BENEFITS OF IMPLEMENTING TIRE PRESURE CONTROL SYSTEMS (TPCS) IN NORTHWESTERN ONTARIO.

by

Jayme D. Caron

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FACULTY OF NATURAL RESOURCE MANAGEMENT

LAKEHEAD UNIVERSITY

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Jayme D. Caron

An Undergraduate Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Honours Bachelor of Science in Forestry

Faculty of Natural Resource Management

Lakehead University

April 2022

Dr. Dzhamal Amishev
Major Advisor

Peter Hamilton R.P.F.
Second Reader

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ABSTRACT

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Transporting raw forest products to processing facilities is one of the highest costs of overall timber production. Many forestry contractors and log truck owners are looking for feasible ways to minimize forest road transportation costs. This study proposes a practical solution to reducing forest resource transportation costs by analyzing the costs and benefits of tire pressure control systems (TPCS) in northwestern Ontario, Canada. Data from four log-hauling contractors in the northwestern Ontario region was collected and used to compare the benefits of implementing TPCS compared to trucks without TPCS. Various models provided by TPC International, TIREBOSS Inc., and FPInnovations were used to compare the costs of log hauling with and without TPCS implemented on log trucks. The findings in this study were compared, summarized, and presented in this thesis. When implemented on log trucks, TPCS can substantially benefit the log truck owner and contractor. The main benefits come in the form of cost savings, specifically reduced tire costs, increased traction, reduced fuel consumption, and increased truck utilization. TPCS also increases truck, trailer, and tire life while lowering the income required by the truck owner to meet their costs and profit margin. Furthermore, the results of this study imply that TPCS can reduce the costs of log-hauling and therefore reduce forest transportation costs.

TABLE OF CONTENTS

LIBRARY RIGHTS STATEMENT III
A CAUTION TO THE READER IV
ABSTRACT V
TABLE OF FIGURES VII
TABLE OF TABLES VII
ACKNOWLEDGEMENTS VIII
1. INTRODUCTION 1

1.1 Objective 3
1.2 Hypothesis 3

2. LITERATURE REVIEW 3

2.1 Forest roads and forest transportation 3
2.1.1 General Costs Associated with Forest Roads and Forest Transportation 4
2.1.2 Log hauling and forest road transportation in Ontario 6
2.1.3 Seasonal weight restrictions on highways in Ontario 8

2.2 Tire Pressure Control Systems 9
2.2.1 Ownership Costs of TPCS 11
2.2.2 Operating Costs of TPCS 12
2.2.3 Benefits of Owning and Operating with TPCS 13

3. MATERIALS AND METHODS 17
4. RESULTS 21

4.1 Results for contractor A 26
4.2 Results for Contractor B 29
4.3 Results for Contractor C 32
4.4 Results for Contractor D 35

5. DISCUSSION 38
6. CONCLUSION 45
7. LITERATURE CITED 47
8. APPENDICES 50

8.1 Appendix A 51
8.2 Appendix B 57
8.3 Appendix C 63
8.4 Appendix D 69

TABLE OF FIGURES

Figure 1. Typical log truck configuration in Ontario. Source: Hajek et al. (2008)........................ 8
Figure 2. Loaded log truck consisting of three truck axles and five trailer axles with the middle two trailer axles lowered. Source: Hajek et al. (2008).. 8
Figure 3. Configuration of TPC Internationals' TIREBOSS TPCS. Source: Bradley 2009. 10
Figure 4. Tire footprint length because of reducing tire pressure. Source: Bradley 1993. 14
Figure 5. Savings per trip associated with TPCS for each contractor in this study. 22
Figure 6. Savings per year associated with TPCS for each contractor in this study. 22
Figure 7. Payback for each contractor based on their TPCS investments. 23
Figure 8. Total TPCS savings based on a 10-year TPCS hardware lifespan. 24
Figure 9. Annual operations savings for Contractor A with TPCS. 27
Figure 10. Annual operations savings summary for Contractor B. 30
Figure 11. Annual operations savings summary for Contractor C. 33
Figure 12. Annual operations savings summary for Contractor D. 36

TABLE OF TABLES

Table 1. Possible locations of TPCS on log trucks. 18
Table 2. Average change between various factors associated with log-hauling costs from all four contractors. 25
Table 3. Average benefits associated with TPCS from all four contractors. 26
Table 4. Summarized haul rate information for all contractors in this study. 26
Table 5. Comparison of various factors associated with log-hauling costs from Contractor A's 8-AXle B-train with and without TPCS. 28
Table 6. Summarized haul rate information for Contractor A. 29
Table 7. Comparison of various factors associated with log-hauling costs from Contractor B's 6-axle semi-trailer with and without TPCS. 31
Table 8. Summarized haul rate information for Contractor B. 32
Table 9. Comparison of various factors associated with log-hauling costs from Contractor C's 6-axle semi-trailer with and without TPCS. 34
Table 10. Summarized haul rate information for Contractor C. 35
Table 11. Comparison of various factors associated with log-hauling costs from Contractor D's 6-axle semi-trailer with and without TPCS. 37
Table 12. Summarized haul rate information for Contractor D. 38

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1. INTRODUCTION

Extracting forest products is a complex problem that requires successful planning and implementing forest harvesting practices and forest transportation (Akay and Suslu 2017). Among all forest harvesting and extraction activities, it is well known through literature that the transportation of wood is one of the highest costs in forestry, making up approximately 40% of total timber production costs (Akay et al. 2021, Akay and Suslu 2017). However, forest roads are critical infrastructures in Northwestern Ontario that allows access to many recreational areas along with access to forest resources. This thesis proposes a feasible solution to minimizing forest road transportation costs by completing a study in northwestern Ontario on the application of Tire Pressure Control Systems (TPCS) on log trucks. Implementing TPCS on log trucks has the potential to reduce the costs of forest road transportation.

Generally, log transportation includes four segments: unloaded on highway, unloaded off-highway, loaded off-highway, and loaded on highway. Typically, log trucks complete over 600 log-haul cycles a year, accumulating over 100,000 km of varying percentages of on and off highway use (Almin and Bradley N/A). Commonly tire inflation pressures on log trucks are set for the vehicle to carry its full payload at highway speeds (Bradley 1993). However, when the vehicle is partially loaded, empty, or traveling at lower speeds its tire pressures are over inflated for the given operating conditions (Bradley 1993). Over-inflated tire can be detrimental to operator ergonomics, tire wear, the road, and result in more tire punctures. Log trucks are constantly being loaded and unloaded and drive on a wide range of road surfaces which results in numerous opportunities for varying tire pressure. TPCS is an effective and efficient way to optimize tire pressure to suit the load weight, road surface and desired speed (Bradley 1993, Bradley 2009).

TPCS are on-board systems that allow the operator of the vehicle to alter and monitor tire pressures to optimally suit the road conditions, vehicle payload, and speed (Bradley 2009). The goal of TPCS is to change the tire pressure to provide the maximum benefit for any given load, speed, or road condition (Altunel and Hoop 1998). This concept is becoming increasing popular in the forestry industry for log hauling as there are many benefits to implementing TPCS on log trucks (Almin and Bradley N/A). TPCS can improve operator ergonomics, reduce vehicle maintenance due to shock and vibration reduction, improve tire life, and improve the ability of log trucks to drive on rougher roads (Kreyns 1994). Log trucks equipped with TPCS can efficiently drive down roads where less maintenance has been done, therefore reducing the amount of road maintenance required. The benefits of implementing TPCS on log trucks can increase the overall efficiency of log trucks, thus decreasing the overall cost of transportation on forest roads.

In this study, I wanted to look at various ways of minimizing transportation costs on forest roads by examining the cost and benefits of implementing TPCS on log trucks in a Northwestern Ontario setting. This study will include how the benefits of owning and operating log trucks equipped with TPCS outweigh the costs. This will be done by collecting data from various log truck owners in Northwestern Ontario and utilizing their data in an annual cost savings model provided by TPC International and FPInnovations. The model will develop a series of annual savings associated with TPCS usage on log trucks and provide a payback period estimate based on the results.

1.1 OBJECTIVE

The overall objective of this thesis is to determine the benefits of implementing TPCS in a Northwestern Ontario setting. This will be done by quantifying the costs and benefits of using TPCS in log hauling operations in Northwestern Ontario. The findings of this thesis will ideally result in a feasible solution to minimizing transportation costs on forest roads while increasing the truck owner's savings.

1.2 HYPOTHESIS

I hypothesize that the benefits resulting from implementing TPCS on log trucks will outweigh the associated costs, making TPCS a feasible option to reduce forest road transportation costs in Northwestern Ontario.

2. LITERATURE REVIEW

2.1 FOREST ROADS AND FOREST TRANSPORTATION

A forest road is an engineered structure constructed to provide access to forested areas where there will be ongoing forestry-related operations (Pulkki 2003, Akay et al. 2020). Forest roads can be broken up into three international categories: primary, secondary, and tertiary (Pulkki 2003). Some major factors affecting the type of forest road to be constructed include the desired road category, terrain conditions, the volume of wood to be removed from the area, and environmental protection factors (Pulkki 2003). Access to forest resources is the first step in the forestry industry and forest supply chain, and a well-planned and designed forest road can be a valuable asset to increase investment returns (Pulkki 2003, Boston 2016, Keramati et al. 2020). The development and maintenance of forest roads have positive and negative effects. Many benefits include improved access for industrial use and non-consumptive resources such as access to outdoor recreation areas (Boston 2016, Keramati et al. 2020).

Typically, the transportation of raw forest products is done by using specialized logging trucks (Akay and Suslu 2017). Road slope, road length, and road condition are all factors that will affect the efficiency of forest transportation, and to improve efficiency, log hauling time should be minimized (Akay and Suslu 2017). One way to minimize forest road transportation time is to improve road standards to allow log trucks to safely drive faster. However, improving road standards is not cheap (Akay and Suslu 2017). Although forest roads provide access to outdoor recreation and forest resources that are crucial to local and national economies, they also have extensive associated costs.

2.1.1 General Costs Associated with Forest Roads and Forest Transportation

When it comes to forest roads, there are many variables affecting the cost of the wood being harvested. Road construction costs and road maintenance costs are viewed as fixed costs (Silva et al. 2016). However, there are also many uncontrollable variables that fluctuate considerably and dictate the cost of log hauling. One main cost associated with forest roads in forestry operations is log hauling (Kuloglu et al. 2019, Pulkki 2003). These costs are determined by the utilization of log trucks, which can further be broken down into different categories, including empty truck driving speed, loaded truck driving speed, average load size, and average load cycle time (Pulkki 2003, Akay and Suslu 2017).

Generally, direct costs of transporting wood are closely related to the required transport distance and forest road quality, as these will directly affect travel time

(Kuloglu et al. 2019, Lopez et al. 2010, Akay et al. 2020). On top of external influences, total log truck transportation costs include truck maintenance, capital improvement, and operating costs (Keramati et al. 2020). Maintenance and capital improvement will vary from truck to truck, whereas operating expenses of log truck transportation are influenced by average fuel price, hourly wage of drivers, and insurance costs (Keramati et al. 2020). For instance, Keramati et al. (2020) found that the cost of operating a log truck without additional aftermarket products ranges from $1.76/km CAD to $1.85/km CAD. Notably, this cost will vary with different terrain conditions, current road conditions, and percent highway to percent forest road ratio per trip (Keramati et al. 2020).

To ensure that empty and loaded log trucks are able to safely drive at desired speeds, regular road maintenance is required (Pulkki 2003, Silva et al. 2016, Kuloglu et al. 2019). The purpose of forest road maintenance is to increase the road quality and extend the life of forest roads (Ryan et al. 2004). Proper road maintenance ensures that forest resources can be extracted with minimal damage and increased log truck speed. The amount and type of surface material present will dictate the level of maintenance required (Ryan et al. 2004). Maintenance on forest roads should be done regularly to ensure a constant flow of log trucks, optimizing the return on the forest products being extracted (Ryan et al. 2004). For instance, Silva et al. (2016) noted that fixed road maintenance costs vary depending on the respective road class and that maintenance costs generally range from $1,100/km CAD - $3,300/km CAD. Road maintenance costs are correlated with the surface materials used and the class of road being maintained (Silva et al. 2016, Akay et al. 2020).

When considering forest road costs, the forest road network can be constructed so that excessive maintenance is not needed, minimizing high total road costs (Akay et al. 2020). Forest transportation costs will increase in areas where the road network is poorly designed and road standards are low. However, Akay et al. (2020) noted that improving road standards can be costly. Hence, an evaluation of desired log truck speeds and forest road standards needs to be done to optimize investment return.

Active forest management and forest resource extraction rely on forest roads for transportation (Boston 2016). Forest road standards are typically based on the merchantable volume of forest resources being extracted from the area forest harvest (Boston 2016). A road could be built to a lower standard, resulting in savings in construction costs. However, lower road standards result in higher log haul costs due to longer travel times and rougher driving conditions (Boston 2016, Akay et al. 2021). Nonetheless, there are technologies such as TPCS that can improve a log truck's ability to drive on roads with lower standards, and previous literature has suggested implementing the use of TPCS on log hauling vehicles can decrease forest road transportation costs (Bradley 2009, Jokai and Bradley 2000, Kreyns 1994).

2.1.2 Log hauling and forest road transportation in Ontario

Most forestry operations in Ontario occur in Northern Ontario (Hajek et al. 2008). Many communities in Northern Ontario are dependent on the forestry industry for economic security and local jobs (Hajek et al. 2008). Raw forest products are transported from forested areas to processing facilities or mills using trucks on forest access roads and provincial highways (Hajek et al. 2008). Ontario has over 100,000 kilometers of forest access roads used for log hauling. To ensure log hauling is economically viable, trucks and trailers are configured to take full advantage of allowable Ontario vehicle weights dimension restrictions (Hajek et al. 2008). In Ontario, vehicles used to haul logs typically consist of three axle trucks and five axle trailers. The truck consists of tandem drive axles and a single steer axle, while the trailer consists of three rear axles and two liftable axles near the tandem axles of the truck (Hajek et al. 2008).

The liftable axles in the middle of the trailer can be raised or lowered to aid in navigating through difficult terrain on rough forest roads (Hajek et al. 2008). These liftable axles allow the load to be transferred to the tractors drive axles which can improve traction in poor road conditions (Hajek et al. 2008). Figure 1 displays a picture of a log truck consisting of three truck axles and five trailer axles. In this image, the front two axles on the trailer are lifted. Furthermore, Figure 2 displays a loaded log truck consisting of the same configuration, with the liftable axles on the trailer lowered. A typical logging truck in Ontario operates at the Gross Vehicle Weight of approximately 61,000 kg. The configuration of log trucks attempts to optimize the weight distribution on log trucks. There are many configurations of log trucks. However, this configuration is the most wide used in Ontario (Hajek et al. 2008).

Figure 1. Typical log truck configuration in Ontario. Source: Hajek et al. (2008).

Figure 2. Loaded log truck consisting of three truck axles and five trailer axles with the middle two trailer axles lowered. Source: Hajek et al. (2008).

2.1.3 Seasonal weight restrictions on highways in Ontario

All Canadian highway agencies restrict the weight limits on heavy vehicles during the spring thaw period (Hajek et al. 2008). Restrictions are put in place to minimize the damage to roads as thawing subgrade road layers makes roads vulnerable to heavy loads (Hajek et al. 2008). Regulations include restrictions in allowable weights per axle are implemented during the spring thaw period to ensure minimal damage is done to road structures (Hajek et al. 2008). The spring thaw period typically ranges from March 1 to May 31, and the maximum allowable weight per axle with dual tires is reduced from 10,000 kg to 5,000 kg. More than two trips may be required to transport the same payload during reduced weight periods, often resulting in log hauling businesses suspending their operations for spring break up (Hajek et al. 2008).

However, when the ground is fully frozen, there are regulations in some jurisdictions that allow an additional 10% of allowable axle weight for vehicles being used to extract raw forest products (Hajek et al. 2008). This increase in weight of raw forest product allowance during frozen periods is to account for additional moisture content in wood that gets trapped and freezes during the cold winter month (Hajek et al. 2008). This 10% increase in allowable axle weight helps improve productivity when the roads are the most solid (Hajek et al. 2008). In turn, this allows the forestry industry to take advantage of this allowance before the freeze-up period is over and the spring thaw starts (Hajek et al. 2008). The typical length of the freeze-up period is between December to early March depending on local conditions (Hajek et al. 2008).

2.2 TIRE PRESSURE CONTROL SYSTEMS

TPCS was developed for use with commercial vehicles to improve mobility of transportation on poor road conditions (Ghaffariyan 2017, Bradley 2009). TPCS is a complex on-board system that allows the operator to change the vehicle's tire pressure while in motion (Menzies 2006, Stuart et al. 1987, Jokai and Bradley 2000, Ghaffariyan 2017). TPCS are a newer system that has evolved from the simpler Central Tire Inflation Systems (CTIS) introduced to North America early in the 1990s (Bradley 2009). TPCS's were developed to incorporate more safety features than the previous CTIS (Bradley 2009). Although there are many manufacturers of TPCS, there are two main manufacturers in North America. These manufacturers are Dana Spicer

Corporation and Tire Pressure Control International Inc (Bradley 2009, Ghaffariyan 2017).

Generally, TPCS are made up of three components: the operator control system, a valve control assembly, and air transfer lines attached to the tires with TPCS (Bradley 2009, Ghaffarivan 2017). The operator control system will display the current tire pressure of the vehicle and provide the operator control over the vehicles tire pressure (Bradley 2009). Often, there are pre-programmed operating modes that can be programmed into the operator control to allow for the efficient change of the vehicle's tire pressure while the vehicle is in motion (Bradley 2009). The valve control assembly measures the tire inflation and varies its pressure by deflating or inflating given the operator's desires (Bradley 2009). Furthermore, the vehicles compressed air supply typically comes from the air brake systems and is used in various air transfer lines to link the valve control assembly to the tires so they can be inflated or deflated (Bradley 2009). An example of TPC International TIREBOSS TPCS is displayed below in Figure 3. This figure shows the configuration of air supply lines, the valve control assembly, and the operator control.

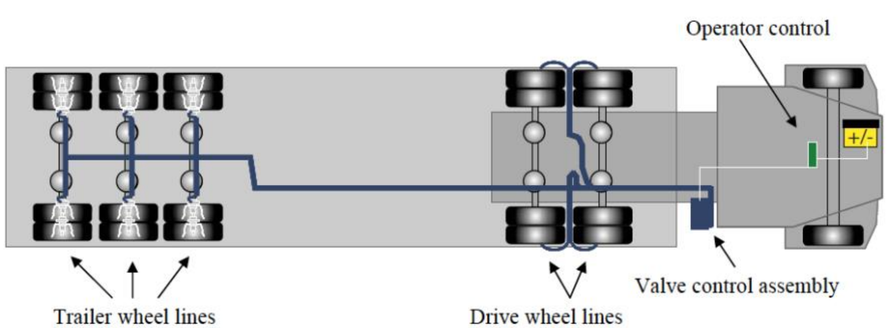


Figure 3. Configuration of TPC Internationals' TIREBOSS TPCS. Source: Bradley 2009.

Furthermore, TPCS's have many uses ranging from highway and urban applications, agricultural use, military operational use, and forestry transportation. When it comes to forestry operations and forest transportation, there is a relationship between tire pressure and forest haul costs (Munro and MacCulloch 2008). TPCS allows the driver to adjust the tire pressure to best suit the given road surface conditions while in motion (Stuart et al. 1987, Menzies 2006, Bradley 2000). A tire's pressure can be lowered on a forest road to improve traction and control then raised again when the truck reaches the highway. Reducing tire pressure on non-paved roads increases the tire to soil contact area and reduces the amount of stress the vehicle applies to the road surface (Bradley 2009). TPCS is an effective and proven technology in North America, and although the benefits of TPCS are well documented through literature, it is important to know the associated costs and understand the positive effects that have.

2.2.1 Ownership Costs of TPCS

Jokai and Bradley (2000) indicated that the purchase price of TPCS ranges from CAD $10,000 to CAD $27,000. Likewise, Munro and MacCulloch (2008) noted that in Scotland, the purchase and installation prices ranged from CAD $6,800 to CAD $26,000. The cost will depend on the number of axels equipped, the system manufacturer, and the number of zones being controlled (Jokai and Bradley 2000, Ghaffariyan 2017, Munro and MacCulloch 2008). For the most part, TPCS are aftermarket systems that can be transferred from truck to truck, and generally, tire pressure systems outlast the life of the truck that they are equipped on (Menzies 2006). Typical TIREBOSS TPCS last on average 10 or more years (Tireboss 2021), while the average tractor life ranges from three to seven years (Jokai and Bradley 2000). Removal of the system costs approximately $1,000, and re-installation costs about $3,000 (Jokai and Bradley 2000). Furthermore, Jokai and Bradley (2000) noted that, on average, a 3.3-year-old TPCS system has an approximate salvage value of 18.5-40% of its original purchase price, while a 6.7-year-old TPCS has a 5-15% salvage value. Given a magnitude of factors, Jokai and Bradley (2000) estimated the ownership costs of a TPCS ranges between $1.37 per machine hour $3.35 per machine hour.

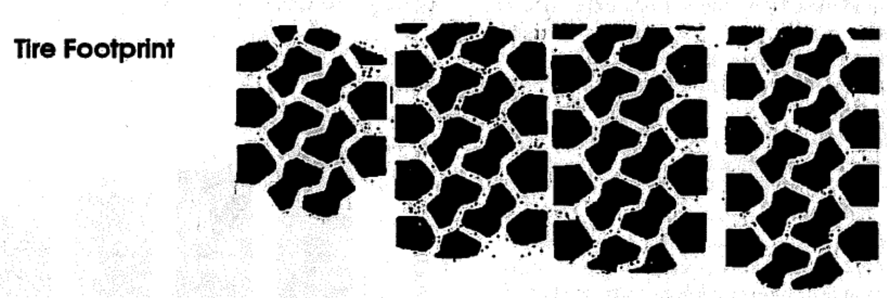
2.2.2 Operating Costs of TPCS

Operating costs of a log truck include fuel, oil, maintenance, and repairs. Notably, fuel is the costliest factor of owning and operating a log truck (Keramati et al. 2020, Menzies 2006). Generally, on hard surfaces, for every ten psi that a truck's tires are underinflated, the fuel economy is reduced by 1% (Ghaffariyan 2017). However, due to the ability to optimize tire pressure for various road surfaces, TPCS can decrease fuel consumption by 1-3% on vehicles that switch between paved and non-paved roads (Kreyns 1994). Nonetheless, with all factors considered, Jokai and Bradley (2000) found that operating costs of TPCS range from $2.35 per machine hour to $5.11 per machine hour, depending on the system configuration and utilization of the truck. It is important to note that third-party add-ons such as upgraded air systems will also decrease the operating costs (Jokai and Bradley 2000, Ghaffariyan 2017). Although the costs of owning and operating trucks equipped with TPCS may be high, in many cases, the benefits of utilizing TPCS outweigh the costs of owning and operating trucks equipped with TPCS.

2.2.3 Benefits of Owning and Operating with TPCS

Operating with lower tire pressure on forest roads increases the tire's surface area and creates a larger tire footprint (Menzies 2006, Kreyns 1994). The thickness of structural and surface road material can be reduced for trucks with lower tire pressures (Stuart et al. 1997), reducing the cost of road construction. Likewise, vehicles equipped with TPCS have been proven through previous literature to outperform vehicles without TPCS on wet or soft road conditions (Stuart et al. 1987, Jokai and Bradley 2000). Due to this fact, log trucks equipped with TPCS can increase the mobility of log trucks and therefore, potentially extend the hauling season.

Optimal tire pressures create an optimal tire footprint for varying road surface conditions. This optimal tire footprint will further reduce stress to both the road surface, the vehicle, and the operator, while increasing traction and reducing tire bounce (Altunel and Hoop 1998). Figure 4 provides a visual representation of how reducing tire pressure can increase a tires footprint. Lowering tire pressure on forest roads will result in more surface-engaged tire thread and the road contact pressure (Woodroffe and Dovile 1997). Additionally, Bradley (1991) found that by lowering tire pressures to match road conditions and speed, wheel hops and log truck spinouts were significantly reduced. This implies that tires using optimal tire pressure will allow log trucks to climb further, slip less, and cause less road damage (Bradley 1991, Altunel and Hoop 1988, Steward 1994). The use of optimal tire pressure via TPCS creates shallower ruts with slopped edges which promotes drainage, therefore reducing the road surface erosion (Woodroffe and Dovile 1997). Lowering tire pressure to match the road and load conditions can decrease rutting by a factor of two and increase traction from 10-42% (Bradley 1991, Steward 1994).



Tire Pressure	**620 kPa**	**414 kPa**	**310 kPa**	**207 kPa**
Print Length	**25.8 cm**	**32.0 cm**	**33.8 cm**	**36.3 cm**
Deflection	**8.5%**	**15%**	**23%**	**30%**

Figure 4. Tire footprint length because of reducing tire pressure. Source: Bradley 1993.

The use of TPCS can influence a truck's fuel consumption in various ways (Bradley 2009). When traveling on unpaved forest roads, fuel consumption is strongly correlated with vehicle speed, floatation, and wheel slip (Bradley 2009). TPCS increases tire floatation on forest roads, decreases the amount of wheel slip, improves traction, and reduces rutting on resulting in an increase in fuel efficiency (Bradley 2009, Munro and MacCulloch 2008). By using optimal tire pressure for different road surfaces, various literature suggests that fuel efficiency can be increased by 1-10% depending on the road surface (Bradley 2009, Munro and MacCulloch 2008, Kreyns 1994). As road surfaces deteriorate, the fuel consumption benefits of using TPCS increase. Surcel (2010) suggested that on average log trucks using TPCS show a 6% increase in fuel efficiency when empty on gravel roads, 14% increase in fuel efficiency with empty truck on muddy roads, and up to 30% increase in fuel efficiency on muddy roads when the truck is loaded. However, Surcel (2010) noted that driver skill and experience can significantly affect these results.

Other than fuel, tires are the highest cost for industrial trucks. Various literature has suggested that CTIS and TPCS can improve tire life by 30-40% (Menzies 2006; Stuart et al. 1987). This additional life comes in the form of slower tread wear, fewer tire punctures, the ability to re-inflate punctured tires, less chaining required, and fewer callouts for tire service (Bradley 2003; Stuart et al. 1987). Additionally, forest road maintenance can be reduced by up to 60% when using trucks equipped with TPCS (Menzies 2006, Stuart et al. 1987), as lower tire pressures decrease road degradation. Furthermore, vehicles equipped with TPCS can increase driving speeds on rougher roads, minimizing the cycle time for each log truck and increasing the utilization of log trucks (Stuart et al. 1987, Jokai and Bradley 2000). Reduced cycles times and improved utilization are both key factors in minimizing the cost of forest road hauling. Moreover, literature has suggested TPCS can mitigate adverse defects that trucks may have on forest roads.

Using TPCS to optimize tire pressure according to the road surface type has been shown to improve road quality in various ways (Jokai and Bradley 2000, Stuart et al. 1987, Menzies 2006, Kreyns 1994, Ghaffariyan 2017, Altunel and Hoop 1998). This includes reduced rutting, washboard, and loss of sedimentation. Through literature, it is well known that TPCS's and CTIS's allow trucks to drive on roads with lower standards (Jokai and Bradley 2000, Stuart et al. 1987, Menzies 2006, Kreyns 1994 Ghaffariyan 2017). In various field tests, Steward (1994) showed that lowering tire pressures on off-highway roads results in less road damage. For instance, lower tire pressure on off-high roads can result in 20 - 30 percent less aggregate material required, 50-90 percent reduction in required road maintenance, and 7-8 percent increase in vehicle gradeability (Steward 1994). Therefore, trucks equipped with TPCS have the potential to minimize road construction and road maintenance costs. Additionally, TPCS also dramatically increases the ergonomics of trucks, making it easier to find and keep drivers.

Finding and keeping log truck drivers is a crucial component to sustaining a constant flow of timber to mills. Trucks equipped with TPCS's will noticeably drive smoother than those without (Munro and MacCulloch 2008, Steward 1994). Furthermore, a group of operators interviewed by Munro and MacCulloch (2008) noted that they felt improved traction, less wheel spin, and more comfortable rides. Likewise, in a study conducted by Steward (1994), drivers reported a more comfortable ride in log trucks equipped with TPCS compared to those without, especially on embedded rock, potholes, and washboards. Drivers also reported less tension in their bodies and less fatigue when driving log trucks with optimized tire pressure around a control track (Steward 1994). TPCS's enhance vehicle safety by maintaining tire pressures which optimizes traction and braking on forest roads (Bradley 2009). As a result of these features, Munro and MacCulloch (2008) noted that timber hauling vehicles equipped with TPCS were less likely to be involved in accidents.

Through my study for this thesis, I am going to attempt to verify what I have found in my literature review. This is going to be done by attempting to quantify the benefits of installing TPCS on log trucks in a Northwestern Ontario setting. A detailed description of what is going to be done is provided in the Materials and Methods section.

3. MATERIALS AND METHODS

This study will be conducted in Kenora, Ontario, in December 2021, and January 2022. For this study, various log truck owners and operators in the Kenora area were asked to participate. The owners and operators chosen for this study were selected based on their willingness to participate. This study attempts to quantify the benefits of using TPCS on log trucks in Northwestern Ontario by using an Excel spreadsheet model of annual operational savings when TPCS is equipped. This model was generously provided by TPC International and will be used to compare the cost and benefits of implementing TPCS on the various log truck owners and operators selected. The model was developed to estimate the potential benefits of installing TPCS on log trucks regarding log hauling operations in forestry. The output results of this model are based on expert research, field trials, and field experience that best quantifies the annual savings of TPCS. The model user can input values into specified cells on the spreadsheet to produce potential savings resulting from installing TPCS. The model is further broken down into various main sections to define the potential savings of using TPCS. These main sections include TIREBOSS price data, tire and maintenance savings, traction benefits and savings, fuel savings, and savings due to increased utilization. Through each of these sections, the user can input their data to determine the benefits that TPCS would provide them. It is important to note that if the input user has insufficient data, the model has default values based on expert research and field studies that can be used.

The first part of this model is TIREBOSS data, where the TPCS hardware and installation costs are defined. This is based on where on the log truck owners will be installing their TPCS hardware. A list of possible locations for TPCS hardware can be seen below in Table 1. To accurately assess the benefits of installing TPCS, each owner and operator participating in this study will be asked to define which axles on the truck and trailers have or will have TPSC hardware. Next, they will be asked if they have any aftermarket air compressors installed or would like one installed. Once each of these sections is filled out, the province in which the hardware was purchased must be disclosed to ensure applicable taxes are included in the model.

Table 1. Possible locations of TPCS on log trucks.

TPCS location
Single steer axle of truck
Tandem steer axle of truck
Single drive axle of truck
Tandem drive axle of truck
Tridem drive axle of truck
Single axle trailer
Tandem axle trailer
Tri-axle trailer
Quad-axle trailer
Single axle second trailer
Tandem axle second trailer
Triaxle second trailer
Quad-axle second trailer

Source: TIREBOSS annual operations savings cost model.

The next part of the model concerns tire maintenance and tire repair savings associated with using TPCS on log trucks. Tire maintenance savings are calculated by determining the tire cost for the truck and trailer per year, then determining the number of tires that require recapping each year. Additionally, the model has a default value for each tire casing and a default average tire recap rejection rate, although local numbers can be used if applicable. Next, the model considers the labour cost of manually checking and adjusting tire pressures. Owners and operators will be asked to disclose labour rates and how many times a year this is done. Then this data will be put into the model to determine annual savings as TPCS automatically maintains tire pressure. Following this, the yearly savings from fewer tire failures leading to “roadside” or “inhouse” service calls will be determined by inputting the annual number of service calls per truck, the typical delay time of these services, the cost of new tires, and the standard labour charge. The model estimates that a specific reduction in the percentage of service calls required when TPCS is equipped on log trucks to calculate savings. The model also provides a section for miscellaneous savings regarding tire maintenance, where owners/operators can input any benefits, they felt were missed by the previous sections.

To quantify the benefits of improved traction when using TPCS, the model is based on how many times a truck gets stuck annually without TPCS. To obtain data to input into the model, owners and operators will be asked to provide data regarding how many times their truck gets stuck and requires assistance from another vehicle each year. This will include the local hourly cost of the equipment or vehicle used to assist the stuck log truck and the productive time lost by the log truck and assisting vehicle. Once the above information is input into the model, there is a default percentage for reducing assistance needed when TPCS is installed. Furthermore, annual tire savings from less chain wear due to less chain use can be determined by the cost of chains per truck. Additionally, another section allows for any other anticipated savings that may occur as a result of traction improvements.

The model requires the input of average fuel consumption, the average cost of local fuel, and average annual distance travel annually to quantify fuel savings. It is important to note that the user can select the percentage of off-highway driving to assess fuel consumption more accurately. The model then assumes a certain reduction percentage in fuel consumption when TPCS is equipped to determine the annual savings regarding fuel consumption.

TPC International's model uses the current annual operating hours, haul rate in $/tonne-hr, and payload of the given log truck in tonnes to quantify the benefits of potential increased hours. The owners/operators will be asked to disclose this data, and from there, the total annual revenue is calculated. Next, the model has default values to quantify the anticipated increase in annual operating hours when TPCS is equipped. The anticipated increase in revenue is then compared to the total annual revenue mentioned earlier to determine the benefits of TPCS extending the hauling season by allowing trucks to drive on roads of a lesser standard.

This model also provides a simple payback period calculation that allows the user to determine the benefits of investing in TPCS technology. This is done by depicting the operational savings from increased tire life, reduced vehicle maintenance, reduced fuel costs, and increasing utilization of log trucks.

Furthermore, a more updated TPCS costing model was also generously provided by FPInnovations and TPC International for the purposes of this study. This updated model used the same inputs collected from each contractor and provides a more detailed analysis of the benefits and owning and operating a log truck with TPCS compared to without. Using the values developed from these two TPCS excel models, accurate estimates of costs and benefits of TPCS were analyzed and discussed.

4. RESULTS

While data was collected from various contractors, some participants wished to remain anonyms. Each participant will be referred to as Contractor A, Contractor B, Contractor C, Contractor D from this point onwards. Furthermore, only results with notable changes are presented in this section. All results for each contractor can be viewed in Appendix A, Appendix B, Appendix C, and Appendix D.

Below, Figure 5 outlines the savings per trip for each contractor when using TPCS compared to not using TPCS. Contractor A was estimated to save $72.34 per trip, and Contractor B is expected to save $70.25 per trip. Meanwhile, Contractor C would save $50.67 per trip, and Contractor D would save $64.25 per trip. Further, Figure 6 depicts each contractor's estimated annual savings per year using TPCS. Contractor D is estimated to save the most out of all four contractors in this study, with $28,142 annually. Contractor C is estimated to save the least with $14,796 in annual savings. Contractor A is estimated to save $21,268 annually, and Contractor B is expected to save $20,513.

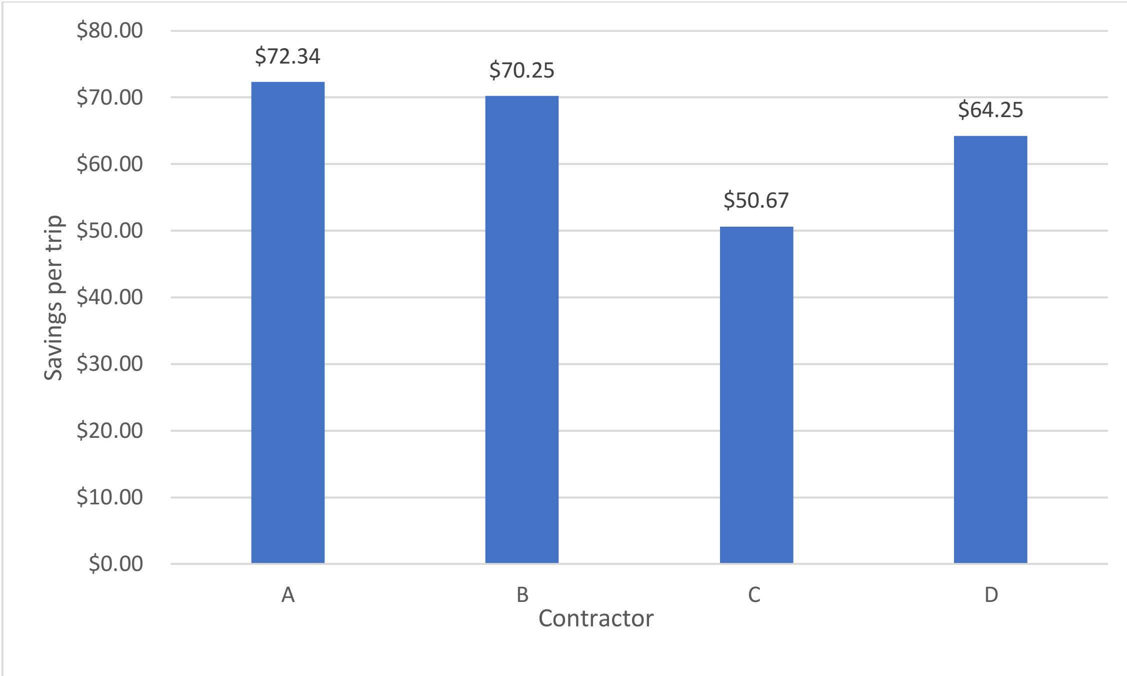


Figure 5. Savings per trip associated with TPCS for each contractor in this study.

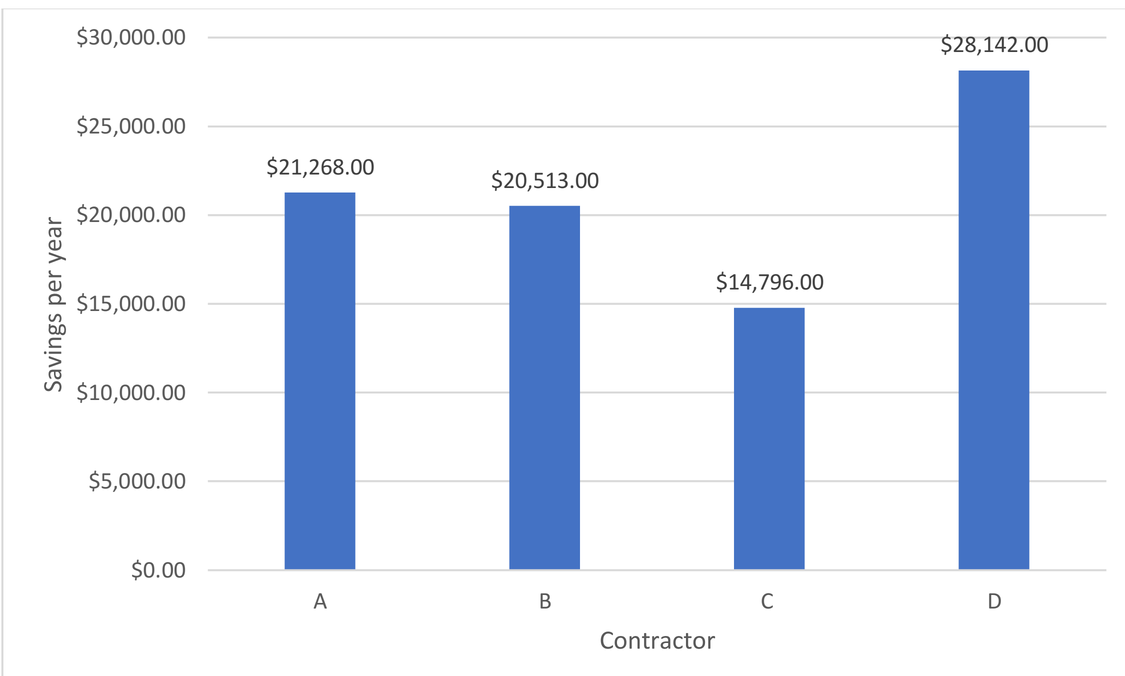


Figure 6. Savings per year associated with TPCS for each contractor in this study.

An estimated payback period for each contractor was also determined based on the savings associated with TPCS. Figure 7 shows each contractor's estimated payback period. Contractor A's TPCS investment cost $27,000, and their estimated payback period is 1.27 years. Contractor B's TPCS investment cost $21,600, and their estimated payback period is 1.05 years. Contractor C's TPCS investment cost $21,600, and their estimated payback period is 1.46 years. Furthermore, contractor D's TPCS investment cost $21,600, and their estimated payback period is 0.77 years.

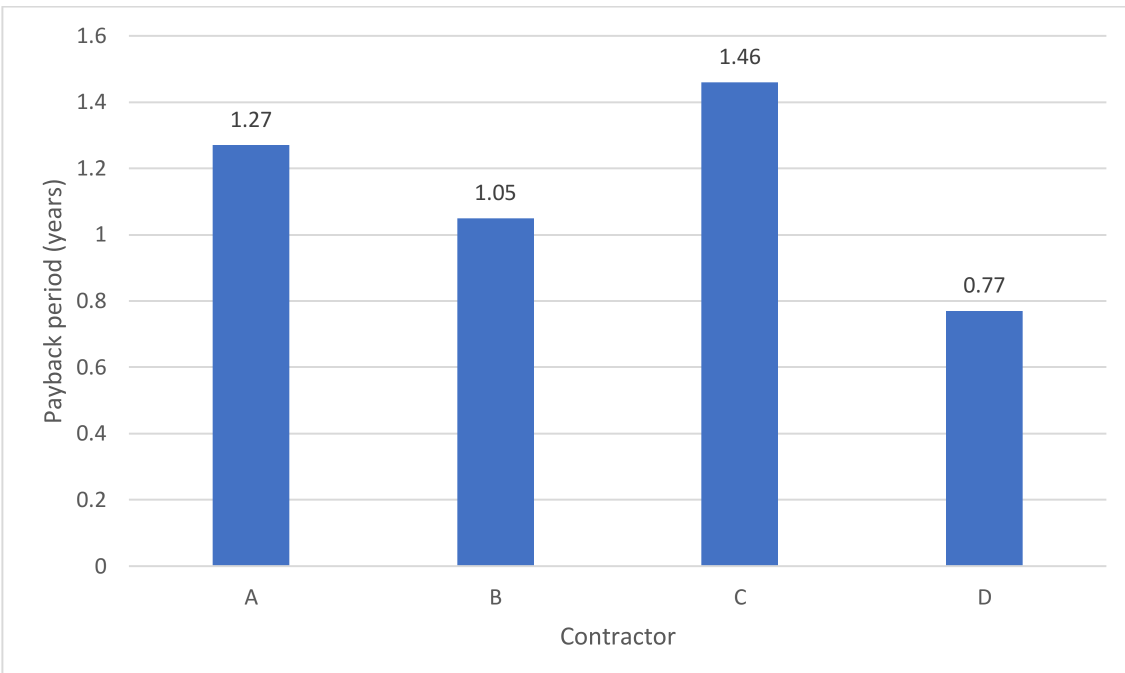


Figure 7. Payback for each contractor based on their TPCS investments.

To further display the benefits of TPCS, a TPCS lifetime savings estimate is provided below in Figure 8. It is important to note that TIREBOSS (2021) estimates that a TPCS will last ten years. Given that a typical tractor lasts about five years when used for log hauling, a transfer of the TPCS hardware to a new truck is required after five years. This transfer cost is approximately $3,500 and was included in this TPCS lifetime savings. Contactor A is estimated to save $185,678; Contractor B is estimated to save $183,528; Contractor C is estimated to save $126,355, and Contractor D is estimated to save $259,813.

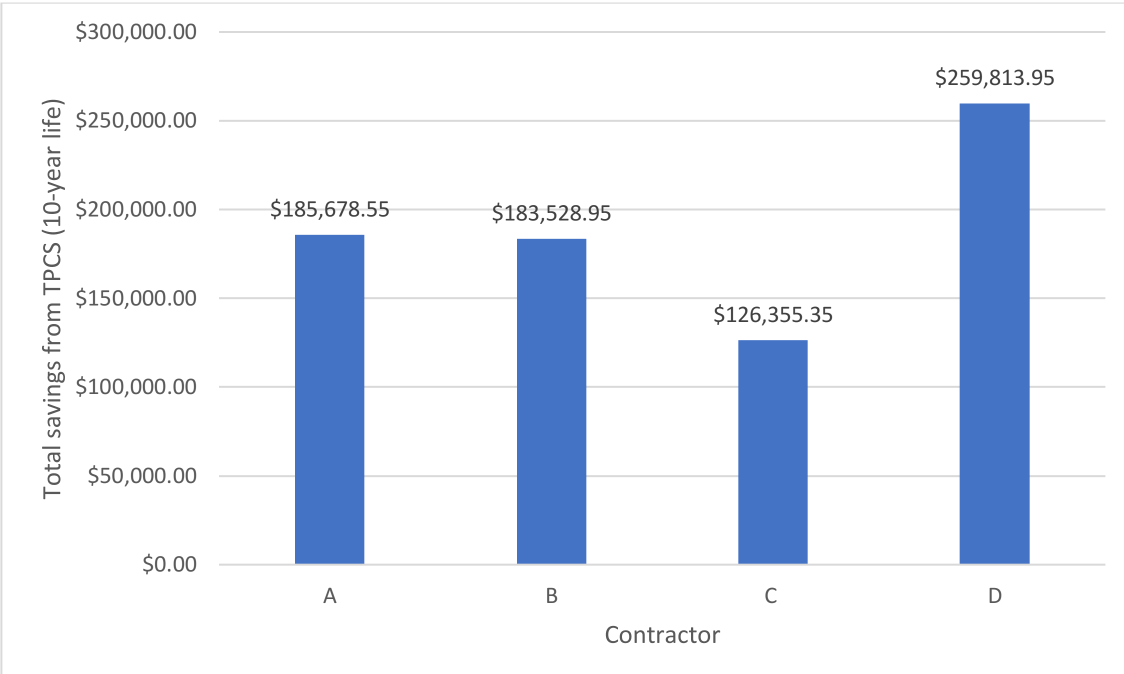


Figure 8. Total TPCS savings based on a 10-year TPCS hardware lifespan.

Table 2 displays the average percent change from all contractors in this study for various factors associated with log hauling costs with and without TPCS. On average productive hours per year, tractor and trailer life were increased by an average of 4.17% when using TPCS. It is important to note that profit per productive machine hour ($/PMH) in this study indicates the income required by the truck owner to meet their costs and profit margin, which was found to be reduced by 5.65%. Meanwhile the fixed cost per productive machine hour was found to increase by 1.64%, and the cost per trip was found to be reduced by 5.64%. Out of all the variables presented in Table 2, yearly tire cost, overall fuel consumption, total maintenance and repair costs, and cost per year were found to be affected the most by the use of TPCS. On average, yearly tire costs were reduced by 58.45%, average overall fuel consumption was reduced by 9.53%, total maintenance and repair costs were reduced by an average of 16.55%, and cost per year was reduced by an average of 13.20%.

Table 2. Average change between various factors associated with log-hauling costs from all four contractors.

Description	% Change with TPCS
Productive hours per year (PMH/year)	4.17%
Profit per PMH ($/PMH)	-5.65%
Fixed cost per PMH ($/PMH)	1.64%
Overall Fuel consumption (L/100 km)	-9.53%
Yearly tire cost ($/year)	-58.45%
Tire life (km)	37.29%
Total maintenance and repair cost ($/year)	-16.55%
Cost per trip ($/trip)	-5.64%
Cost per year ($/year)	-13.20%
Tractor life (km)	4.17%
Trailer life (km)	4.17%

Below, the average benefits of the four contractors in this study are presented in Table 3. On average, contractors saved $7,528 on annual tire-related savings, $838 on annual traction-related savings, $5,653 on yearly fuel savings, and $6,405 on increased truck utilization savings. The average savings per trip was found to be $64.38, and the average savings per year when using TPCS was found to be $21,180. In addition, the average TPCS 10-year lifetime savings were found to be $188,844.

Table 3. Average benefits associated with TPCS from all four contractors.

Benefit	Result
Tire savings	$7,528.50
Traction savings	$838.50
Fuel savings	$5,653.50
Increased utilization savings	$6,405.28
Savings per trip	$64.38
Savings per year	$21,179.53
Total lifetime savings from TPCS	$188,844.20

Table 4 shows the average change in total rate per PHM, rate per tonne, and rate per m^3 found in this study as a result of using TPCS. The total rate per productive machine hour was found to reduce by an average of 5.64%, the rate per tonne average was reduced by 5.33%, and the rate per m^3 was found to be reduced by an average of 5.33%.

Table 4. Summarized haul rate information for all contractors in this study.

Description	% Change with TPCS
Total rate per PMH	-5.64%
Rate per tonne ($/t)	-5.33%
Rate per m^3 ($\$/m^3$)	-5.33%

4.1 RESULTS FOR CONTRACTOR A

Contractor A provided data for an eight-axle B-train log truck, consisting of one steer axle, tandem drive axles, a tri-axle front trailer, and a tandem axle second trailer. Furthermore, this contractor estimated that they spend $500 in additional annual maintenance on their TPCS hardware. By investing in TPCS, Contractor A is estimated to save $9,432 in tire life and tire maintenance, $1,158 from traction-related savings,

$3,031 in fuel, and $6,517 because of TPCS increasing their annual operating hours. Contractor A's total annual savings from using TPCS is $21,268. This can be seen in Figure 9.

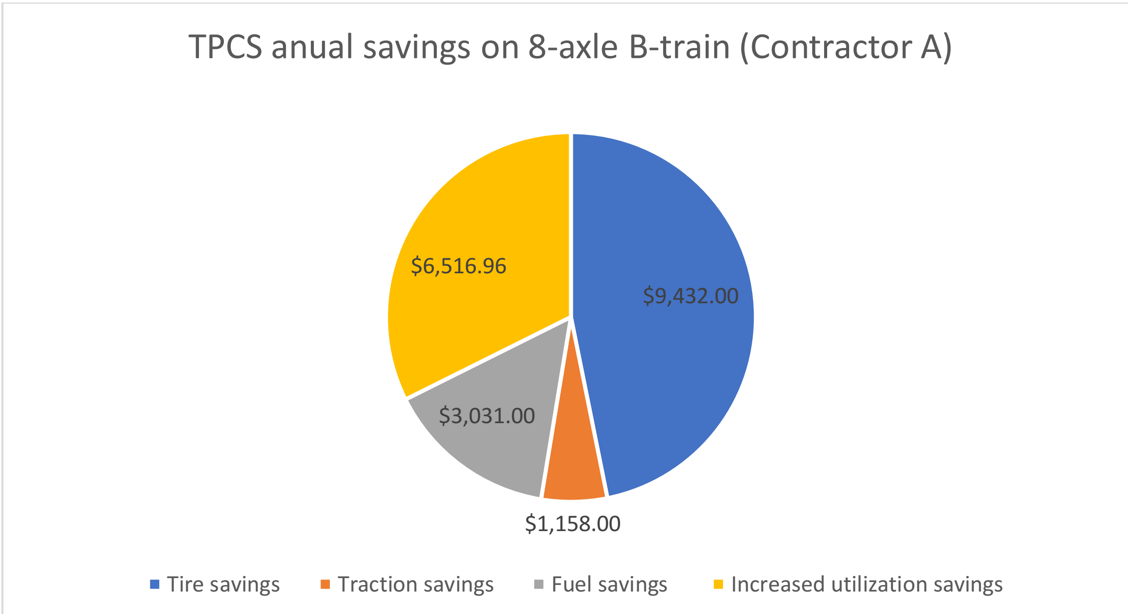


Figure 9. Annual operations savings for Contractor A with TPCS.

Various factors associated with log-hauling costs were compared with and without TPCS. Below, Table 5 illustrates the main findings from this comparison for Contractor A. Notably, contractor A's yearly tire cost was reduced by 97.31%, and tire life was increased by 53.31% by utilizing TPCS. Furthermore, total maintenance and repair costs on the tractor and trailer were found to be reduced by 26.64%, and fuel consumption was also found to be reduced by 6.82%. Table 5 shows the change associated with TPCS for productive hours per year, profit per productive machine hour, fixed cost per productive machine hour, cost per trip, cost per year, and tractor and trailer life. Full results for Contractor A can be viewed in Appendix A.

Table 5. Comparison of various factors associated with log-hauling costs from Contractor A's 8-AXle B-train with and without TPCS.

Description	Scenario 1 Contractor A 6-axle semi-trailer	Scenario 2 Contractor A 6-axle semi-trailer (TPCS)	% Change with TPCS
Productive hours per year (PMH/year)	2484	2592	4.17%
Profit per PMH ($/PMH)	$13.86	$13.11	-5.72%
Fixed cost per PMH ($/PMH)	$35.99	$36.66	1.83%
Overall Fuel consumption (L/100 km)	68.9	64.5	-6.82%
Yearly tire cost ($/year)	$20,313.00	$10,295.00	-97.31%
Tire life (km)	125,000	267,650	53.31%
Total maintenance and repair cost ($/year)	$49,438.00	$39,037.00	-26.64%
Cost per trip ($/trip)	$1,344.86	$1,272.52	-5.68%
Cost per year ($/year)	$378,621.00	$373,831.00	-1.28%
Tractor life (km)	605295	631612	4.17%
Trailer life (km)	1210590	1263225	4.17%

It is important to note that profit per PMH ($/PMH) in this study indicates the income required by the truck owner to meet their costs and profit margin. Below, Table 6 summarizes the changes in haul rate information for Contractor A. By using TPCS, it is estimated that Contractor A's total rate per productive machine hour will be reduced by 5.68%, rate per tonne reduced by 5.44%, and rate per m^3 reduced by 5.42%.

Table 6. Summarized haul rate information for Contractor A.

Description	Units	Scenario 1 Contractor D 6-axle semi-trailer	Scenario 2 Contractor D 6-axle semi-trailer (TPCS)	% Change with TPCS
Total rate per PMH	\$/PMH	\$152.42	\$144.23	-5.68%
Rate per tonne	\$/t	\$31.57	\$29.94	-5.44%
Rate per m^3	\$/m^3	\$26.83	\$25.45	-5.42%

4.2 RESULTS FOR CONTRACTOR B

Contractor B has a log truck with tandem drive axles and a single trailer with three axles. Contractor B also reported that they spent $1,650 in additional maintenance on their TPCS hardware. Nonetheless, Figure 10 shows the estimated annual savings that Contractor B can expect when using TPCS. Based on the data provided from Contractor B, TPCS provides savings in tire life and tire maintenance of $6,049, $913 in traction-related savings, $7,515 in fuel-related savings, and $6,049 in increased utilization savings. Together this adds up to $20,177 in total savings, as seen in Figure 10.

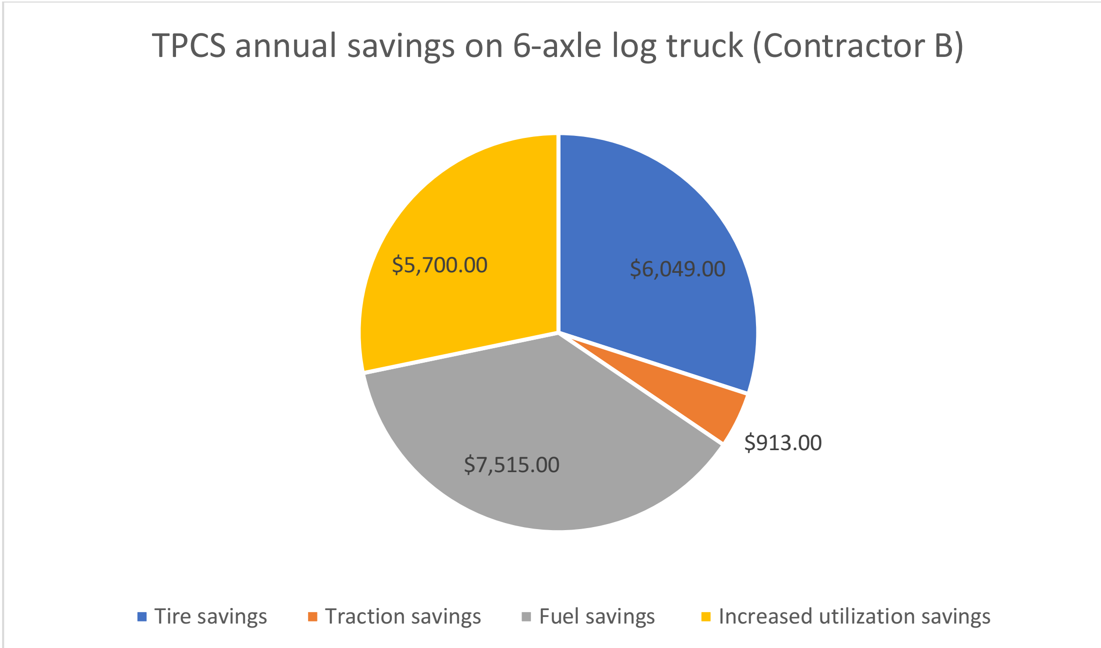


Figure 10. Annual operations savings summary for Contractor B.

Below, Table 7 illustrates the main findings from comparing costs with and without TPCS for Contractor B. Most notably, Contractor B's yearly tire cost was reduced by 46.33%, and tire life was increased by 33.58% by utilizing TPCS. Total maintenance and repair costs on the tractor and trailer were found to be reduced by 12.26%, and fuel consumption was also found to be reduced by 12.62%. Table 2 also shows the change associated with TPCS for productive hours per year, profit per productive machine hour, fixed cost per productive machine hour, cost per trip, cost per year, and tractor and trailer life for Contractor B. Full results for Contractor B can be viewed in Appendix B.

Table 7. Comparison of various factors associated with log-hauling costs from Contractor B's 6-axle semi-trailer with and without TPCS.

Description	Scenario 1 Contractor A 6-axle semi-trailer	Scenario 2 Contractor A 6-axle semi-trailer (TPCS)	% Change with TPCS
Productive hours per year (PMH/year)	2484	2592	4.17%
Profit per PMH ($/PMH)	$12.44	$11.72	-6.14%
Fixed cost per PMH ($/PMH)	$30.25	$30.74	1.59%
Overall Fuel consumption (L/100 km)	58	51.5	-12.62%
Yearly tire cost ($/year)	$20,210.00	$13,811.00	-46.33%
Tire life (km)	125,000	188,200	33.58%
Total maintenance and repair cost ($/year)	$49,335.00	$43,948.00	-12.26%
Cost per trip ($/trip)	$1,214.31	$1,144.05	-6.14%
Cost per year ($/year)	$339,857.00	$334,116.00	-1.72%
Tractor life (km)	601737	627899	4.17%
Trailer life (km)	1203474	1255799	4.17%

Below, Table 8 summarizes the changes in haul rate information for Contractor B. By using TPCS, it is estimated that Contractor B's total rate per productive machine hour will be reduced by 6.14%, rate per tonne reduced by 5.82%, and rate per m^3 reduced by 5.81%.

Table 8. Summarized haul rate information for Contractor B.

Description	Units	Scenario 1 Contractor B 6-axle semi-trailer	Scenario 2 Contractor B 6-axle semi-trailer (TPCS)	% Change with TPCS
Total rate per PMH	$/PMH	$136.82	$128.90	-6.14%
Rate per tonne	$/t	$37.48	$35.42	-5.82%
Rate per m^3	$/$m^3$	$31.86	$30.11	-5.81%

4.3 RESULTS FOR CONTRACTOR C

Similar to Contractor B, Contractor C has a log truck with tandem drive axles and a single trailer with three axles. Contractor C estimated that they spent $1,200 in additional maintenance on their TPCS hardware. However, Contractor C was found to save $14,592 annually in TPCS related savings. Of the estimated $14,592 in annual savings, $4,472 comes from increased tire life and reduced tire maintenance, $656 in traction-related savings, $4,008 in reduced fuel costs, and $5,456 from increased truck utilization as a result of TPCS. Figure 11 visually displays the estimated annual savings for contractor C from using TPCS.

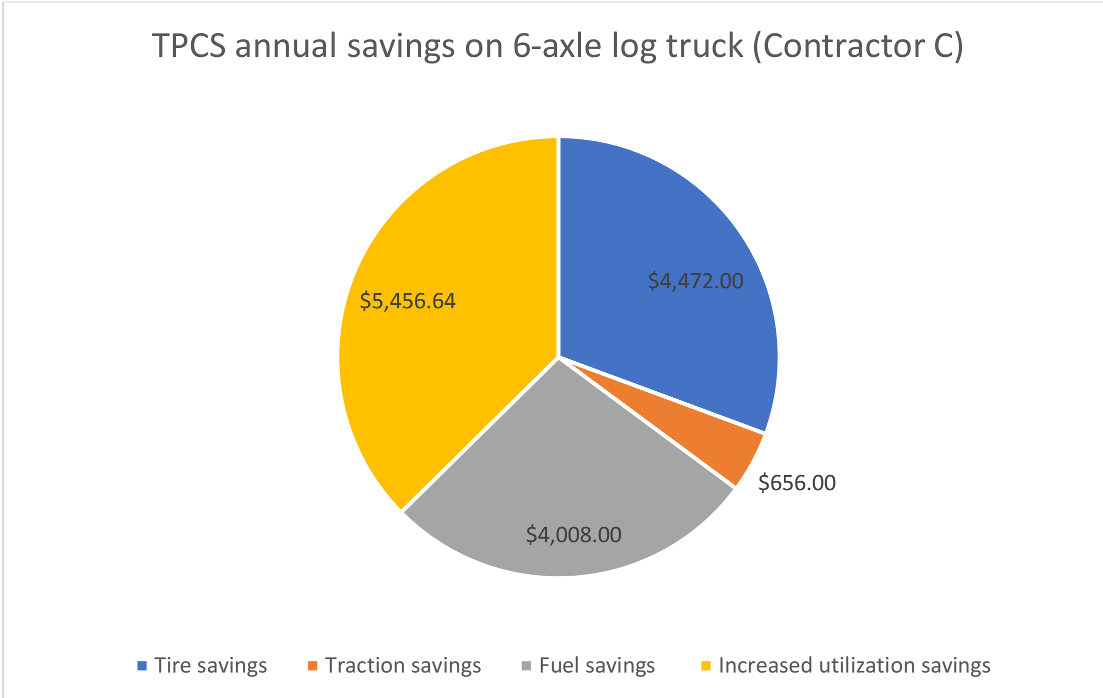


Figure 11. Annual operations savings summary for Contractor C.

Below, Table 9 illustrates the main findings from comparing costs with and without TPCS for Contractor C. The most prominent factor was found to be cost per year which is reduced by 47.87% by utilizing TPCS. Yearly tire costs for Contractor C was found to be reduced by 30.40%; tire life was found to be increased by 24.25%; fuel consumption was found to be reduced by 8.61%, and total maintenance and repair costs per year was found to be reduced by 8.56%. Table 9 also shows the change associated with TPCS for productive hours per year, profit per productive machine hour, fixed cost per productive machine hour, cost per trip, and tractor and trailer life for Contractor C. Full results for Contractor C can be seen in Appendix C.

Table 9. Comparison of various factors associated with log-hauling costs from Contractor C's 6-axle semi-trailer with and without TPCS.

Description	Scenario 1 Contractor A 6-axle semi-trailer	Scenario 2 Contractor A 6-axle semi-trailer (TPCS)	% Change with TPCS
Productive hours per year (PMH/year)	2484	2592	4.17%
Profit per PMH ($/PMH)	$12.44	$11.92	-4.36%
Fixed cost per PMH ($/PMH)	$30.25	$30.74	1.59%
Overall Fuel consumption (L/100 km)	58	53.4	-8.61%
Yearly tire cost ($/year)	$20,210.00	$15,499.00	-30.40%
Tire life (km)	125,000	165,010	24.25%
Total maintenance and repair cost ($/year)	$49,335.00	$45,443.00	-8.56%
Cost per trip ($/trip)	$1,214.31	$1,163.64	-4.35%
Cost per year ($/year)	$339,857.00	$229,836.00	-47.87%
Tractor life (km)	601737	627899	4.17%
Trailer life (km)	1203474	1255799	4.17%

Below, Table 10 summarizes the changes in haul rate information for Contractor C. By using TPCS, it is estimated that Contractor C's total rate per productive machine hour will be reduced by 4.36%, rate per tonne reduced by 4.02%, and rate per m^3 reduced by 4.05%.

Table 10. Summarized haul rate information for Contractor C.

Description	Units	Scenario 1 Contractor C 6-axle semi-trailer	Scenario 2 Contractor C 6-axle semi-trailer (TPCS)	% Change with TPCS
Total rate per PMH	$/PMH	$136.82	$131.11	-4.36%
Rate per tonne	$/t	$37.48	$36.03	-4.02%
Rate per m^3	$/$m^3$	$31.86	$30.62	-4.05%

4.4 RESULTS FOR CONTRACTOR D

Similar to Contractor B and Contractor C, Contractor D has a log truck with tandem drive axles and a single trailer with three axles. Further, Contractor D estimated that they spent an additional $2,000 on additional annual TPCS hardware-related maintenance. Contractor D is expected to save $26,795 annually using TPCS. $10,161 comes from increased tire life and reduced tire maintenance, $627 comes from traction-related savings, $8,060 comes from fuel-related savings, and $7,947 comes from increasing the truck's hours. A visual representation of this is seen in Figure 12.

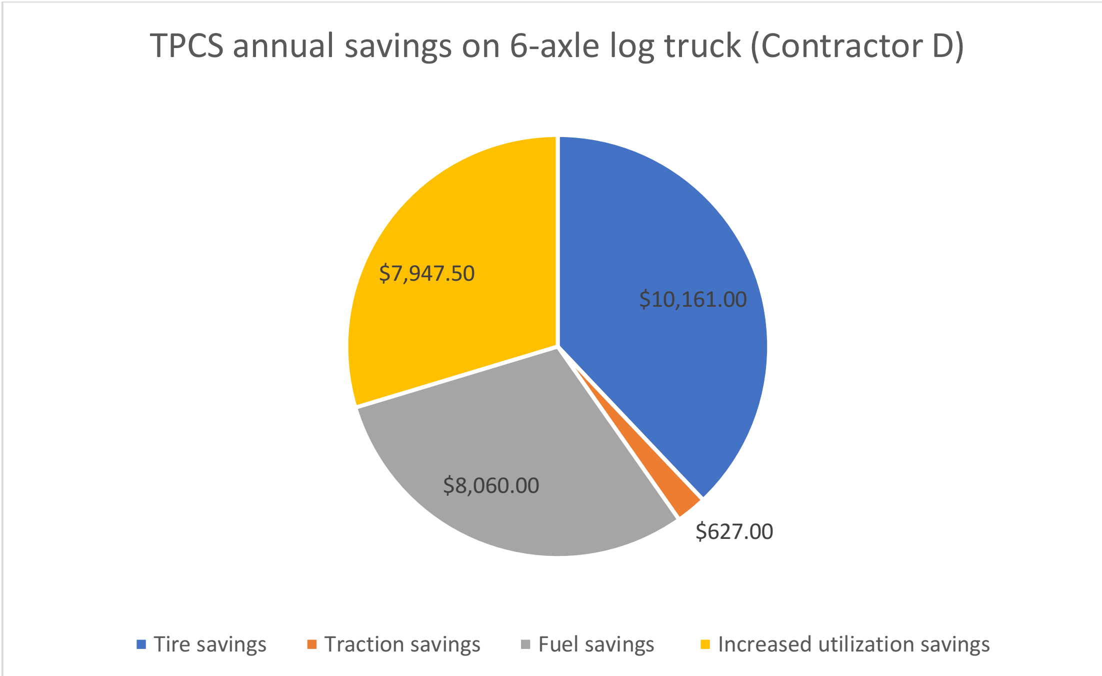


Figure 12. Annual operations savings summary for Contractor D.

Below, Table 11 illustrates the main findings from comparing costs with and without TPCS for contractor D. Most notably, contractor D's yearly tire cost was reduced by 59.77%, and tire life was found to increase by 40.01% by utilizing TPCS. Total maintenance and repair costs on the tractor and trailer were found to be reduced by 18.74%, and fuel consumption was also found to be reduced by 10.06%. Table 11 also shows the change associated with TPCS for productive hours per year, profit per productive machine hour, fixed cost per productive machine hour, cost per trip, cost per year, and tractor and trailer life for contractor D. Full results for contractor D can be viewed in Appendix D.

Table 11. Comparison of various factors associated with log-hauling costs from Contractor D's 6-axle semi-trailer with and without TPCS.

Description	Scenario 1 Contractor A 6-axle semi-trailer	Scenario 2 Contractor A 6-axle semi-trailer (TPCS)	% Change with TPCS
Productive hours per year (PMH/year)	3726	3888	4.17%
Profit per PMH ($/PMH)	$11.00	$10.34	-6.38%
Fixed cost per PMH ($/PMH)	$20.17	$20.49	1.56%
Overall Fuel consumption (L/100 km)	58	52.7	-10.06%
Yearly tire cost ($/year)	$28,875.00	$18,073.00	-59.77%
Tire life (km)	125,000	208,360	40.01%
Total maintenance and repair cost ($/year)	$58,000.00	$48,846.00	-18.74%
Cost per trip ($/trip)	$1,073.92	$1,009.67	-6.36%
Cost per year ($/year)	$450,851.00	$442,307.00	-1.93%
Tractor life (km)	902605	941849	4.17%
Trailer life (km)	1805211	1883698	4.17%

Below, Table 12 summarizes the changes in haul rate information for Contractor D. By using TPCS, it is estimated that Contractor D's total rate per PMH will be reduced by 6.36%, rate per tonne reduced by 6.05%, and rate per m^3 reduced by 6.02%.

Table 12. Summarized haul rate information for Contractor D.

Description	Units	Scenario 1 Contractor D 6-axle semitrailer	Scenario 2 Contractor D 6-axle semi-trailer (TPCS)	% Change with TPCS
Total rate per PMH	$/PMH	$121.00	$113.76	-6.36%
Rate per tonne	$/t	$33.15	$31.26	-6.05%
Rate per m^3	$/$m^3$	$28.17	$26.57	-6.02%

5. DISCUSSION

Although TPCS investments range from $6,000 to over $30,000, the results produced by the model provided by TPC International show exceptional savings. The average annual savings in this study was found to be $21,180. This can be further broken down into savings per trip which on average was found to be $64.38. As a result of significant savings per year, an average payback period for each contractor TPCS was found to be approximately 1.14 years. Contractor D had by far the lowest payback period with an estimated period of 0.77 years. This substantial difference between the other three contractors is likely because Contractor D double shifts their trucks, and such are scheduled to be used for 18 hours a day. It is important to note that all contractors in this study are stump-to-dump contractors, where the contractor is responsible for everything from planning and laying out the cut blocks, harvesting the forest stands, and transporting the raw forest products to processing facilities (B.C. Forest Service 2005). This will further influence the savings and costs associated with log hauling compared to contractors that only haul logs.

With TPCS expecting to have a 10-year lifespan, an estimate of total TPCS life savings was calculated to be an average of $188,844. The average economic tractor and trailer life range from three to five years (Jokai and Bradley 2000), which means that the TPCS hardware would need to be transferred from one tractor-trailer unit to another. This transfer cost was estimated to be $3,500 and was included in the 10-year TPCS lifespan estimate. After the pay pack period, which was found to be an average of 1.14 years, TPCS savings could be viewed as additional profit.

Log haulers are always looking for viable ways of minimizing their haul cost, and through this study, the average haul rate per m^3 ($/$m^3$) was found to be reduced by 5.33% when using TPCS. A 5.33% reduction in haul rate per m^3 is very significant. In this thesis, the average haul rate was found to be reduced by $1.58/$m^3$. For instance, a stump to dump contractor, Debastos & Sons Ltd, in Timmins Ontario reported that they deliver approximately 475,000 m^3 of wood annually. If every truck delivering wood for Debastos & Sons Ltd had TPCS, they could expect to save $750,000 annually in reduced haul rate expenses.

Although TPCS increases the fixed costs of owning a log truck, it also dramatically decreases operating costs such as fuel, required maintenance and repair, increased utilization, and tire costs, which reduces haul rates. Haul costs also vary depending on the weight of the wood. For instance, log trucks in Ontario extracting raw forest products can haul 110% of their legal axle weights and GVW during winter months as there is less risk of damaging roads (Munro and MacCulloch 2008). Typically, there are seasonal variations in moisture content of wood which also effects the weight of wood which can impact haul costs by potentially reducing the total volume of timber per load.

Furthermore, distance on primary, secondary, and tertiary roads along with distance off-highway will affect the haul rate (Pulkki 2003). Stuart et al. (1987) and Jokai and Bradley (2000) suggested that savings from TPCS will be higher when off-highway utilization increases. This correlated with findings in this study as well. For instance, Contractor D in this study reported that 30-60% of their driving per trip is off-highway, and their haul rate per m^3 was found to be reduced the most out of all contractors in this study. All factors that affect the speed of the log truck will affect haul rate as well. TPCS can mitigate some of these impacts and allow log trucks to navigate successfully through rougher and sloppier road conditions which can account for part of the reduction in haul rate costs found in this study.

One of the most important benefits of TPCS is the potential to increase truck utilization by increasing the length of the hauling season; therefore, increasing productive machine hours. Productive machine hours per year can was found to increase by an average of 4.17% because of these contractors using TPCS. However, this increase in productive hours also results in a marginal increase in fixed cost per machine hour, which was on average found to be an average of $29.17/PMH without TPCS and $29.66/PMH with TPCS. Fixed costs per productive machine hour have increased because of using TPCS as fixed costs include the TPCS investment cost on top of all other required fixed costs such as insurance, licensing, safety checks, and many other common fixed costs associated with log trucks.

Profit per productive machine hour ($/PMH) which shows the income per machine hour required by the truck owner to meet their costs and profit margin was found to be reduced by an average of 5.65%. The values for profit per productive machine hour in this study indicates the income required by the truck owner to meet their costs and profit margin, which can be viewed as the break-even point plus the operators profit margin. Therefore, this study further proves the benefits of TPCS. Log hauling contractors using TPCS can reduce the costs to break-even and meet their profit margin substantially as a result of lower tire costs, fuel costs, traction savings, and increase in truck productivity/utilization.

Although fixed costs per productive machine hour have been estimated to increase, and profit per productive machine hour has been estimated to decrease due to TPCS, contractors can expect an average of $21,180 in additional revenue per year from TPCS related savings. Further, by using TPCS, the contractors in this study reduced their costs per year by an average of 13.20%. This significant reduction in costs results from TPCS increasing traction of the log truck, reducing fuel consumption, increasing the truck's productive hours, and reducing the total cost of tires.

It is important to note that traction savings may vary between contractors as the conditions of the roads being driven on will be different. For instance, Bradley (1991) and Steward (1994) found that TPCS can increase traction from 10-42% depending on the road condition. The average traction savings from this thesis was found to be $838 per year. TPCS results in log trucks getting stuck less, therefore, requiring less assistance from other machines. This will not only increase the productivity of the log truck, but it will also reduce lost time for the other piece of equipment that typically assists log trucks get unstuck. Additionally, the length of each trip spent off-highway may also affect this cost. However, all contractors did confirm that using TPCS has resulted in less time being stuck, less time requiring another machine to assist with climbing a hill, getting through soft soil or snow/ice conditions, and fewer lost trips. Not only does this save money by increasing the utilization/productivity of the log truck, but it also reduces the lost time of other machines used to assist the log truck. It is also important to note that no contractors in this study reported to use chains as the conditions of forest roads in northwestern Ontario do not typically require chain use.

Increased traction can directly affect the fuel consumption of log trucks when on off-highway roads (Bradley 2009). TPCS reduces the amount of wheel slip, increases the vehicle's floatation, and reduce the amount of rutting and cumulative damage to the forest road. By optimizing tire pressure according to road conditions, the average fuel consumption in this study was reduced by an astonishing 9.53% compared to the same type of truck completing the same trips. This correlates with an abundance of previous literature (Bradley 2009, Munro and MacCulloch 2008, Kreyns 1994) that found TPCS can reduce fuel consumption by 1-10% depending on the road surface conditions. As a result, the average annual savings related to fuel consumption per year in this study was found to be $5,653. Further, each truck may vary in fuel consumption as operator skill and experience both have a significant impact on fuel consumption as well.

Other than fuel, tires are often found to be the highest cost for industrial trucks. In this study, yearly tire cost was reduced by an average of 58.45% when using TPCS compared to not using TPCS. The annual average tire-related savings in this study was found to be $7,528. Tire-related savings were found to be higher than all other savings associated with TPCS. This average reduction in tire costs is mainly a result of tire punctures resulting in flat tires requiring roadside assistance or in-house assistance at a shop. However, the total amount of tire-related savings will vary depending on a variety of reasons. The quality of the road being driven on, total annual truck usage, and amount of highway usage compared to off-highway usage will result in changes to tire-related savings. For instance, Contractor D in this study was found to have the highest annual tire-related savings resulting in $10,161 per year. Contractor D double shifts their trucks and reported to drive 30-60% off-highway, whereas all the other contractors in this study reported to drive 10-30% off-highway.

Another essential benefit of TPCS is reduced wear on tires, resulting in longer tire life (Menzies 2006; Stuart et al. 1987). This study's average increase in tire life is based on estimated increased kilometers before the tire needs to be replaced. Contractor A who drives an 8-axle B-train log truck, was found to have the highest increased tire life with an estimated increase of 53.31%. This estimated increase in tire life is substantially higher than previous literature has suggested. Nonetheless, the average increase in tire life from all four contractors was found to be 37.29%, which correlates with findings from Menzies (2006) and Stuart et al. (1987), who suggested that TPCS can increase tire life by 30-40%. Furthermore, this study estimated that tire blowouts per year are reduced from an average of five to an average of three times per year. This would result in fewer roadside assistance calls and fewer in-house repairs related to tires and increase total savings related to tires and associated costs.

It is well known through literature that TPCS can increase the hauling season for log haul contractors by increasing traction by using optimal tire pressure (Menzies 2006, Kreyns 1994). In this study, an estimate of an increase in 120 hours per year was provided and used to compare the benefits of TPCS. This resulted in productive hours per year being increased by an average of 4.17%. On average, contractors are estimated to save $6,405 annually due to increased utilization from TPCS. Higher utilization results in more loads of wood delivered per year, increasing profits, and lowering overall haul rate costs. However, when comparing the profit of a truck with TPCS to without, the truck without will receive higher profits as there is no fixed cost TPCS hardware included. Although TPCS results in lower profits, it makes up for this loss in a magnitude of savings.

TPCS will extend the life of tractors and trailers when used in log hauling. This study found that TPCS increases tractor and trailer life by 4.17%. This increase in truck and trailer life is likely an indirect result of TPCS reducing shock vibration. Furthermore, Kreyns (1994) found that reduced shock vibration on trucks with TPCS resulted in much lower vehicle maintenance and repairs required when compared to trucks without TPCS. In this study, total maintenance and repair cost was reduced by an average of 16.55% per year. This reduction in total maintenance is outlined extensively in previous literature, and indirectly results in more savings when using TPCS.

Furthermore, in light of the current ongoing events causing significant inflation, fuel prices have significantly increased since data was collected for this thesis. The results shown in this thesis are based on a fuel price of $1.50/L, whereas currently, they are roughly $1.99/L. A simple sensitivity analysis was conducted to determine the effects of this increase in fuel price. A direct relationship between the increase in fuel price and fuel savings was found. For instance, since the data was collected, fuel prices have risen 25% ($1.50/L to 1.99/L) in the Kenora, Ontario area. When used in the model, the fuel savings increase by 25% as well. When fuel costs escalate, so do the savings associated with using TPCS, further highlighting the benefits of TPCS.

Not only does reduced vibration improve truck and trailer life while reducing repair and maintenance costs on log trucks, but it also increases operator ergonomics (Munro and MacCulloch 2008, Steward 1994). Unfortunately, no formal data on how TPCS affects operator ergonomics was able to be collected in this study. However, through general information discussions with various log hauling contractors who installed TPCS on their trucks, operator comfort and ergonomics appeared to be dramatically improved in trucks with TPCS. Moreover, previous literature and common knowledge would suggest that if the truck and trailer are receiving less damage due to reduced shock vibrations, then it is most likely that operator comfort and ergonomics would also be increased.

Although previous literature suggests that TPCS can reduce road construction costs, no data was collected in this study to support that. Further, the need to keep quality maintenance records becomes increasingly important when utilizing technology such as TPCS. To promote the use of technology such as TPCS, there needs to be a thorough understanding of the costs and benefits associated with the system. It is challenging to conduct research to confirm the benefits of these systems. Log hauling contractors need to keep quality records to allow for proper scientific and economic analyses to ensure accurate studies can be completed.

6. CONCLUSION

Transportation of raw forest products accounts for a large portion of timber production costs. Through previous literature, TPCS is proven to provide many benefits to log truck drivers. TPCS allows for truck operators to adjust the tire pressure to optimally suit the given road conditions which in turn provides extensive savings through increased tire life, reduced fuel consumption, increased traction, and provides operators with the ability to drive on poorer-quality forest roads. The objective to determine the benefits of utilizing TPCS on log trucks in northwestern Ontario was successfully completed. The hypothesis can be accepted as the benefits of TPCS substantially outweigh the associated costs; therefore, making TPCS a feasible way to minimize forest road transportation costs, while substantially increasing the log truck owner's savings.

This study provided accurate estimates of the numerical savings as a result of implementing TPCS in northwestern Ontario. Log trucks with TPCS increase the efficiency, performance, and lifespan of the log truck and trailer, while decreasing the associated cost of log hauling. Nonetheless, the importance of log truck owners keeping detailed records of their operations and associated costs needs to be highlighted. Accurate records are crucial to complete studies similar to this and provide accurate information regarding the use of different technologies such as TPCS.

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8. APPENDICES

8.1 APPENDIX A

FPInnovations truck costing model/rate model

Description	Units	Scenario 1 Contractor A 8-Axle B-train	Scenario 2 Contractor A 8-Axle B-train
SCHEDULE			
Scheduled operator hours per shift	SMH	12	12
Hours per day - Contractor Management	SMH	0	0
Shift per day	shift/day	1	1
Scheduled days per week	days/week	5	5
Scheduled weeks (total)	weeks	46	48
Utilization rate	%	90	90
Paid stoppage time	min./trip	75	75
Days per year	days/year	230	240
Scheduled hours per year	SMH/year	2,760	2,880
Productive hour per year	PMH/year	2,484	2,592
LABOR			
Operator labor rate	$/PMH	25.00	25.00
Contractor Rate	$/PMH	20.00	20.00
Fringe Benefits	%	25	25
Labor cost per PMH	$/PMH	31.25	31.25
INTEREST RATE & PROFIT			
Interest Rate	%	6	6
Profit Margin	%	10	10
Profit per PMH	$/PMH	13.86	13.11
VEHICLE AND EQUIPMENT COST			
TRACTOR & TRAILER			
Tractor life	Years	5	5
Tractor purchase price	$	200,000	200,700
Tractor salvage value	$	60,000	60,000
Trailer life	Years	10	10
Trailer purchase price	$	160,000	160,000

Trailer salvage value	$	16,000	16,000
Tractor + trailer yearly fixed cost	$/year	57,360	57,526
ONBOARD LOADER (set price to 0$ if not present)			
Purchase price	$	0	0
Salvage Value	$	0	0
Life	Years	10	10
Tare weight	Tonnes	3	3
Loader yearly fixed cost	$/year	0	0
OTHER EQUIPMENT (set price to 0$ if not present)			
Tire Pressure Control System (TPCS)	$	0	27,000
Onboard Weigh Scale	$	2,500	2,500
Cab Protector	$	6,000	6,000
Onboard Computer	$	1,250	1,250
Misc. Equipment (Radio, Cell, Chains etc.)	$	3,000	3,000
Other equipment total purchase cost	$	12,750	39,750
Other equipment yearly fixed cost	$/year	2,550	7,950
SERVICE COSTS			
Insurance (% of purchase)	%	5	5
Insurance	$/year	18,000	18,035
Licensing	$/year	5,200	5,200
Professional Services (accounting, legal)	$/year	3,800	3,800
Safety Check (CMVI) Truck+Trailer	$/year	1,500	1,500
Communications fees (cell, satelilte, OBC)	$/year	1,000	1,000
Total Service Costs	$/year	29,500	29,535
Total yearly fixed cost	$/year	89,410	95,011
Fixed Cost per PMH	$/PMH	35.99	36.66
WEIGHTS			
Tractor+Trailer Tare Weight	Tonnes	20.50	20.55
Allowable Gross Vehicle Weight (GVW)	Tonnes	63.50	63.50
Payload buffer	Tonnes	1.50	1.50
Merchantable Wood Density	kg/m3	850	850
Normal Period Payload	Tonnes	41.50	41.45
Normal Period Merchantable Volume	m3	48.82	48.76
SEASONAL ALLOWANCES			
Winter period	weeks	8	8

Winter allowable GVW	Tonnes	69.85	69.85
Winter payload	Tonnes	47.85	47.80
Winter Period Merchantable Volume	m3	56.29	56.24
Winter fuel consumption increase	%	5	5
Spring load restriction period	weeks	0	0
Spring allowable GVW	Tonnes	35.00	35.00
Spring payload	Tonnes	13.00	12.95
Spring Period Merchantable Volume	m3	15.29	15.24
Average payload for year	Tonnes	42.60	42.50
Average merchantable volume	m3	50.12	50.00
DISTANCE BY ROAD TYPE			
Paved Road	km	120	120
Class 1 Road	km	45	45
Class 2 Road	km	35	35
Class 3+ Roads	km	15	15
One Way Distance	km	215	215
SPEEDS			
LOADED			
Paved Road	km/h	75	75
Class 1	km/h	55	55
Class 2	km/h	40	40
Class 3+	km/h	23	23
Average Speed Loaded (calculated)	km/h	54.49	54.49
UNLOADED			
Paved Road	km/h	80	80
Class 1	km/h	60	60
Class 2	km/h	45	45
Class 3+	km/h	25	25
Average Speed Empty (calculated)	km/h	59	59
Overall Average Speed	km/h	56.78	56.78
FUEL CONSUMPTION			
Fuel Price	$/L	1.50	1.50
Idle Fuel Consumption	L/hr	4.00	4.00
DEF Price	$/L	0.80	0.80
DEF Consumption (% of Fuel Consumption)	%	4	4
LOADED			
Paved Road - Loaded	L/100km	81.89	81.83

Class 1 - Loaded	L/100km	90.41	88.97
Class 2 - Loaded	L/100km	114.81	112.77
Class 3+ - Loaded	L/100km	139.09	118.51
Average Consumption Loaded	L/100km	93.02	90.92
UNLOADED			
Paved Road - Unloaded	L/100km	36.73	36.78
Class 1 - Unloaded	L/100km	43.55	42.25
Class 2 - Unloaded	L/100km	48.78	46.94
Class 3+ - Unloaded	L/100km	52.62	48.54
Average Consumption Empty	L/100km	41.23	40.40
Total Rolling Fuel Consumption (FPI)	L/100km	67.71	66.21
Overall Fuel Consumption including Idle	L/100km	68.87	64.49
Rolling Hourly Fuel Consumption (no Idle)	L/hr	38.44	35.95
Hourly Fuel Consumption including Idle	L/hr	33.56	31.43
Fuel & DEF Cost per PMH	$/PMH	51.42	48.15
MAINTENANCE & REPAIR COSTS			
SCHEDULED MAINTENANCE (Oil and filters changes, lube, etc.)			
Interval between sessions	Weeks	4	4
Cost per sessions	$	550	550
Scheduled maintenance yearly cost	$/year	6,325	6,600
REPAIRS			
Drivetrain (Engine, transmission, axles)	$/year	4,000	4,000
Suspension and brakes	$/year	6,000	4,842
Electrics	$/year	2,000	2,000
Truck Frame + Chassis	$/year	1,000	1,000
Hydraulics (if so equipped)	$/year	0	0
Trailer	$/year	4,800	4,800
Others	$/year	5,000	5,000
TPCS	$/year	0	500
Total yearly repairs costs	$/year	22,800	22,142
TIRE COSTS			
Tire purchase cost	$/units	600	600
Number of wheels	#	30	30
Tire life	Km	125,000	267,650

# Blowouts per year	#	5	3
Yearly Tire Cost	$/year	20,313	10,295
Total maintenance and repair cost	$/year	49,438	39,037
Maintenance and repair per PMH	$/PMH	19.90	15.06
TOTAL RATE PER PMH	$/PMH	152.42	144.23
Labor	$/h	31.25	31.25
Fixed	$/h	35.99	36.66
Fuel	$/h	51.42	48.15
Maintenance and repair	$/h	19.90	15.06
Profit	$/h	13.86	13.11
RATE PER TONNE	$/t	31.57	29.94
Labor	$/t	6.47	6.49
Fixed	$/t	7.46	7.61
Fuel	$/t	10.65	10.00
Maintenance and repair	$/t	4.12	3.13
Profit	$/t	2.87	2.72
RATE PER m3	$/m3	26.83	25.45
Labor	$/m³	5.50	5.51
Fixed	$/m³	6.34	6.47
Fuel	$/m³	9.05	8.50
Maintenance and repair	$/m³	3.50	2.66
Profit	$/m³	2.44	2.31
$/t savings from baseline		0.00	1.63
SUMMARY INFORMATION			
INFORMATION BY TRIP			
Rolling time (no stoppage time)	PMH/trip	7.57	7.57
Round trip time	PMH/trip	8.82	8.82
Lost time per trip	H/trip	0.98	0.98
Percent idle time	%	14	14
Round trip distance	Km	430	430
Fuel consumed per trip	L/trip	296	277
DEF consumed per trip	L/trip	11.85	11.09
Cost per trip	$/trip	1,345	1,273
INFORMATION BY YEAR			
Trips per year	#	282	294
Tonnes per year	Tonnes	11,993	12,485
Annual distance	km	121,059	126,322
Yearly Fuel Consumption	L/year	83,373	81,460

Yearly DEF Consumption	L/year	3,334	3,258
Costs per year	$/year	378,620	373,831
Labor	$/year	77,625	81,000
Fixed	$/year	89,410	95,012
Fuel&DEF	$/year	127,728	124,797
Maintenance and repair	$/year	49,438	39,037
Profit	$/year	34,420	33,985
LIFETIME INFORMATION			
Tractor life hours	PMH	12,420	12,960
Trailer life hours	PMH	24,840	25,920
Loader Life		NA	NA
Tractor life km	km	605,295	631,612
Trailer life km	km	1,210,590	1,263,225
PERCENT COST BREAKDOWN			
Labor		21%	22%
Fixed		24%	25%
Fuel & DEF		34%	33%
Maintenance and repair		13%	10%
Profit		9%	9%

8.2 APPENDIX B

FPInnovations truck costing model/rate model

Description	Units	Scenario 1 Contractor B 6-axle semi-trailer	Scenario 2 Contractor B 6-axle semi-trailer (TPCS)
	SCHEDULE		
Scheduled operator hours per shift	SMH	12	12
Hours per day - Contractor Management	SMH	0	0
Shift per day	shift/day	1	1
Scheduled days per week	days/week	5	5
Scheduled weeks (total)	weeks	46	48
Utilization rate	%	90	90
Paid stoppage time	min./trip	75	75
Days per year	days/year	230	240
Scheduled hours per year	SMH/year	2,760	2,880
Productive hour per year	PMH/year	2,484	2,592
LABOR			
Operator labor rate	$/PMH	25.00	25.00
Contractor Rate	$/PMH	20.00	20.00
Fringe Benefits	%	25	25
Labor cost per PMH	$/PMH	31.25	31.25
INTEREST RATE & PROFIT			
Interest Rate	%	6	6
Profit Margin	%	10	10
Profit per PMH	$/PMH	12.44	11.72
	VEHICLE AND EQUIPMENT COST		
TRACTOR & TRAILER			
Tractor life	Years	5	5
Tractor purchase price	$	200,000	200,700
Tractor salvage value	$	60,000	60,000
Trailer life	Years	10	10

Trailer purchase price	$	80,000	80,000
Trailer salvage value	$	8,000	8,000
Tractor + trailer yearly fixed cost	$/year	47,098	47,264
ONBOARD LOADER (set price to 0$ if not present)			
Purchase price	$	0	0
Salvage Value	$	0	0
Life	Years	10	10
Tare weight	Tonnes	3	3
Loader yearly fixed cost	$/year	0	0
OTHER EQUIPMENT (set price to 0$ if not present)			
Tire Pressure Control System (TPCS)	$	0	21,600
Onboard Weigh Scale	$	2,500	2,500
Cab Protector	$	6,000	6,000
Onboard Computer	$	1,250	1,250
Misc. Equipment (Radio, Cell, Chains etc.)	$	3,000	3,000
Other equipment total purchase cost	$	12,750	34,350
Other equipment yearly fixed cost	$/year	2,550	6,870
SERVICE COSTS			
Insurance (% of purchase)	%	5	5
Insurance	$/year	14,000	14,035
Licensing	$/year	5,200	5,200
Profesional Services (accounting, legal)	$/year	3,800	3,800
Safety Check (CMVI) Truck+Trailer	$/year	1,500	1,500
Communications fees (cell, satelilte, OBC)	$/year	1,000	1,000
Total Service Costs	$/year	25,500	25,535
Total yearly fixed cost	$/year	75,148	79,669
Fixed Cost per PMH	$/PMH	30.25	30.74
WEIGHTS			
Tractor+Trailer Tare Weight	Tonnes	16.7	16.8
Allowable Gross Vehicle Weight (GVW)	Tonnes	49.7	49.7
Payload buffer	Tonnes	1.5	1.5
Merchantable Wood Density	kg/m3	850	850
Normal Period Payload	Tonnes	31.50	31.45

Normal Period Merchantable Volume	m3	37.06	37.00
SEASONAL ALLOWANCES			
Winter period	weeks	8	8
Winter allowable GVW	Tonnes	54.67	54.67
Winter payload	Tonnes	36.47	36.42
Winter Period Merchantable Volume	m3	42.91	42.85
Winter fuel consumption increase	%	5	5
Spring load restriction period	weeks	0	0
Spring allowable GVW	Tonnes	35.00	35.00
Spring payload	Tonnes	16.80	16.75
Spring Period Merchantable Volume	m3	19.76	19.71
Average payload for year	Tonnes	32.40	32.30
Average merchantable volume	m3	38.12	38.00
DISTANCE BY ROAD TYPE			
Paved Road	km	120	120
Class 1 Road	km	45	45
Class 2 Road	km	35	35
Class 3+ Roads	km	15	15
One Way Distance	km	215	215
SPEEDS			
LOADED			
Paved Road	km/h	75	75
Class 1	km/h	55	55
Class 2	km/h	40	40
Class 3+	km/h	23	23
Average Speed Loaded (calculated)	km/h	54.49	54.49
UNLOADED			
Paved Road	km/h	80	80
Class 1	km/h	60	60
Class 2	km/h	45	45
Class 3+	km/h	23	23
Average Speed Empty (calculated)	km/h	58	58
Overall Average Speed	km/h	56.39	56.39
FUEL CONSUMPTION			
Fuel Price	$/L	1.50	1.50

Idle Fuel Consumption	L/hr	4.00	4.00
DEF Price	$/L	0.80	0.80
DEF Consumption (% of Fuel Consumption)	%	4%	4%
LOADED			
Paved Road - Loaded	L/100km	67.05	66.99
Class 1 - Loaded	L/100km	75.01	73.88
Class 2 - Loaded	L/100km	93.11	91.51
Class 3+ - Loaded	L/100km	110.67	94.64
Average Consumption Loaded	L/100km	76.00	74.35
UNLOADED			
Paved Road - Unloaded	L/100km	32.70	32.76
Class 1 - Unloaded	L/100km	39.37	38.32
Class 2 - Unloaded	L/100km	42.89	41.40
Class 3+ - Unloaded	L/100km	44.90	41.60
Average Consumption Empty	L/100km	36.61	35.95
Total Rolling Fuel Consumption (FPI)	L/100km	56.79	55.61
Overall Fuel Consumption including Idle	L/100km	57.95	51.52
Rolling Hourly Fuel Consumption (no Idle)	L/hr	32.03	28.40
Hourly Fuel Consumption including Idle	L/hr	28.08	24.96
Fuel & DEF Cost per PMH	$/PMH	43.02	38.24
MAINTENANCE & REPAIR COSTS			
SCHEDULED MAINTENANCE (Oil and filters changes, lube, etc.)			
Interval between sessions	Weeks	4	4
Cost per sessions	$	550	550
Scheduled maintenance yearly cost	$/year	6,325	6,600
REPAIRS			
Drivetrain (Engine, transmission, axles)	$/year	4,000	4,000
Suspension and brakes	$/year	6,000	5,087
Electrics	$/year	2,000	2,000
Truck Frame + Chassis	$/year	1,000	1,000
Hydraulics (if so equipped)	$/year	0	0
Trailer	$/year	4,800	4,800
Others	$/year	5,000	5,000

TPCS	$/year	0	1,650
Total yearly repairs costs	$/year	22,800	23,537
<u>TIRE COSTS</u>			
Tire purchase cost	$/units	600	600
Number of wheels	#	30	30
Tire life	Km	125,000	188,200
# Blowouts per year	#	5	3
Yearly Tire Cost	$/year	20,210	13,810
Total maintenance and repair cost	$/year	49,335	43,947
Maintenance and repair per PMH	$/PMH	19.86	16.96
TOTAL RATE PER PMH	$/PMH	136.82	128.90
Labor	$/h	31.25	31.25
Fixed	$/h	30.25	30.74
Fuel	$/h	43.02	38.24
Maintenance and repair	$/h	19.86	16.96
Profit	$/h	12.44	11.72
RATE PER TONNE	$/t	37.48	35.42
Labor	$/t	8.56	8.59
Fixed	$/t	8.29	8.45
Fuel	$/t	11.78	10.51
Maintenance and repair	$/t	5.44	4.66
Profit	$/t	3.41	3.22
RATE PER m3	$/m3	31.86	30.11
Labor	$/m³	7.28	7.30
Fixed	$/m³	7.04	7.18
Fuel	$/m³	10.02	8.93
Maintenance and repair	$/m³	4.62	3.96
Profit	$/m³	2.90	2.74
$/t savings from baseline		0.00	2.06
SUMMARY INFORMATION			
<u>INFORMATION BY TRIP</u>			
Rolling time (no stoppage time)	PMH/trip	7.63	7.63
Round trip time	PMH/trip	8.88	8.88
Lost time per trip	H/trip	0.99	0.99
Percent idle time	%	14	14
Round trip distance	Km	430	430
Fuel consumed per trip	L/trip	249.21	221.55

DEF consumed per trip	L/trip	9.97	8.86
Cost per trip	$/trip	1,214	1,144
INFORMATION BY YEAR			
Trips per year	#	280	292
Tonnes per year	Tonnes	9068	9433
Annual distance	km	120,347	125,580
Yearly Fuel Consumption	L/year	69,747	64,703
Yearly DEF Consumption	L/year	2,790	2,588
Costs per year	$/year	339,857	334,116
Labor	$/year	77,625	81,000
Fixed	$/year	75,148	79,669
Fuel&DEF	$/year	106,853	99,125
Maintenance and repair	$/year	49,335	43,948
Profit	$/year	30,896	30,374
LIFETIME INFORMATION			
Tractor life hours	PMH	12,420	12,960
Trailer life hours	PMH	24,840	25,920
Loader Life		NA	NA
Tractor life km		601,737	627,899
Trailer life km		1,203,474	1,255,799
PERCENT COST BREAKDOWN			
Labor		23%	24%
Fixed		22%	24%
Fuel & DEF		31%	30%
Maintenance and repair		15%	13%
Profit		9%	9%

8.3 APPENDIX C

FPInnovations truck costing model/rate model

Description	Units	Scenario 1 Contractor C 6-axle semi-trailer	Scenario 2 Contractor C 6-axle semi-trailer (TPCS)
SCHEDULE			
Scheduled operator hours per shift	SMH	12	12
Hours per day - Contractor Management	SMH	0	0
Shift per day	shift/day	1	1
Scheduled days per week	days/week	5	5
Scheduled weeks (total)	weeks	46	48
Utilization rate	%	90	90
Paid stoppage time	min./trip	75	75
Days per year	days/year	230	240
Scheduled hours per year	SMH/year	2,760	2,880
Productive hour per year	PMH/year	2,484	2,592
LABOR			
Operator labor rate	$/PMH	25.00	25.00
Contractor Rate	$/PMH	20.00	20.00
Fringe Benefits	%	25%	25%
Labor cost per PMH	$/PMH	31.25	31.25
INTEREST RATE & PROFIT			
Interest Rate	%	6	6
Profit Margin	%	10	10
Profit per PMH	$/PMH	12.44	11.92
VEHICLE AND EQUIPMENT COST			
TRACTOR & TRAILER			
Tractor life	Years	5	5
Tractor purchase price	$	200,000	200,700
Tractor salvage value	$	60,000	60,000

Trailer life	Years	10	10
Trailer purchase price	$	80,000	80,000
Trailer salvage value	$	8,000	8,000
Tractor + trailer yearly fixed cost	$/year	47,098	47,264
Onboard Loader (set price to 0$ if not present)			
Purchase price	$	0	0
Salvage Value	$	0	0
Life	Years	10	10
Tare weight	Tonnes	3	3
Loader yearly fixed cost	$/year	0	0
OTHER EQUIPMENT (set price to 0$ if not present)			
Tire Pressure Control System (TPCS)	$	0	21,600
Onboard Weigh Scale	$	2,500	2,500
Cab Protector	$	6,000	6,000
Onboard Computer	$	1,250	1,250
Misc. Equipment (Radio, Cell, Chains etc.)	$	3,000	3,000
Other equipment total purchase cost	$	12,750	34,350
Other equipment yearly fixed cost	$/year	2,550	6,870
SERVICE COSTS			
Insurance (% of purchase)	%	5	5
Insurance	$/year	14,000	14,035
Licensing	$/year	5,200	5,200
Profesional Services (accounting, legal)	$/year	3,800	3,800
Safety Check (CMVI) Truck+Trailer	$/year	1,500	1,500
Communications fees (cell, satelilte, OBC)	$/year	1,000	1,000
Total Service Costs	$/year	25,500	25,535
Total yearly fixed cost	$/year	75,148	79,669
Fixed Cost per PMH	$/PMH	30.25	30.74
WEIGHTS			
Tractor+Trailer Tare Weight	Tonnes	16.7	16.75
Allowable Gross Vehicle Weight (GVW)	Tonnes	49.7	49.7
Payload buffer	Tonnes	1.5	1.5
Merchantable Wood Density	kg/m3	850	850

Normal Period Payload	Tonnes	31.5	31.45
Normal Period Merchantable Volume	m3	37.1	37
SEASONAL ALLOWANCES			
Winter period	weeks	8	8
Winter allowable GVW	Tonnes	54.67	54.67
Winter payload	Tonnes	36.47	36.42
Winter Period Merchantable Volume	m3	42.91	42.85
Winter fuel consumption increase	%	5	5
Spring load restriction period	weeks	0	0
Spring allowable GVW	Tonnes	35	35
Spring payload	Tonnes	16.8	16.75
Spring Period Merchantable Volume	m3	19.76	19.71
Average payload for year	Tonnes	32.4	32.3
Average merchantable volume	m3	38.12	38
DISTANCE BY ROAD TYPE			
Paved Road	km	120	120
Class 1 Road	km	45	45
Class 2 Road	km	35	35
Class 3+ Roads	km	15	15
One Way Distance	km	215	215
SPEEDS			
LOADED			
Paved Road	km/h	75	75
Class 1	km/h	55	55
Class 2	km/h	40	40
Class 3+	km/h	23	23
Average Speed Loaded (calculated)	km/h	54.49	54.49
UNLOADED			
Paved Road	km/h	80	80
Class 1	km/h	60	60
Class 2	km/h	45	45
Class 3+	km/h	23	23
Average Speed Empty (calculated)	km/h	58	58
Overall Average Speed	km/h	56.39	56.39
FUEL CONSUMPTION			
Fuel Price	$/L	1.5	1.5
Idle Fuel Consumption	L/hr	4	4

DEF Price	$/L	0.8	0.8
DEF Consumption (% of Fuel Consumption)	%	4%	4%
LOADED			
Paved Road - Loaded	L/100km	67.05	66.99
Class 1 - Loaded	L/100km	75.01	73.88
Class 2 - Loaded	L/100km	93.11	91.51
Class 3+ - Loaded	L/100km	110.67	94.64
Average Consumption Loaded	L/100km	76.00	74.35
UNLOADED			
Paved Road - Unloaded	L/100km	32.70	32.76
Class 1 - Unloaded	L/100km	39.37	38.32
Class 2 - Unloaded	L/100km	42.89	41.40
Class 3+ - Unloaded	L/100km	44.90	41.60
Average Consumption Empty	L/100km	36.61	35.95
Total Rolling Fuel Consumption (FPI)	L/100km	56.79	55.61
Overall Fuel Consumption including Idle	L/100km	57.95	53.45
Rolling Hourly Fuel Consumption (no Idle)	L/hr	32.03	29.48
Hourly Fuel Consumption including Idle	L/hr	28.08	25.90
Fuel & DEF Cost per PMH	$/PMH	43.02	39.67
MAINTENANCE & REPAIR COSTS			
SCHEDULED MAINTENANCE (Oil and filters changes, lube, etc.)			
Interval between sessions	Weeks	4	4
Cost per sessions	$	550	550
Scheduled maintenance yearly cost	$/year	6,325	6,600
REPAIRS			
Drivetrain (Engine, transmission, axles)	$/year	4,000	4,000
Suspension and brakes	$/year	6,000	5,344
Electrics	$/year	2,000	2,000
Truck Frame + Chassis	$/year	1,000	1,000
Hydraulics (if so equipped)	$/year	0	0
Trailer	$/year	4,800	4,800
Others	$/year	5,000	5,000
TPCS	$/year	0	1,200

Total yearly repairs costs	$/year	22,800	23,344
TIRE COSTS			
Tire purchase cost	$/units	600	600
Number of wheels	#	30	30
Tire life	Km	125,000	165,010
# Blowouts per year	#	4.8	3
Yearly Tire Cost	$/year	20,210	15,499
Total maintenance and repair cost	$/year	49,335	45,442
Maintenance and repair per PMH	$/PMH	19.86	17.53
TOTAL RATE PER PMH	$/PMH	136.82	131.11
Labor	$/h	31.25	31.25
Fixed	$/h	30.25	30.74
Fuel	$/h	43.02	39.67
Maintenance and repair	$/h	19.86	17.53
Profit	$/h	12.44	11.92
RATE PER TONNE	$/t	37.48	36.03
Labor	$/t	8.56	8.59
Fixed	$/t	8.29	8.45
Fuel	$/t	11.78	10.90
Maintenance and repair	$/t	5.44	4.82
Profit	$/t	3.41	3.28
RATE PER m3	$/m3	31.86	30.62
Labor	$/m³	7.28	7.30
Fixed	$/m³	7.04	7.18
Fuel	$/m³	10.02	9.27
Maintenance and repair	$/m³	4.62	4.09
Profit	$/m³	2.90	2.78
$/t savings from baseline		0.00	1.45
SUMMARY INFORMATION			
INFORMATION BY TRIP			
Rolling time (no stoppage time)	PMH/trip	7.63	7.63
Round trip time	PMH/trip	8.88	8.88
Lost time per trip	H/trip	0.99	0.99
Percent idle time	%	14%	14%
Round trip distance	Km	430	430
Fuel consumed per trip	L/trip	249.21	229.83
DEF consumed per trip	L/trip	9.97	9.19
Cost per trip	$/trip	1,214	1,164

INFORMATION BY YEAR			
Trips per year	#	280	292
Tonnes per year	Tonnes	9068	9433
Annual distance	km	120,347	125,580
Yearly Fuel Consumption	L/year	69,747	67,121
Yearly DEF Consumption	L/year	2,790	2,685
Costs per year	$/year	339,857	339,836
Labor	$/year	77,625	81,000
Fixed	$/year	75,148	79,669
Fuel&DEF	$/year	106,852	102,830
Maintenance and repair	$/year	49,335	45,443
Profit	$/year	30,892	30,894
LIFETIME INFORMATION			
Tractor life hours	PMH	12,420	12,960
Trailer life hours	PMH	24,840	25,920
Loader Life		NA	NA
Tractor life km		601,737	627,899
Trailer life km		1,203,474	1,255,799
PERCENT COST BREAKDOWN			
Labor		23%	24%
Fixed		22%	23%
Fuel & DEF		31%	30%
Maintenance and repair		15%	13%
Profit		9%	9%

8.4 APPENDIX D

FPInnovations truck costing model/rate model

Description	Units	Scenario 1 Contractor D 6-axle semi-trailer	Scenario 2 Contractor D 6-axle semi-trailer (TPCS)
SCHEDULE			
Scheduled operator hours per shift	SMH	12	12
Hours per day - Contractor Management	SMH	0	0
Shift per day	shift/day	2	2
Scheduled days per week	days/week	5	5
Scheduled weeks (total)	weeks	46	48
Utilization rate	%	90	90
Paid stoppage time	min./trip	75	75
Days per year	days/year	230	240
Scheduled hours per year	SMH/year	4,140	4,320
Productive hour per year	PMH/year	3,726	3,888
LABOR			
Operator labor rate	$/PMH	25.00	25.00
Contractor Rate	$/PMH	20.00	20.00
Fringe Benefits	%	25	25
Labor cost per PMH	$/PMH	31.25	31.25
INTEREST RATE & PROFIT			
Interest Rate	%	6	6
Profit Margin	%	10	10
Profit per PMH	$/PMH	11.00	10.34
VEHICLE AND EQUIPMENT COST			
Tractor & Trailer			
Tractor life	Years	5	5
Tractor purchase price	$	200,000	200,700
Tractor salvage value	$	60,000	60,000
Trailer life	Years	10	10

Trailer purchase price	$	80,000	80,000
Trailer salvage value	$	8,000	8,000
Tractor + trailer yearly fixed cost	$/year	47,098	47,264
Onboard Loader (set price to 0$ if not present)			
Purchase price	$	0	0
Salvage Value	$	0	0
Life	Years	10	10
Tare weight	Tonnes	3	3
Loader yearly fixed cost	$/year	0	0
Other Equipment (set price to 0$ if not present)			
Tire Pressure Control System (TPCS)	$	0	21,600
Onboard Weigh Scale	$	2,500	2,500
Cab Protector	$	6,000	6,000
Onboard Computer	$	1,250	1,250
Misc. Equipment (Radio, Cell, Chains etc.)	$	3,000	3,000
Other equipment total purchase cost	$	12,750	34,350
Other equipment yearly fixed cost	$/year	2,550	6,870
Service Costs			
Insurance (% of purchase)	%	5	5
Insurance	$/year	14,000	14,035
Licensing	$/year	5,200	5,200
Profesional Services (accounting, legal)	$/year	3,800.00	3,800
Safety Check (CMVI) Truck+Trailer	$/year	1,500.00	1,500
Communications fees (cell, satelilte, OBC)	$/year	1,000	1,000
Total Service Costs	$/year	25,500	25,535
Total yearly fixed cost	$/year	75,148	79,669
Fixed Cost per PMH	$/PMH	20.17	20.49
	WEIGHTS		
Tractor+Trailer Tare Weight	Tonnes	16.7	16.75
Allowable Gross Vehicle Weight (GVW)	Tonnes	49.7	49.7
Payload buffer	Tonnes	1.5	1.5
Merchantable Wood Density	kg/m3	850	850
Normal Period Payload	Tonnes	31.5	31.5

Normal Period Merchantable Volume	m3	37.1	37.0
SEASONAL ALLOWANCES			
Winter period	weeks	8	8
Winter allowable GVW	Tonnes	54.67	54.67
Winter payload	Tonnes	36.47	36.42
Winter Period Merchantable Volume	m3	42.91	42.85
Winter fuel consumption increase	%	5	5
Spring load restriction period	weeks	0	0
Spring allowable GVW	Tonnes	35.00	35.00
Spring payload	Tonnes	16.80	16.75
Spring Period Merchantable Volume	m3	19.76	19.71
Average payload for year	Tonnes	32.40	32.30
Average merchantable volume	m3	38.12	38.00
DISTANCE BY ROAD TYPE			
Paved Road	km	120	120
Class 1 Road	km	45	45
Class 2 Road	km	35	35
Class 3+ Roads	km	15	15
One Way Distance	km	215	215
SPEEDS			
LOADED			
Paved Road	km/h	75	75
Class 1	km/h	55	55
Class 2	km/h	40	40
Class 3+	km/h	23	23
Average Speed Loaded (calculated)	km/h	54.49	54.49
UNLOADED			
Paved Road	km/h	80	80
Class 1	km/h	60	60
Class 2	km/h	45	45
Class 3+	km/h	23	23
Average Speed Empty (calculated)	km/h	58	58
Overall Average Speed	km/h	56.39	56.39
FUEL CONSUMPTION			
Fuel Price	$/L	1.50	1.50
Idle Fuel Consumption	L/hr	4.00	4.00
DEF Price	$/L	0.80	0.80

DEF Consumption (% of Fuel Consumption)	%	4	4
LOADED			
Paved Road - Loaded	L/100km	67.05	66.99
Class 1 - Loaded	L/100km	75.01	73.88
Class 2 - Loaded	L/100km	93.11	91.51
Class 3+ - Loaded	L/100km	110.67	94.64
Average Consumption Loaded	L/100km	76.00	74.35
UNLOADED			
Paved Road - Unloaded	L/100km	32.70	32.76
Class 1 - Unloaded	L/100km	39.37	38.32
Class 2 - Unloaded	L/100km	42.89	41.40
Class 3+ - Unloaded	L/100km	44.90	41.60
Average Consumption Empty	L/100km	36.61	35.95
Total Rolling Fuel Consumption (FPI)	L/100km	56.79	55.61
Overall Fuel Consumption including Idle	L/100km	57.95	52.70
Rolling Hourly Fuel Consumption (no Idle)	L/hr	32.03	29.06
Hourly Fuel Consumption including Idle	L/hr	28.08	25.53
Fuel & DEF Cost per PMH	$/PMH	43.02	39.12
MAINTENANCE & REPAIR COSTS			
SCHEDULED MAINTENANCE (Oil and filters changes, lube, etc.)			
Interval between sessions	Weeks	4	4
Cost per sessions	$	550	550
Scheduled maintenance yearly cost	$/year	6,325	6,600
Repairs			
Drivetrain (Engine, transmission, axles)	$/year	4,000	4,000
Suspension and brakes	$/year	6,000	5,373
Electrics	$/year	2,000	2,000
Truck Frame + Chassis	$/year	1,000	1,000
Hydraulics (if so equipped)	$/year	0	0
Trailer	$/year	4,800	4,800
Others	$/year	5,000	5,000
TPCS	$/year	0	2,000
Total yearly repairs costs	$/year	22,800	24,173

Tire cost			
Tire purchase cost	$/units	600	600
Number of wheels	#	30	30
Tire life	Km	125,000	208,360
# Blowouts per year	#	5	3
Yearly Tire Cost	$/year	28,875	18,073
Total maintenance and repair cost	$/year	58,000	48,846
Maintenance and repair per PMH	$/PMH	15.57	12.56
TOTAL RATE PER PMH	$/PMH	121.00	113.76
Labor	$/h	31.25	31.25
Fixed	$/h	20.17	20.49
Fuel	$/h	43.02	39.12
Maintenance and repair	$/h	15.57	12.56
Profit	$/h	11.00	10.34
RATE PER TONNE	$/t	33.15	31.26
Labor	$/t	8.56	8.59
Fixed	$/t	5.52	5.63
Fuel	$/t	11.78	10.75
Maintenance and repair	$/t	4.26	3.45
Profit	$/t	3.01	2.84
RATE PER m3	$/m3	28.17	26.57
Labor	$/m³	7.28	7.30
Fixed	$/m³	4.70	4.79
Fuel	$/m³	10.02	9.14
Maintenance and repair	$/m³	3.62	2.93
Profit	$/m³	2.56	2.42
$/t savings from baseline		0.00	1.89
SUMMARY INFORMATION			
INFORMATION BY TRIP			
Rolling time (no stoppage time)	PMH/trip	7.63	7.63
Round trip time	PMH/trip	8.88	8.88
Lost time per trip	H/trip	0.99	0.99
Percent idle time	%	14%	14%
Round trip distance	Km	430	430
Fuel consumed per trip	L/trip	249.21	226.61
DEF consumed per trip	L/trip	9.97	9.06
Cost per trip	$/trip	1,074	1,010
INFORMATION BY YEAR			

Trips per year	#	420	438
Tonnes per year	Tonnes	13,602	14,150
Annual distance	km	180,521	188,370
Yearly Fuel Consumption	L/year	104,621	99,270
Yearly DEF Consumption	L/year	4,185	3,971
Costs per year	$/year	450,851	442,307
Labor	$/year	116434	121,500
Fixed	$/year	75,148	79,669
Fuel&DEF	$/year	160,279	152,082
Maintenance and repair	$/year	58,000	48,846
Profit	$/year	40,986	40,210
LIFETIME INFORMATION			
Tractor life hours	PMH	18,630	19,440
Trailer life hours	PMH	37,260	38,880
Loader Life		NA	NA
Tractor life km		902,605	941,849
Trailer life km		1,805,211	1,883,698
PERCENT COST BREAKDOWN			
Labor		26%	27%
Fixed		17%	18%
Fuel & DEF		36%	34%
Maintenance and repair		13%	11%
Profit		9%	9%