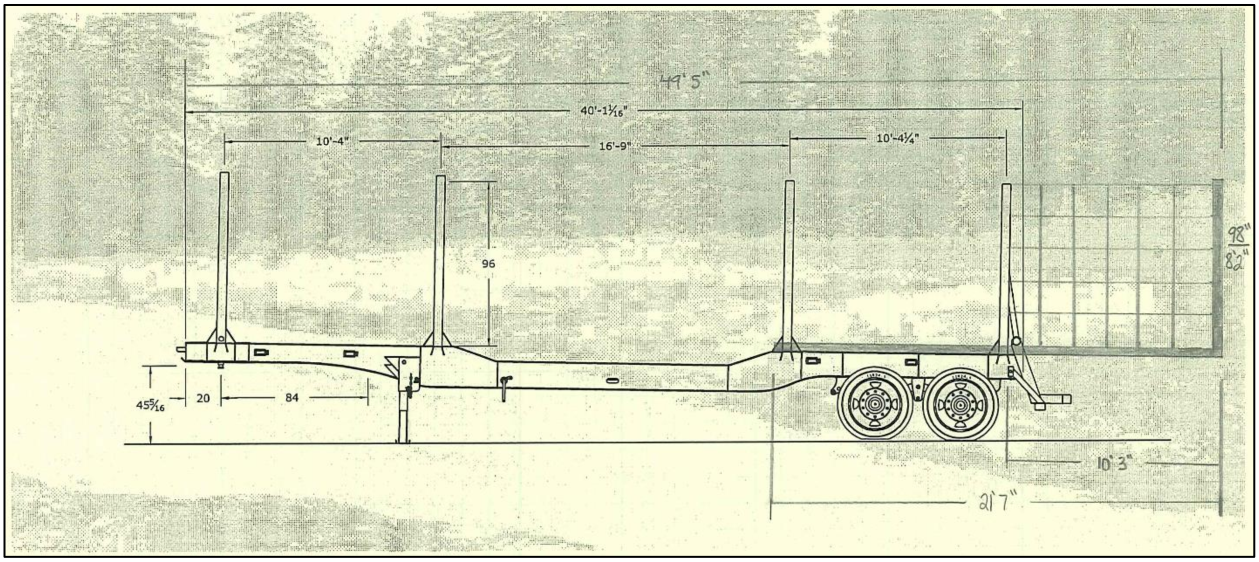
Swinging gate design load force analysis: (a) location and magnitude of weight forces acting on the modified trailer and location of resulting moment force and (b) load force analysis calculations for rearmost standards that gates are attached to.

4.2.3 Extendable Bolster Design

The extendable bolster design (Figure 3) places an additional bolster with two standards on a sliding rail system at the rear of the trailer. The bolster and standards slide out of the rear of the trailer, increasing its total length to accommodate the crowns overhanging from the rear of the trailer. The modification slides from a collapsed position (Figure 3a), where the bolster and standards are positioned right behind the rearmost bunk of the trailer, to the extended position (Figure 3b). When extended, the sliding support beams (i.e. sliding rail system) theoretically accommodates the additional weight of the crowns. This keeps the crown material lifted up and prevents it from drooping and coming in contact with the surface of the highway while in transport. In addition, a cross-hatched chain net is strung between the standards on the sliding bolster and the standards of the rearmost bolster of the trailer. In the extended position the chain net is taut and serves to retain limbs within the legal width limit for transportation. In the closed position, the chain net is no longer taut and has slack thereby allowing it to hang loosely between the standards.



(a)



(b)

Figure 3. Extendable bolster design.

Extendable bolster design for the modified trailer method of unprocessed timber transportation: (a) collapsed position for unloaded transportation and (b) extended position for loaded transportation.

The concept of this design is that the crowns of trees loaded onto the trailer are contained by the taut chain nets and additional two standards and are also supported from underneath by the additional bolster and sliding rail system to prevent them from coming in contact with the surface of the road. By retaining limbs and not removing them to adhere to legal width limits, biomass material can be transported to the timber processing depot, while still attached to the stems that will be used for other products, in a safe and legal manner.

The 4-inch wide, 3-inch deep, and ½-inch thick size tubing was selected for the sliding support beam because of its relation to the size of the bolsters that it slides through. The bolster on the Pitts LT40-8L trailer are 10 inches from the bottom of the bolster to the top. The larger the hole that is cut through the trailer's bolsters for the sliding support beam, the weaker the bolsters becomes at supporting the weight of the loaded timber. Therefore, a 4-inch wide beam was selected to ensure that more than half of the width of the bolsters remained intact. Tubing and solid material were both analyzed for structural strength in the design. Tubing was selected for a lightweight option, while the solid material was selected for more robust support in the event that the tubing did not meet the yield strength requirements.

An important part of the design process entailed calculating the forces acting on the sliding support beam at the location where it is most likely to yield. Unlike the swinging gate design, the extendable bolster design must support the additional weight of the crown material (i.e. biomass) along with the weight of the modification itself. This location is found on the support beams just past the point where the beams emerge from the slots cut into the rearmost bolster of the trailer that allows the support beams to slide through it. This location is indicated by the red arrow on Figure 4a.

The estimated 1,384 pounds of material used to construct the modification (Table 6) along with an estimated 13,365 pounds of biomass material the modification will support creates a resulting moment force of 78,538 ft lbf (Figure 4b) on each of the two support beams. This assumes that the 13,365 pounds of biomass is not a distributed load force where the true actual magnitude of weight acting on the design would be less due to a portion of the weight being suspended over the end of the trailer rather than acting directly on the modification. Rather, it is assumed that the 13,365 pounds of biomass is considered severed from the stem and the full magnitude of the weight of the biomass is acting on the design to create a worst case scenario calculation.

The estimated biomass gain of 13,365 pounds was calculated using the whole tree green weight of a hypothetical load of 45 trees 12 inches in DBH and 60 feet tall subtracted from the 6-inch merchantable top green weight of the same 45 trees. Green weights were obtained from a Georgia forest research paper (Clark and Saucier, 1990).

Table 6. Extendable bolster design materials list and estimated modification weight.

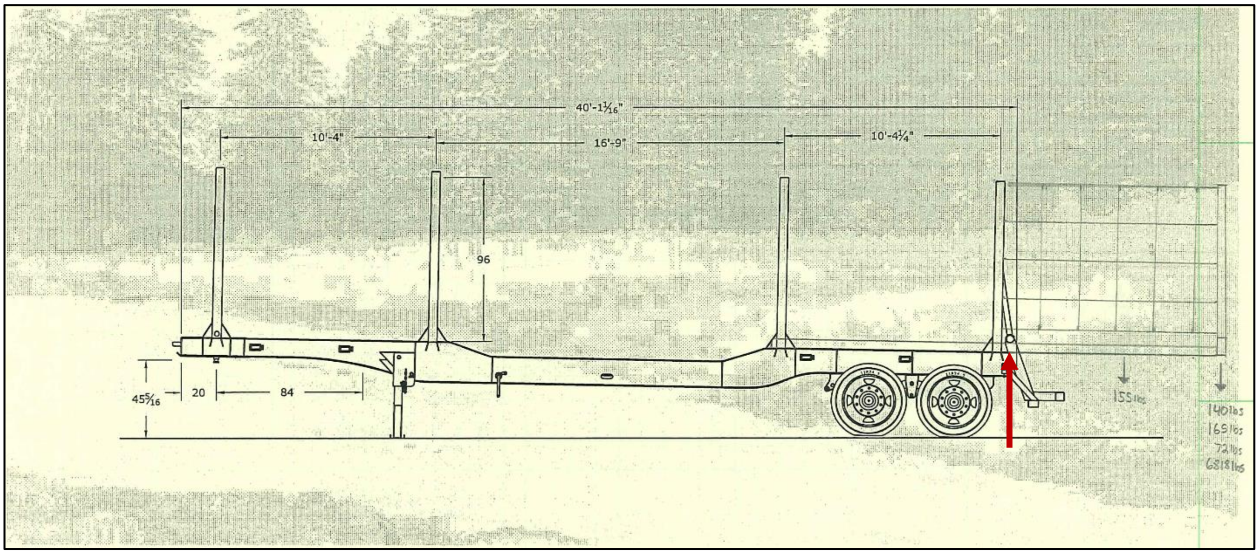
Item	Quantity	Depth (in)	Width (in)	Length (ft)	Thickness (in)	Density (lbs/ft)	Weight (lbs)
Standards	2	5.0	5.0	7.36	0.375	22.37	329
Bolster	1	4.0	10.0	8.50	0.375	32.58	277
Extension Slide	2	4.0	3.0	21.59	0.375	14.71	635
Chain Netting	2	10.5	8.0	76.50	0.3125	0.93	142
Total Modification Weight (lbs)							1384

ASTM A36 mild low-carbon steel used in the construction of the modification has a yield strength of 36,300 psi. A single 4-inch wide, 3-inch deep, and ½-inch thick support beam in this design would therefore need to be subjected to a 10,588 ft lbf moment before it would yield (Figure 4b). The 78,538 ft lbf moment generated by the biomass and modification weight acting on the location shown is nearly 7.5 times more than what the support beam is capable of withstanding. If a solid 4-inch wide and 3-inch deep support beam replaces the hollow ½-inch thick tubing beam, it would need to be subjected to a 13,613 ft lbf moment before it would yield. Still, the 78,538 ft lbf moment acting on the beam is nearly 5.8 times more than it is capable of withstanding. Therefore, the structural integrity of the support beams are compromised and the modification fails in its intended design.

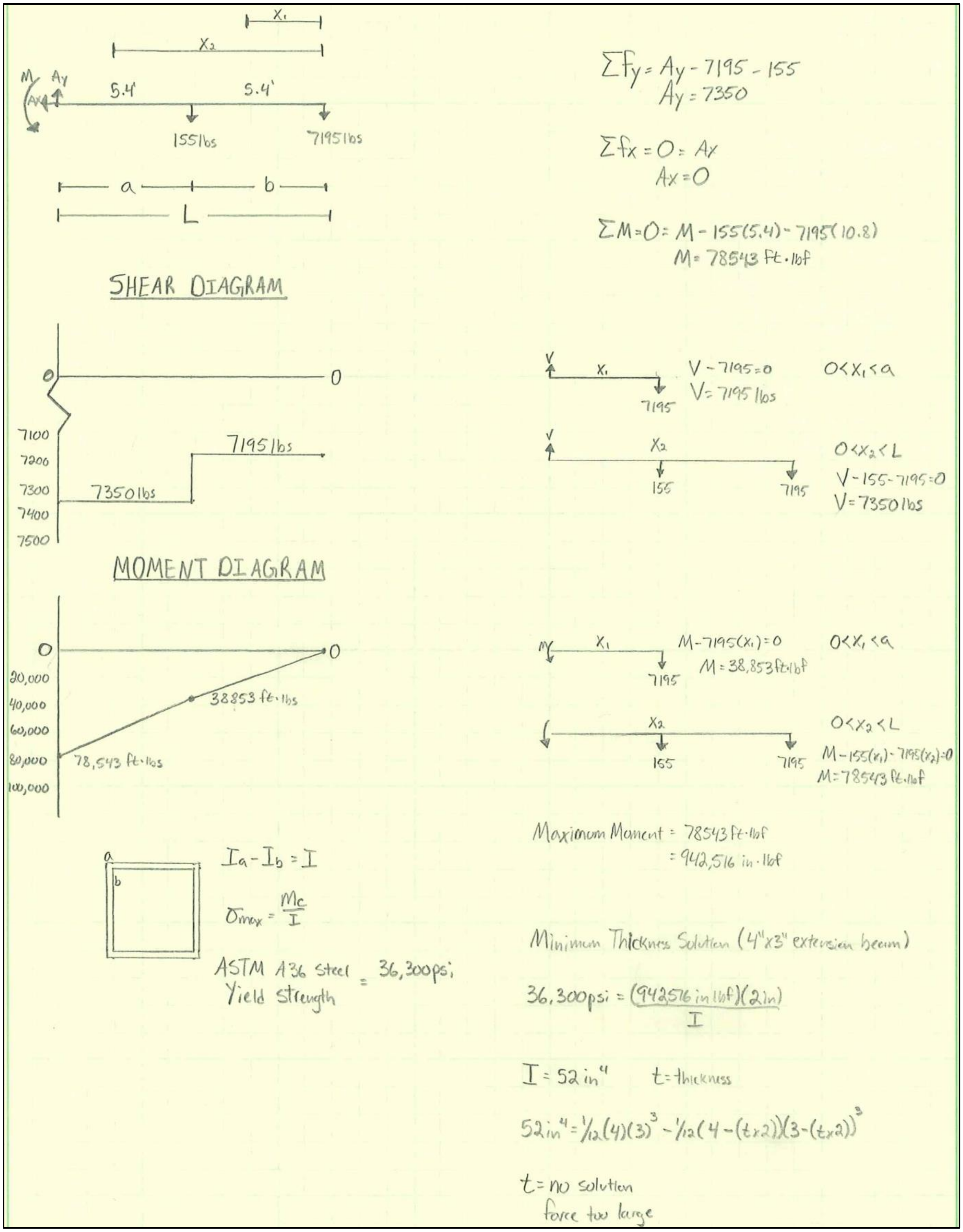
The estimated cost of the modification is $1,835.28 (Table 7). The extendable bolster design came in over budget and overweight of the goals of 1,200 pounds and $1,500. In addition, the design of this modification contains materials that compromise the structural integrity of the modification under the estimated load weight. However, the estimated overall length of the design mounted on the Pitts LT40-8L trailer is under the 53-foot maximum length and maintains the trailer width and height of 102 inches and 13 feet six inches, respectively. With all factors considered, this design is unfeasible for implementation due to the concerns regarding structural integrity issues relating to overloading the sliding support beam.

Table 7. Extendable bolster design estimated cost.

Item	Unit Cost ($/ft)	Cost
Standards	$ 25.89	$ 381.10
Bolster	$ 29.96	$ 254.66
Extension Slide	$ 22.50	$ 971.55
Chain Netting	$ 1.49	$ 227.97
Modification Cost (USD)		$ 1,835.28



(a)



$\Sigma f_y = A_y - 7195 - 155$

$A_y = 7350$

$\Sigma f_x = 0 = A_x$

$A_x = 0$

$\Sigma M = 0 = M - 155(5.4) - 7195(10.8)$

$M = 78543$ ft·lbf

$V - 7195 = 0$ $\quad 0 < x_1 < a$

$V = 7195$ lbs

$0 < x_2 < L$

$V - 155 - 7195 = 0$

$V = 7350$ lbs

$M - 7195(x_1) = 0$ $\quad 0 < x_1 < a$

$M = 38{,}853$ ft·lbf

$0 < x_2 < L$

$M - 155(x_1) - 7195(x_2) = 0$

$M = 78543$ ft·lbf

$I_a - I_b = I$

$\sigma_{max} = \frac{Mc}{I}$

ASTM A36 Steel Yield strength = 36,300psi

Maximum Moment = 78543 ft·lbf

= 942,516 in·lbf

Minimum Thickness Solution (4"x3" extension beam)

$36{,}300\text{psi} = \frac{(942516 \text{ in lbf})(2\text{in})}{I}$

$I = 52 \text{ in}^4$ $\quad t$ = thickness

$52\text{in}^4 = \frac{1}{12}(4)(3)^3 - \frac{1}{12}(4-(t \times 2))(3-(t \times 2))^3$

t = no solution

force too large

(b)

Figure 4. Extendable bolster design load force analysis.

Extendable bolster design load force analysis: (a) location and magnitude of weight forces acting on the modification and location of resulting moment force and (b) load force analysis calculations for support beams on sliding rail system.

4.2.4 Implemented Design

The swinging gate design was chosen and implemented on a trailer that was donated specifically for this project (Figure 5). The swinging gate design was chosen because its design was under the weight and cost goals, and there were no concerns about compromising the structural integrity of the trailer by adding the modification to it. Discrepancies existed between the Pitts LT40-8L trailer that was used for the design of the modification on paper and the actual trailer donated for the experiment. Most notably, the donated trailer (Figure 5) was a Union Camp Corporation pulpwood trailer, and its configuration was very different than the Pitts LT40-8L trailer used in the design process. Alterations were made to the trailer to transform its configuration into a more modern double bunk log trailer (Figure 6) much like the Pitts LT40-8L trailer used in the design process.

Figure 5. Former Union Camp pulpwood trailer donated for this project.

Figure 6. Donated trailer after alteration to a modern double bunk configuration.

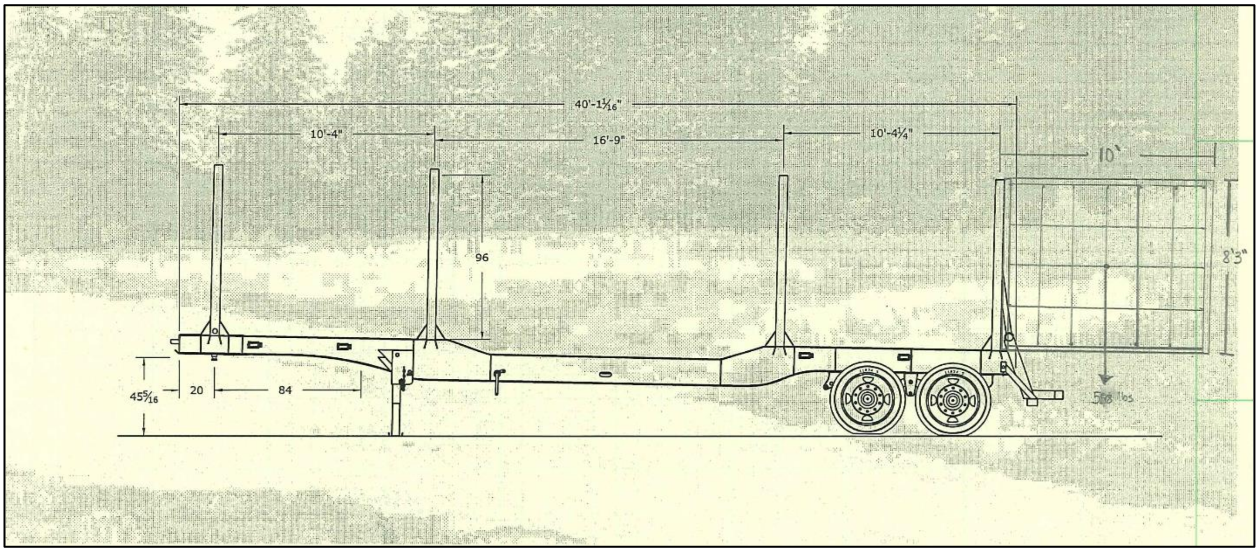
Once the donated trailer was altered into a standard double bunk configuration, the constructed gates were added (Figure 7). Due to the variation between the donated trailer's altered dimensions and the dimensions of the Pitts LT40-8L trailer, the machinist made a few minor changes to the design of the gates. Since the distance between the bunks on the Pitts trailer and the distance between the bunks on the donated trailer with its new configuration varied slightly, the gates were shortened slightly from the designed length so that they would fit between the standards of the bunks. The machinist also used 3-inch wide, 3-inch deep, and ¼-inch thick steel tubing for the outside framing and 2-inch wide, 2-inch deep, and 3/16-inch thick steel tubing for the cross-hatch material rather than the materials listed in Table 4. The change in materials was due to a combination of the machinist's recommendation based on familiarity of working with steel tubing and knowing its limitations, density per linear foot, and the availability of materials on hand to construct the gates.

Figure 7. Constructed swinging gate modification.

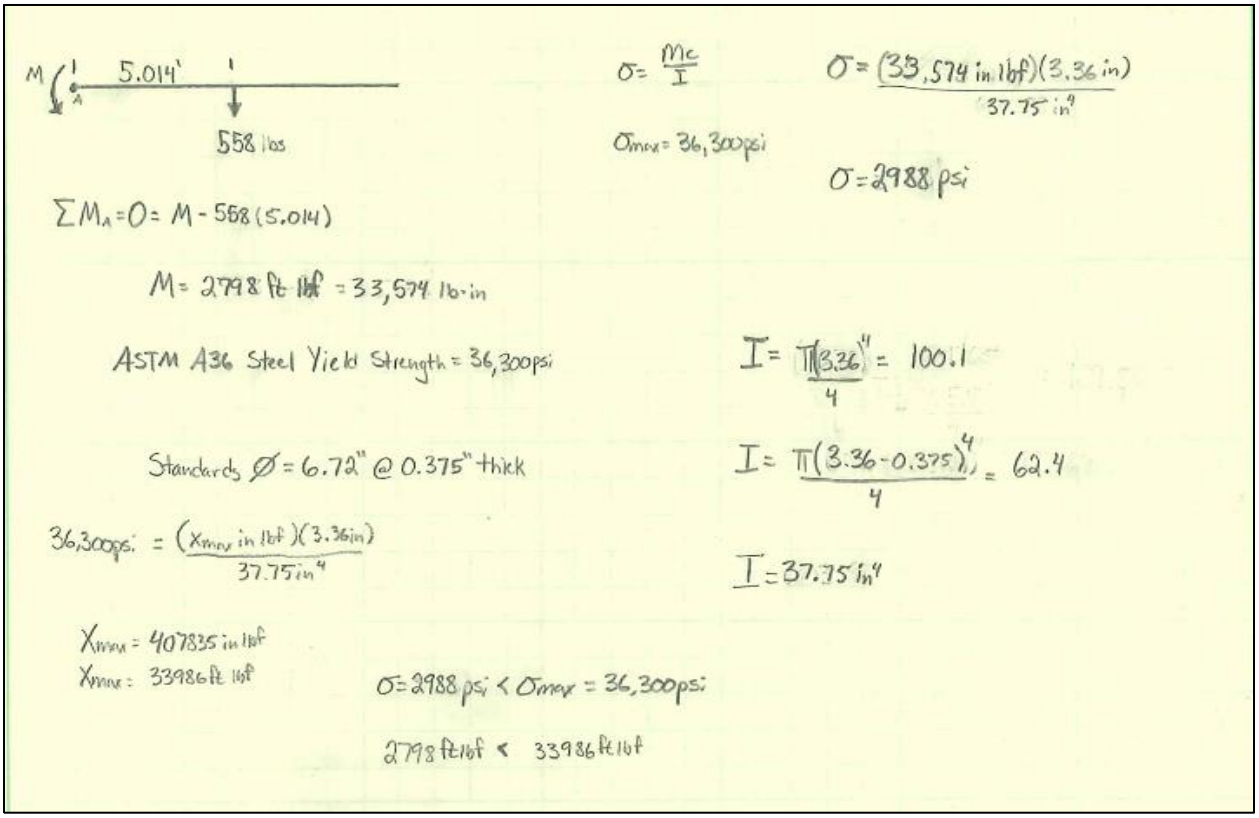
Swinging gate design implemented on the donated trailer used for the trial load testing phase of this project. The near gate is in the open position and the far gate is in the closed position. The red arrow indicates the location of the resulting moment force acting on the standard generated from the weight force of the gate

The variation in the rearmost standards that the gates hang from between the donated trailer and the Pitts trailer were extreme and questions arose as to whether or not the force analysis conducted on the Pitts trailer would be accurate on the donated trailer since the standards on the Pitts trailer were square steel tubing (5” x 5” x 5/16” thick) and the standards on the donated trailer after alteration were round steel tubing (6.72” diameter x 3/8” thick). Therefore, force analysis calculations on the donated trailer were calculated to ensure its accuracy. Calculations showed that the weight of one gate acting on a standard generated a moment force of 2,798 ft lbf at the location just below the collar, indicated by the red arrow in

Figure 7. The weight and dimensions of the actual gates constructed for this project were used in the calculation of the moment force. The constructed gates weighed 558 pounds each, just slightly less than the designed gates. This is most likely due to the constructed gates smaller overall length and smaller material size compared to the designed gates. The 3/8-inch thick 6.72-inch diameter steel tubing serving as the rearmost bolster of the trailer was assumed to have a 36,300 psi yield strength comparable to ASTM A36 mild low-carbon steel since the exact material the standards were made from was unknown. A yield strength of 36,300 psi is a conservative estimate since it ranks toward the bottom end of the yield strength range for various types of steel. Calculations show that a 33,986 ft lbf moment would need to be generated at the location indicated by the red arrow in Figure 7 in order for the yield to exceed the 36,300 psi mark and permanently bend the standards (Figure 8). Since each gate only exerts a moment force of 2,798 ft lbf, there are no concerns that the material used to construct the standards failing as long as the assumption of the maximum yield strength for the material holds true.



(a)



$\Sigma M_A = 0 = M - 558(5.014)$

$M = 2798 \text{ ft lbf} = 33{,}574 \text{ lb}\cdot\text{in}$

ASTM A36 Steel Yield Strength = 36,300psi

Standards $\varnothing = 6.72''$ @ $0.375''$ thick

$36{,}300\text{psi} = \dfrac{(X_{max} \text{ in lbf})(3.36\text{in})}{37.75\text{in}^4}$

$X_{max} = 407835 \text{ in lbf}$

$X_{max} = 33986 \text{ ft lbf}$

$\sigma = \dfrac{Mc}{I}$

$\sigma_{max} = 36{,}300\text{psi}$

$\sigma = \dfrac{(33{,}574 \text{ in lbf})(3.36 \text{ in})}{37.75 \text{ in}^4}$

$\sigma = 2988 \text{ psi}$

$I = \dfrac{\pi(3.36)^4}{4} = 100.1$

$I = \dfrac{\pi(3.36-0.375)^4}{4} = 62.4$

$I = 37.75 \text{ in}^4$

$\sigma = 2988 \text{ psi} < \sigma_{max} = 36{,}300\text{psi}$

$2798 \text{ ftlbf} < 33986 \text{ ftlbf}$

(b)

Figure 8. Swinging gate design load force analysis for constructed gates.

Swinging gate design load force analysis for constructed gates: (a) location and magnitude of weight forces acting on the modified trailer and location of resulting moment force and (b) load force analysis calculations for rearmost standards that gates are attached to.

The estimated cost of the actual modification constructed for the research project is $1,737.85 (Table 8), and the actual weight measured 1,095 pounds (Table 9). The constructed swinging gate design came in over budget but underweight of the goals of 1,200 pounds and $1,500, respectively. In addition, the design of this modification does not compromise the structural integrity of the standards on the log trailer. The estimated overall length of the design mounted on the modified trailer is under the 53-foot maximum length, and maintains the trailer width and height of 102 inches and 13 feet six inches, respectively.

The constructed gates are easily attachable and detachable and the process requires a knuckleboom loader, crane, shop lift, or other piece of equipment capable of lifting 500 or more pounds. To remove the gates, they are lifted straight up to allow the collars of the gate to slide up and off of the standards. Attaching the gates to the trailer is as simple as reversing the process and sliding the collars back over and down the standards until the top of the standards is in contact with the cap welded to the top of the upper collar.

Table 8. Constructed swinging gate design materials list and estimated modification weight.

Item	Quantity	Depth (in)	Width (in)	Length (ft)	Thickness (in)	Density (lbs/ft)	Weight (lbs)
Vertical Frame	4	3.0	3.0	7.00	0.25	8.81	247
Horizontal Frame	4	3.0	3.0	9.67	0.25	8.81	341
Horizontal Hatch	6	2.0	2.0	9.67	0.1875	4.32	251
Vertical Hatch	20	2.0	2.0	1.40	0.1875	4.32	121
Vertical Hatch	20	2.0	2.0	1.58	0.1875	4.32	137
Total Modification Weight (lbs)							1095
Weight of Single Gate (lbs)							548

Table 9. Constructed swinging gate design estimated cost.

Item	Unit Cost ($/ft)	Cost
Vertical Frame	$ 13.21	$ 369.88
Horizontal Frame	$ 13.21	$ 510.79
Horizontal Hatch	$ 7.29	$ 422.82
Vertical Hatch	$ 7.29	$ 203.51
Vertical Hatch	$ 7.29	$ 230.85
Modification Cost (USD)		$ 1,737.85

4.3 Trial Load Testing

4.3.1 Net Load Weights

Modified trailer loads (n = 9) of unprocessed whole trees weighed during the course of this project were examined with respect to the variable of product class. Two different product classes were tested during the trial load testing phase of this project. The first product class was chip and saw (CNS) sized trees (n = 6) and the second product class was pulpwood (PWD) sized trees (n = 3). Loads 1 through 6 were loaded with CNS trees while loads 7 through 9 were loaded with PWD trees (Figure 9). The values for each individual load can be found in Appendix 3.

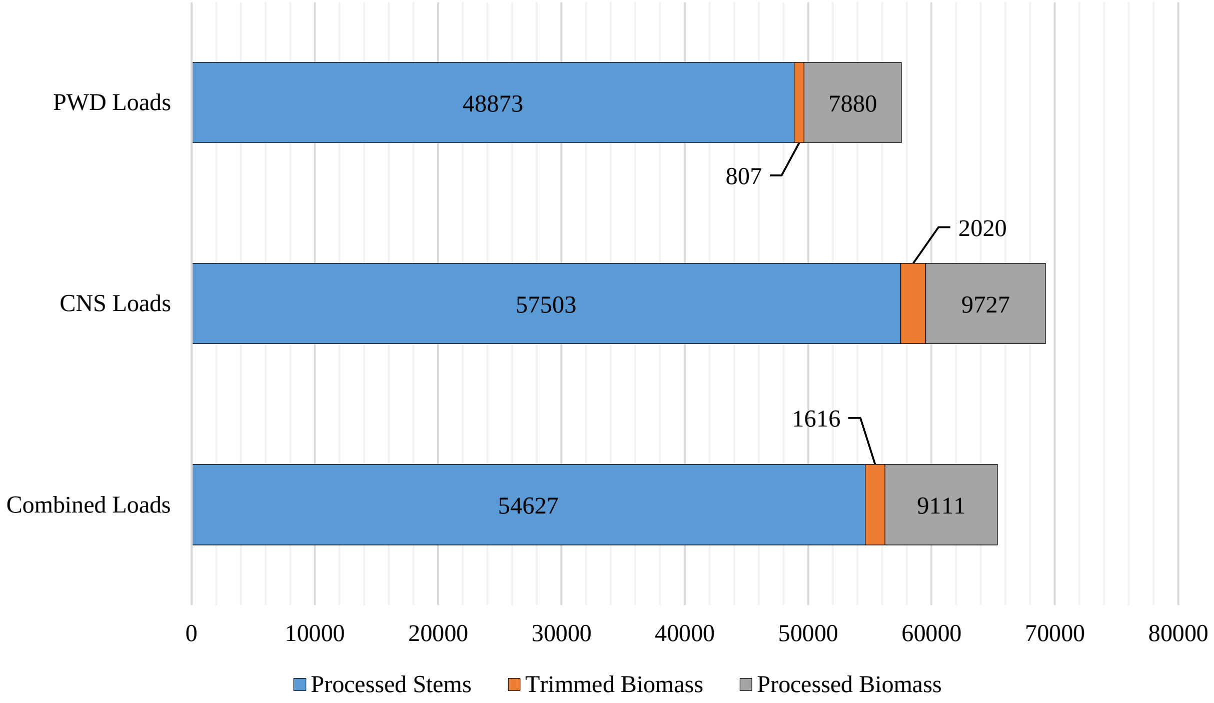


Figure 9. Modified trailer load weight averages for PWD, CNS, and Combined loads.

Modified trailer loads averaged 9,111 pounds (± 1,481, 95% CI) of processed biomass material (i.e. material removed during processing) when product class was ignored (i.e. combined loads). When the product class variable was considered, CNS loads (1 – 6) averaged 9,727 pounds (± 1,868, 95% CI) of processed biomass material, while PWD loads (7 – 9) averaged 7,880 pounds (± 1,645, 95% CI) of processed biomass material (Figure 9). The biomass material removed by processing (i.e. processed biomass) would be the material left unprocessed but trimmed and attached to the stem that the timber processing depot would receive in this transportation method. Statistical testing ($\alpha = 0.05$) indicated that there was no significant difference between the distributions of CNS loads and the PWD load (Table 10).

Table 10. Results from statistical testing for significant differences between product classes.

	CNS Average	PWD Average	Test Type	p-value
Trimmed Biomass	2020	807	Mann-Whitney Wilcoxon	0.1667
Processed Biomass	9727	7880	Mann-Whitney Wilcoxon	0.1667

On average, 2 percent of the unprocessed whole tree load weight for combined loads was removed after it was trimmed to adhere to transportation regulations (Figure 10). When the variable of product class was applied, the average changed to 1 percent and 3 percent for the PWD and CNS loads, respectively. However, the average percentage of biomass removed from a modified trailer load when the trees were processed to a merchantable top was 14 percent, regardless of whether the variable of product class was considered or not (Figure 10). Since the PWD loads only had a sample size of 3, it is understood that caution should be used in stating the averages associated with this product class. A larger sample size is needed to confirm with confidence the percentages of the PWD loads due to the large 95% confidence interval surrounding the processed biomass and processed stem percentages (Table 11).

Table 11. Percentages of the modified trailer net load weight and 95% confidence intervals.

	PWD		CNS		Combined	
	Average	95% CI	Average	95% CI	Average	95% CI
Trimmed Biomass	1%	1%	3%	2%	2%	1%
Processed Biomass	14%	10%	14%	2%	14%	2%
Processed Stems	85%	11%	83%	3%	84%	3%

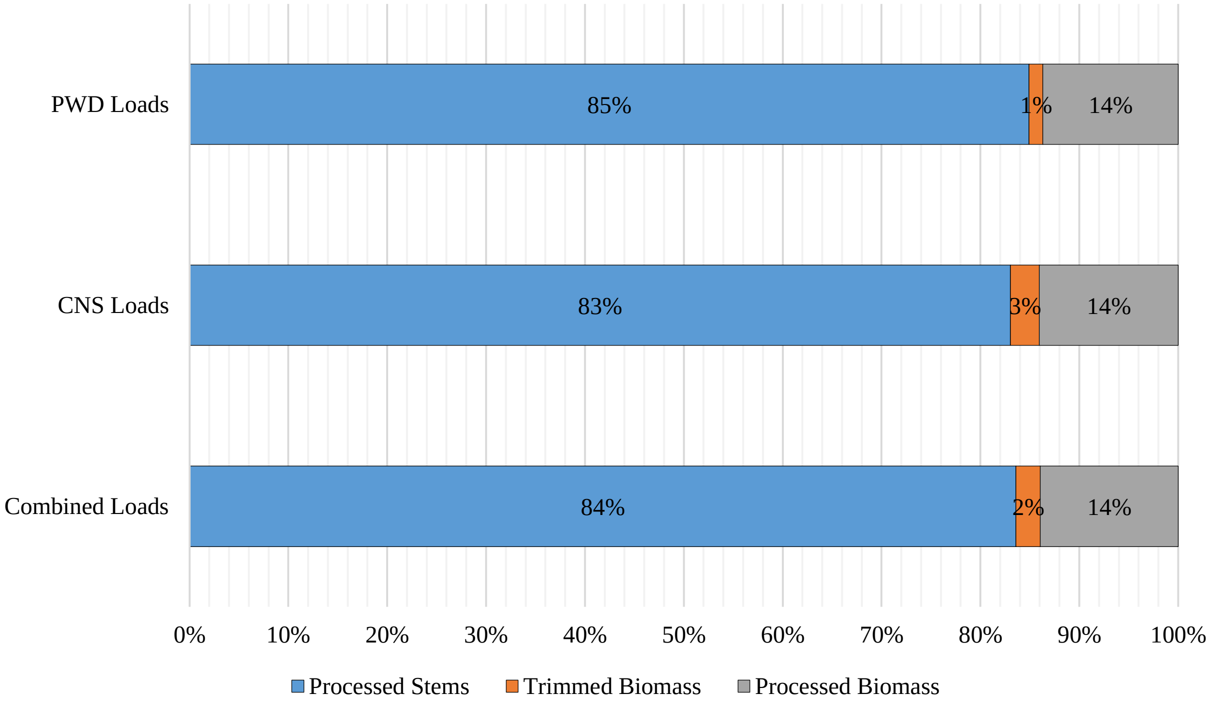


Figure 10. Modified trailer load weight averages as a percentage of the net load weight.

The CNS loads when trimmed (i.e. what would actually be transported to the timber processing depot) extended well beyond the end of the modified trailer. Much of the crown and biomass material was still located beyond the reach of the swinging gates in the open position (Figure 11a). This indicates that this method might not be feasible despite an average biomass gain of nearly 9,700 pounds. The gates appear to serve no purpose when loaded with CNS stems since the crown material is out of their reach. Reconsidering some type of stem size reduction (i.e. bucking of 16 foot saw log from stem) might make CNS loads more feasible as it would reduce the overall length of the trees and bring the crowns within reach of the swinging gates. However, when the trimmed PWD loads were measured, more of the crowns (biomass material) were within reach of the swinging gates in the open position because the trees had shorter heights relative to the CNS trees (Figure 11b).


(a) (b)

Figure 11. Trimmed loads on modified trailer.

Modified trailer loads of timber after being trimmed to adhere with transportation laws: (a) CNS load and (b) PWD load.

A noticeable height difference between the first load and last two loads of PWD was observed. This can be explained by the changing site index over the location of harvest for the PWD. The trees for the first load were harvested from the upper portion of a slope near the peak of a ridge that divided two drainage basins, while the trees for the last two loads were harvested from the middle and lower portion of a slope closer to a riparian area. Site index often increases from the upper to middle portion of a slope and from the middle to the lower portion of a slope. The affect that site index played on the PWD loads was obvious in the length of overhang from the rear of the trailer, as well as the amount of biomass material retained by gates on the modified trailer. It is understood that an increased sample size would increase the reputability of the PWD load results, but the PWD loads are shown here only as a reference to the CNS loads to shed light on the advantage of choosing PWD loads for this method of transportation over CNS loads.

Although there was no statistically significant difference between the PWD and CNS loads (Table 10), other points of consideration can show that other significant differences exist between transporting these two product class loads and that hauling PWD loads instead of CNS loads could be more efficient. Despite the differences between the first and last two PWD loads, an average biomass gain of 7,880 pounds was still measured. This is only 0.92 tons short of the average biomass gain in CNS loads. Analysis showed that the amount of biomass lost from trimming a load is a statistically significant amount and PWD loads averaged 2 percent less material trimmed from each load when compared to the CNS loads. Considering this along with the fact that the modified trailer yields an average of 14 percent of a whole tree load in gained biomass, a higher proportion of the whole tree weight is transported to the depot with PWD loads than with CNS loads.

A comparison of transporting the two product classes is given as follows. If, for instance, in one day a logger can produce 5 unprocessed loads based on the PWD and CNS averages reported, that logger will deliver 19 percent less biomass to the depot but trim 60 percent less material when hauling PWD loads (compared to CNS loads). The ratio of biomass delivered to biomass trimmed for PWD loads at the end of the day is two times greater compared to CNS loads (9.8 PWD, 4.8 CNS). Also, the lower trimmed PWD net load weights (56,000 pounds PWD, 67,000 pounds CNS) leaves more of the unutilized allowable gross weight to be allocated to the weight of the truck and trailer (i.e. less chance of exceeding gross vehicle weight limit). If the goal of the depot is to capture as much biomass as possible, PWD loads are better suited to meet that goal as they will have less biomass lost to trimming. However, more loads to the mill will be required to get that material there.

4.3.2 Axle Grouping Weights

Tandem axle weights (n = 9) for the truck and trailer were examined with respect to the variables of unprocessed (i.e. untrimmed) load, trimmed load, and processed load. All sample, regardless of product class, were used for this analysis because of the lack of statistical significance between CNS and PWD load weight differences. The tandem axle weights for the truck averaged 35,802 pounds (± 2,892, 95% CI), 35,913 pounds (± 2,753, 95% CI), and 38,853 pounds (± 2,698, 95% CI) for the untrimmed, trimmed, and processed loads, respectively (Figure 12). The tandem axle weights for the modified trailer averaged 54,180 pounds (± 4,419, 95% CI), 52,500 pounds (± 4,152, 95% CI), and 40,327 pounds (± 2,953, 95% CI) for the untrimmed, trimmed and processed loads, respectively.

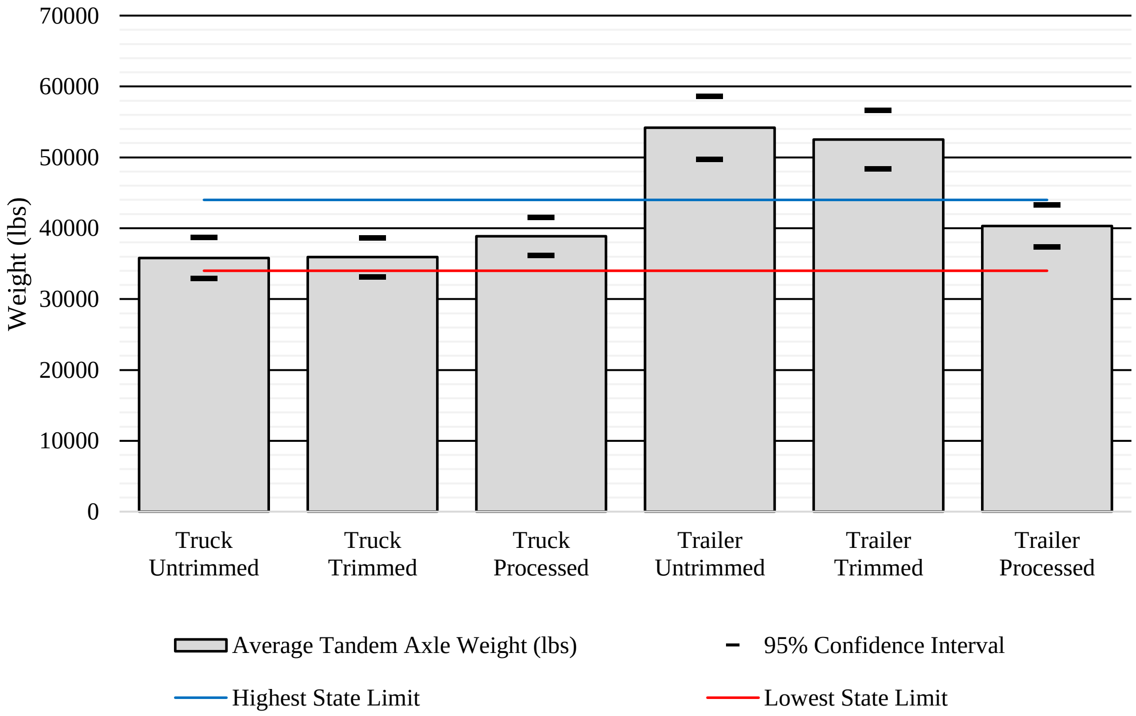


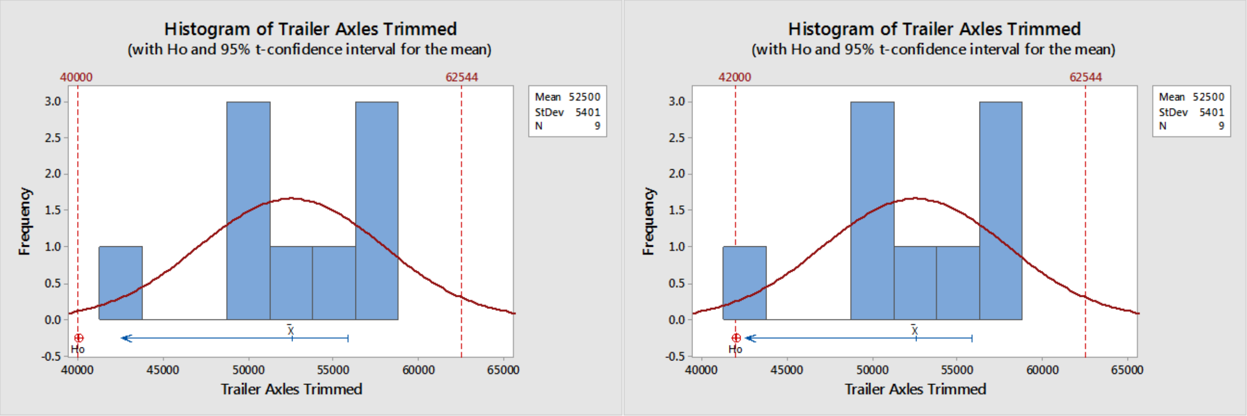
Figure 12. Average tandem axle weights.

Average tandem axle weights for the log trucks drive axles (left 3 columns) and the modified trailer axles (right 3 columns) when loaded with an untrimmed, trimmed, and processed to a merchantable top load of timber. Highest State Limit: Florida, 44,000 lbs. and Lowest State Limit: Various States, 34,000 lbs.

The results indicate that the average tandem axle weights for the untrimmed and trimmed trailer exceed the tandem axle weight limit for all states listed in Table 2. Since the trimmed load is the one of most concern (i.e. the one that would be transported to the timber processing depot), it is evident that this method of transportation is not feasible and changes are needed for the method to be legal according to state regulations and remain a feasible one for the timber processing depot. Options include reducing the number of trees from the load, lobbying for increased gross vehicle and tandem axle weight limits, or investigating the potential of adding a third axle to the trailer to increase its payload potential.

The idea of converting the modified trailer from a tandem axle configuration to a tridem axle (three axle) is promising. Many states increase the load weight limit for tridem axle semi-trucks and trailers (Table 2), meaning that the average trimmed load weight that is overloaded on a tandem axle trailer might be brought into adherence with transportation laws on a tridem axle trailer. An analysis conducted on tandem and tridem axle weight limits using the trimmed trailer axle weights compares the potential for this method in the states of Alabama and Georgia. One assumption taken for this analysis is that the trimmed loaded weights measured in the project have a normal distribution about the mean.

In Alabama, the percentage of the trailer tandem axle distribution (μ = 52,500 lbs.) that falls below the state limit of 40,000 pounds was found to be 2 percent for the trimmed load (Figure 13a). However, when those same averages are analyzed against the state’s tridem axle weight limit, the percentage of the trimmed load distribution that falls below the state limit of 42,000 pounds was found to be 4 percent (Figure 13b). The red dashed line indicating 62,544 pounds serves as a reference to show the point where 95 percent of the distribution is found. The histogram plots with distribution curves for the truck and trailer untrimmed, trimmed, and processed tandem and tridem axle weight analysis can be found in Appendix 4. The analysis shows that even with the increase in weight limit afforded by the additional axle, the percentage of the distribution that falls below the legal weight limit only increase by 2 percent. This method seems to be unfeasible in the state of Alabama unless regulations are changed to increase the tridem axle weight limit from 42,000 pounds.

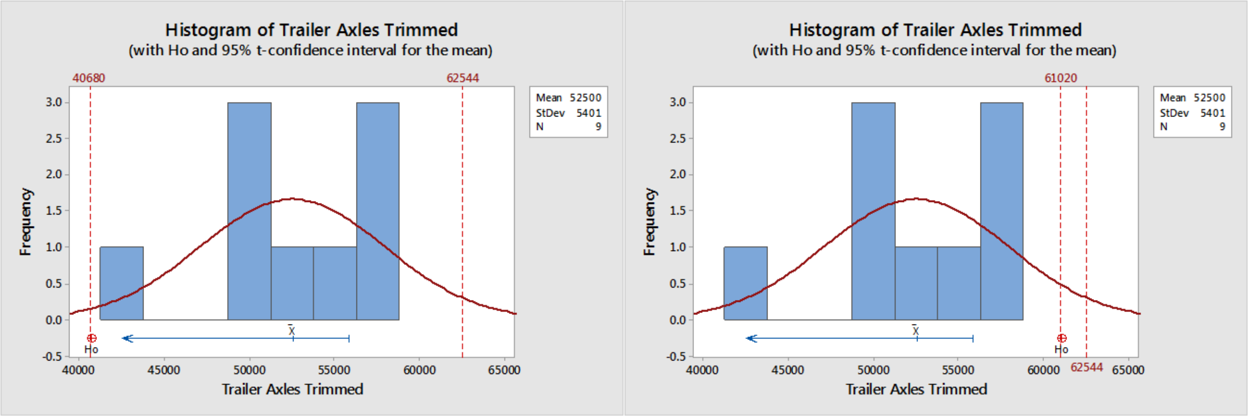


(a) **(b)**

Figure 13. Axle weight comparison for the state of Alabama.

Distribution of load weights measured for trimmed loads on the modified trailer (μ = 52,500 lbs.) compared against the legal axle grouping weight limit in the state of Alabama for: (a) tandem axle and (b) tridem axle.

In Georgia, the percentage of the trailer tandem axle distribution (μ = 52,500 lbs.) that falls below the state limit of 40,680 pounds was found to be 3 percent for the trimmed loads (Figure 14a). However, when those same averages are analyzed against the state's tridem axle weight limit, the percentages of the trimmed load distribution that falls below the state limit of 61,050 pounds was found to be 92 percent (Figure 14b). The red dashed line indicating 62,544 pounds serves as a reference to show the point where 95 percent of the distribution is found. The histogram plots with distribution curves for the truck and trailer untrimmed, trimmed, and processed tandem and tridem axle weight analysis can be found in Appendix 5. This analysis shows that the increase in the weight limit afforded by the additional axle increases the percentage of the distribution that falls below the legal weight limit by 89 percent. Therefore, this method seems to be more feasible in the state of Georgia, along with other states that have a large legal weight limit for tridem axles.



(a) **(b)**

Figure 14. Axle weight comparison for the state of Georgia.

Distribution of load weights measured for trimmed loads on the modified trailer (μ = 52,500 lbs.) compared against the legal axle grouping weight limit in the state of Alabama for: (a) tandem axle and (b) tridem axle.

The feasibility of the modified trailer method of transportation seems unlikely as long as the current trailer with tandem axles is considered for the timber processing depot delivery system. However, in states such as Georgia, Florida, and Arkansas where the tridem axle weight limit is much greater than the tandem axle weight limit, the modified trailer method is much more likely to be feasible.

4.3.3 Anecdotal Observations

During the trial load testing phase of this project, many anecdotal observations were made that are believed to have a significant impact on the success of this method of transportation. These observations are presented chronologically from the time the modified trailer loading began until the time the gates were fastened in the open position and the load was trimmed and ready to be transported.

One of the first observations noted was that trees skidded to the landing had broken limbs and missing foliage (Figure 16). Therefore, an unknown percentage of biomass material will be unrecovered by the modified trailer method. Although the focus of this project was on the design of the modified trailer, the data was available to draw conclusions regarding the topic of complete biomass removal from the harvested stand. Two assumptions were made to calculate the results reported, and all results concerning unrecovered biomass reported here are contingent on those assumption holding true. The first assumption made was that the average difference in weight between the measured load of stems processed to a merchantable top and the calculated combined weight of the same trees processed to a 6-inch top would also exist between the measured load of unprocessed trees and the calculated combined weight of the same whole trees. The second assumption was that the knuckleboom loader operator processed each stem to a 6-inch top so that the measured load weight of stems processed to a merchantable top was as close as possible to the weights calculated for stems processed to a 6-inch top using the Georgia forest research paper (Clark and Saucier, 1990).

The data indicates that an average of 7 percent (green weight) of the measured standing CNS trees loaded together was lost between the time the trees were felled and loaded (Figure 15). It confirms what was observed during the trial load testing when trees were skidded to the landing with obvious portions of the crowns already broken off and missing (Figure 16). This further indicates that during the process of a biomass harvest where unprocessed whole trees are delivered to the timber processing depot, the harvested stand will not be left completely barren of residual biomass material that are necessary for and an important part of nutrient recycling. It can be expected from these results that approximately 7 percent (±3%, 95% CI) of the standing whole tree weight of all trees in the stand, in addition to the 3 percent (±2%, 95% CI) removed from trimming, will go unrecovered and will be available for nutrient recycling (Table 12).

It is understood that there are no guarantees as to the accuracy of the results stated above and only a new study focusing specifically on the amount of unrecovered biomass left in a stand will accurately estimate the answer to this question. However, the 7 percent loss reported above is only half the loss which was estimated by Stokes and Watson (1991). Differences between the 7 percent loss stated here and the 16 percent reported by Watson and Stokes could be attributed to the harvest of different species of southern yellow pine at different age and product classes.

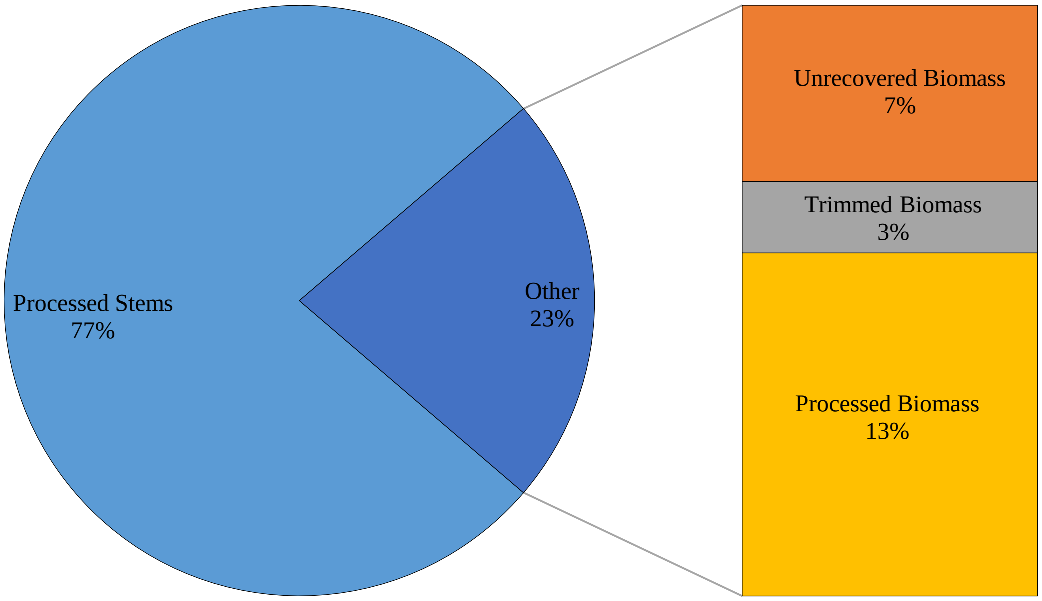


Figure 15. Whole tree weight percentage.

Percentages of average combined calculated whole tree weights for a single load based on the product category that percentage of material ended up as.

Table 12. Average weight and percentage of combined calculated whole tree weights.

	Average Weight	95% CI	Average Percentage	95% CI
Unrecovered Biomass	5000	3206	7%	3%
Trimmed Biomass	2020	1529	3%	2%
Processed Biomass	9727	1961	13%	2%
Processed Stems	57503	3106	78%	2%

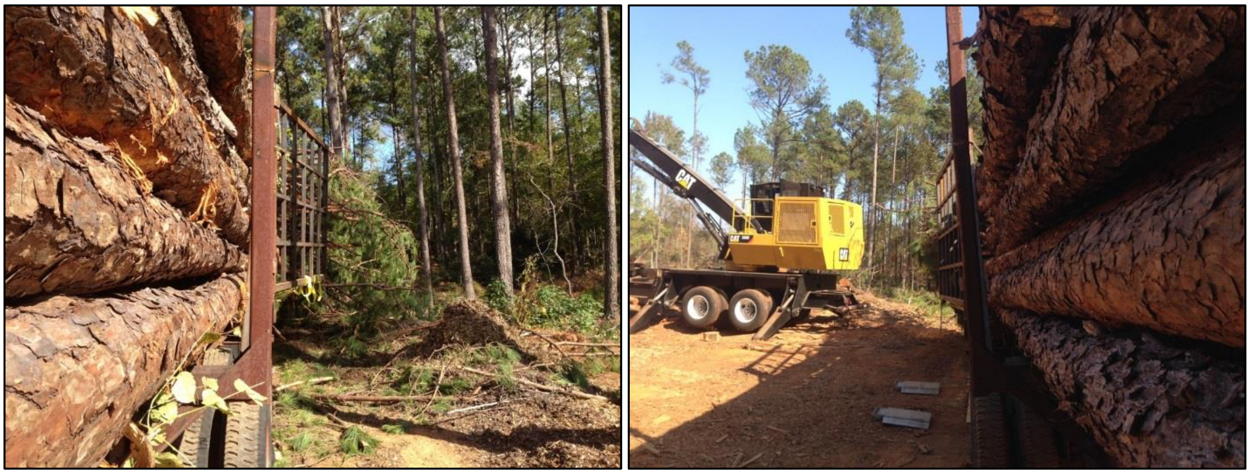

(a) **(b)**

Figure 16. Biomass loss from felling and skidding.

Felled and unprocessed trees skidded to the landing displaying the amount of crown material (biomass) that is lost between the time the tree is felled and when it is loaded onto the modified trailer. Most biomass loss can be attributed to the skidding process, where material is broken off as it slides over the ground and comes into contact with other objects.

Another observation noted was the difficulty the loader operator experienced while trying to load the unprocessed trees onto the modified trailer. When the gate on the far side of the trailer from the knuckleboom loader was fully closed, the operator had trouble using the standards on the bunks to leverage the stem of the tree into the position where he wanted it on the trailer. The same issue occurred when the gate on the near side of the trailer to the loader was fully opened. Also, loading the first three to four trees onto the trailer was cumbersome because the crown of the tree being loaded by the knuckleboom loader would catch the crowns of the trees already on the trailer and slide their stems toward the cab of the truck. This presents a danger to any log truck that does not have a headache rack to prevent the butt end of loaded stems from puncturing the cab. A solution to this problem might be a small steel plate welded to the front of the trailer on a horizontal axis that spans the width of the trailer and acts as a barrier to catch the butts of the trees and prevent them from sliding forward into the cab of the log truck.

One of the biggest issues with the swinging gate method that was not realized during the design process was the difficulty in setting the gates to the fully open position once the trailer was loaded. The limbs protruding from the load were very inflexible and prevented setting the gates at the 102-inch width required by law. Figure 17a shows an example of the gate opened as far as possible under human strength. Even after binding the gates together with ratchet straps, the gates were never set to the 102-inch mark.



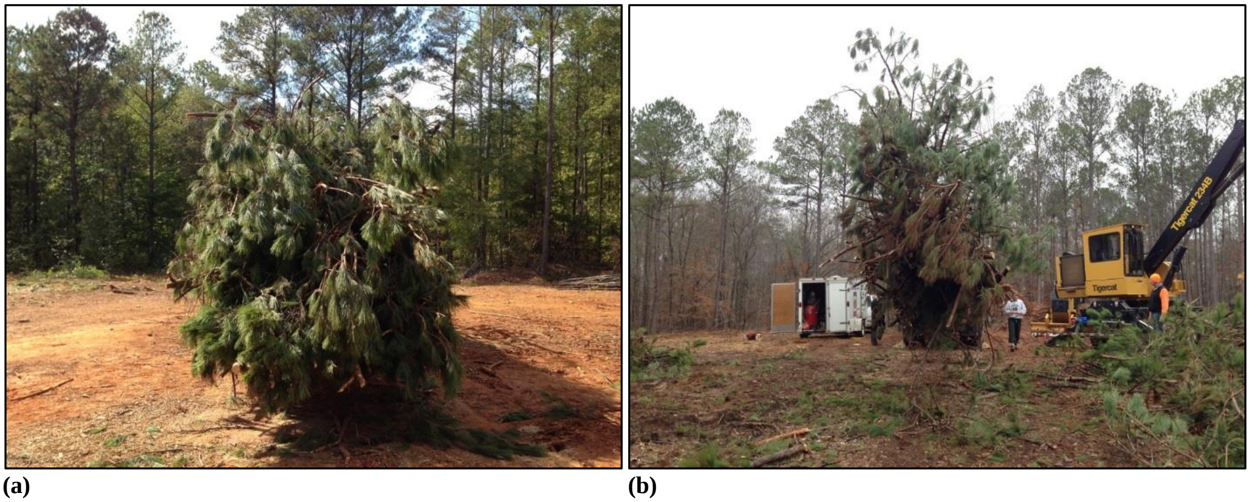
(a) **(b)**

Figure 17. Issues with opening the swinging gates.

View of swinging gate: (a) opened as far as possible but prevented from reaching 102 inch width limit by protruding limbs, as seen from the left plane of the trailer and (b) opened as far as possible but prevented from reaching the 102 inch width limit by stems forced outside of the plane of the trailer by other stems, as seen from the right plane of the trailer.

Setting the gates fully open presented an even larger problem for some of the loads. Depending on how the trees were stacked on the trailer by the knuckleboom loader, portions of some stems extending from the rear of the trailer were bent, due to their flexibility, and forced outside of the 102-inch limit (Figure 17b). In these cases, it was impossible to set the gates fully open at the legal width limit without unloading and then repositioning the stem on the trailer with the loader.

One solution to the problem of setting the gates to the required 102-inch width would lie in redesigning the modification to allow it to be preset to the 102-inch width before trees were loaded. Having the modification preset at the legal width limit and keeping it rigid and inflexible during the loading process would force the limbs and crown material to be funneled into the preset dimension. Another potential solution would be to redesign the modification to include a hydraulic closing and opening system that would be strong enough to bend the limbs and force the gates to reach the 102-inch width. However, this idea would add additional weight to the trailer thereby reducing the available payload capacity. It would also require additional capital as well as presenting a more challenging task when the gates need to be removed from or added to the trailer. There is also the potential for the limbs to puncture the hydraulic lines potentially rendering the entire modification and trailer out of service.



(a) **(b)**

Figure 18. Loaded modified trailer as seen from behind.

View of the rear end of the modified trailer loaded with unprocessed timber that has been trimmed to adhere with transportation regulations.

Another issue involved is the visibility of trailer lights. Even after trimming the load, the foliage and limbs covered up the bumper of the trailer where the tail lights are located (Figure 18). One solution to this problem might lie in attaching lights to the back end of the gates so that they are visible to traffic behind the modified trailer when the gates are in the open position. This would require wiring the lights through the trailer and modification. Wiring would be vulnerable to being severed if ran through the modification, especially at the point where the wiring is exposed and transitions from the trailer into the gate. However, the gates still cannot be seen in Figure 18 which indicates that there is still the potential that lights attached to the back of the gates may not be visible to traffic behind the modified trailer. In this case, loose tail lights connected to a spool of wiring may need to be attached to the stems of individual trees on the end of the load, much like the tail lights used by tow trucks which are magnetically attached to the trunks of cars they are towing.

Another observation was the amount of overhang from the rear of the trailer as a result of the large size of the CNS trees and the resulting amount of necessary trimming for the load to meet transportation regulations. CNS loads had average heights ranging from 69 feet to 73 feet, while the modified trailer is 39 feet long when the gates are closed. The excessive overhang led to a large amount of crown material, and even some stems themselves, coming into contact with the ground. This required additional trimming work to prevent the load from contacting the ground. The trimming of crowns from the sides of the load as well as underneath took roughly 20 to 40 minutes per load to trim with two people working simultaneously using a chainsaw and a pole saw while others worked to remove limbs that were underfoot of the sawyers which had been cut from the load. The amount of additional trimming required due to the excess crown material that extended beyond the modification raises a legitimate safety concern for this method. It will require additional trimming in dangerous places such as under the load to meet transportation regulations. A redesign of the modification could develop a method to support the stems that overhang from the trailer and lift them up to prevent contact with the ground. Another solution would be to sacrifice some of the processing at the depot and allow loggers to remove a portion of the stem as a butt log to shorten the residual stem that would be loaded unprocessed and transported to the depot. This would bring more of the crown and biomass material within reach of the gates thereby reducing the overhang and the amount of trimming. Otherwise, we anticipate that PWD size trees might be a more efficient and effective product class for this method because of the shorter tree height that brings the crowns into contact with the gates as well as the reduction in the average amount of material that needs to be trimmed from each PWD load.

V. Conclusion

5.1 Conclusion

A project to develop a new method of delivering unprocessed timber to a timber processing depot was designed, and trial load testing was conducted. Two modifications were designed that could be easily attached to an existing standard double bunk log trailer. The swinging gate design has two large gates with a cross-hatched inner section that rotate from a closed position where the gates are located between the standards of the two rear bunks to an open position extending directly beyond the back of the trailer. These two gates capture the limbs needed for biomass energy production, thereby reducing the amount of limbs that need to be trimmed off to adhere to transportation laws. This effectively increases the availability and supply of woody biomass feedstock material. The extendable bolster design has an additional bolster and two standards that slide out from the rear of the trailer and pull a cross-hatched chain net taut to capture the limbs. The bolster on the sliding rail system also supports the additional weight of the stems and biomass material hanging off of the back of the modified trailer and reduces the amount of trimming needed to prevent contact between the ground and the tree crowns. The limbs captured by this design also increase the availability and supply of woody biomass feedstock material.

A log trailer donated to the researchers designing and studying this new method was used in the trial loading tests. The swinging gate design was selected over the extendable bolster design because it is less expensive, weighed less, and there were no issues concerning the forces acting on the modified trailer compromising the structural integrity of the modification and the trailer. The gates actually constructed for the trailer weighed 558 pounds each, and generated a moment force of 2,798 foot pounds of force on the standards that support the gates. The standards are capable of withstanding a moment force of 33,986 foot pounds of force.

Six loads of chip and saw sized loblolly pine timber were felled and loaded onto the modified trailer. The loads averaged 57,503 pounds (83%) of processed timber (weight to a merchantable top, excluding all biomass material). To adhere to transportation regulations, 2,020 pounds (3%) of limbs were trimmed from the load, leaving 9,727 pounds (14%) of limbs for biomass material available to the timber processing depot. Three loads of pulpwood sized timber were also felled and loaded onto the modified trailer. The loads averaged 48,873 pounds (85%) of processed timber (weight to a merchantable top, excluding all biomass material). To adhere to transportation regulations 807 pounds (1%) of limbs were trimmed from the load, leaving 7,880 pounds (14%) of limbs for biomass material available to the timber processing depot. Statistical testing ($\alpha = 0.05$) indicated that there was no significant difference between the distributions of CNS loads and the PWD load for either the trimmed or processed biomass quantities measured.

Analysis on the tandem axles of the truck and trailer show that the method is unfeasible due to overloaded tandem axle. Distributions of the samples weighed in this study for the the trimmed load of timber ($\mu = 52{,}500$ pounds) on the tandem axles of the trailer were created. Comparisons of the distributions against the tandem axle limits of Alabama (40,000 pounds) and Georgia (40,680 pounds) showed that 2 percent and 3 percent of the distributions fell below the legal weight limits. However, if the trailers were outfitted with a third axle, the weight limit allowed on the set of axles would increase and potentially allow the trailer to fall below the legal limit. Comparisons of the same distributions against the tridem axle limits of Alabama (42,000 pounds) and Georgia (61,020 pounds) show that 4 percent and 92 percent of the distributions fell below the legal weight limits. Therefore, the feasibility of this method of transportation will depend on the state in which it is utilized, with the biggest factor being the legal weight limit for the axle groupings.

Anecdotal observations noted during this project highlighted that number of crowns skidded to the landing with broken tops and missing biomass material. The trees harvested for the six loads of chip and saw timber were also measured prior to being harvested for a calculation of the whole tree green weight. The weights of the unprocessed loads of timber were subtracted from the calculated combined whole tree weight for the same trees. Approximately 7 percent (green weight) on average of the standing trees loaded together was lost between the time the trees were felled and loaded. This confirmed the notion that a timber harvest hauling unprocessed trees to the timber processing depot would not effectively remove all of the biomass material available from the stand.

Another observation noted during this project was the difficulties of loading the modified trailer with unprocessed timber. Specifically, the difficulty of placing timber onto the trailer because of the position of the swinging gates. Additionally, there is a need for a device to prevent trees loaded on the trailer from sliding forward into the cab of the log truck when their crowns become entangled by the crown of another tree being place onto the trailer. Another observation noted was the difficulty experienced in swinging the gates into the open position to meet the 102-inch width limit because of the inflexibility of the protruding limbs and the resulting forces acting against the swinging gate. Suggested solutions to this problem were developing a way to lock the gates in the open position at the 102-inch width before the trees are loaded as well as designing a hydraulic closing and opening system strong enough to force the gates to reach the 102-inch width. Finally, it was observed that the dense foliage and crowns of the trimmed but unprocessed timber extending from the rear of the trailer blocked the view of the tail lights on the trailer. A solution was to attach lights to the back of the gates so they could be seen in the open position.

The feasibility of the transporting a load of unprocessed CNS timber using a trailer modified with swinging gates seems unlikely based on facts such as the excessive amount of trimming required and the problems associated with the large height of the trees loaded onto a relatively short trailer. However, transporting PWD timber seems more feasibility based on the facts that less trimming was required, there were less problems associated with the size of the timber relative to the trailer length, and more biomass can be delivered to the depot relative to the amount trimmed off. Although, it is likely that a third axle be added to the trailer to bring the load weight into adherence with transportation laws. Delivering PWD sized loblolly pine trees to the timber processing depot using the modified trailer method described here has the potential to increase the amount of biomass available to the timber processing depot, thereby increasing the supply woody biomass feedstock needed to supplement the country’s fossil fuel energy production.

References

Abbasi, S.A., and N. Abbasi. 2000. The likely adverse environmental impacts of renewable energy sources. Applied Energy 65(1–4): 121–144.

Angus-Hankin, C., B. Stokes, and A. Twaddle. 1995. The Transportation of Fuelwood from Forest to Facility. Biomass and Bioenergy 9(1–5): 191–203.

Asif, M., and T. Muneer. 2007. Energy supply, its demand and security issues for developed and emerging economies. Renewable and Sustainable Energy Reviews 11(7): 1388–1413.

Barlev, D., R. Vidu, and P. Stroeve. 2011. Innovation in concentrated solar power. Solar Energy Materials and Solar Cells 95(10): 2703–2725.

British Petroleum. 2016. BP Statistical Review of World Energy 2016. London, England, UK.

Cai, X., X. Zhang, and D. Wang. 2011. Land Availability for Biofuel Production. Environ. Sci. Technol. 45(1): 334–339.

do Canto, J.L., J. Klepac, B. Rummer, P. Savoie, and F. Seixas. 2011. Evaluation of two round baling systems for harvesting understory biomass. Biomass and Bioenergy 35(5): 2163–2170.

Caputo, A.C., M. Palumbo, P.M. Pelagagge, and F. Scacchia. 2005. Economics of biomass energy utilization in combustion and gasification plants: effects of logistic variables. Biomass and Bioenergy 28(1): 35–51.

Clark, A.I., and J.R. Saucier. 1990. Tables for estimating total-tree weights, stem weights, and volumes of planted and natural southern pines in the Southeast. Georgia Forest Research Paper 79 (USA)

Daniels, F., and Duffie. 1955. Solar energy research. Available at https://www.osti.gov/scitech/biblio/5053840 (verified 8 February 2017).

Dauble, D.D., T.P. Hanrahan, D.R. Geist, and M.J. Parsley. 2003. Impacts of the Columbia River Hydroelectric System on Main-Stem Habitats of Fall Chinook Salmon. North American Journal of Fisheries Management 23(3): 641–659.

Demirbaş, A. 2001. Biomass resource facilities and biomass conversion processing for fuels and chemicals. Energy Conversion and Management 42(11): 1357–1378.

Dickmann, D.I. 2006. Silviculture and biology of short-rotation woody crops in temperate regions: Then and now. Biomass and Bioenergy 30(8–9): 696–705.

Dincer, I. 2000. Renewable energy and sustainable development: a crucial review. Renewable and Sustainable Energy Reviews 4(2): 157–175.

Drew, A.P., L. Zsuffa, and C.P. Mitchell. 1987. Terminology Relating to Woody Plant Biomass and its Production. Biomass 12(1): 79–82.Fridleifsson, I.B. 2001. Geothermal energy for the benefit of the people. Renewable and Sustainable Energy Reviews 5(3): 299–312.

Fridley, J.L., and T.H. Burkhardt. 1984. Densifying forest biomass into large round bales. Transactions of the ASAE 27(5): 1277–1281.

Fthenakis, V., J.E. Mason, and K. Zweibel. 2009. The technical, geographical, and economic feasibility for solar energy to supply the energy needs of the US. Energy Policy 37(2): 387–399.

Galik, C.S., R. Abt, and Y. Wu. 2009. Forest Biomass Supply in the Southeastern United States—Implications for Industrial Roundwood and Bioenergy Production. Journal of Forestry 107(2): 69–77.
Guo, M., W. Song, and J. Buhain. 2015. Bioenergy and biofuels: History, status, and perspective. Renewable and Sustainable Energy Reviews 42: 712–725.

Haberl, H., T. Beringer, S.C. Bhattacharya, K.-H. Erb, and M. Hoogwijk. 2010. The global technical potential of bio-energy in 2050 considering sustainability constraints. Current Opinion in Environmental Sustainability 2(5–6): 394–403.

Huttrer, G.W. 2001. The status of world geothermal power generation 1995–2000. Geothermics 30(1): 1–27.

Kaldellis, J.K., and D. Zafirakis. 2011. The wind energy (r)evolution: A short review of a long history. Renewable Energy 36(7): 1887–1901.

Kestin, J., R. DiPippo, H.E. Khalifa, and D.J. (eds) Ryley. 1980. Sourcebook on the Production of Electricity from Geothermal Energy. Brown Univ., Providence, RI (USA).

Klepac, J., and B.; Rummer. 2010. Harvesting understory biomass with a baler. p. 6–9.

Langholtz, M.H., B.J. Stokes, and L.M.; Eaton. 2016. 2016 Billion-ton report: Advancing domestic resources for a thriving bioeconomy, Volume 1: Economic availability of feedstock.

McKendry, P. 2002. Energy production from biomass (part 1): overview of biomass. Bioresource Technology 83(1): 37–46.

McKinney, M.L., and R.M. Schoch. 2003. Environmental Science: Systems and Solutions. Jones & Bartlett Learning.

Mitchell, D. 2009. Bundling Logging Residues with a Modified John Deere B-380 Slash Bundler. p. 58–63. *In* Woody Biomass Utilization Conference Preceedings. Forest Products Society.

Muehlenfeld, K. 2003. Assessment of wood-based syngas potentialfor use in combined cycle power plants in Alabama: A guide for economic development opportunities.

Nurmi, J. 2007. Recovery of logging residues for energy from spruce (Pices abies) dominated stands. Biomass and Bioenergy 31(6): 375–380.

Nyland, R.D. 1996. Silviculture: concepts and applications. The McGraw Hill Companies, Inc., New York, N.Y.

Oswalt, S.N., W.B. Smith, P.D. Miles, and S.A.; Pugh. 2014. Forest Resources of the United States, 2012: a technical document supporting the Forest Service 2010 update of the RPA Assessment.

Panwar, N.L., S.C. Kaushik, and S. Kothari. 2011. Role of renewable energy sources in environmental protection: A review. Renewable and Sustainable Energy Reviews 15(3): 1513–1524.

Perlack, R.D., L.L. Wright, A.F. Turhollow, R.L. Graham, B.J. Stokes, and D.C. Erbach. 2005. Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply. Oak Ridge National Laboratory, Oak Ridge, TN.

Peterson, C.L., and T. Hustrulid. 1998. Carbon Cycle for Rapseed Oil Biodiesel Fuels. Biomass and Bioenergy 14(2): 91–101.

Radics, K., and J. Bartholy. 2008. Estimating and modelling the wind resource of Hungary. Renewable and Sustainable Energy Reviews 12(3): 874–882.

Ranta, T., and S. Rinne. 2006. The profitability of transporting uncomminuted raw materials in Finland. Biomass and Bioenergy 30(3): 231–237.

Rathore, N.S., and N.L. Panwar. 2007. Renewable Energy Sources for Sustainable Development. New India Publishing.

Rosenberg, D., R.A. Bodaly, and P.J. Usher. 1995. Environmental and social impacts of large scale hydroelectric development: who is listening? Global Environmental Change 5(2): 127–148.

Sato, M. 1990. Thermochemistry of the formation of fossil fuels. Fluid-Mineral Interactions: A Tribute to HP Eugster: 271–283.

Scheuter, F. 2008. General guide for accurate weighing with portable wheel load scales.

Schlamadinger, B., and G. Marland. 1996. The role of forest and bioenergy strategies in the global carbon cycle. Biomass and Bioenergy 10(5): 275–300.

Scott, D.A., and A. Tiarks. 2008. Dual-Cropping Loblolly Pine for Biomass Energy and Conventional Wood Products. Southern Journal of Applied Forestry 32(1): 33–37.Shafiee, S., and E. Topal. 2009. When will fossil fuel reserves be diminished? Energy Policy 37(1): 181–189.

Sims, R.E.H., H.-H. Rogner, and K. Gregory. 2003. Carbon emission and mitigation cost comparisons between fossil fuel, nuclear and renewable energy resources for electricity generation. Energy Policy 31(13): 1315–1326.

Smith, A.H.V. 1997. Provenance of Coals from Roman Sites in England and Wales. Britannia 28: 297–324.

Stokes, B.J., and W. Watson. 1991. Wood Recovery with In-Woods Flailing and Chipping. Tappi Journal 74(9).

Stewart, G.B., A.S. Pullin, and C.F. Coles. 2005. Effects of Wind Turbines on Bird Abundance.

Thompson, J., J. Klepac, and D. Mitchell. 2015. Loading productivity of untrimmed and trimmed pulpwood. p. 31–36.

Thompson, J., J. Klepac, and D. Mitchell. 2015. Loading productivity of untrimmed and trimmed pulpwood. p. 31–36.

Thompson, J., D. Mitchell, and J.; Klepac. 2014. Advantages and disadvantages of untrimmed wood in the supply chain.

Tuskan, G.A. 1998. Short-rotation woody crop supply systems in the United States: what do we know and what do we need to know? Biomass and Bioenergy 14(4): 307–315.

U.S. Department of Energy. 2016. How Fossil Fuels Were Formed. U.S. Department of EnergyAvailable at http://www.fe.doe.gov/education/energylessons/coal/gen_howformed.html (verified 2 August 2016).

U.S. Energy Information Administration. 2016a. How much carbon dioxide is produced per kilowatthour when generating electricity with fossil fuels? Frequently Asked QuestionsAvailable at https://www.eia.gov/tools/faqs/faq.cfm?id=74&t=11 (verified 10 August 2016).

U.S. Energy Information Administration. 2016b. April 2016 Monthly Energy Review.

U.S. Energy Information Administration. 2016c. International Energy Outlook 2016.

Watson, W., and B.J. Stokes. 1987. Review of whole-tree harvesting systems in the southern United States. *In* Proceedings of an A-1 Technical Group Meeting. IEA/Bioenergy Project A-1 Report No. 3, Vancouver, Canada.

Wright, L.L. 1994. Production technology status of woody and herbaceous crops. Biomass and Bioenergy 6(3): 191–209.

Appendix

	Load 1 Measured Trees						Green Weight (Tons)	
	Tree	DBH	Total Height	HLC	LCR	BA	Whole Tree	6 Inch Top
	0	11.1	67.32	40.26	40.2%	0.67	1331	1002
	1	10.9	62.04	34.32	44.7%	0.65	1183	879
	2	9.7	60.72	37.62	38.0%	0.51	917	619
	3	10.8	58.74	35.64	39.3%	0.64	1100	811
	4	10.5	64.02	36.96	42.3%	0.60	1133	821
	5	10.2	73.26	53.46	27.0%	0.57	1223	868
	6	9.6	71.28	42.90	39.8%	0.50	1055	706
	7	10.8	76.56	53.46	30.2%	0.64	1433	1063
	8	10.0	80.52	60.72	24.6%	0.55	1292	903
	9	11.8	78.54	54.78	30.3%	0.76	1755	1369
	10	9.5	70.62	45.54	35.5%	0.49	1023	677
	11	9.5	73.92	46.20	37.5%	0.49	1071	709
	12	11.0	66.66	38.94	41.6%	0.66	1295	969
	13	11.0	67.98	52.14	23.3%	0.66	1320	988
	14	12.0	72.6	43.56	40.0%	0.79	1678	1316
	15	11.3	71.94	39.60	45.0%	0.70	1474	1123
	16	13.3	68.64	40.92	40.4%	0.96	1949	1586
	17	13.4	81.18	46.20	43.1%	0.98	2339	1914
	18	11.8	65.34	42.24	35.4%	0.76	1460	1135
	19	13.1	71.94	45.54	36.7%	0.94	1981	1606
	20	10.5	65.34	40.26	38.4%	0.60	1156	838
	21	12.7	74.58	46.20	38.1%	0.88	1930	1550
	22	12.0	79.86	46.86	41.3%	0.79	1846	1451
	23	10.4	71.28	43.56	38.9%	0.59	1238	892
	24	10.4	74.58	49.50	33.6%	0.59	1295	934
	25	10.3	71.94	50.16	30.3%	0.58	1225	876
	26	13.7	70.62	36.96	47.7%	1.02	2127	1747
	27	10.5	79.2	52.80	33.3%	0.60	1402	1019
	28	10.7	70.62	46.86	33.6%	0.62	1298	955
	29	10.8	66.66	40.26	39.6%	0.64	1248	923
	30	11.5	78.54	54.78	30.3%	0.72	1667	1284
	31	10.7	76.56	53.46	30.2%	0.62	1407	1037
	32	12.6	77.88	47.52	39.0%	0.87	1984	1590
	33	12.4	82.5	57.42	30.4%	0.84	2036	1623
	34	12.7	68.64	36.30	47.1%	0.88	1777	1424
	35	11.9	77.88	49.50	36.4%	0.77	1770	1385
	36	10.1	70.62	45.54	35.5%	0.56	1156	813
	37	14.2	84.48	52.80	37.5%	1.10	2733	2273
	38	11.5	84.48	56.76	32.8%	0.72	1793	1383
	39	13.3	69.3	35.64	48.6%	0.96	1967	1601
	40	12.6	77.88	50.16	35.6%	0.87	1984	1590
	41	12.9	87.78	52.80	39.8%	0.91	2344	1898
	42	13.0	79.86	46.20	42.1%	0.92	2166	1755
	43	13.3	77.88	52.80	32.2%	0.96	2211	1804
	44	12.0	77.88	55.44	28.8%	0.79	1800	1414
	45	11.8	69.96	54.12	22.6%	0.76	1563	1216
	46	13.8	78.54	47.52	39.5%	1.04	2400	1979
	47	12.2	75.9	45.54	40.0%	0.81	1813	1434
	48	9.6	67.98	48.84	28.2%	0.50	1006	673
	49	9.5	69.3	48.18	30.5%	0.49	1004	664
	50	11.0	71.94	39.60	45.0%	0.66	1397	1047
$\overline{x}$		11.5	73.22	46.58	36.5%	0.73	1583	1218
QMD		11.6						
Σ							80758	62134
Δ							18624	

Appendix 1 - 1. Load 1 Measured Trees.

		Load 2 Measured Trees					Green Weight (Tons)	
	Tree	DBH	Total Height	HLC	LCR	BA	Whole Tree	6 Inch Top
	1	9.5	63.36	43.56	31.3%	0.49	918	606
	2	13.4	69.3	36.30	47.6%	0.98	1997	1629
	3	11.4	72.6	47.52	34.5%	0.71	1514	1159
	4	13.7	69.96	47.52	32.1%	1.02	2107	1730
	5	10.3	64.68	46.20	28.6%	0.58	1102	786
	6	12.2	71.94	48.84	32.1%	0.81	1718	1358
	7	11.6	69.3	42.90	38.1%	0.73	1497	1155
	8	13.3	72.6	48.84	32.7%	0.96	2061	1679
	9	12.4	62.7	46.86	25.3%	0.84	1547	1227
	10	11.6	69.3	47.52	31.4%	0.73	1497	1155
	11	9.6	67.32	46.86	30.4%	0.50	996	666
	12	11.0	69.96	44.88	35.8%	0.66	1359	1018
	13	10.2	67.32	44.88	33.3%	0.57	1124	797
	14	10.4	67.98	41.58	38.8%	0.59	1180	850
	15	9.6	70.62	43.56	38.3%	0.50	1045	699
	16	11.8	71.94	53.46	25.7%	0.76	1608	1252
	17	11.5	75.24	47.52	36.8%	0.72	1597	1229
	18	13.1	71.28	47.52	33.3%	0.94	1963	1591
	19	11.2	67.32	50.82	24.5%	0.68	1355	1025
	20	10.9	67.98	50.16	26.2%	0.65	1296	965
	21	11.4	68.64	42.90	37.5%	0.71	1432	1094
	22	10.4	71.28	48.84	31.5%	0.59	1238	892
	23	10.7	73.26	44.88	38.7%	0.62	1346	991
	24	11.4	67.98	40.92	39.8%	0.71	1418	1084
	25	11.6	70.62	45.54	35.5%	0.73	1525	1177
	26	14.4	72.6	42.90	40.9%	1.13	2416	2009
	27	9.5	63.36	39.60	37.5%	0.49	918	606
	28	9.5	64.68	44.88	30.6%	0.49	937	619
	29	13.3	80.52	47.52	41.0%	0.96	2286	1866
	30	14.2	78.54	53.46	31.9%	1.10	2541	2110
	31	13.6	82.5	52.80	36.0%	1.01	2449	2013
	32	10.7	64.02	44.88	29.9%	0.62	1177	864
	33	13.8	69.3	42.90	38.1%	1.04	2118	1742
	34	10.4	60.72	34.98	42.4%	0.59	1054	757
	35	11.7	64.02	37.62	41.2%	0.75	1407	1088
	36	9.7	60.06	42.90	28.6%	0.51	907	612
	37	11.6	68.64	42.24	38.5%	0.73	1482	1143
	38	10.4	62.7	38.94	37.9%	0.59	1089	782
	39	11.8	68.64	42.90	37.5%	0.76	1534	1193
	40	9.8	51.48	38.28	25.6%	0.52	794	539
	41	11.6	64.68	42.90	33.7%	0.73	1397	1076
	42	11.5	64.02	40.92	36.1%	0.72	1359	1042
	43	13.7	65.34	39.60	39.4%	1.02	1968	1614
	44	14.5	78.54	50.82	35.3%	1.15	2650	2211
	45	9.5	68.64	51.48	25.0%	0.49	994	658
	46	13.0	81.84	56.76	30.6%	0.92	2220	1800
	47	12.0	66.66	52.14	21.8%	0.79	1541	1207
	48	9.9	77.22	54.78	29.1%	0.53	1215	840
	49	9.7	73.26	54.78	25.2%	0.51	1107	749
	50	13.3	79.2	52.80	33.3%	0.96	2248	1835
$\bar{x}$		11.5	69.31	45.88	33.7%	0.74	1525	1176
QMD		11.6						
Σ							76247	58786
Δ							17460	

Appendix 1 - 2. Load 2 Measured Trees.

	Load 3 Measured Trees						Green Weight (Tons)	
	Tree	DBH	Total Height	HLC	LCR	BA	Whole Tree	6 Inch Top
	1	11.0	71.28	48.84	31.5%	0.66	1384	1037
	2	9.7	69.3	46.86	32.4%	0.51	1047	708
	3	9.7	75.9	52.14	31.3%	0.51	1146	777
	4	11.3	76.56	54.12	29.3%	0.70	1569	1196
	5	9.6	78.54	52.80	32.8%	0.50	1162	779
	6	9.7	73.92	58.08	21.4%	0.51	1116	756
	7	13.6	73.26	46.86	36.0%	1.01	2174	1783
	8	12.8	73.92	42.90	42.0%	0.89	1944	1565
	9	13.4	73.26	48.84	33.3%	0.98	2111	1724
	10	11.0	71.94	48.84	32.1%	0.66	1397	1047
	11	11.6	73.26	42.90	41.4%	0.73	1582	1222
	12	11.7	70.62	53.46	24.3%	0.75	1552	1203
	13	11.9	73.92	46.20	37.5%	0.77	1680	1314
	14	12.1	76.56	48.18	37.1%	0.80	1799	1418
	15	11.8	71.28	50.16	29.6%	0.76	1593	1240
	16	13.6	73.26	49.50	32.4%	1.01	2174	1783
	17	12.7	71.94	43.56	39.4%	0.88	1862	1494
	18	11.3	67.32	46.20	31.4%	0.70	1380	1049
	19	12.8	67.98	48.18	29.1%	0.89	1788	1437
	20	11.2	69.3	46.20	33.3%	0.68	1395	1056
	21	10.7	71.94	48.84	32.1%	0.62	1322	973
	22	11.1	75.24	52.80	29.8%	0.67	1488	1122
	23	9.5	71.94	50.82	29.4%	0.49	1042	690
	24	9.5	75.24	44.22	41.2%	0.49	1090	722
	25	11.9	74.58	49.50	33.6%	0.77	1695	1326
	26	13.6	79.2	51.48	35.0%	1.01	2351	1931
	27	13.1	82.5	54.78	33.6%	0.94	2272	1847
	28	11.0	71.94	50.82	29.4%	0.66	1397	1047
	29	12.6	75.9	56.10	26.1%	0.87	1934	1549
	30	13.0	71.94	42.90	40.4%	0.92	1951	1578
	31	10.8	75.24	48.18	36.0%	0.64	1409	1044
	32	12.3	83.82	56.10	33.1%	0.83	2035	1618
	33	14.0	80.52	44.22	45.1%	1.07	2532	2097
	34	11.6	73.92	48.18	34.8%	0.73	1596	1233
	35	11.8	75.24	54.12	28.1%	0.76	1681	1310
	36	11.3	72.6	48.84	32.7%	0.70	1488	1133
	37	11.0	76.56	53.46	30.2%	0.66	1487	1116
	38	10.6	73.92	47.52	35.7%	0.61	1333	975
	39	11.4	72.6	45.54	37.3%	0.71	1514	1159
	40	12.7	74.58	45.54	38.9%	0.88	1930	1550
	41	10.3	64.68	46.20	28.6%	0.58	1102	786
	42	10.5	66	38.28	42.0%	0.60	1168	846
	43	10.4	63.36	50.82	19.8%	0.59	1100	791
	44	9.9	65.34	43.56	33.3%	0.53	1028	709
	45	10.8	69.96	50.82	27.4%	0.64	1310	969
	46	12.3	66.66	36.96	44.6%	0.83	1619	1281
	47	13.0	66.66	43.56	34.7%	0.92	1808	1460
	48	11.6	63.36	44.88	29.2%	0.73	1368	1054
	49	12.4	66.66	45.54	31.7%	0.84	1645	1306
	50	10.2	55.44	40.26	27.4%	0.57	926	654
$\bar{x}$		11.5	72.22	48.19	33.2%	0.74	1570	1209
QMD		11.6						
Σ							78479	60462
Δ							18016	

Appendix 1 - 3. Load 3 Measured Trees.

	Load 4 Measured Trees						Green Weight (Tons)	
	Tree	DBH	Total Height	HLC	LCR	BA	Whole Tree	6 Inch Top
	1	11.3	65.34	44.22	32.3%	0.70	1339	1018
	2	12.8	64.02	33.00	48.5%	0.89	1683	1351
	3	14.2	64.68	31.68	51.0%	1.10	2093	1731
	4	13.3	66	43.56	34.0%	0.96	1874	1524
	5	11.0	75.9	46.86	38.3%	0.66	1474	1106
	6	12.2	71.94	43.56	39.4%	0.81	1718	1358
	7	13.6	71.94	40.92	43.1%	1.01	2135	1751
	8	9.8	71.28	51.48	27.8%	0.52	1099	751
	9	14.0	66.66	46.20	30.7%	1.07	2097	1729
	10	9.5	67.32	48.84	27.5%	0.49	975	645
	11	12.8	72.6	48.84	32.7%	0.89	1909	1536
	12	10.4	72.6	44.22	39.1%	0.59	1260	908
	13	12.0	71.94	46.86	34.9%	0.79	1663	1304
	14	14.4	77.88	38.28	50.8%	1.13	2591	2158
	15	12.1	66	36.30	45.0%	0.80	1551	1219
	16	9.5	59.4	32.34	45.6%	0.49	861	567
	17	14.0	67.32	34.98	48.0%	1.07	2117	1747
	18	11.0	56.76	34.32	39.5%	0.66	1102	822
	19	12.1	69.96	40.26	42.5%	0.80	1644	1294
	20	12.8	71.28	44.22	38.0%	0.89	1874	1508
	21	13.2	73.92	38.94	47.3%	0.95	2067	1681
	22	10.7	69.96	40.26	42.5%	0.62	1286	946
	23	14.2	81.18	52.14	35.8%	1.10	2627	2182
	24	12.0	77.88	49.50	36.4%	0.79	1800	1414
	25	12.4	69.96	43.56	37.7%	0.84	1726	1372
	26	11.6	75.24	45.54	39.5%	0.73	1625	1256
	27	13.6	79.2	58.08	26.7%	1.01	2351	1931
	28	11.2	79.86	58.74	26.4%	0.68	1608	1220
	29	13.8	80.52	46.20	42.6%	1.04	2461	2030
	30	10.5	69.3	50.82	26.7%	0.60	1226	890
	31	10.5	74.58	53.46	28.3%	0.60	1320	959
	32	12.4	73.92	50.16	32.1%	0.84	1824	1451
	33	12.8	75.9	48.84	35.7%	0.89	1996	1607
	34	12.5	79.2	45.54	42.5%	0.85	1986	1587
	35	11.6	75.24	42.24	43.9%	0.73	1625	1256
	36	10.7	78.54	50.82	35.3%	0.62	1443	1064
	37	11.5	69.96	39.60	43.4%	0.72	1485	1141
	38	9.8	64.02	36.96	42.3%	0.52	987	674
	39	12.0	69.96	38.94	44.3%	0.79	1617	1268
	40	11.3	72.6	52.80	27.3%	0.70	1488	1133
	41	11.8	75.24	51.48	31.6%	0.76	1681	1310
	42	12.1	77.22	55.44	28.2%	0.80	1814	1431
	43	13.4	73.92	49.50	33.0%	0.98	2130	1740
	44	9.8	63.36	42.90	32.3%	0.52	977	666
	45	11.1	73.92	47.52	35.7%	0.67	1462	1102
	46	11.7	79.86	58.74	26.4%	0.75	1755	1363
	47	9.7	79.86	66.66	16.5%	0.51	1206	818
	48	12.2	71.94	47.52	33.9%	0.81	1718	1358
	49	9.5	60.72	41.58	31.5%	0.49	880	580
	50	9.8	64.68	48.84	24.5%	0.52	997	681
$\bar{x}$		11.8	71.65	45.69	36.4%	0.78	1645	1283
QMD		11.9						
Σ							82229	64136
Δ							18092	

Appendix 1 - 4. Load 4 Measured Trees.

			Load 5 Measured Trees				Green Weight (Tons)	
	Tree	DBH	Total Height	HLC	LCR	BA	Whole Tree	6 Inch Top
	1	13.0	70.62	41.58	41.1%	0.92	1915	1548
	2	12.1	74.58	39.60	46.9%	0.80	1752	1381
	3	13.0	67.32	38.28	43.1%	0.92	1826	1475
	4	10.5	69.96	39.60	43.4%	0.60	1238	898
	5	12.0	66.66	36.30	45.5%	0.79	1541	1207
	6	12.3	74.58	34.32	54.0%	0.83	1811	1436
	7	10.1	68.64	35.64	48.1%	0.56	1124	790
	8	13.3	82.5	50.82	38.4%	0.96	2342	1913
	9	12.1	76.56	51.48	32.8%	0.80	1799	1418
	10	13.0	74.58	45.54	38.9%	0.92	2023	1637
	11	14.1	79.2	45.54	42.5%	1.08	2527	2095
	12	10.9	69.3	37.62	45.7%	0.65	1322	984
	13	10.7	69.96	44.22	36.8%	0.62	1286	946
	14	11.3	68.64	42.24	38.5%	0.70	1407	1070
	15	10.1	59.4	38.28	35.6%	0.56	973	682
	16	12.4	71.94	35.64	50.5%	0.84	1775	1412
	17	11.8	73.26	45.54	37.8%	0.76	1637	1275
	18	11.8	71.28	48.84	31.5%	0.76	1593	1240
	19	10.5	59.4	42.24	28.9%	0.60	1051	760
	20	10.7	72.6	39.60	45.5%	0.62	1334	982
	21	12.5	75.24	45.54	39.5%	0.85	1887	1506
	22	10.8	69.96	47.52	32.1%	0.64	1310	969
	23	13.1	77.22	46.86	39.3%	0.94	2127	1727
	24	11.7	73.26	45.54	37.8%	0.75	1610	1248
	25	13.6	76.56	44.22	42.2%	1.01	2272	1865
	26	13.5	79.2	46.20	41.7%	0.99	2316	1899
	27	11.9	70.62	39.60	43.9%	0.77	1605	1254
	28	10.8	69.3	40.92	41.0%	0.64	1297	960
	29	14.0	70.62	42.90	39.3%	1.07	2221	1834
	30	11.3	64.02	43.56	32.0%	0.70	1312	997
	31	13.3	67.98	44.88	34.0%	0.96	1930	1570
	32	12.5	71.94	42.90	40.4%	0.85	1804	1439
	33	14.4	66.66	38.28	42.6%	1.13	2218	1842
	34	9.6	64.02	38.28	40.2%	0.50	947	633
	35	12.4	66	36.96	44.0%	0.84	1629	1293
	36	10.9	74.58	41.58	44.2%	0.65	1422	1060
	37	10.9	75.9	49.50	34.8%	0.65	1447	1079
	38	12.1	69.3	49.50	28.6%	0.80	1628	1281
	39	10.7	72.6	46.20	36.4%	0.62	1334	982
	40	12.5	64.68	40.92	36.7%	0.85	1622	1291
	41	11.5	64.02	40.92	36.1%	0.72	1359	1042
	42	9.6	62.7	43.56	30.5%	0.50	928	619
	43	12.0	67.32	41.58	38.2%	0.79	1556	1219
	44	12.5	72.6	44.88	38.2%	0.85	1821	1452
	45	10.9	71.28	48.84	31.5%	0.65	1359	1013
	46	11.7	69.96	36.30	48.1%	0.75	1537	1191
	47	12.4	72.6	47.52	34.5%	0.84	1792	1425
	48	12.8	73.26	45.54	37.8%	0.89	1926	1550
	49	11.2	66.66	36.96	44.6%	0.68	1342	1015
	50	12.0	79.86	50.82	36.4%	0.79	1846	1451
$\bar{x}$		11.9	70.82	42.83	39.4%	0.78	1634	1277
QMD		12.0						
Σ							81680	63856
Δ							17824	

Appendix 1 - 5. Load 5 Measured Trees.

			Load 6 Measured				Green Weight (Tons)	
	Tree	DBH	Total Height	HLC	LCR	BA	Whole Tree	6 Inch Top
	1	12.9	82.5	49.50	40.0%	0.91	2203	1782
	2	12.0	66.66	44.22	33.7%	0.79	1541	1207
	3	13.0	67.32	40.92	39.2%	0.92	1826	1475
	4	10.5	71.28	41.58	41.7%	0.60	1261	916
	5	13.8	81.18	48.18	40.7%	1.04	2481	2047
	6	10.4	74.58	49.50	33.6%	0.59	1295	934
	7	11.3	74.58	52.14	30.1%	0.70	1528	1165
	8	12.6	74.58	46.86	37.2%	0.87	1900	1521
	9	11.3	72.6	47.52	34.5%	0.70	1488	1133
	10	10.9	70.62	50.16	29.0%	0.65	1347	1003
	11	10.1	71.28	46.20	35.2%	0.56	1167	821
	12	13.8	77.88	49.50	36.4%	1.04	2380	1962
	13	12.2	74.58	51.48	31.0%	0.81	1782	1408
	14	11.6	76.56	50.82	33.6%	0.73	1653	1278
	15	9.5	79.2	54.12	31.7%	0.49	1147	761
	16	9.5	82.5	66.66	19.2%	0.49	1195	793
	17	11.8	81.18	57.42	29.3%	0.76	1814	1416
	18	10.8	77.88	51.48	33.9%	0.64	1458	1081
	19	11.7	80.52	51.48	36.1%	0.75	1769	1375
	20	10.8	77.88	51.48	33.9%	0.64	1458	1081
	21	10.3	64.02	48.18	24.7%	0.58	1090	778
	22	12.2	75.24	48.84	35.1%	0.81	1797	1421
	23	11.2	73.92	63.36	14.3%	0.68	1488	1128
	24	11.3	67.32	50.16	25.5%	0.70	1380	1049
	25	12.7	76.56	47.52	37.9%	0.88	1982	1592
	26	10.0	67.98	47.52	30.1%	0.55	1091	760
	27	12.1	73.26	52.14	28.8%	0.80	1721	1356
	28	12.9	79.86	50.82	36.4%	0.91	2133	1724
	29	12.7	75.24	50.16	33.3%	0.88	1948	1564
	30	11.3	71.28	52.14	26.9%	0.70	1461	1112
	31	10.8	75.24	58.08	22.8%	0.64	1409	1044
	32	12.5	73.92	47.52	35.7%	0.85	1854	1479
	33	10.7	67.32	44.88	33.3%	0.62	1237	909
	34	11.0	71.94	52.14	27.5%	0.66	1397	1047
	35	11.8	70.62	42.90	39.3%	0.76	1578	1228
	36	11.1	73.92	46.20	37.5%	0.67	1462	1102
	37	12.1	69.96	42.24	39.6%	0.80	1644	1294
	38	9.8	72.6	62.04	14.5%	0.52	1119	766
	39	13.5	68.64	45.54	33.7%	0.99	2008	1641
	40	13.0	79.2	55.44	30.0%	0.92	2148	1740
	41	12.0	75.9	49.50	34.8%	0.79	1754	1378
	42	12.0	79.2	60.72	23.3%	0.79	1830	1439
	43	11.3	67.32	41.58	38.2%	0.70	1380	1049
	44	13.5	80.52	52.80	34.4%	0.99	2355	1931
	45	10.9	67.32	48.18	28.4%	0.65	1284	955
	46	9.5	71.94	43.56	39.4%	0.49	1042	690
	47	12.4	73.92	50.16	32.1%	0.84	1824	1451
	48	13.1	75.9	49.50	34.8%	0.94	2090	1697
	49	9.7	65.34	46.20	29.3%	0.51	987	667
	50	11.5	75.9	42.24	44.3%	0.72	1611	1240
$\bar{x}$		11.6	73.93	49.87	32.5%	0.74	1616	1248
QMD		11.6						
Σ							80798	62388
Δ							18410	

Appendix 1 - 6. Load 6 Measured Trees.

		Load 1 Actual Loaded					Green Weight (Tons)	
	Tree	DBH	Total Height	HLC	LCR	BA	Whole Tree	6 Inch Top
	3	10.8	58.74	35.64	0.39	0.64	1100	811
	4	10.5	64.02	36.96	0.42	0.60	1133	821
	5	10.2	73.26	53.46	0.27	0.57	1223	868
	7	10.8	76.56	53.46	0.30	0.64	1433	1063
	8	10.0	80.52	60.72	0.25	0.55	1292	903
	12	11.0	66.66	38.94	0.42	0.66	1295	969
	13	11.0	67.98	52.14	0.23	0.66	1320	988
	16	13.3	68.64	40.92	0.40	0.96	1949	1586
	17	13.4	81.18	46.20	0.43	0.98	2339	1914
	18	11.8	65.34	42.24	0.35	0.76	1460	1135
	19	13.1	71.94	45.54	0.37	0.94	1981	1606
	20	10.5	65.34	40.26	0.38	0.60	1156	838
	21	12.7	74.58	46.20	0.38	0.88	1930	1550
	22	12.0	79.86	46.86	0.41	0.79	1846	1451
	23	10.4	71.28	43.56	0.39	0.59	1238	892
	24	10.4	74.58	49.50	0.34	0.59	1295	934
	25	10.3	71.94	50.16	0.30	0.58	1225	876
	26	13.7	70.62	36.96	0.48	1.02	2127	1747
	27	10.5	79.20	52.80	0.33	0.60	1402	1019
	28	10.7	70.62	46.86	0.34	0.62	1298	955
	29	10.8	66.66	40.26	0.40	0.64	1248	923
	30	11.5	78.54	54.78	0.30	0.72	1667	1284
	32	12.6	77.88	47.52	0.39	0.87	1984	1590
	33	12.4	82.50	57.42	0.30	0.84	2036	1623
	34	12.7	68.64	36.30	0.47	0.88	1777	1424
	35	11.9	77.88	49.50	0.36	0.77	1770	1385
	36	10.1	70.62	45.54	0.36	0.56	1156	813
	37	14.2	84.48	52.80	0.38	1.10	2733	2273
	38	11.5	84.48	56.76	0.33	0.72	1793	1383
	39	13.3	69.30	35.64	0.49	0.96	1967	1601
	40	12.6	77.88	50.16	0.36	0.87	1984	1590
	41	12.9	87.78	52.80	0.40	0.91	2344	1898
	42	13.0	79.86	46.20	0.42	0.92	2166	1755
	43	13.3	77.88	52.80	0.32	0.96	2211	1804
	44	12.0	77.88	55.44	0.29	0.79	1800	1414
	45	11.8	69.96	54.12	0.23	0.76	1563	1216
	46	13.8	78.54	47.52	0.39	1.04	2400	1979
	47	12.2	75.90	45.54	0.40	0.81	1813	1434
	48	9.6	67.98	48.84	0.28	0.50	1006	673
	49	9.5	69.30	48.18	0.30	0.49	1004	664
	50	11.0	71.94	39.60	0.45	0.66	1397	1047
$\bar{x}$		11.7	73.87	47.25	0.36	0.76	1655	1285
QMD		11.8						
Σ							67863	52698
Δ							15165	

Appendix 1 - 7. Load 1 Actual Loaded Trees.

	Load 2 Actual Loaded						Green Weight (Tons)	
	Tree	DBH	Total Height	HLC	LCR	BA	Whole Tree	6 Inch Top
	1	9.5	63.36	43.56	0.31	0.49	918	606
	2	13.4	69.30	36.30	0.48	0.98	1997	1629
	3	11.4	72.60	47.52	0.35	0.71	1514	1159
	4	13.7	69.96	47.52	0.32	1.02	2107	1730
	5	10.3	64.68	46.20	0.29	0.58	1102	786
	6	12.2	71.94	48.84	0.32	0.81	1718	1358
	7	11.6	69.30	42.90	0.38	0.73	1497	1155
	8	13.3	72.60	48.84	0.33	0.96	2061	1679
	9	12.4	62.70	46.86	0.25	0.84	1547	1227
	10	11.6	69.30	47.52	0.31	0.73	1497	1155
	11	9.6	67.32	46.86	0.30	0.50	996	666
	12	11.0	69.96	44.88	0.36	0.66	1359	1018
	13	10.2	67.32	44.88	0.33	0.57	1124	797
	14	10.4	67.98	41.58	0.39	0.59	1180	850
	15	9.6	70.62	43.56	0.38	0.50	1045	699
	16	11.8	71.94	53.46	0.26	0.76	1608	1252
	17	11.5	75.24	47.52	0.37	0.72	1597	1229
	18	13.1	71.28	47.52	0.33	0.94	1963	1591
	19	11.2	67.32	50.82	0.25	0.68	1355	1025
	20	10.9	67.98	50.16	0.26	0.65	1296	965
	21	11.4	68.64	42.90	0.38	0.71	1432	1094
	22	10.4	71.28	48.84	0.31	0.59	1238	892
	23	10.7	73.26	44.88	0.39	0.62	1346	991
	24	11.4	67.98	40.92	0.40	0.71	1418	1084
	25	11.6	70.62	45.54	0.36	0.73	1525	1177
	26	14.4	72.60	42.90	0.41	1.13	2416	2009
	27	9.5	63.36	39.60	0.38	0.49	918	606
	28	9.5	64.68	44.88	0.31	0.49	937	619
	33	13.8	69.30	42.90	0.38	1.04	2118	1742
	34	10.4	60.72	34.98	0.42	0.59	1054	757
	35	11.7	64.02	37.62	0.41	0.75	1407	1088
	36	9.7	60.06	42.90	0.29	0.51	907	612
	37	11.6	68.64	42.24	0.38	0.73	1482	1143
	38	10.4	62.70	38.94	0.38	0.59	1089	782
	39	11.8	68.64	42.90	0.38	0.76	1534	1193
	40	9.8	51.48	38.28	0.26	0.52	794	539
	41	11.6	64.68	42.90	0.34	0.73	1397	1076
	42	11.5	64.02	40.92	0.36	0.72	1359	1042
	43	13.7	65.34	39.60	0.39	1.02	1968	1614
	44	14.5	78.54	50.82	0.35	1.15	2650	2211
	46	13.0	81.84	56.76	0.31	0.92	2220	1800
	47	12.0	66.66	52.14	0.22	0.79	1541	1207
	50	13.3	79.20	52.80	0.33	0.96	2248	1835
$\bar{x}$		11.5	68.39	44.99	0.34	0.74	1500	1155
QMD		11.6						
Σ							64479	49686
Δ							14792	

Appendix 1 - 8. Load 2 Actual Loaded Trees.

		Load 3 Actual Loaded					Green Weight (Tons)	
	Tree	DBH	Total Height	HLC	LCR	BA	Whole Tree	6 Inch Top
	1	11	71.28	48.84	31%	0.66	1384	1037
	2	9.7	69.3	46.86	32%	0.51	1047	708
	3	9.7	75.9	52.14	31%	0.51	1146	777
	4	11.3	76.56	54.12	29%	0.70	1569	1196
	5	9.6	78.54	52.8	33%	0.50	1162	779
	6	9.7	73.92	58.08	21%	0.51	1116	756
	7	13.6	73.26	46.86	36%	1.01	2174	1783
	8	12.8	73.92	42.9	42%	0.89	1944	1565
	9	13.4	73.26	48.84	33%	0.98	2111	1724
	10	11	71.94	48.84	32%	0.66	1397	1047
	11	11.6	73.26	42.9	41%	0.73	1582	1222
	12	11.7	70.62	53.46	24%	0.75	1552	1203
	13	11.9	73.92	46.2	38%	0.77	1680	1314
	14	12.1	76.56	48.18	37%	0.80	1799	1418
	15	11.8	71.28	50.16	30%	0.76	1593	1240
	16	13.6	73.26	49.5	32%	1.01	2174	1783
	17	12.7	71.94	43.56	39%	0.88	1862	1494
	18	11.3	67.32	46.2	31%	0.70	1380	1049
	19	12.8	67.98	48.18	29%	0.89	1788	1437
	20	11.2	69.3	46.2	33%	0.68	1395	1056
	21	10.7	71.94	48.84	32%	0.62	1322	973
	22	11.1	75.24	52.8	30%	0.67	1488	1122
	23	9.5	71.94	50.82	29%	0.49	1042	690
	24	9.5	75.24	44.22	41%	0.49	1090	722
	25	11.9	74.58	49.5	34%	0.77	1695	1326
	26	13.6	79.2	51.48	35%	1.01	2351	1931
	27	13.1	82.5	54.78	34%	0.94	2272	1847
	28	11	71.94	50.82	29%	0.66	1397	1047
	29	12.6	75.9	56.1	26%	0.87	1934	1549
	30	13	71.94	42.9	40%	0.92	1951	1578
	33	14	80.52	44.22	45%	1.07	2532	2097
	36	11.3	72.6	48.84	33%	0.70	1488	1133
	40	12.7	74.58	45.54	39%	0.88	1930	1550
	41	10.3	64.68	46.2	29%	0.58	1102	786
	42	10.5	66	38.28	42%	0.60	1168	846
	43	10.4	63.36	50.82	20%	0.59	1100	791
	44	9.9	65.34	43.56	33%	0.53	1028	709
	45	10.8	69.96	50.82	27%	0.64	1310	969
	46	12.3	66.66	36.96	45%	0.83	1619	1281
	47	13	66.66	43.56	35%	0.92	1808	1460
	48	11.6	63.36	44.88	29%	0.73	1368	1054
	50	10.2	55.44	40.26	27%	0.57	926	654
$\bar{x}$		11.5	72.22	48.19	33%	0.74	1566	1207
QMD		11.6						
Σ							65778	50701
Δ							15076	

Appendix 1 - 9. Load 3 Actual Loaded Trees.

		Load 4 Actual Loaded					Green Weight (Tons)	
	Tree	DBH	Total Height	HLC	LCR	BA	Whole Tree	6 Inch Top
	1	11.3	65.34	44.22	32%	0.70	1339	1018
	2	12.8	64.02	33	48%	0.89	1683	1351
	3	14.2	64.68	31.68	51%	1.10	2093	1731
	4	13.3	66	43.56	34%	0.96	1874	1524
	5	11	75.9	46.86	38%	0.66	1474	1106
	6	12.2	71.94	43.56	39%	0.81	1718	1358
	7	13.6	71.94	40.92	43%	1.01	2135	1751
	11	12.8	72.6	48.84	33%	0.89	1909	1536
	12	10.4	72.6	44.22	39%	0.59	1260	908
	13	12	71.94	46.86	35%	0.79	1663	1304
	14	14.4	77.88	38.28	51%	1.13	2591	2158
	15	12.1	66	36.3	45%	0.80	1551	1219
	16	9.5	59.4	32.34	46%	0.49	861	567
	17	14	67.32	34.98	48%	1.07	2117	1747
	18	11	56.76	34.32	40%	0.66	1102	822
	19	12.1	69.96	40.26	42%	0.80	1644	1294
	20	12.8	71.28	44.22	38%	0.89	1874	1508
	21	13.2	73.92	38.94	47%	0.95	2067	1681
	22	10.7	69.96	40.26	42%	0.62	1286	946
	23	14.2	81.18	52.14	36%	1.10	2627	2182
	24	12	77.88	49.5	36%	0.79	1800	1414
	25	12.4	69.96	43.56	38%	0.84	1726	1372
	26	11.6	75.24	45.54	39%	0.73	1625	1256
	27	13.6	79.2	58.08	27%	1.01	2351	1931
	28	11.2	79.86	58.74	26%	0.68	1608	1220
	29	13.8	80.52	46.2	43%	1.04	2461	2030
	30	10.5	69.3	50.82	27%	0.60	1226	890
	31	10.5	74.58	53.46	28%	0.60	1320	959
	33	12.8	75.9	48.84	36%	0.89	1996	1607
	34	12.5	79.2	45.54	43%	0.85	1986	1587
	35	11.6	75.24	42.24	44%	0.73	1625	1256
	36	10.7	78.54	50.82	35%	0.62	1443	1064
	37	11.5	69.96	39.6	43%	0.72	1485	1141
	38	9.8	64.02	36.96	42%	0.52	987	674
	39	12	69.96	38.94	44%	0.79	1617	1268
	40	11.3	72.6	52.8	27%	0.70	1488	1133
	41	11.8	75.24	51.48	32%	0.76	1681	1310
	42	12.1	77.22	55.44	28%	0.80	1814	1431
	43	13.4	73.92	49.5	33%	0.98	2130	1740
	44	9.8	63.36	42.9	32%	0.52	977	666
	45	11.1	73.92	47.52	36%	0.67	1462	1102
	47	9.7	79.86	66.66	17%	0.51	1206	818
	48	12.2	71.94	47.52	34%	0.81	1718	1358
	49	9.5	60.72	41.58	32%	0.49	880	580
	50	9.8	64.68	48.84	24%	0.52	997	681
$\bar{x}$		11.9	71.63	45.09	37%	0.78	1655	1293
QMD		12.0						
Σ							74479	58196
Δ							16283	

Appendix 1 - 10. Load 4 Actual Loaded Trees.

			Load 5 Actual Loaded				Green Weight (Tons)	
	Tree	DBH	Total Height	HLC	LCR	BA	Whole Tree	6 Inch Top
	5	12	66.66	36.3	46%	0.79	1541	1207
	6	12.3	74.58	34.32	54%	0.83	1811	1436
	7	10.1	68.64	35.64	48%	0.56	1124	790
	8	13.3	82.5	50.82	38%	0.96	2342	1913
	9	12.1	76.56	51.48	33%	0.80	1799	1418
	10	13	74.58	45.54	39%	0.92	2023	1637
	11	14.1	79.2	45.54	43%	1.08	2527	2095
	12	10.9	69.3	37.62	46%	0.65	1322	984
	13	10.7	69.96	44.22	37%	0.62	1286	946
	15	10.1	59.4	38.28	36%	0.56	973	682
	17	11.8	73.26	45.54	38%	0.76	1637	1275
	18	11.8	71.28	48.84	31%	0.76	1593	1240
	19	10.5	59.4	42.24	29%	0.60	1051	760
	20	10.7	72.6	39.6	45%	0.62	1334	982
	21	12.5	75.24	45.54	39%	0.85	1887	1506
	22	10.8	69.96	47.52	32%	0.64	1310	969
	23	13.1	77.22	46.86	39%	0.94	2127	1727
	24	11.7	73.26	45.54	38%	0.75	1610	1248
	25	13.6	76.56	44.22	42%	1.01	2272	1865
	26	13.5	79.2	46.2	42%	0.99	2316	1899
	27	11.9	70.62	39.6	44%	0.77	1605	1254
	28	10.8	69.3	40.92	41%	0.64	1297	960
	29	14	70.62	42.9	39%	1.07	2221	1834
	30	11.3	64.02	43.56	32%	0.70	1312	997
	31	13.3	67.98	44.88	34%	0.96	1930	1570
	32	12.5	71.94	42.9	40%	0.85	1804	1439
	33	14.4	66.66	38.28	43%	1.13	2218	1842
	34	9.6	64.02	38.28	40%	0.50	947	633
	35	12.4	66	36.96	44%	0.84	1629	1293
	36	10.9	74.58	41.58	44%	0.65	1422	1060
	37	10.9	75.9	49.5	35%	0.65	1447	1079
	38	12.1	69.3	49.5	29%	0.80	1628	1281
	39	10.7	72.6	46.2	36%	0.62	1334	982
	40	12.5	64.68	40.92	37%	0.85	1622	1291
	41	11.5	64.02	40.92	36%	0.72	1359	1042
	42	9.6	62.7	43.56	31%	0.50	928	619
	43	12	67.32	41.58	38%	0.79	1556	1219
	44	12.5	72.6	44.88	38%	0.85	1821	1452
	46	11.7	69.96	36.3	48%	0.75	1537	1191
	48	12.8	73.26	45.54	38%	0.89	1926	1550
	49	11.2	66.66	36.96	45%	0.68	1342	1015
	50	12	79.86	50.82	36%	0.79	1846	1451
$\bar{x}$		11.9	70.81	43.06	39%	0.78	1634	1277
QMD		11.9						
Σ							68615	53635
Δ							14980	

Appendix 1 - 11. Load 5 Actual Loaded Trees.

	Load 6 Actual Loaded						Green Weight (Tons)	
	Tree	DBH	Total Height	HLC	LCR	BA	Whole Tree	6 Inch Top
	6	10.4	74.58	49.5	34%	0.59	1295	934
	7	11.3	74.58	52.14	30%	0.70	1528	1165
	8	12.6	74.58	46.86	37%	0.87	1900	1521
	9	11.3	72.6	47.52	35%	0.70	1488	1133
	10	10.9	70.62	50.16	29%	0.65	1347	1003
	11	10.1	71.28	46.2	35%	0.56	1167	821
	12	13.8	77.88	49.5	36%	1.04	2380	1962
	13	12.2	74.58	51.48	31%	0.81	1782	1408
	14	11.6	76.56	50.82	34%	0.73	1653	1278
	15	9.5	79.2	54.12	32%	0.49	1147	761
	16	9.5	82.5	66.66	19%	0.49	1195	793
	17	11.8	81.18	57.42	29%	0.76	1814	1416
	18	10.8	77.88	51.48	34%	0.64	1458	1081
	19	11.7	80.52	51.48	36%	0.75	1769	1375
	20	10.8	77.88	51.48	34%	0.64	1458	1081
	21	10.3	64.02	48.18	25%	0.58	1090	778
	22	12.2	75.24	48.84	35%	0.81	1797	1421
	23	11.2	73.92	63.36	14%	0.68	1488	1128
	24	11.3	67.32	50.16	25%	0.70	1380	1049
	25	12.7	76.56	47.52	38%	0.88	1982	1592
	26	10	67.98	47.52	30%	0.55	1091	760
	27	12.1	73.26	52.14	29%	0.80	1721	1356
	28	12.9	79.86	50.82	36%	0.91	2133	1724
	29	12.7	75.24	50.16	33%	0.88	1948	1564
	31	10.8	75.24	58.08	23%	0.64	1409	1044
	32	12.5	73.92	47.52	36%	0.85	1854	1479
	33	10.7	67.32	44.88	33%	0.62	1237	909
	34	11	71.94	52.14	28%	0.66	1397	1047
	35	11.8	70.62	42.9	39%	0.76	1578	1228
	36	11.1	73.92	46.2	38%	0.67	1462	1102
	37	12.1	69.96	42.24	40%	0.80	1644	1294
	38	9.8	72.6	62.04	15%	0.52	1119	766
	39	13.5	68.64	45.54	34%	0.99	2008	1641
	40	13	79.2	55.44	30%	0.92	2148	1740
	41	12	75.9	49.5	35%	0.79	1754	1378
	42	12	79.2	60.72	23%	0.79	1830	1439
	43	11.3	67.32	41.58	38%	0.70	1380	1049
	44	13.5	80.52	52.8	34%	0.99	2355	1931
	45	10.9	67.32	48.18	28%	0.65	1284	955
	46	9.5	71.94	43.56	39%	0.49	1042	690
	47	12.4	73.92	50.16	32%	0.84	1824	1451
	48	13.1	75.9	49.5	35%	0.94	2090	1697
	50	11.5	75.9	42.24	44%	0.72	1611	1240
$\bar{x}$		11.5	74.21	50.48	32%	0.73	1606	1237
QMD		11.6						
Σ							69038	53183
Δ							15855	

Appendix 1 - 12. Load 6 Actual Loaded Trees.

Measured Timber

	x̄								Σ			Δ	Δ
	DBH	QMD	Total Height	HLC	LCR	BA	Whole Tree	6 Inch Top	Count	Whole Tree	6 Inch Top	(lbs)	(tons)
Load 1	11.5	11.6	73.22	46.58	0.37	0.73	1583	1218	51	80758	62134	18624	9.31
Load 2	11.5	11.6	69.31	45.88	0.34	0.74	1525	1176	50	76247	58786	17460	8.73
Load 3	11.5	11.6	72.22	48.19	0.33	0.74	1570	1209	50	78479	60462	18016	9.01
Load 4	11.8	11.9	71.65	45.69	0.36	0.78	1645	1283	50	82229	64136	18092	9.05
Load 5	11.9	12.0	70.82	42.83	0.39	0.78	1634	1277	50	81680	63856	17824	8.91
Load 6	11.6	11.6	73.93	49.87	0.33	0.74	1616	1248	50	80798	62388	18410	9.21

Actual Loaded Timber

	x̄								Σ			Δ	Δ
	DBH	QMD	Total Height	HLC	LCR	BA	Whole Tree	6 Inch Top	Count	Whole Tree	6 Inch Top	(lbs)	(tons)
Load 1	11.7	11.8	73.87	47.25	36%	0.76	1655	1285	41	67863	52698	15165	7.58
Load 2	11.5	11.6	68.39	44.99	34%	0.74	1500	1155	43	64479	49686	14792	7.40
Load 3	11.5	11.6	72.22	48.19	33%	0.74	1566	1207	42	65778	50701	15076	7.54
Load 4	11.9	12.0	71.63	45.09	37%	0.78	1655	1293	45	74479	58196	16283	8.14
Load 5	11.9	11.9	70.81	43.06	39%	0.78	1634	1277	42	68615	53635	14980	7.49
Load 6	11.5	11.6	74.21	50.48	32%	0.73	1606	1237	43	69038	53183	15855	7.93

Appendix 1 - 13. Summary of Measured and Actual Loaded Trees

Load	Axle	Empty		Loaded Untrimmed		Loaded Trimmed		Loaded Processed		Totals	
		Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger		
1	1	4980	4320	5300	4600	5120	4300	5320	4360	33100	Empty
	2	3640	2780	8940	7180	9440	7200	10280	8520	101120	Loaded Untrimmed
	3	3420	3180	9400	6160	8560	7400	10680	8740	100040	Loaded Trimmed
	4	2280	3020	15980	14240	17300	13000	13420	6800	89960	Loaded Processed
	5	2640	2840	18760	10560	17280	10440	10180	11660		
2	1	4600	4180	4700	4220	5320	4340	5240	4640	32860	Empty
	2	3820	2620	9920	9740	11480	7360	10100	9180	99440	Loaded Untrimmed
	3	3560	3200	10240	8560	9540	9000	11000	8100	97240	Loaded Trimmed
	4	2520	2640	12340	12480	11900	11800	9300	7500	89260	Loaded Processed
	5	2720	3000	13820	13420	11720	14780	11900	12300		
3	1	4640	4180	4420	3960	4420	3960	4420	3960	35620	Empty
	2	4520	3760	11080	9500	10340	9520	11680	8960	106960	Loaded Untrimmed
	3	4140	3180	10600	9400	9480	8580	11980	8740	102260	Loaded Trimmed
	4	2920	3940	14500	14020	14140	13500	11240	11900	91040	Loaded Processed
	5	2180	2160	14620	14860	14300	14020	8000	10160		
4	1	4640	4180	4420	3960	4420	3960	4420	3960	35360	Empty
	2	5140	4040	12060	8200	13100	9260	13440	10500	108800	Loaded Untrimmed
	3	3540	2940	12940	8440	12920	8200	13800	9260	108240	Loaded Trimmed
	4	2520	2640	15120	13900	14540	13380	12080	10680	95920	Loaded Processed
	5	2720	3000	14480	15280	13800	14660	9160	8620		
5	1	4640	4180	4420	3960	4420	3960	4420	3960	35340	Empty
	2	4280	3920	10640	9020	12120	9660	13060	9920	104960	Loaded Untrimmed
	3	4260	3180	11560	9160	11400	8740	12940	8820	103480	Loaded Trimmed
	4	2520	2640	13480	13920	12820	13100	12240	9800	94180	Loaded Processed
	5	2720	3000	13980	14820	13680	13580	10440	8580		
6	1	4740	4300	4360	3960	4180	3880	4220	3980	35280	Empty
	2	4580	3640	10880	8320	10760	9200	11580	8480	101620	Loaded Untrimmed
	3	4180	2840	10160	8460	10320	8240	12140	7500	99680	Loaded Trimmed
	4	3400	3600	13400	14140	12860	12980	12620	9440	92220	Loaded Processed
	5	2000	2000	14640	13300	13640	13620	13240	9020		
7	1	4200	4620	4340	4460	4440	4500	4300	4600	33240	Empty
	2	3320	3600	9140	8600	9620	8240	8040	9580	85640	Loaded Untrimmed
	3	3580	2880	9200	7780	9140	7420	8880	8900	84700	Loaded Trimmed
	4	2740	3880	8760	12340	8320	12080	7340	8220	74920	Loaded Processed
	5	2580	1840	8500	12520	8660	12280	7720	7340		
8	1	4200	4620	4480	4420	4340	4580	4120	4540	33240	Empty
	2	3320	3600	7520	8820	8520	8680	8340	10220	93360	Loaded Untrimmed
	3	3580	2880	8740	8380	8360	8480	8880	9540	92680	Loaded Trimmed
	4	2740	3880	10600	14640	10220	14180	9440	11660	85740	Loaded Processed
	5	2580	1840	10100	15660	10040	15280	8000	11000		
9	1	4200	4620	4300	4380	4480	4660	4320	4560	33240	Empty
	2	3320	3600	7300	9300	8720	9200	8320	9160	93400	Loaded Untrimmed
	3	3580	2880	8740	8280	8240	7540	8460	9920	92600	Loaded Trimmed
	4	2740	3880	10780	14160	10700	13360	9460	12060	85680	Loaded Processed
	5	2580	1840	11160	15000	11380	14320	8820	10600		

Appendix 2 - 1. Axle weight raw data by load number and load type.

C-Calculated | M-Measured	Load Weights 1	2	3	4	5	6	7	8	9
Loaded Untrimmed (M)	68020	66740	71340	73440	69620	66340	52400	60120	60160
Loaded Trimmed (M)	66940	64380	66640	72880	68140	64400	51460	59440	59360
Loaded Processed (M)	56860	56400	55420	60560	58840	56940	41680	52500	52440

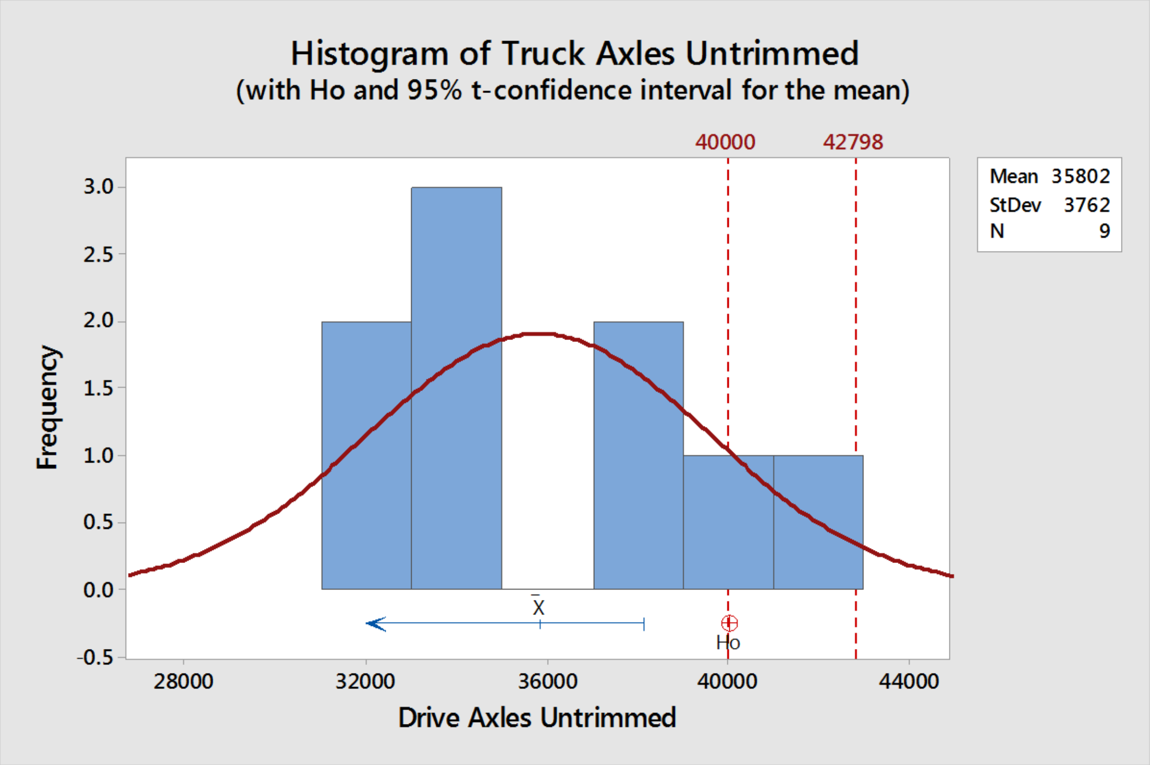
Appendix 3 - 1. Net load weights from all loads combined.

C-Calculated | M-Measured	Load Weights 1	2	3	4	5	6
Whole Tree Standing (C)	67863	64479	65778	74479	68615	69038
Loaded Untrimmed (M)	68020	66740	71340	73440	69620	66340
Loaded Trimmed (M)	66940	64380	66640	72880	68140	64400
Loaded Processed (M)	56860	56400	55420	60560	58840	56940
Processed 6" Top (C)	52698	49686	50701	58196	53635	53183

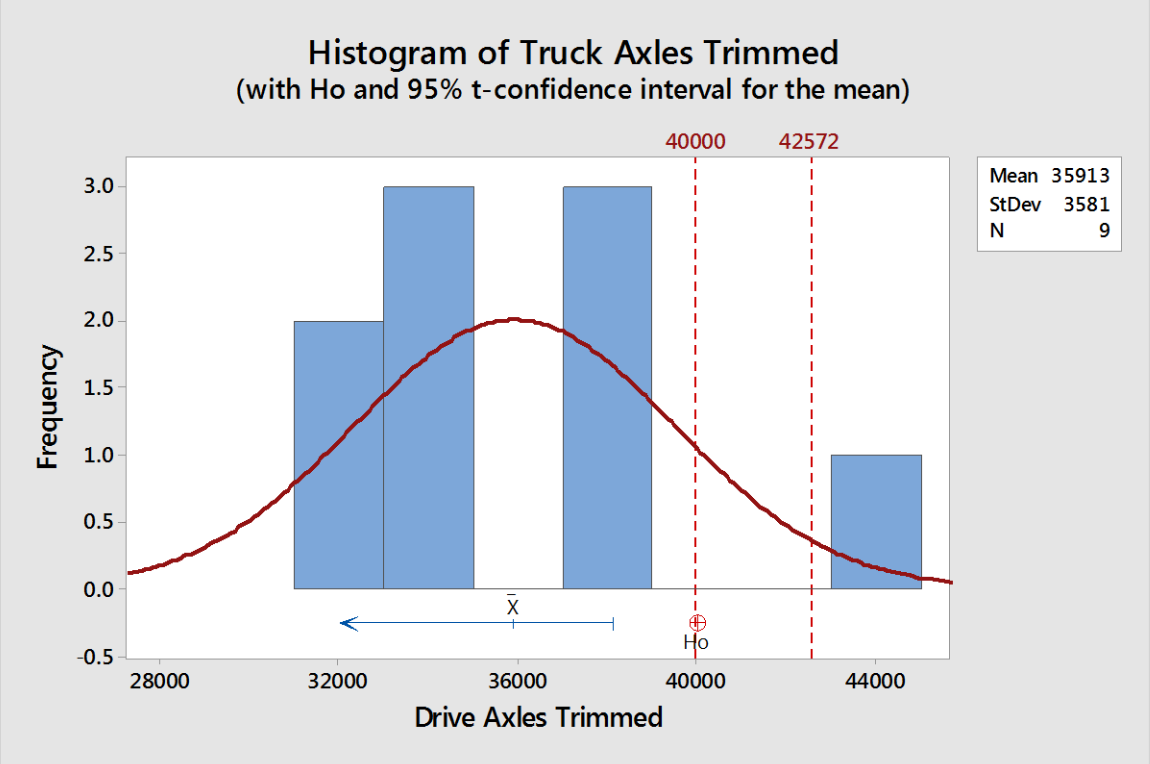
Appendix 3 -2. Net load weights from CNS loads.

C-Calculated | M-Measured	Load Weights 7	8	9
Loaded Untrimmed (M)	52400	60120	60160
Loaded Trimmed (M)	51460	59440	59360
Loaded Processed (M)	41680	52500	52440

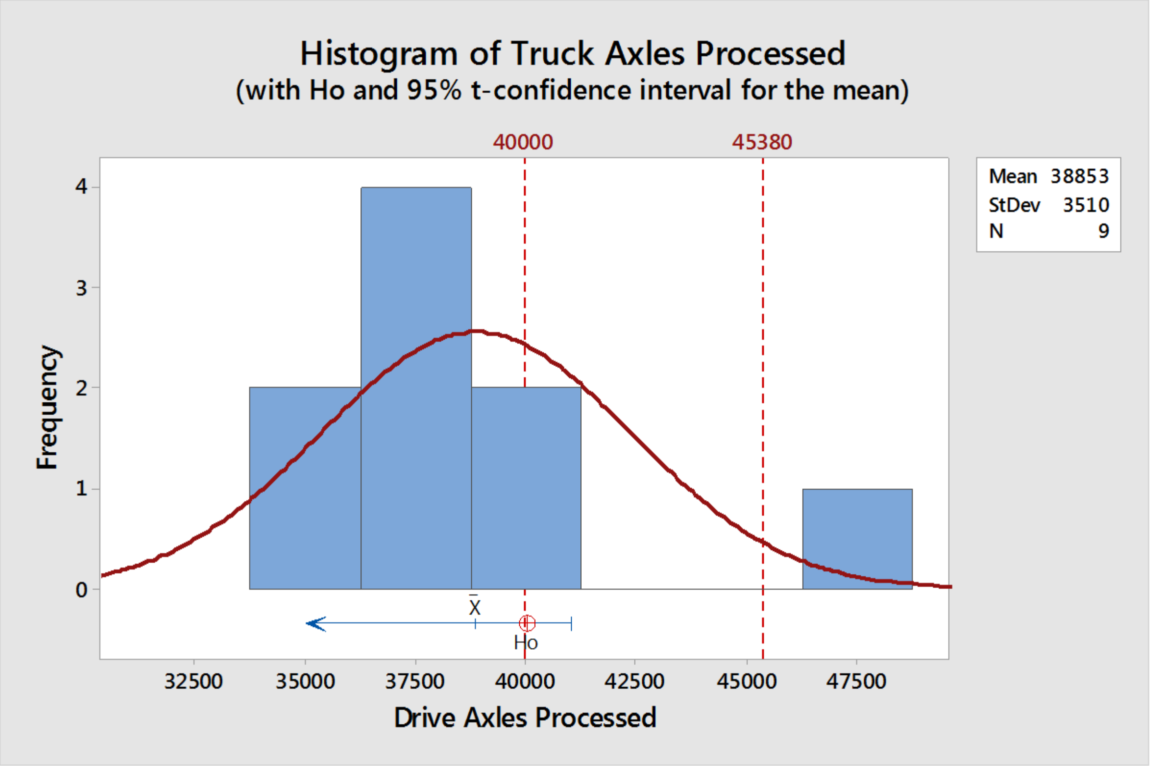
Appendix 3 - 3. Net load weights from PWD loads.



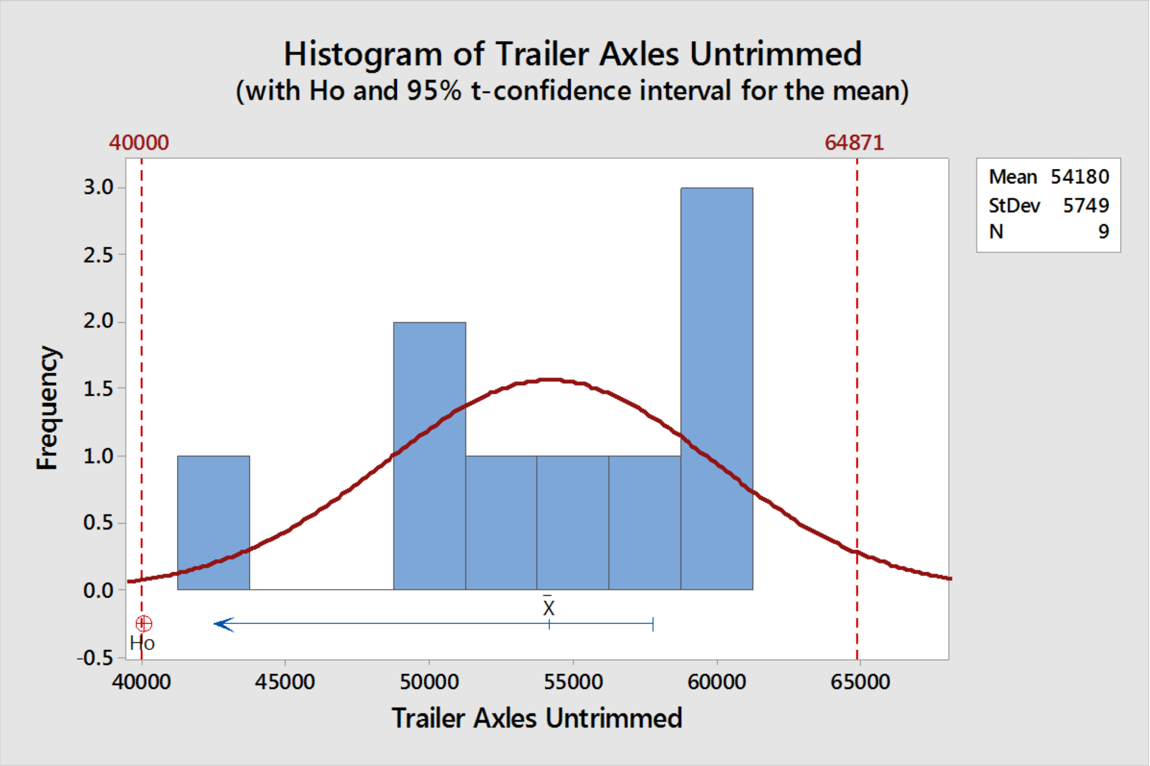
Appendix 4 - 1. Untrimmed load weight distribution comparison for Alabama tandem axle weight limit - Truck.



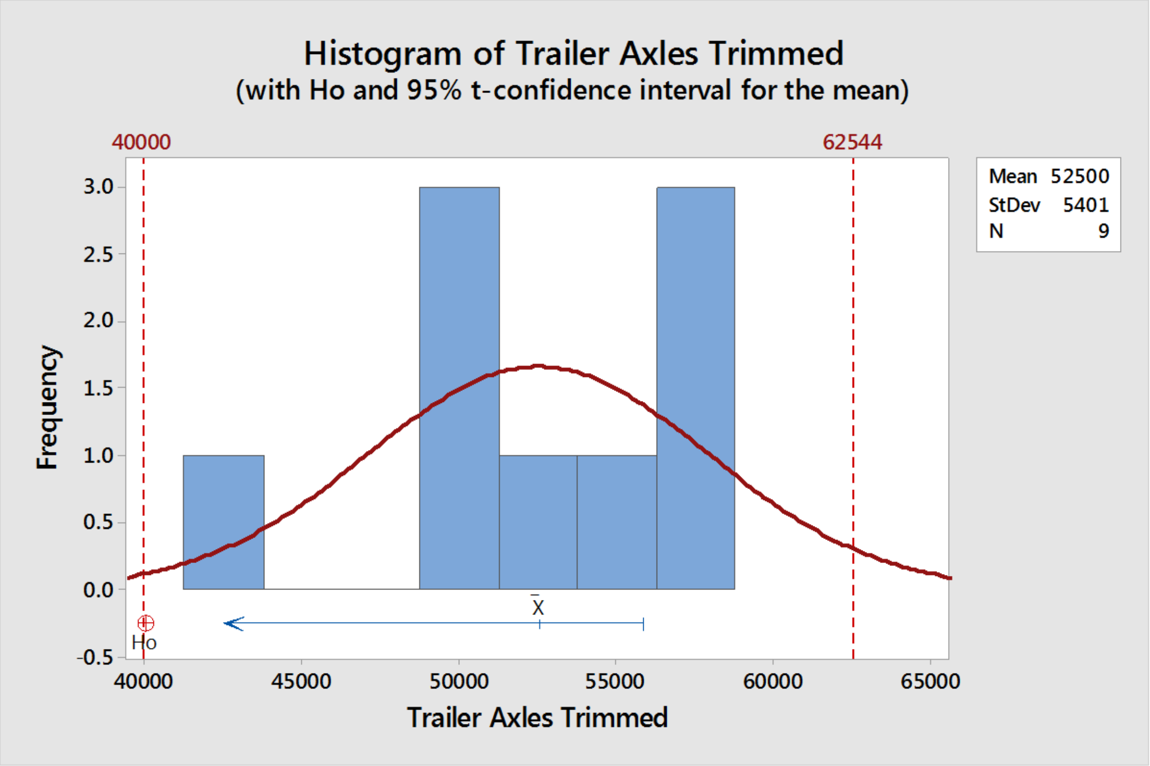
Appendix 4 - 2. Trimmed load weight distribution comparison for Alabama tandem axle weight limit - Truck.



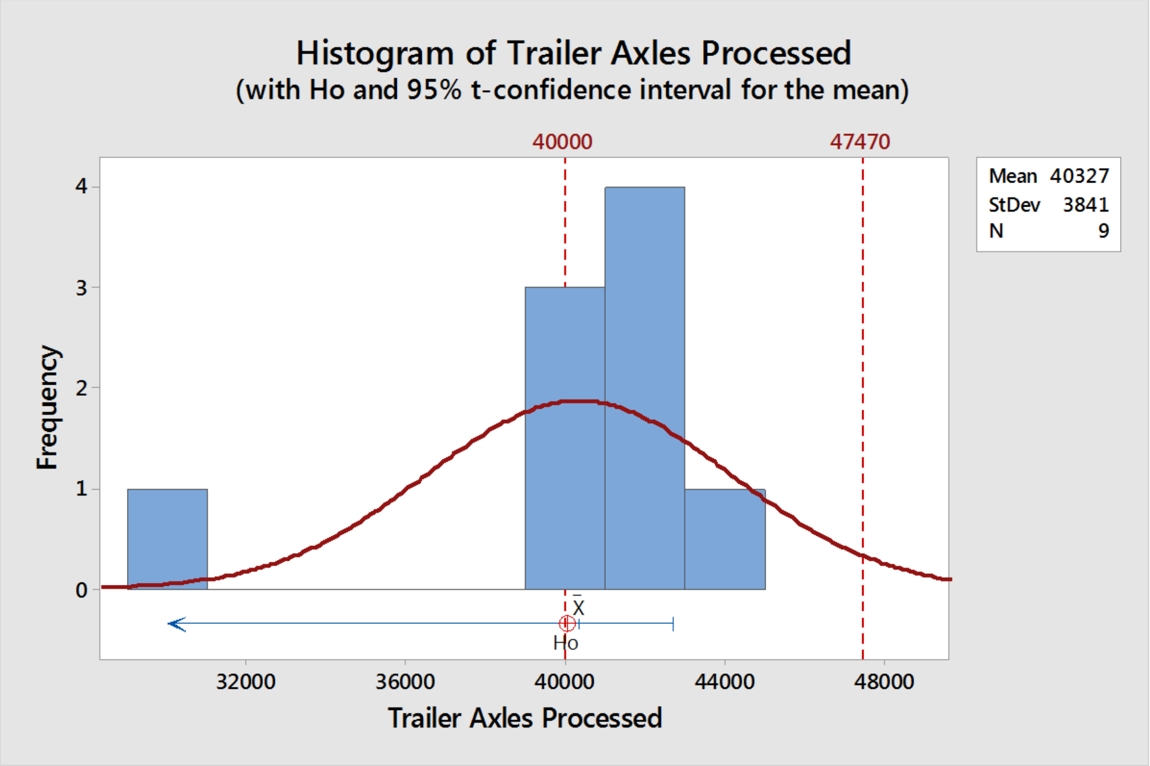
Appendix 4- 3. Processed load weight distribution comparison for Alabama tandem axle weight limit - Truck.



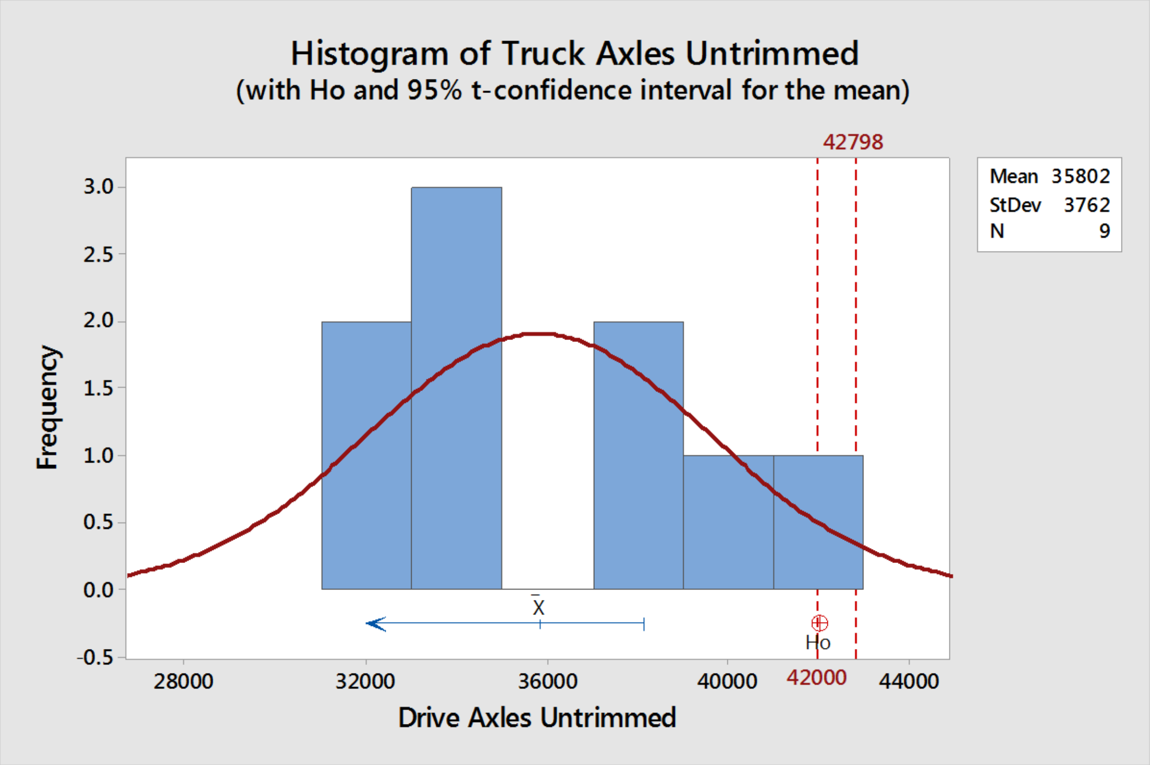
Appendix 4 - 4. Untrimmed load weight distribution comparison for Alabama tandem axle weight limit - Trailer.



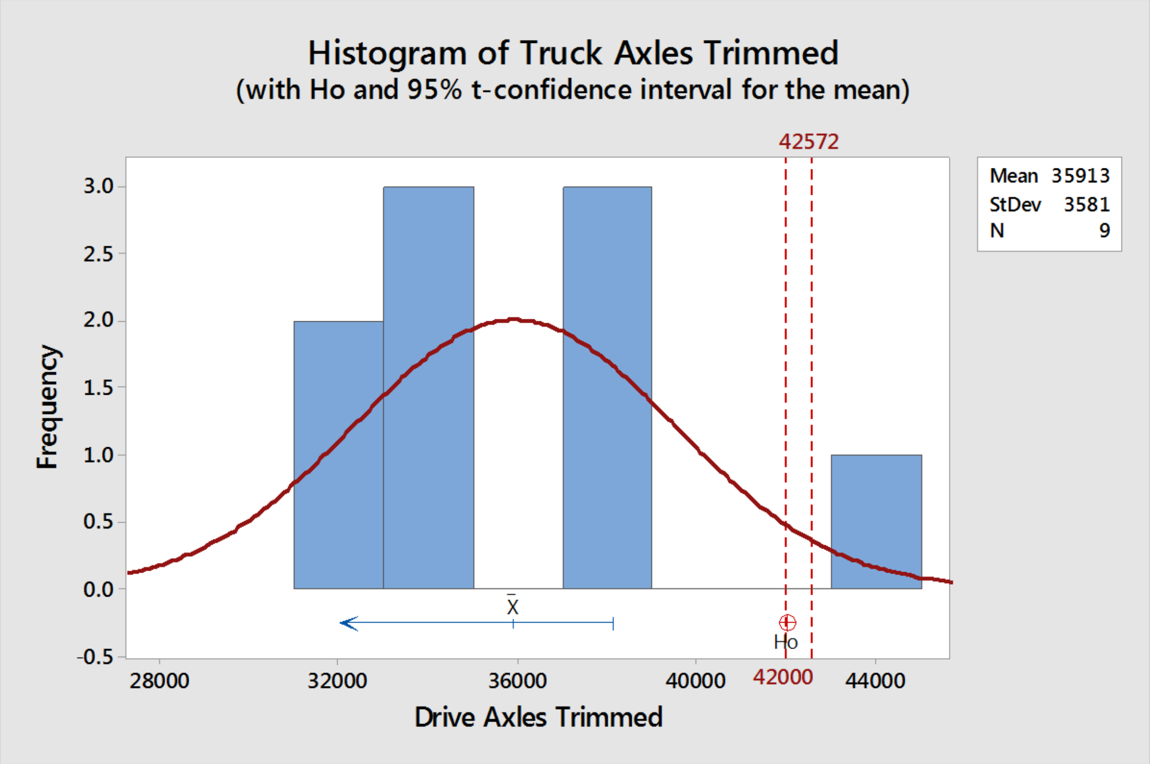
Appendix 4 - 5. Trimmed load weight distribution comparison for Alabama tandem axle weight limit - Trailer.



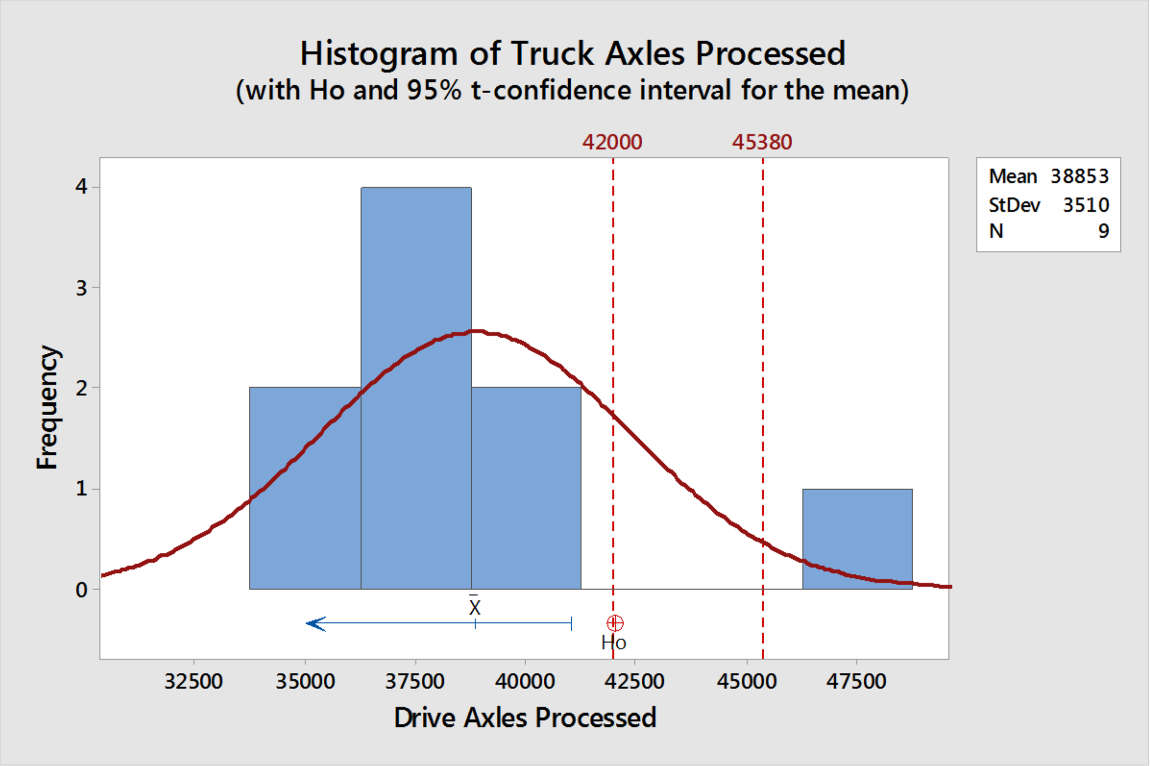
Appendix 4 - 6. Processed load weight distribution comparison for Alabama tandem axle weight limit - Trailer.



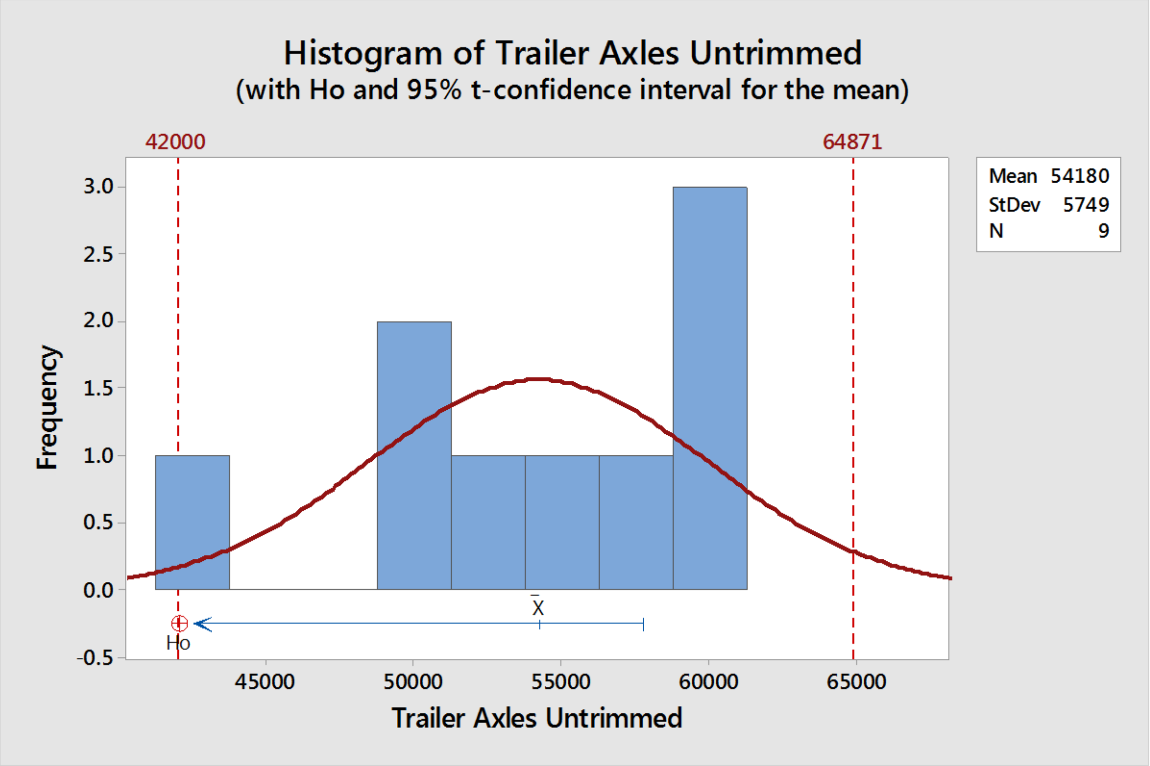
Appendix 4 - 7. Untrimmed load weight distribution comparison for Alabama tridem axle weight limit - Truck.



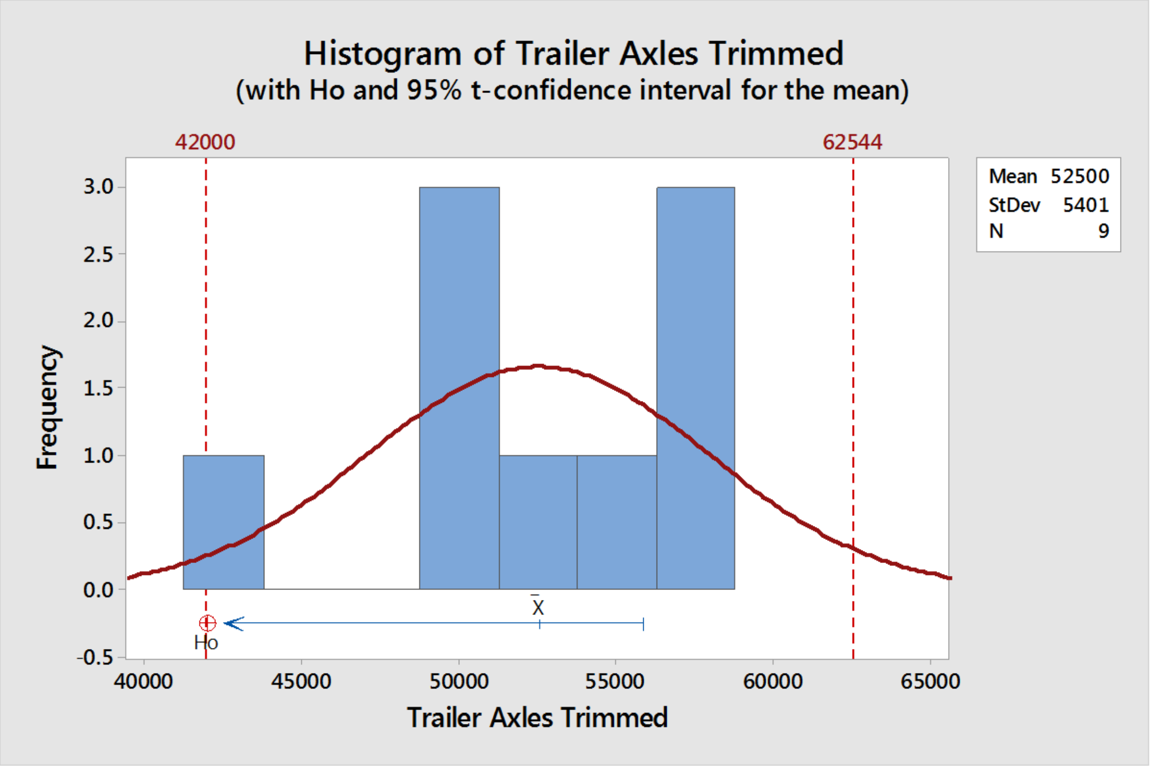
Appendix 4 - 8. Trimmed load weight distribution comparison for Alabama tridem axle weight limit - Truck.



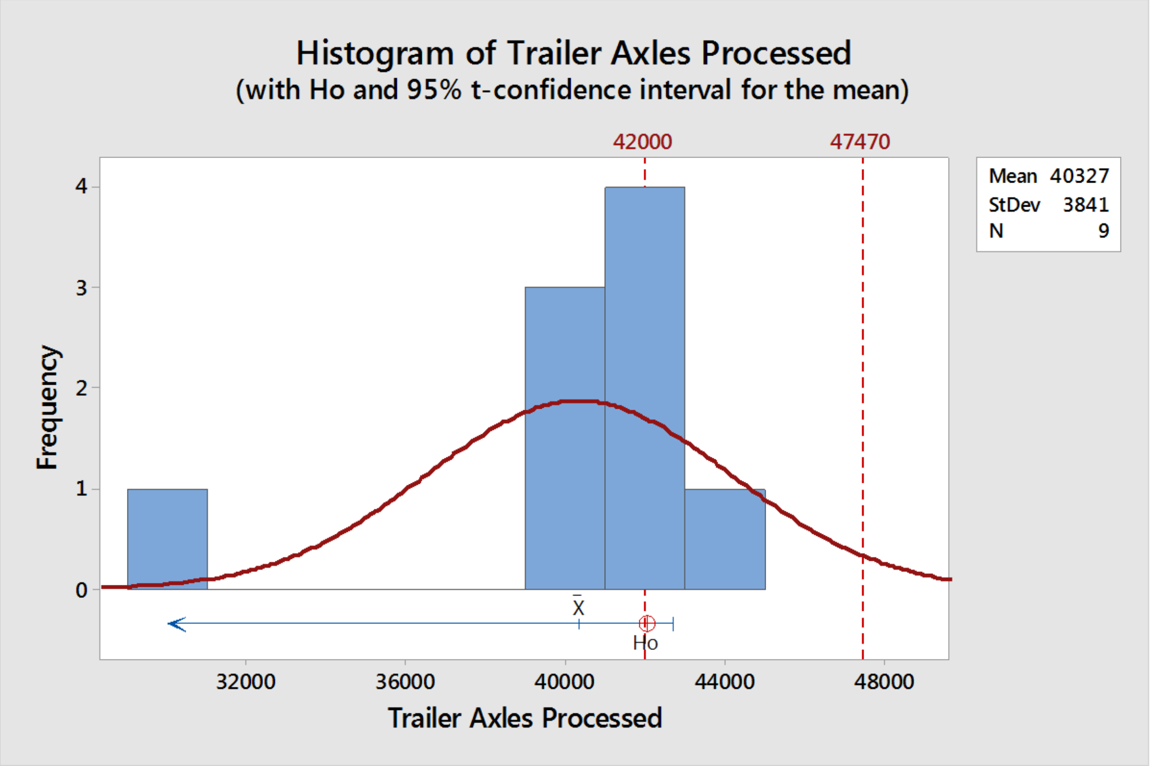
Appendix 4 - 9. Processed load weight distribution comparison for Alabama tridem axle weight limit - Truck.



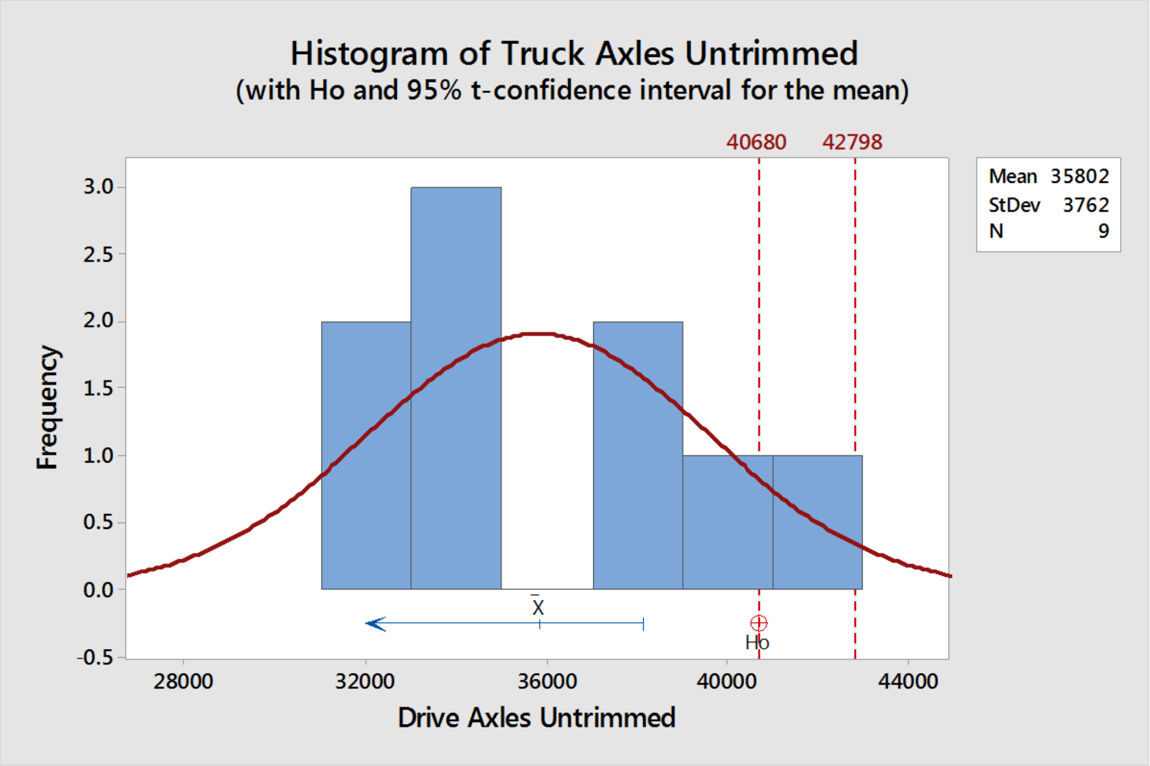
Appendix 4 - 10. Untrimmed load weight distribution comparison for Alabama tridem axle weight limit - Trailer.



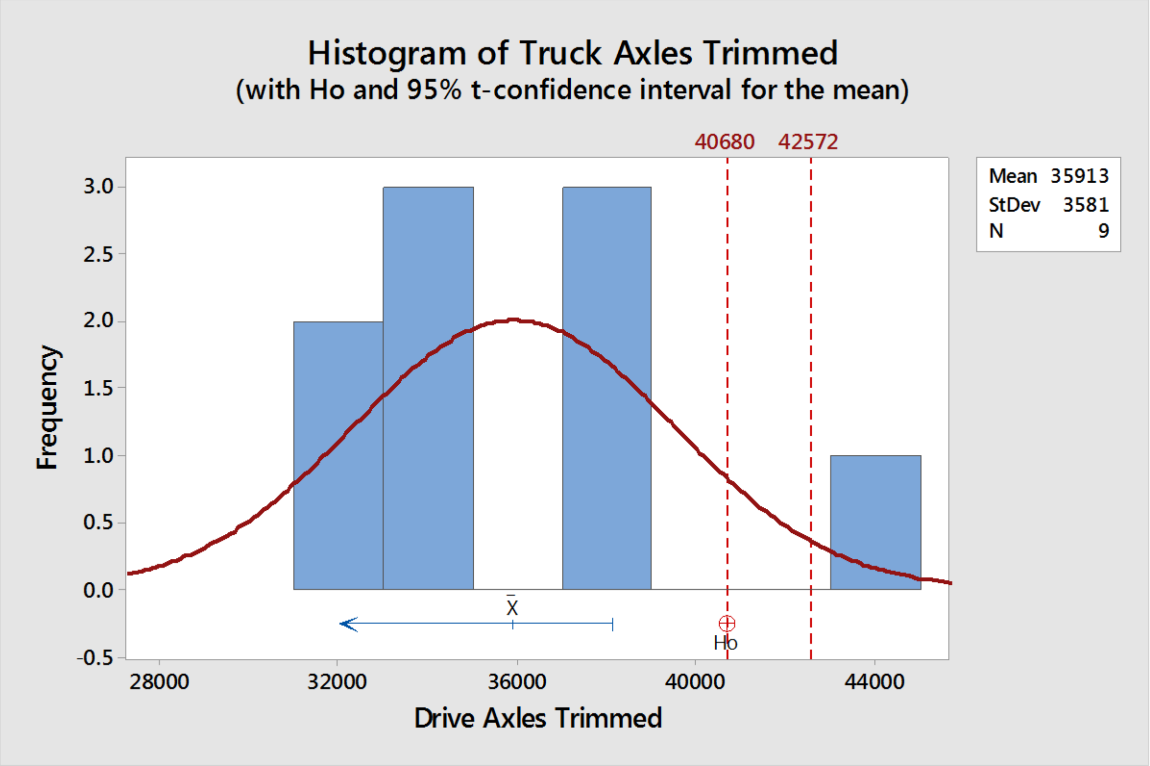
Appendix 4 - 11. Trimmed load weight distribution comparison for Alabama tridem axle weight limit - Trailer.



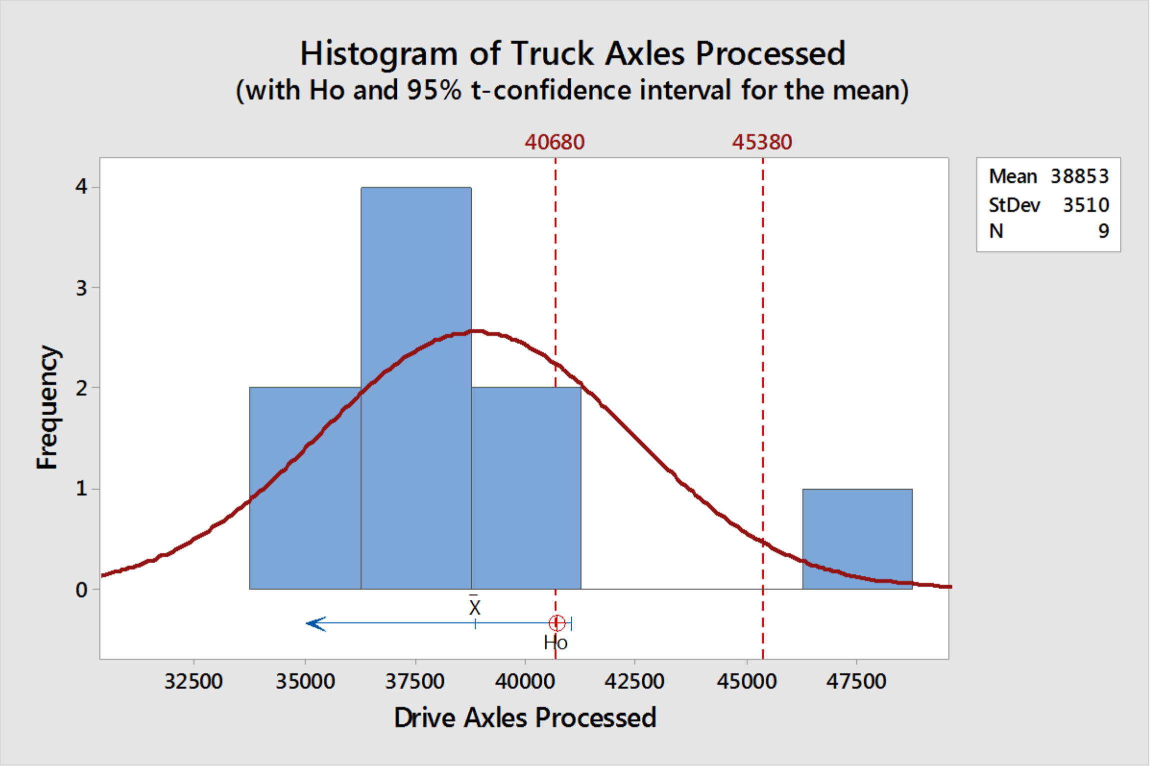
Appendix 4 - 12. Processed load weight distribution comparison for Alabama tridem axle weight limit - Trailer.



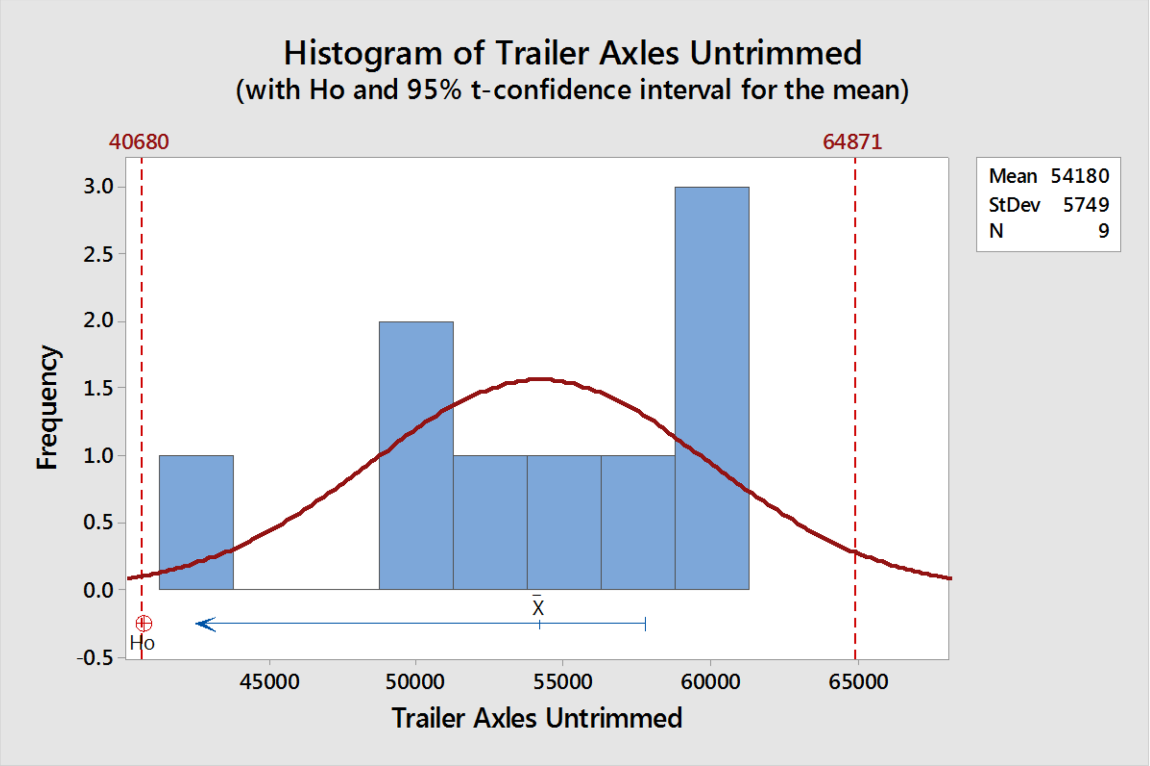
Appendix 5 - 1. Untrimmed load weight distribution comparison for Georgia tandem axle weight limit - Truck.



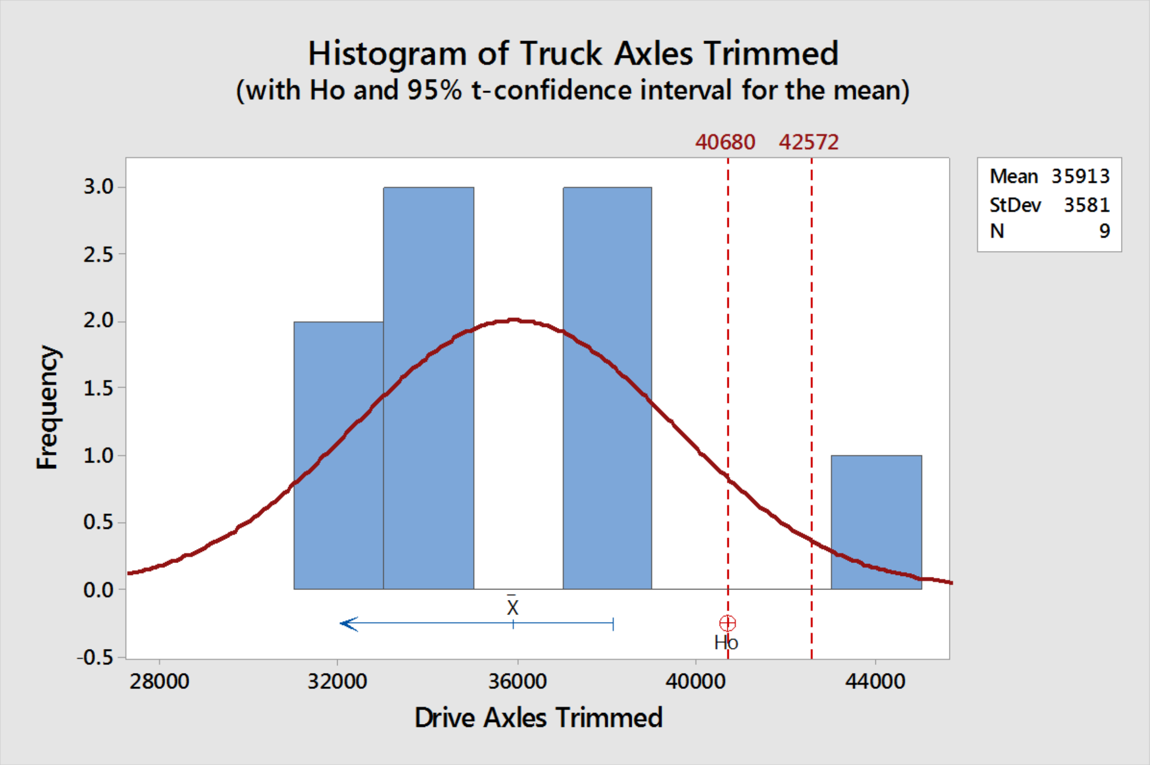
Appendix 5 - 2. Trimmed load weight distribution comparison for Georgia tandem axle weight limit - Truck.



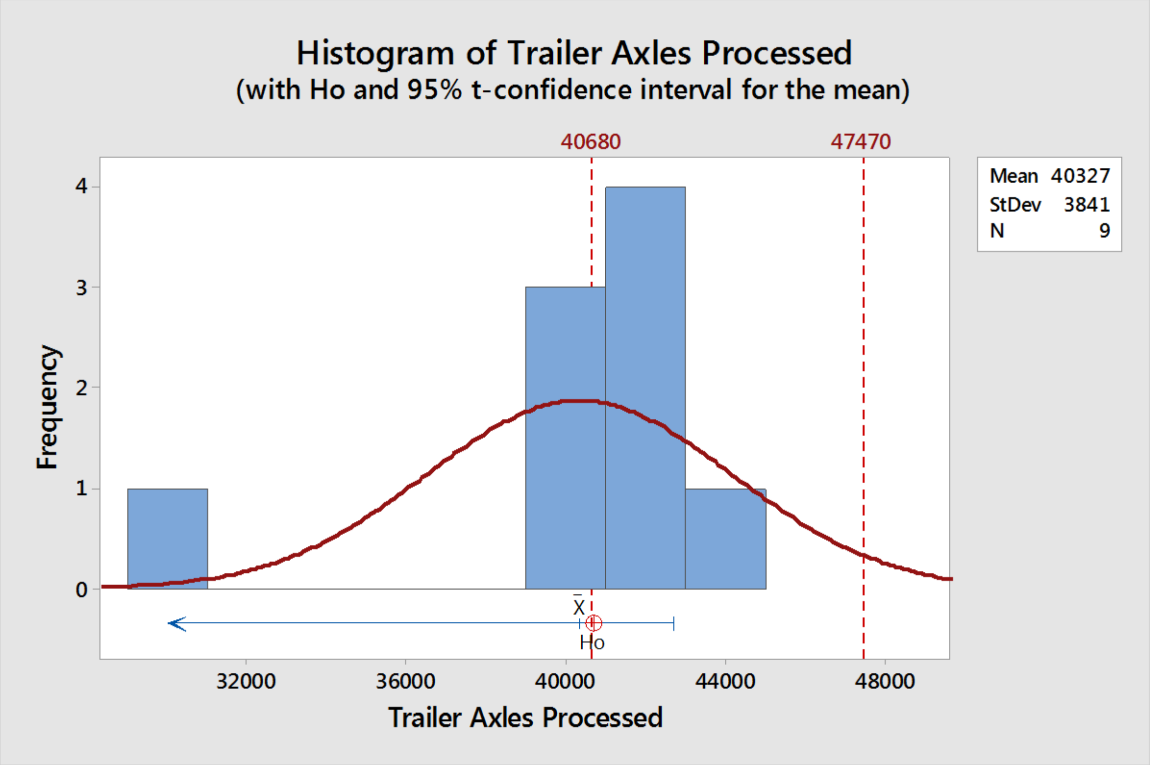
Appendix 5 - 3. Processed load weight distribution comparison for Georgia tandem axle weight limit - Truck.



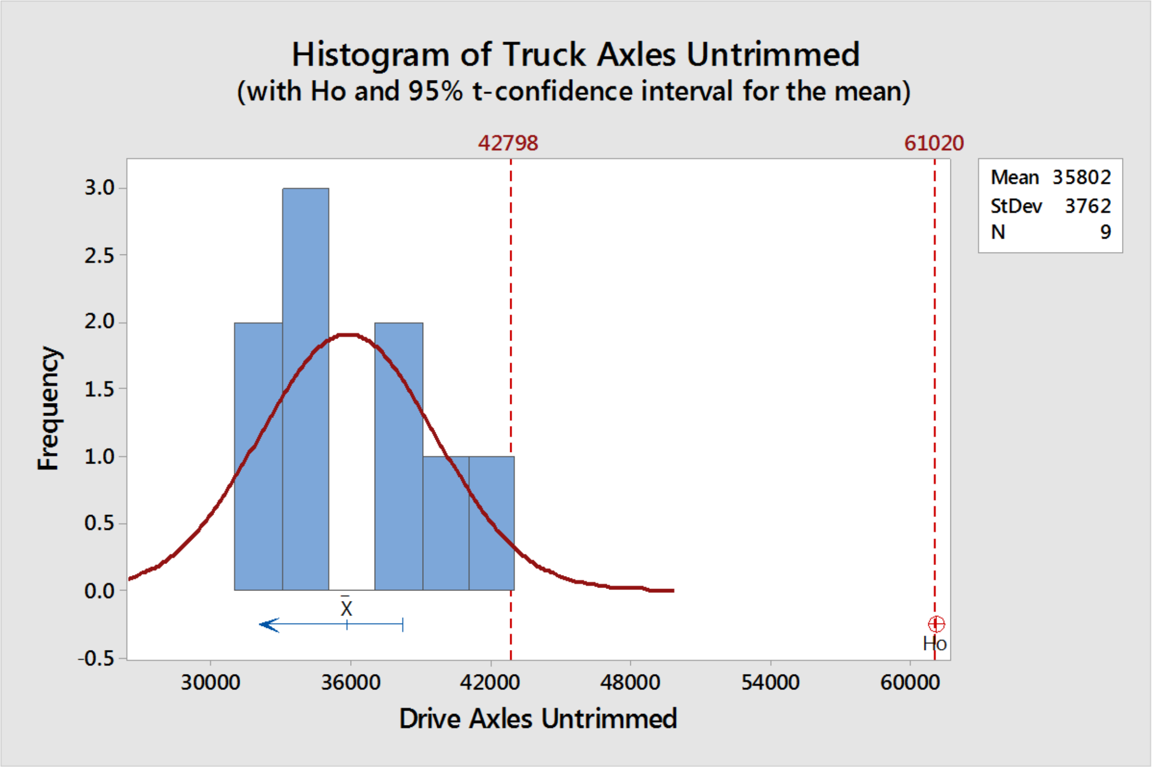
Appendix 5 - 4. Untrimmed load weight distribution comparison for Georgia tandem axle weight limit - Trailer.



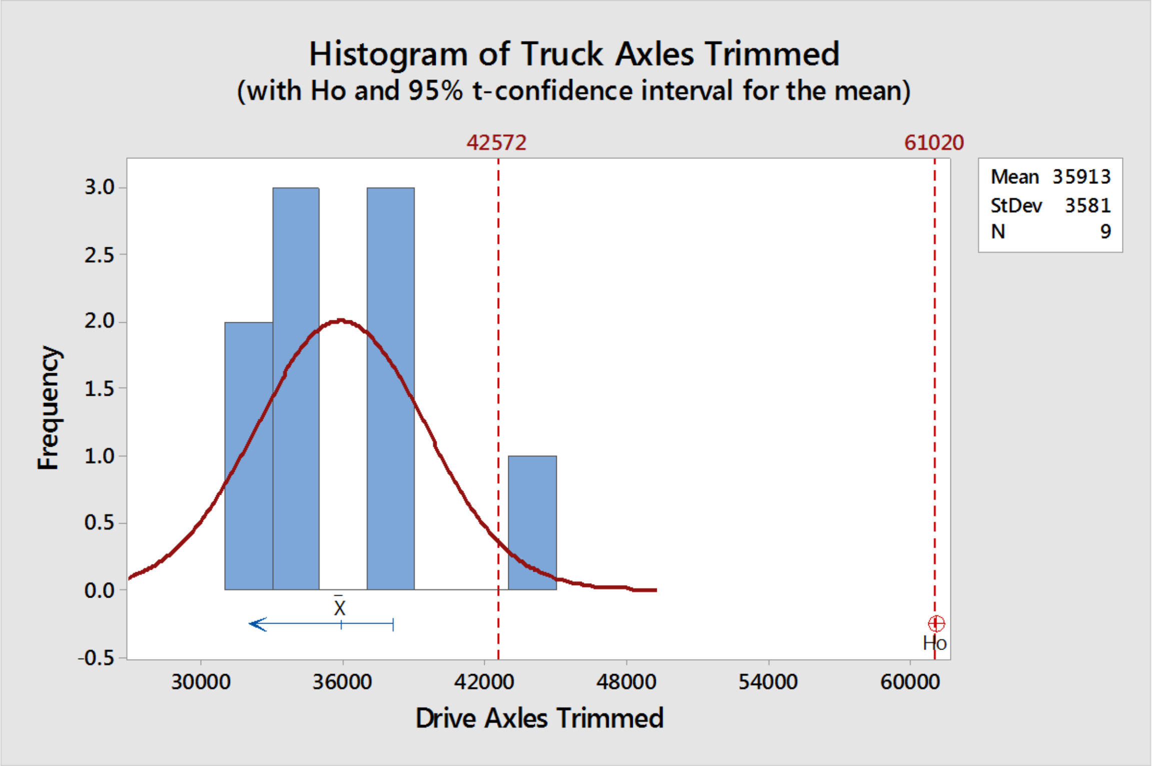
Appendix 5 - 5. Trimmed load weight distribution comparison for Georgia tandem axle weight limit - Trailer.



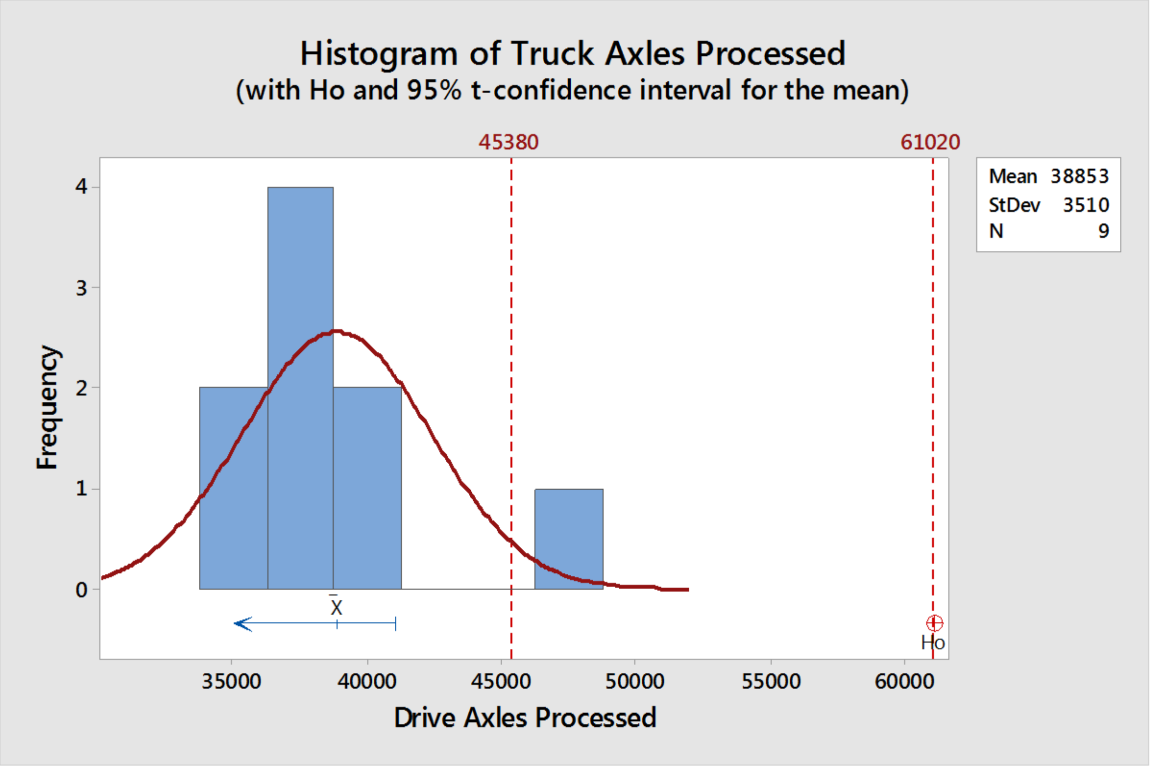
Appendix 5 - 6. Processed load weight distribution comparison for Georgia tandem axle weight limit - Trailer.



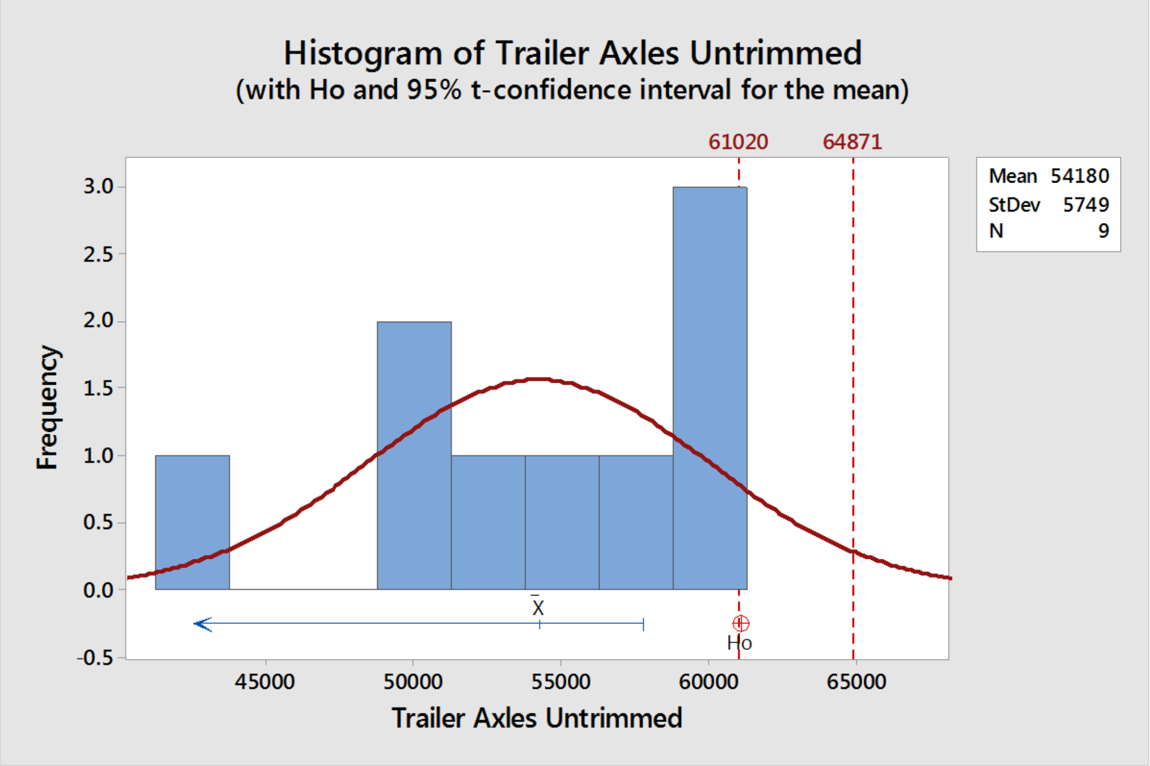
Appendix 5 - 7. Untrimmed load weight distribution comparison for Georgia tridem axle weight limit - Truck.



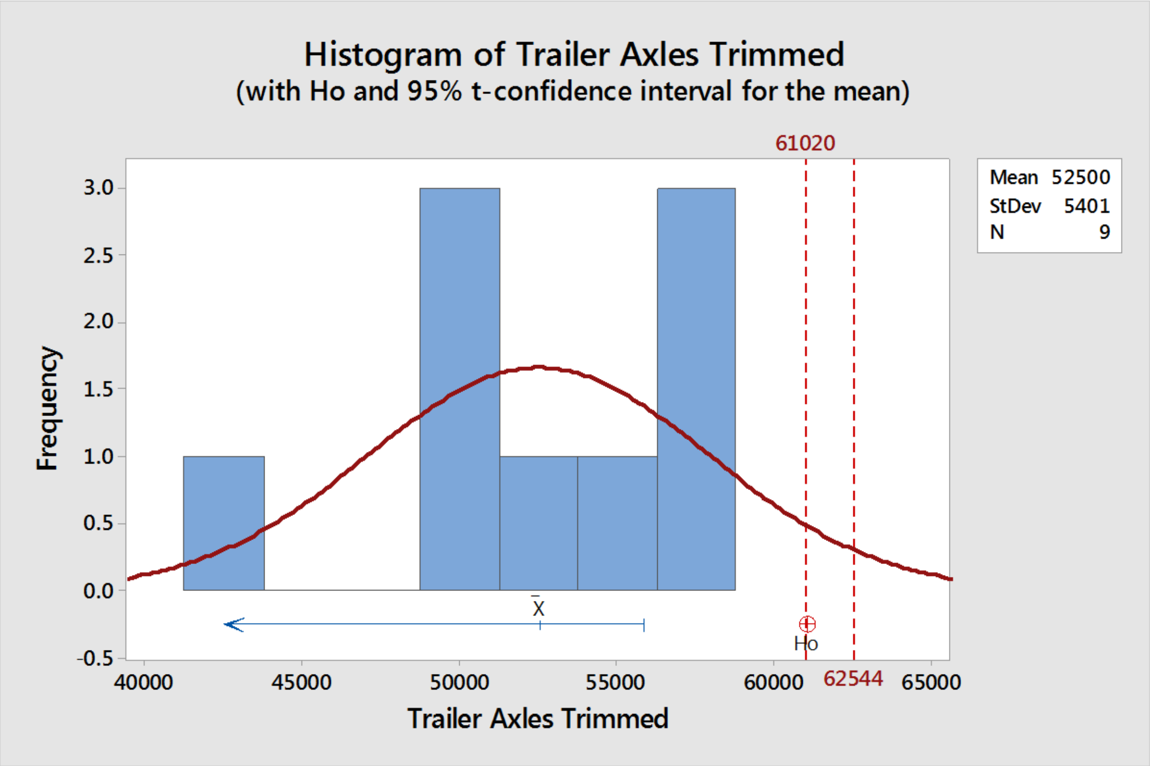
Appendix 5 - 8. Trimmed load weight distribution comparison for Georgia tridem axle weight limit - Truck.



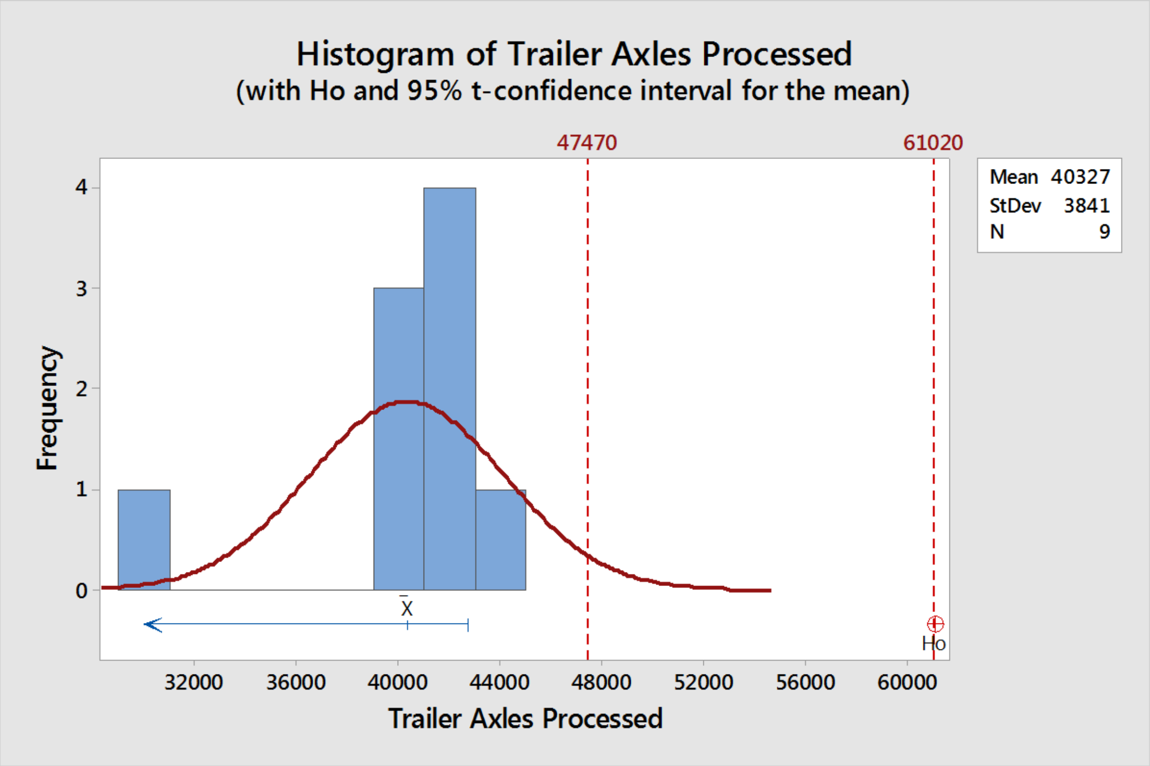
Appendix 5 - 9. Processed load weight distribution comparison for Georgia tridem axle weight limit - Truck.



Appendix 5 - 10. Untrimmed load weight distribution comparison for Georgia tridem axle weight limit - Trailer.



Appendix 5 - 11. Trimmed load weight distribution comparison for Georgia tridem axle weight limit - Trailer.



Appendix 5 - 12. Processed load weight distribution comparison for Georgia tridem axle weight limit - Trailer.