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Contents

Ownership and operating cost analysis of log trucks equipped with CTI systems or TPCS

Abstract

Tire pressure control systems (TPCS) or central tire inflation (CTI) systems are becoming popular in Canadian forestry operations as a means of increasing the mobility of log trucks and extending the hauling season. However, very little information is available that quantifies their ownership and operating costs. The Forest Engineering Research Institute of Canada (FERIC) monitored the Redline-Eltek TPCS and the Eaton TPCS over a three-year period. The study involved 24 log trucks of various configurations working at six locations in western Canada. This report presents the TPCS ownership and operating costs of these 24 trucks and describes how truck utilization affects the TPCS and truck ownership costs.

Keywords

Logging trucks, Central tire inflation system, Tire pressure control system, Costs, Performance

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Introduction

In western Canada, TPCS or CTI systems are gaining popularity with forest companies and their contractors as a means of increasing the mobility of log trucks and extending the hauling season. While the benefits of optimized tire pressures are well documented, limited information is available on the ownership and operating costs of TPCS or CTI systems. Both cost and benefit information are important to forest companies and their contractors if they are to determine the value of these systems in their operations.

Two systems are available for commercial use: the Redline-Eltek TPCS, manufactured by Tire Pressure Control International Ltd. (TPC International) of Edmonton, Alberta; and the Eaton TPCS, manufactured by Eaton Corporation of Cleveland, Ohio. In this report, TPCS will be used when referring to these systems and to the technology in general.

In 1995, FERIC began a study to document the ownership and operating costs of TPCS operating on log trucks in western Canada. The study involved documenting TPCS maintenance and ownership costs of 24 log trucks of various configurations working for six forest companies in B.C. and Alberta. These trucks were equipped with either the Eaton or Redline-Eltek TPCS. Due to the small sample size and differing truck configurations and working conditions, a case study approach detailing the experiences of these trucks was adopted rather than a statistical comparison of the results. During the three-year study period (1995–1998), data were collected for the subject trucks, in some cases dating back to 1993. The data represented over 180 000 accumulated engine operating hours with TPCS.

[1] Allan Bradley resigned from FERIC in Feb. 2000.

Methodology

FERIC members with hauling contractors using TPCS-equipped trucks were approached to participate in this study. Candidate contractors were interviewed and study cooperators were selected on the following basis: enthusiasm for the project, good maintenance record-keeping practices, and TPCS type. Once a cooperator was identified, retroactive repair histories for the TPCS on each truck were compiled. Arrangements were made to collect additional data as repair and maintenance incidents occurred.

Appendix I provides information on the cooperators for this study and the trucks studied. Appendix II lists the details for the TPCS and cooperating trucks monitored during this study. Half of the trucks monitored were used predominantly for off-highway hauls. These trucks typically carried heavier payloads and consequently had greater tire loading than those used for on-highway hauls. Figures 1 and 2 show trucks equipped with the two brands of TPCS studied. The truck in Figure 1 is a five-axle, off-highway, self-loading configuration equipped with an Eaton TPCS, while in Figure 2 the on/off-highway B-train uses a Redline-Eltek TPCS (identified by the external air supply hoses on the drive axles).

Figure 1. Self-loading 5-axle off-highway truck equipped with an Eaton TPCS.

Figure 2. TAC configured B-train equipped with a Redline-Eltek 3-zone TPCS.

Of the 24 trucks participating in the study, 15 were maintained by the hauling contractors' own mechanics, while 9 relied on the drivers and local service facilities for repairs. The hourly labour rates used for repairs and maintenance performed by drivers and contractor mechanics were $30 and $50, respectively. Of the 24 trucks, 18 were driven by hired drivers and 6 were driven by owner-operators. Many of the maintenance and repair activities were undertaken by the fleet mechanics or drivers and by the owner-operators themselves. The initial skill level of the mechanics and drivers in operating and maintaining the TPCS is not known. However, as the study progressed, the skill levels of those involved with repairs improved. For most of the cooperators, more complicated repairs were done by the TPCS manufacturers' authorized service facilities.

Study cooperators were provided with log books to record repairs done to either the TPCS or to the truck's air delivery system (air dryer and compressor), and to identify truck engine hours when the repair occurred. The truck's onboard engine hour meter was used to calculate utilization levels and to determine the hourly TPCS operating costs. Periodic field visits were made by FERIC personnel to update and review the repair records. During visits, the researcher rode in the study trucks and reviewed the repair and maintenance events with the drivers. This

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helped verify the repair details and ensured that all repairs had been included. When invoices were provided, the cost on the invoice with all applicable taxes was used for costing. In B.C., this included the 7% Goods and Services Tax (GST) and 7% Provincial Sales Tax (PST), and in Alberta, only the GST. When invoices were not available, spare parts prices recommended by the manufacturers were used. The repair costs recorded are the actual costs of the repair at that time; they have not been adjusted to present values.

The costs were entered incident by incident into a database and assigned to one of the following three categories:

- Direct TPCS costs included parts and labour for repairs specific to the TPCS.
- Indirect TPCS costs included parts and labour for repairs and maintenance to related components and systems that were made necessary by the operation of the TPCS. For example, the cost of repairing rims and tires that were damaged as a result of a TPCS malfunction was tallied.
- Air delivery system costs included parts and labour for repairs and maintenance to the air delivery system, focusing primarily on the air dryer and compressor. Only repairs to air system components upstream of the TPCS were included. The components included in this category are not supplied as part of the TPCS or manufactured by the TPCS manufacturer.

Variable tire pressure operation may influence, positively or negatively, other aspects of truck operation such as fuel consumption, drive train component wear, and tire life. These influences were not documented in this study.

The database was used to generate detailed repair summaries for each of the three cost categories for each truck. Repair costs covered by warranty were noted in the database so that TPCS hourly operating costs for non-warranty repairs could be calculated. For warranty repairs, the data summary includes the number of incidents and an estimated cost to indicate the magnitude of each incident. The costs for repairs covered by warranty are not included in any of the operating costs presented in this report.

Results

Warranty repairs

Although repair costs covered by original equipment manufacturers' warranty were not included in the final cost determination, indirect costs do arise from these repairs which are not covered by warranty. These indirect costs stem largely from the time that the truck is unproductive (i.e., "downtime") and normally represent a cost to the truck owner who is not compensated.

Warranty repairs in Table 1 are presented as number of events for the three most frequently repaired components for each

Table 1. TPCS warranty repairs and estimated repair costs

TPCS type	Failed TPCS component	Trucks (no.)	Warranty repairs (no.)	Estimated repair cost ($/repair)
Eaton	Pneumatic control unit	8	9	2 400
	Drive axle seals	8	17	900
	Wheel	8	19	650
Redline-Eltek	Rotary unions	16	14	350
	Electronic control unit	16	13	250
	General repairs	16	6	210

system, with an estimated repair cost. Downtime costs associated with these repairs will vary with access to service centres and parts availability. In six of the eight Eaton TPCS, neither Eaton Corporation nor its repair facilities provided FERIC with details on warranty repairs, so repair costs were estimated from spare part prices, manufacturer-recommended labour guidelines, and similar non-warranty repairs. For the Redline-Eltek TPCS, FERIC was provided with detailed repair cost information from TPC International or its repair facilities.

Eaton TPCS

Of the three most frequently warranted repairs to the Eaton TPCS in the study, the replacement of the pneumatic control unit (PCU) (Figure 3) was estimated as the most costly at $2 400 per warranty incident. Nine PCU failures occurred during the study period. The PCU is a solenoid-controlled manifold activated by the electronic control unit (ECU). This mechanism directs airflow to and from the tires. Oil, water, and rust flakes carried with the airflow can contaminate the PCU causing it to malfunction, leading to its replacement or overhaul. Most of the PCU failures in the study group are believed to have resulted from excessive levels of airflow contaminants. PCU failures caused by contaminants can be reduced or eliminated by ensuring the air delivery system is producing clean, dry air. Since the monitoring period, Eaton has modified its PCU to reduce its sensitivity to contamination.

Seventeen drive-axle TPCS seals for the study group required warranty repairs, with an estimated cost of $900 per repair. Many of these drive-axle seal leaks occurred in cold weather, below -30 degrees C, as a result of the rubber seal material hardening and shrinking at low temperatures. Consequently, many of these were replaced under warranty. Eaton acknowledges that these seals may leak if the rubber hardens and shrinks at colder temperatures, and suggests warming the seals by operating the truck for one-half hour

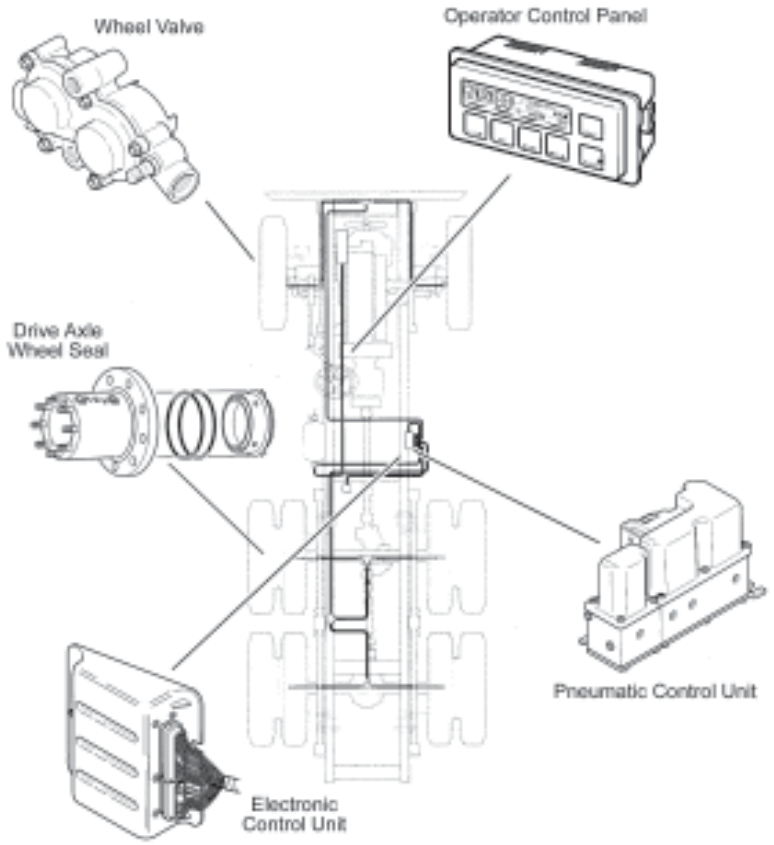


Figure 3. Illustration of main components of Eaton TPCS on tractor (Eaton 1994).

before operating the TPCS. Based on this, some seals may have been replaced prematurely under warranty. Some study cooperators addressed the leaking seal problem by disconnecting the TPCS over the winter, when its benefits are less pronounced.

Drive-axle TPCS seals have also been replaced as a preventative measure as a standard part of a drive axle overhaul. Although these seals may not have been leaking at the time, repair facilities occasionally deemed it prudent to install new seals when a drive axle overhaul was performed. The replacement of the TPCS axle seals adds both parts and labour cost to a drive axle overhaul.

For the study group, 19 wheel valves required warranty repairs, with an estimated cost of $650 per repair. Some of the early Eaton systems experienced problems with the older style of wheel valves; they would not work at high altitudes and the internal springs were subject to corrosion. Eaton corrected the high altitude problem by lowering the required operating vacuum from 19 to 17 inches of mercury. As wheel valves are also susceptible to failure from airborne contaminants, wheel valve filters should be changed regularly and the supply air should be free from oil and water contamination.

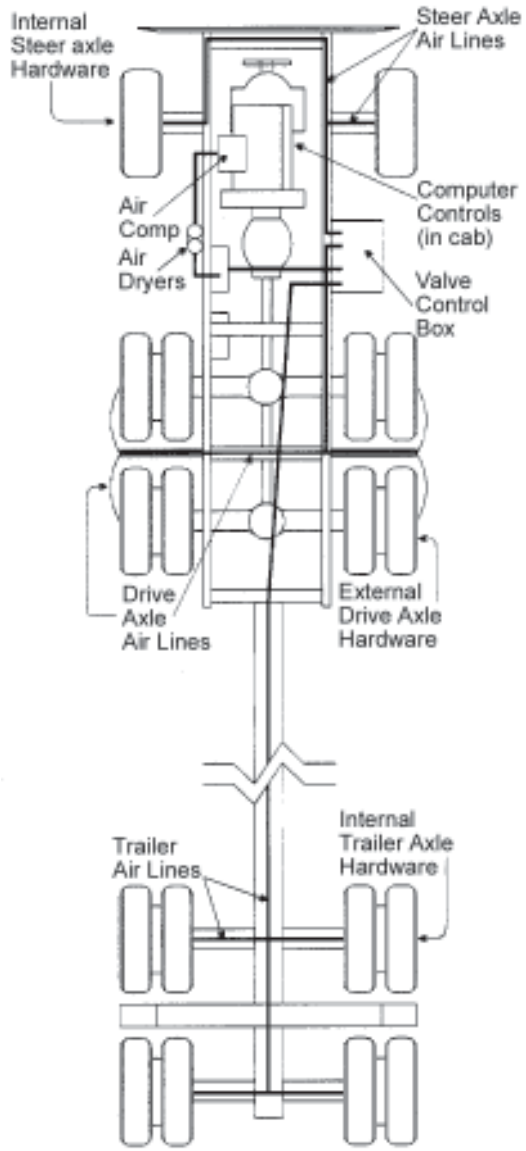


Figure 4. Illustration of a 3-zone Redline-Eltek TPCS, on a log truck (TPC International 1999).

Redline-Eltek TPCS

For Redline-Eltek TPCS in the study, replacement of rotary unions was the most frequent and costly warranty repair, occurring 14 times at an average cost of $360 per repair. These rotary unions are installed at the axle ends and make an air link between stationary air lines and the rotating tire (Figure 4). Rotary unions on steering and trailer axles are mounted inside the axle-end oil reservoirs where they experience longer life than on drive axles. Rotary unions for the drive tires are mounted externally on the drive axle ends and are more susceptible to damage from impact and corrosion.

Since the Redline-Eltek TPCS was introduced, the design of the rotary unions has been modified four times to prolong seal and bearing life. For some warranty repairs, modified rotary unions were given to customers on a trial or promotional basis. Some of the rotary unions failed because they cracked where the external air line fitting was attached (Figure 5). TPC International says this cracking is caused by the difference in thermal expansion characteristics between the material in the rotary union and the fitting, and can be avoided by using brass rather than steel fittings.

The Redline-Eltek ECU activates valve packs for each zone to feed air to and from the tires. During the study, the integrated-circuit control board in the Redline-Eltek ECU required 13 warranty repairs, with an average estimated cost of $250 per repair.

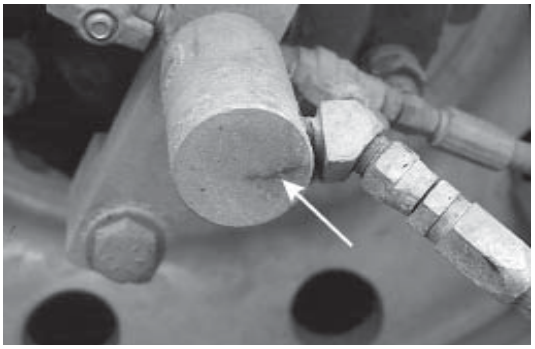


Figure 5. Cracked Redline-Eltek drive axle rotary union.

The ECU experienced two problems: interference with a two-way radio channel, and memory loss caused by power interuptions. Both the radio interference problem, which were confined to the Kelowna area, and the memory loss problem were solved by hardware changes to the ECU. These refinements are incorporated into the newer TPCS versions.

Earlier Redline-Eltek TPCS used passages drilled through the wall and stub ends of the trailer axles to feed air to and from the tires. One type of failure included in the general repairs category was caused by welding slag remaining inside the axle tube from the manufacturing process, which plugged the TPCS air passages and wheel hoses. The Redline-Eltek TPCS now avoids this problem by installing air lines within the trailer axle tubes. General repairs related to the TPCS occurred six times, with an average cost of $70 per repair.

Air system

A TPCS increases the workload on a truck's air delivery system. Where TPCS controls six or more axles, manufacturers typically recommend using a 30 cubic feet per minute (CFM) air compressor and air dryer assembly. The two air system components that required the most warranty repairs are identified in Table 2.

The first widely-used air dryer specifically recommended by Rockwell-Wabco for high duty cycle applications such as TPCS was its System Saver Twin Air Dryer. Eighteen of the study cooperators used this air dryer, and many experienced failures. An internal shuttle mechanism that alternates airflow between its two dryer canisters is susceptible to sticking due to oil and water residue buildup. Thus, all the airflow is directed to one canister which becomes saturated, allowing oil and water contaminants to flow to the rest of the air system. Many of these dryers were replaced under warranty, but the same problems returned.

TPC International experimented with different drying arrangements and eventually achieved satisfactory performance from a pair of Brakemaster Turbo-2000 air dryers with purge tanks, plumbed in parallel. These units have replaced almost all of the malfunctioning Rockwell-Wabco twin dryers. Some of the Eaton TPCS users were also using this drying system. However, Eaton does not take an active role in recommending air system components to be used with its systems. Warranted air dryer costs were for repairing the shuttle mechanism and for the replacement of the Rockwell-Wabco twin dryers.

Most 30-CFM air compressors used for TPCS applications are either the Bendix Tu-Flo 1400 or the Holset ST676. The seven study trucks equipped with Holset compressors averaged two warranty repairs per truck, at an estimated average cost of $4 000 per incident. When the study began, Holset compressors that failed under warranty were replaced with more expensive new units, because remanufactured Holset 30-CFM compressors (at half the cost) were unavailable. There were some minor warranty

Table 2. Air system warranty repairs

Manufacturer	Component	Trucks (no.)	Avg. repairs (repairs/truck)	Est .cost ($/repair)
Rockwell-Wabco	Twin air dryer	19	1.5	550
Holset	30-CFM compressor	8	2.0	4 000

repairs done to the Bendix Tu Flo 1400 compressors in the study and three were replaced under warranty.

TPCS on commercial trucks is relatively new and tire inflations typically involve pumping air for prolonged periods at high back pressures. Early plumbing arrangements were too restrictive and did not make adequate provision for dissipation of heat from the compressed air. This resulted in the compressor overheating and delivering hot, contaminated air to the system. These high temperatures tended to shorten compressor life (Holset 1996). Compressor plumbing improvements using larger diameter air lines have reduced discharge air temperature, improved air quality, and extended compressor life.

TPCS operating costs

This section describes operating costs that can be directly or indirectly attributed to the TPCS or to the air delivery system. These costs were not covered under warranty and represent a direct cost to the TPCS owner.

Direct costs

Costs incurred repairing or maintaining the TPCS are referred to in this report as direct TPCS costs. Trucks having similar TPCS configuration (i.e., the same manufacturer, number of zones, TPCS-controlled axles, and province of operation) were grouped together. Direct TPCS costs, expressed in dollars per engine operating hour, are shown in Figure 6. This figure illustrates the extent to which these direct costs varied (within and between the groupings). The length of the vertical line represents the standard deviations on both sides of the average direct cost, with the average cost being the horizontal line in the middle. This variation was influenced by a number of factors, such as operating conditions, repair and maintenance practices, and operator training.

The variation in direct TPCS costs between the two TPCS manufacturers may be explained in part by the cost of replacement parts. The Redline-Eltek TPCS incorporates many commonly available components, while the Eaton TPCS incorporates many parts that are unique to this system. As a result, many of the Redline-Eltek replacement parts were less expensive compared to those for the Eaton system. For example, a replacement for non-driven wheel end assemblies can be compared. The Redline-Eltek system incorporates conventional axle hubcaps, a special spacer, and the internal hose assembly. The 1999 approximate retail cost for this assembly is about $120. For the Eaton system, a hubcap assembly consisting of a hubcap modified to accept the wheel valve, and the inner hose assembly had a 1999 retail cost of over $400. The components presented in this comparison are generally not considered wear items; however, in logging operations they are subject to damage from rocks and logging debris.

Driver and mechanic training in the proper operation and maintenance of TPCS can significantly reduce operating costs.

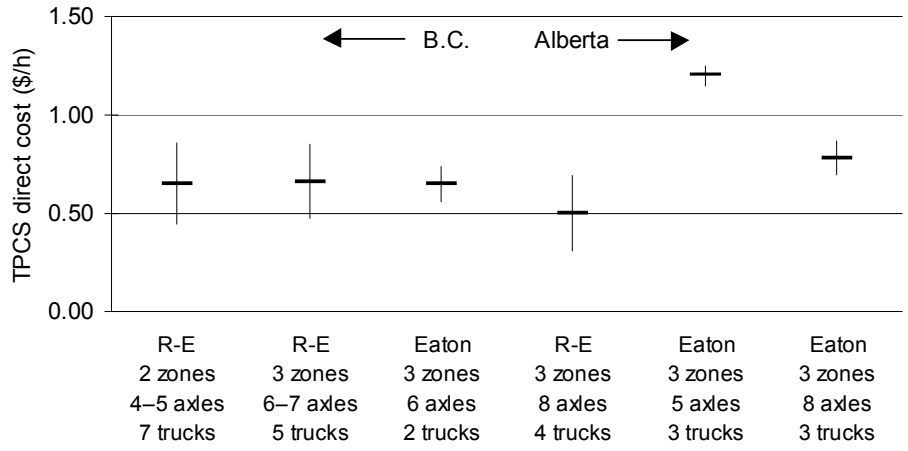


Figure 6. Range of TPCS direct costs.

During the study, mechanics and drivers became more knowledgeable about the systems' operations and were able to do more repairs themselves. This reduced repair costs and associated downtime. When the project ended, more cooperators were performing repairs and maintenance that previously would have been done by the local service facilities. The ability of the drivers to identify small problems and quickly resolve them improved as the project progressed. By correcting the small problems, such as a plugged tire hose, the drivers prevented more costly repairs, such as replacing destroyed tires and rims.

Some cooperators experienced developmental problems with the Eaton TPCS during its introductory period. In some cases, Eaton extended warranty coverage to help its customers with these early difficulties. For one cooperator, the TPCS warranty coverage was extended 2.5 years and considerably reduced the direct TPCS costs.

Contrary to expectation, there was no correlation between total TPCS operating costs and the number of axles controlled by the TPCS. Other factors, such as differences in operating conditions, operator training, and varying repair and maintenance practices, may have obscured such a relationship.

Indirect costs

On several occasions, cooperators reported repairs for non-TPCS components that they felt were caused by TPCS use. These repairs were considered for inclusion in this study on a case by case basis; when included, they were categorized as indirect TPCS costs. One notable example, worn and cracked aluminum rims, is discussed.

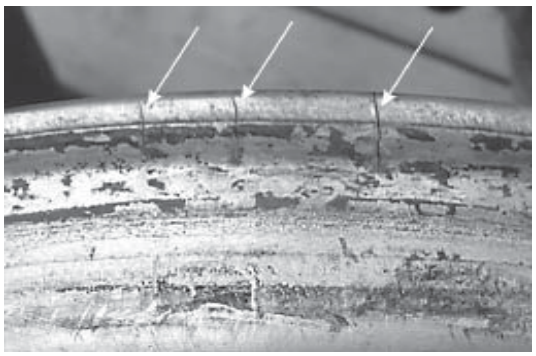


Figure 7. Cracking in the bead area of aluminum rims.

Increased wear and cracking in the bead area of aluminum rims were problems that most cooperators in the Kelowna area experienced (Figure 7). They state that they did not experience these problems prior to TPCS installations, when they were operating exclusively at high tire pressures. The cracks frequently resulted when the rim flange hit rocks on rough, new forest roads, and deflating the tires increases the likelihood of this type of damage. Wear in the bead area is also a common problem with aluminum rims. This wear occurs when the tire sidewall deflects and scrubs against the rim flange, and is accelerated by a variety of factors including heavy tire loads, shifting or unbalanced loads, and low tire pressures (ALCOA 1998). The trucks that experienced most of the aluminum rim problems were self-loading trucks working on rough, new forest roads. Some of their rim failures were judged to have been the result of reducing tire pressures despite difficult operating conditions, and these repair costs are therefore included in the analysis. Other failures, where it was determined that tire and rim load ratings were exceeded, are not included. There were no TPCS-related problems identified with steel rims.

Air system costs

Trucks with or without a TPCS will incur air system maintenance costs. The addition of a TPCS increases the duty cycle of the compressor and dryer, but by how much is unknown. Therefore, all non-warranty air compressor and dryer repair and maintenance costs are included. To estimate the proportion of these air system costs directly attributable to the TPCS, further data from the air systems of comparable non-TPCS trucks would need to be gathered and compared.

Figure 8 illustrates the average TPCS operating costs, which include direct and indirect TPCS and air system costs. The lowest average operating cost was $0.98/h for the seven B.C. trucks with 2-zone Redline-Eltek TPCS and 13.5–16.5-CFM air compressors. The highest average

operating cost of $2.04/h was for a pair of six-axle B.C. trucks with 3-zone Eaton TPCS and 30-CFM air systems. Nearly 50% of the operating cost for these two Eaton systems is attributed to repairs and maintenance on their Holset air compressors and Rockwell-Wabco twin air dryers. It is important to note that these air system components are not made by the TPCS manufacturers. The seven B.C. trucks equipped with Redline-Eltek 2-zone TPCS, the original 13.2–16.5-CFM air compressors, and a single-canister Bendix air dryer, had the lowest average air system maintenance cost of the study group, at $0.16 per truck engine hour. Fifteen of the remaining trucks used the larger 30-CFM compressors with either the Rockwell-Wabco twin dryers or Brakemaster dual dryers with purge tanks. The average air system costs for these trucks was $0.37 per truck engine hour. Unwarranted air dryer costs occurred predominantly to replace contaminated desiccant cartridges, and to repair or replace malfunctioning Rockwell-Wabco twin air dryers.

TPCS ownership costs

The variables that influence ownership cost (e.g., purchase price, expected service life, depreciation rate, salvage value, and interest rate) varied considerably within the study group. Therefore, to quantify representative TPCS ownership costs, FERIC used its equipment costing model and assumed typical values for each of the variables. Appendix III shows the calculations for 8-axle Redline-Eltek and Eaton trucks operating at 1800 hours per year.

Purchase prices for TPCS range from $10 000 to $27 000, depending on system manufacturer, number of zones controlled, and number of axles equipped. To quantify TPCS ownership costs, current system costs (applicable taxes included) less the estimated salvage value were financed at 8.5% annually, over the life of one tractor working 12 000 hours. Depending on the annual operating hours used in the analysis, tractor life can range from 3.3 to 6.7 years.

The ownership costs of three TPCS used in Alberta are presented as a function of truck utilization in Figure 9. As the annual operating hours increase, the ownership costs decrease.

The Redline-Eltek TPCS is an aftermarket system and therefore can be transferred from truck to truck relatively easily. The salvage values used were based on information from the manufacturer and from system owners. It was estimated that a 3.3-year-old system has a salvage value of 40% of its original purchase price, while a 6.7-year-old system has a value of only 15%. Most of the cooperators who replaced their trucks

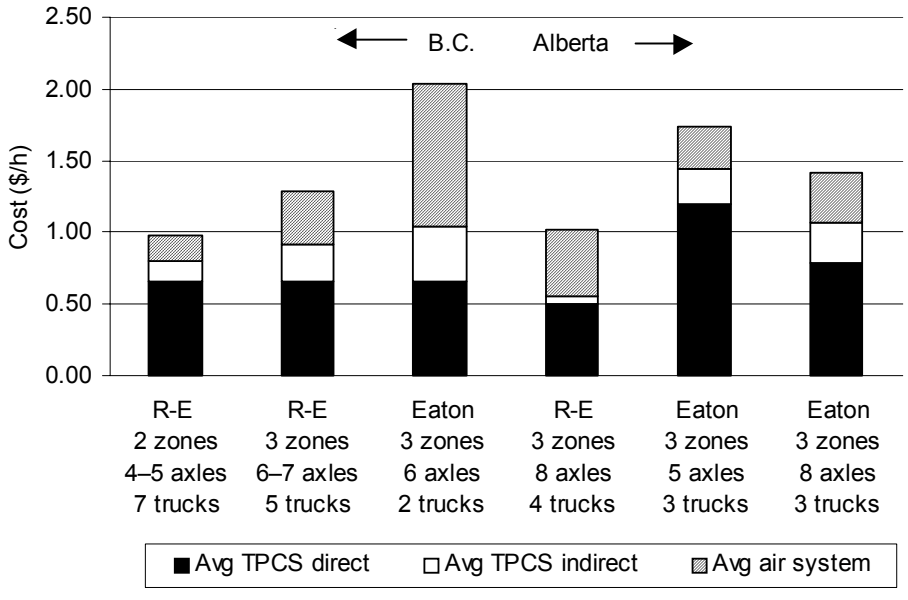
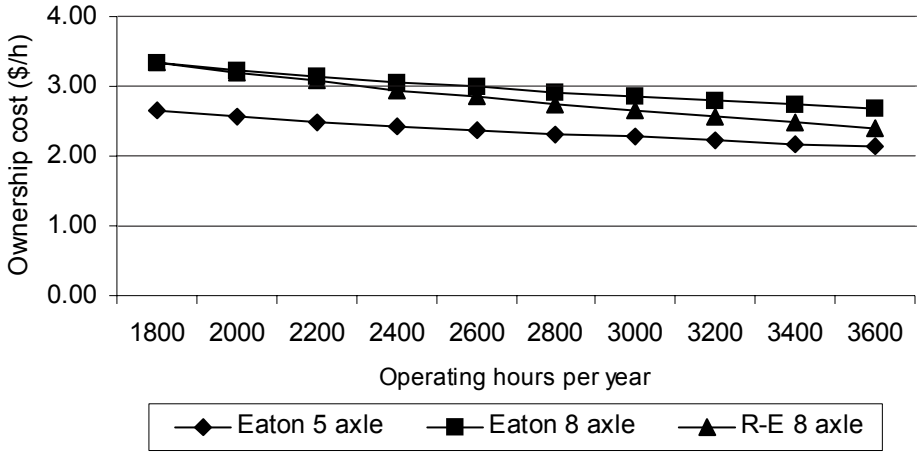


Figure 8
Average TPCS operating costs.

Figure 9
Range of TPCS ownership costs for Alberta cooperators.



during the study period transferred their Redline-Eltek TPCS to the new truck. Removal of the system costs about $1 000 and re-installation about $3 000.

Presently, the Eaton system is only available as a factory option from truck manufacturers. It is not easily transferred from truck to truck, and this is reflected in its low salvage value. Based on discussions with cooperators and truck dealerships, the Eaton TPCS adds little to the tractor's trade-in value. The salvage value of a 3.3-year-old system is estimated at 18.5% of its original price, while a 6.7-year-old system is reduced to 5%. None of the cooperators who replaced their tractors during the study period transferred their Eaton TPCS to the new tractor. Prior to selling his tractor, one cooperator removed the Eaton TPCS to try to sell it separately. Another cooperator received about 15% of the TPCS purchase price in trade-in allowance.

The differences in slope of the lines shown in Figure 9 are due to the difference in salvage values between the Eaton and Redline-Eltek TPCS. At the time of this report, the purchase price of an Eaton system was slightly less than of a similar Redline-Eltek TPCS. However, the greater salvage value of the Redline-Eltek TPCS results in a lower hourly ownership cost.

TPC International recommends upgrading the truck's compressor and air dryers to 30-CFM capacity when its TPCS is to service six or more axles. All of the trucks in the study that were equipped with the Eaton system had 30-CFM air systems. The cost of the larger air compressor and dryer will vary depending on component and truck manufacturers. For this study, an estimated cost of $4 500 was used for a factory upgraded air system on a new truck. If the air system is upgraded after the truck is built, these components will cost considerably more than $4 500. All of the 3-zone TPCS in this study had 30-CFM air delivery systems, and the ownership costs in this report include an extra $4 500 to account for this upgrade. The 2-zone TPCS did not have upgraded air systems. Based on discussions with truck dealerships and with TPCS owners, no additional trade-in allowance is given for 30-CFM air systems because there is a low demand for tractors with high capacity air delivery systems for other than TPCS applications.

Figure 10 presents estimates of the ownership costs as ranges, varying with truck utilization. The estimated maximum ownership cost (corresponding to 1 800 annual operating hours) ranged from $2.14/h to $3.35/h, and the minimum ownership cost (corresponding to 3 600 annual operating hours) ranged from $1.37/h to $2.70/h.

The 2-zone Redline-Eltek TPCS in the study had the lowest ownership costs because they were the least expensive systems to purchase, and required no air system upgrading. Some purchasers of new TPCS are reducing ownership costs by eliminating

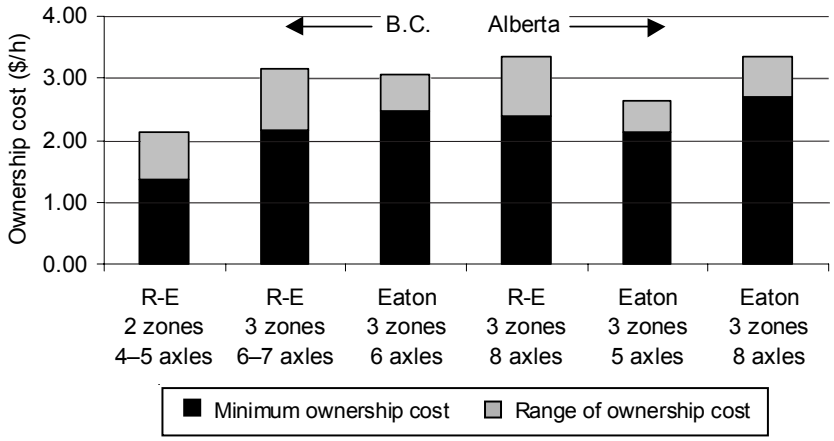


Figure 10. Range of TPCS ownership cost for study group.

the third TPCS zone controlling the steering tires. While noting that 3-zone TPCS will provide the user with better performance, the manufacturers of the Redline-Eltek TPCS say that there are applications where the additional cost of equipping the steer axle tires outweigh the potential benefits.

"When the vehicle is using standard size tires on a conventional truck and the weights do not change significantly from unloaded to loaded [by less than 500 kg], we advise to set the tires at a constant reduced pressure matching an acceptable deflection for highway and off-highway travel [instead of equipping a steering axle TPCS zone]." (TPC International 1999)

Eliminating the steering axle zone reduces the purchase price by approximately $4 500 for a Redline-Eltek TPCS, and $2 100 for an Eaton TPCS.

TPCS combined ownership and operating costs

The total cost of owning and operating TPCS (excluding warranty costs) for the study group is shown in Figure 11. The total cost of each type of TPCS configuration is presented as the sum of the ownership and operating costs plus the range of ownership cost (depending on utilization). The 2-zone Redline-Eltek systems had the lowest total TPCS costs, which varied from $2.35 to $3.12/h. This configuration had the lowest overall costs because eliminating the steering axle zone reduced purchase prices, eliminated the need for air system upgrades, and lowered overall operating costs. The Eaton 3-zone TPCS had total costs that ranged from $3.88/h to $5.11/h, depending on truck configuration and utilization. Total costs for the 3-zone Redline-Eltek TPCS ranged from $3.40/h to $4.43/h, depending on configuration and utilization.

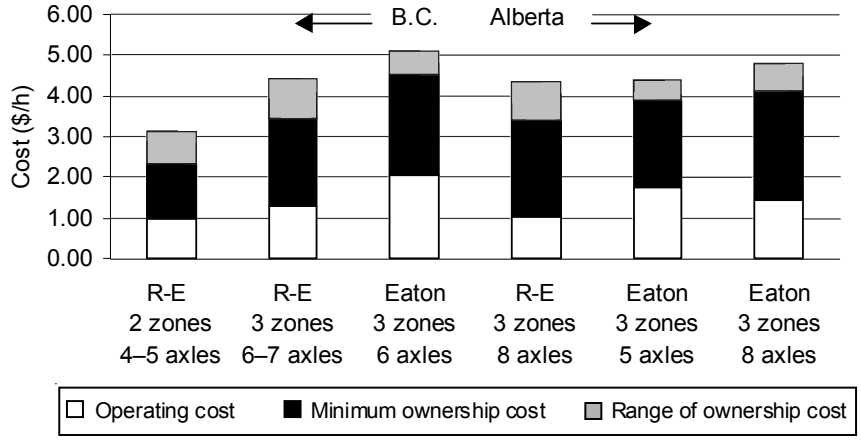


Figure 11. Range of TPCS ownership and operating costs for study group.

Influence of truck utilization

Using optimized tire pressures instead of normal highway tire pressures has been shown to reduce rutting, washboard, and stream sedimentation on forest roads (Bradley 1997). Some Canadian forest operations have taken advantage of the benefits from this technology by continuing to work during soft road conditions. The TPCS trucks in this study experienced a range of utilization increases (i.e., from 0% to 90%) when compared to trucks without TPCS. Some cooperators were able to increase annual truck utilization to 2 800 h in single-shift operation, and to more than 3 600 h in double-shift operation. Increasing the truck's annual utilization allows the contractor to amortize the fixed truck costs over more operating hours, thereby reducing hourly ownership cost.

An example of how truck ownership costs can be reduced through greater utilization is shown in Figure 12. Truck ownership costs for a six-axle log truck were calculated using FERIC's costing model, for various levels of annual utilization. Truck and trailer purchase prices were estimated at $145 000 and $55 000, respectively. The tractor was financed over 12 000 h and the trailer over 24 000 h, at an annual interest rate of 8.5%. The cost of insurance was assumed to be $4 500 per year.

Many factors influence the trade-in value of a truck and trailer, including its age and condition. In this example, the tractor was assumed to have accumulated 12 000 operating hours before it was traded in. By varying annual utilization between 1 800 and 3 600 hours, tractor age at trade-in varied between 3.3 and 6.7 years. A tractor that is only 3.3 years old typically has 1.7 years of warranty coverage remaining (assuming a 5-year warranty) and this will increase its trade-in value. Tractor trade-in value was assumed to vary linearly between 50% and 25% of the purchase price for age between 3.3 and 6.7 years.

Testing by the Nevada Automotive Test Center (NATC) found that low-pressure tires imparted about one-half the vertical energy of the loaded vehicle into the chassis compared to high-pressure tires over a washboard test section (NATC 1987). In the long term, this reduced shock and vibration is expected to decrease vibration-related component damage. Fleets of TPCS-equipped trucks operating in Washington State have also identified reductions in vibration-related repairs over the longer term (Kreyns 1993). Kreyns estimates that reduced component damage due to TPCS use would likely extend the life of the USDA Forest Service TPCS-equipped dump trucks by one year, on average. In FERIC's study, no extension in truck life was assumed for the ownership cost example. Some of the potential savings created by longer truck life may be partially offset by higher maintenance costs.

The model estimates that if annual utilization can be doubled (i.e., from 1 800 to 3 600 h) then truck ownership costs would be reduced by 36% (from $19.34/h to $12.32/h) and TPCS ownership cost would

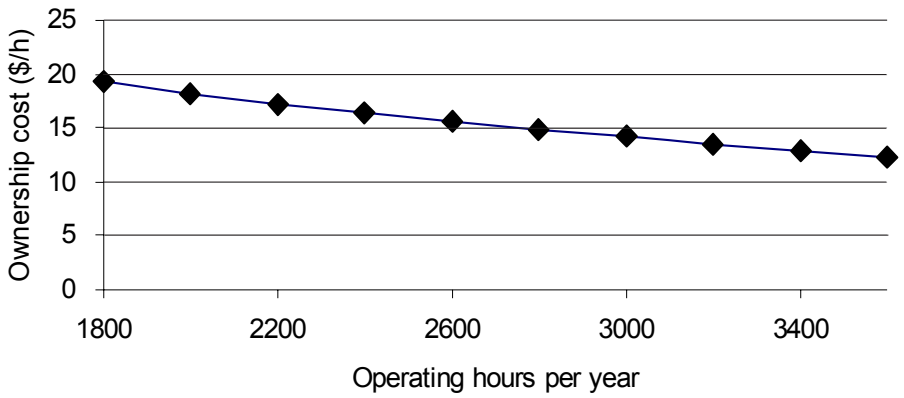


Figure 12. Influence of annual utilization on truck ownership costs.

be reduced by 31% (from $3.15/h to $2.15/h). Depending on utilization, the savings in truck and TPCS ownership costs could be as much as $8.02/h, and would either partially or fully offset the $2.35/h to $5.11/h cost of owning and operating the TPCS.

Conclusions

Based on the data collected, the ownership and operating cost of TPCS for these trucks ranged from $2.35 to $5.11 per truck engine hour, depending on system type and manufacturer, air system capacity, truck utilization, number of zones, and number of CTI-equipped axles. These amounts excluded the costs associated with warranty repairs and downtime. Other cost components or factors that may be influenced by TPCS use, such as driveline and tire sidewall damage and fuel consumption, were not included in the cost results presented.

Operating costs presented included costs directly and indirectly associated with the operation of a TPCS. Operating cost is a function of truck/trailer configuration, spare parts pricing, working conditions, and operator experience and training. It is strongly influenced by the performance of the air delivery system and its ability to provide clean dry air to the TPCS.

Ownership costs are dependent on system price, truck and TPCS utilization, and truck and TPCS salvage values. Reduced tire pressures have demonstrated the ability to reduce road rutting and damage when compared to high pressure tires. This can potentially lead to a shorter spring break-up period if TPCS-equipped trucks are used during soft road conditions. Increasing the annual operating hours would allow the contractor to amortize the fixed truck and trailer ownership costs over more operating hours, and the resulting savings can partially (or in some cases fully) offset the ownership and operating cost of a TPCS.

Since this project started, manufacturers have made significant improvements in the design of both the air delivery system and the TPCS. The changes incorporated into the new systems are aimed at reducing the frequency and cost of repairs, compared to some of the earliest systems in this study. These improvements should reduce the operating costs for new systems for both the Redline-Eltek TPCS and the Eaton TPCS.

Implementation

When purchasing a TPCS, one should consider the service facilities and their expertise in troubleshooting and repairing these systems. While purchase price is an important consideration, spare parts pricing and availability should also be considered, as they can influence the operating costs and length of downtime.

Air system purchase and repair costs are components of the ownership and operating costs of TPCS. For the 30-CFM capacity air systems, proper compressor and dryer installation is critical. Compressor and dryer plumbing should be done according to manufacturers' recommendation and be of sufficient size to reduce heat build-up and back pressures. Ensuring that proper installation procedures are followed will help increase compressor and air dryer service life. Providing the TPCS with clean dry air will reduce contamination-related failures and TPCS operating costs. If the TPCS services five or fewer axles, TPC International recommends a 16.5-CFM air system. When four or more axles are TPCS-equipped, TPC International recommends a dual dryer system.

Driver training in proper system operation and maintenance can reduce TPCS operating costs and TPCS-related downtime. Training will help achieve driver acceptance and proper system operation. These will ensure that the full benefits of optimized tire pressures are achieved. If the truck is equipped with some basic spare parts and tools, repairs and troubleshooting can be performed in the field, and associated downtime costs will be reduced.

TPCS users should adhere to manufacturer-recommended maintenance

schedules. Many study cooperators performed a thorough TPCS preventative maintenance inspection during spring break-up. This strategy helps reduce TPCS-related downtime and corrects problems which may otherwise result in more expensive damage and downtime.

Extending the operating season should be a principal goal of TPCS owners. The potential reductions in fixed truck and TPCS ownership costs can partially, or fully, offset the cost of owning and operating a TPCS-equipped truck. By providing longer-term employment, contractors may find it easier to find and keep experienced drivers.

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Appendix I

Project cooperators

Forest company	Mill location	Contractor	Trucks (no.)	Truck application
Weyerhaeuser Canada Limited	Okanagan Falls, B.C.	Shirell Contracting Corp.	3	Off-hwy
		Spruce Valley Contracting Ltd.	3	Off-hwy
Riverside Forest Products Limited	Kelowna, B.C.	J and T Holdings Ltd.	2	On/off-hwy
		Roadby Contracting Ltd.	1	On/off-hwy
		Al Reis Logging Ltd.	1	On/off-hwy
		Darryl Hanet Holdings Ltd.	1	On/off-hwy
Tolko Industries Ltd.	Quesnel, B.C.	Timber Service Ltd.	1	On/off-hwy
Crestbrook Forest Industries Ltd.	Cranbrook, B.C.	Company-owned truck	1	On/off-hwy
Weyerhaeuser Canada Limited	Grande Prairie, Alta	South Cariboo Ent. Ltd.	2	Off-hwy
		I-Nor Contracting Ltd.	1	Off-hwy
		Lorne LaRochelle Trucking	1	Off-hwy
Alberta-Pacific Forest Industries Inc.	Boyle, Alta.	McLoja Enterprises Ltd.	1	On/off-hwy
		J and K Trucking Ent. Ltd.	1	On/off-hwy
		Michael Mallock Trucking	1	On/off-hwy
		Supertrain Inc.	1	On/off-hwy
		Gold Creek Trucking Ltd.	1	On/off-hwy
		Keyano College	2	On/off-hwy

Appendix II

Truck configurations and TPCS in study

TPCS type	TPCS (no.)	TPCS-equipped axles (no.)	Zones [a] (no.)	Configuration
Eaton	3	5	3	Tractor/pole trailer
	1	6	3	Tractor/jeep/pole trailer
	1	6	3	Tractor/triaxle trailer
	3	8	3	TAC B-train
Redline-Eltek	6	4	2	Tractor/pole trailer
	3	6	3	Tractor/jeep/pole trailer
	1	7	3	Tractor/quadaxle trailer
	1	7	3	Tractor/jeep/triaxle trailer
	1	5	3	Tractor/tridem semi-trailer
	4	8	3	TAC B-train

[a] A zone is a group of TPCS-equipped axles that are interconnected and controlled as one group.

Appendix III

TPCS ownership costs[a]

	Redline-Eltek 8-axle	Eaton 8-axle
Ownership costs		
Total purchase price (P) $ (GST included)	28 890	27 285
Expected life (Y) y	6.67	6.67
Expected life (H) h	12 000	12 000
Scheduled hours/year (h)=(H/Y) h	1 800	1 800
Salvage value as % of P (s) %	15	5
Interest rate (Int) %	8.5	8.5
Salvage value (S)=((P•s)/100) $	4 334	1 364
Average investment (AVI)=((P+S)/2) $	16 612	14 325
Loss in resale value ((P-S)/H) $/h	2.05	2.16
Interest ((Int•AVI)/h) $/h	0.78	0.68
Total ownership costs (OW) $/h	2.83	2.84
Air system upgrade (GST included)	0.51	0.51
Total ownership cost	3.34	3.35

[a] These costs are based on FERIC's costing methodology for determining machine ownership costs. These costs do not include profit or overhead, and are not the actual costs incurred by the contractors or companies involved in the study.