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User experiences with the Central Tire Inflation system on timber trucks in Finland

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Abstract

The purpose of this research was to study user experiences related to Central Tire Inflation (CTI) in Finnish timber transportation by interviewing the owners of timber trucks equipped with this system and recording their views on its benefits and costs, and then analyzing the distribution of opinions between operators.

The data were collected in autumn 2017 by phone interviews using a semi-structured questionnaire. The operators reported that CTI allowed them to transport only a little more timber than with a regular truck and offered only minor assistance when operating under difficult conditions. Tire pressures were adjusted both outside the frost heave season and on roads that could have been operated on under normal tire pressures. The use of CTI nevertheless reduced rutting of the roads and vibration of the truck.

The results indicate that Finnish timber transportation companies are not content with CTI, because the benefits of the system do not match its costs. The investments involved would require the charging higher rates for transport by vehicles equipped with CTI. The number of CTI-enabled roads within the transportation area also affects the profitability of the system, as does the number of stands located beside such roads to be serviced during frost heave seasons. Better overall planning of the wood procurement chain,taking CTI into account at all stages,would be necessary to maximize the utilization rate of the system.

Keywords:Central Tyre Inflation Systems, Tyre Pressure Control Systems, timber transport, user experiences

1. Introduction

Efforts have been made to improve the cost-effectiveness of Finnish timber transportation by increasing the size of the vehicles, now that the most recent reform of the legislation, that of 2013,sets the maximum mass of a truck and trailer combination

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at76 tonnes. Moreover, High Capacity Transport vehicles with a total mass of up to 104 tonnes have been tested for use in timber transportation, information systems have been developed and various control systems have been introduced (Hämäläinen, 2017). According to the Finnish timber transportation representatives interviewed by Malinen et al. (2014), the winter maintenance of the roads was the most significant single bottleneck, while year-around bearing capacity, frost-damaged roads and the condition and grading of road surface,together with the size of turning points, crossings and storage sites, were considered important factors.

Due to Finland's geographical location, weather conditions substantiallyaffect the usefulness of the low volume road network, above all on account of temperatures, rainfall and wind, either by causing damage to the roadsthemselves or by affecting their maintenance. The thawing of the ground frost affects the bearing capacity of the roads in spring, whereas the bearing capacity in autumn is reduced by the abundant rainfall, which softens the structure of the road. As winter arrives, the bearing capacity improvesasthe frost hardens the road surface, but the snow cover and the resulting slipperiness will directly affect accessibility, so that intensified maintenance will be required to enable transportation and ensure its safety.

The above-mentioned seasonal limitations on bearing capacity hamper year-round wood procurement, so that in order to ensure the continuous manufacture of wood-based products, the forest industries have to increase buffer storage at production plants and terminals, entailing extra costs and affecting the quality of their raw materials. According to Rieppo (2006), seasonal bearing capacity problems are responsible for additional cost of about EUR 100 million per year for the Finnish forest sector, out of which about 65 million is due to frost heave. Uneven year-round use of harvesting and transportation equipment is an additional cost factor when acquisitions are planned on the basis of the peak winter harvesting season but some of the machines stand idle for weeks due to bearing capacity problems (Rieppo, 2006).

According to Perälä et al. (2011), the total length of weight restricted low-volume roads attributable tolow bearing capacity varied annually from 801 to 3229 kilometers during the first decade of the new millennium, a considerably lower figure than in the 1980s or 1990s. Although the government authorities carry out seasonal repairs on low-volume roads, it is difficult to estimate the needs of the timber transportation sector due to the continually changing harvesting sites.In the future, variations in frost conditions caused by climate change will pose additional challenges for road maintenance and design (Jylhä et al., 2009).

Suitable tire pressuresare important for ensuring the safety and reliability of transportation using heavyvehicles and for maximizing the achievable benefits (Anonymous, 2013). Optimal tire pressures vary according to the load, speed, and road conditions, but in most vehicles constant pressures are used which corresponds to the most demanding transportation conditions, such as high speed or full load, despite the above-mentioned variations (Bradley, 2009). Too low a pressure can cause tire damage as a result of abnormal warming due to tangling of the outer edge of the tire, and also uneven surface wear, while the increase in rolling resistance will raise fuel consumption (Sidders, 2017). Correspondingly, too high a tire pressure can cause irregular wear and thus damage to the tires. A bursttire may lead to a loss of vehicle control and serious road accidents, especially where heavy vehicles are concerned, due to the unpredictable movements of the vehicle itself and possible loosening of the load.

With the Central Tire Inflation (CTI) system, a driver can change the tire pressure of the vehicle while driving to conform to the prevailing road conditions and the load situation. According to the literature, the benefits of CTI include increased vehicle mobility, an extended hauling season and reduced road requirements, reduced rutting and road maintenance, reduced driver fatigue and medical complaints thanks to decreased vibration, lower vehicle operating costs following a decreased in tire fatigue, and increased service life due to less tire damage (Ghaffariyan, 2017). The systems was originally developed for military use, to improve the mobility of vehicles on difficult terrain by reducing their tire pressures and thus extending the area in contact with the ground and reducing the surface pressure of the vehicle. The applicability of CTI systems has been extended to forestry, however, and it is commonly used in Australia, New Zealand and North America, for example.

In addition to reducing pressure on the road surface, a lowertire pressure will increase the contact surface, providing greater friction and improving both grip and braking properties under slippery conditions (Anonymous, 2010). Vuorimies et al. (2012) nevertheless found hardly any influence of CTI system on traction on a slippery, yet hard and homogeneous surface, although in their opiniontire pressure adjustment may have a significant effect on friction in situations where slippery and non-slippery surfaces alternate during the journey. Sturos et al. (1995) found that, although pull increased by 37% on icy roads and 31% on freshly packed snow with an unloaded truck, a loaded truck had a traction increase of 6% on ice and there was no difference on freshly packed snow. On the other hand, the adjustment of tire pressure is important factor in improving transportability on steep roads in mountainous regions. According to simulations conducted by Bulley and Blair (2001), trucks with reduced tire pressures were able to run on slopes without any external assistance, unlike trucks using normal tire pressures, and this accelerated the transportation cycle by about 3% and eliminated the costs of the assisting vehicle.

According to Blair and Eng (2000), the driving restrictions imposed by the Canadian authorities in the province of British Columbia may last from six to ten weeks in spring. Even though the major highways and the smallest forest tracks, which would still be frozen, would allow the passage of heavy vehicles, condition on the secondary roads in between these would prevent the transportation of timber, especially since driving with a reduced load would not be economically viable. In Canada, the restrictions are often applied to paved roads, where CTI primarily serves to prevent breakage of the paving but does not necessarily reduce damage to the underlying layers, especially with roads built on weak basematerials (Mabood et al., 2008).

According to Blair and Eng (2000), the use of CTI in British Columbia extended the transportation season for 25 days and did not cause any significant damage to the road. Moreover, trucks equipped with a CTI system were able to carry full loads, even in the last few weeks of restriction period without any clear increase in rutting or craking of the road (Mabood et al., 2008). There was evidence in a study by Owende et al. (2001) that an empty truck with a high tire pressure (770 kPa) will induce as much fatigue damage in the road pavement as a fully loaded truck operated at low tire pressure (350 kPa).

In Sweden, where both the transportation environment and the challenges facing the forest industriesin obtaining raw material all yearround are similar to those in Finland, SCA Skog, the branch of the Swedish forestry company SCA which manages its forests and supplies raw material to its mills, has been using CTI in its operations and has built roads designed for CTI trucks (Ramén, 2014). The upper structural course of these roads is about 40% thinner than on a normal road, which results in savings not only in the amount of overlay material required, but also in the costs of transporting this material to the forest roads (Ramén, 2014).

CTI also balances the pressures between the tires onone axle or group of axels, which in the case of double wheels, for example, permits a better distribution of the load between the tires and smoother contact withthe road surface, evening out the wear onboth the tires and the road (Bradley, 2009; Munro and MacCulloch, 2008). When driving on gravel roads, reduced tire pressures can reduce the risk of tire damage due to unevenness in the road surface (Bradley, 2009). Vehicle vibration is also reduced when using a CTI, which affects the driver's command over the vehicle and its steerability (Granlund, 2006a).

Granlund (2006a) observed that fuel consumption per kilometer increased upon the use of CTI but fuel consumption per tonne decreased, since the reduced tire pressures allowed larger loads to be transported on roads with poor carrying capacity. Corresponding results were found with regard to environmental emissions. When driving empty, the fuel consumption did not change at lower tire pressures, but when driving loaded the fuel consumption increased by 3.6% (Granlund, 2006a). Driving with reduced tire pressures accounts for only about 6-7% of the average transportation cycle, however, so that this factor is of little significance for overall fuel consumption. According to d'Ambrosio and Vitolo, standard pressure, regardless of different vehicle working conditions, maintained by CTI system, can reduce fuel consumption up to 2 % in real-world driving by passenger vehicle.

It is claimed in the literature that the benefits of CTI systems are divided between the stakeholders in the timber procurement chain, although it is usually the timber trucking company that is responsible for the initial investment. Bjerketvedt and Fjeld (2016), who investigated challenges related to the introduction of CTI in Norway through interviews with various stakeholders, noted that although the respondents' expectations regarding the benefits of the CTI system corresponded of the results of previous studies, no clear solution for was found for funding the system. Division of the costs among the various interest groups was clearly the most popular option, but it proved impossible to devise an appropriate cost allocation model.

Although the CTI systems and their benefits for timber transportation have been studied under various combinations of experimental conditions, there have been only a few studies based on the opinions of timber transportation companies with a lengthy period of practical experience, and the positive impacts on operational use that have been described are based on CTI-manufacturers' observations or non-peer reviewed studies (Ghaffariyan, 2017). The aimshere were to draw upon timber transportation companies' experiences of CTI through interviews and to investigate their perceptions of the benefits of the system for the various stakeholders. They were also asked how the costs of using the system should be met by the transport companies.

2. Material and methods

2.1 Material

The material was collected in autumn 2017 by means of telephone interviews with owners of one or more timber trucks with a CTI system. In Finland it has been Metsähallitus, a state-owned company that conducts operations in Finnish forests, that has been the responsible for promoting the use of CTI systems, while Metsäteho Oy, a limited company owned by the leading forest industry organizations and specialized on research and development related to timber procurement, has been the main agency responsible for research into CTI (Siekkinen and Korpilahti, 2015). Ari Siekkinen, a development specialist with Metsähallitus, and Pirjo Venäläinen, a senior researcher with Metsäteho, together drew up a list of all known owners of a CTI truck in Finland. The list contained 21 entrepreneurs, 16 (76 %) of which were reached and interviewed by phone. The remaining five did not answer the phone or call back.

2.2 The survey

The survey consisted of a semi-structured interview form that was divided into four sections, 1) company background, 2) basic information on the CTI system used, 3) experiences of CTI use and 4) distribution of costs and benefits. The questions were formulated according to research literature and commercial claims regarding the benefits of CTI in timber trucking, with emphasis on existing Finnish research into this subject (Siekkinen and Korpilahti, 2015). The company background and basic information on CTI were elicited by means of open questions, after which experiences with operating the CTI system and opinions on the distribution of costs and benefits were studied using five-level Likert scales. Following the principle of semi-structured interviews, however, these items were followed by open questions, giving the respondents an opportunity to justify and explain the answers they had given.

2.3 Classification of the companies

The companies were classified geographically according to whether their hauling areas were in Northern (11 companies) or Southern Finland (5 companies) (Figure 1). Those operating throughout the country were classified based on the main range of the movement of their CTI trucks. Giving that about half of Finland’s approximately 700 timber trucking companies own one truck each and about 25 % own two (Venäläinen 2016), the average number of trucks owned by the companies studied here, 12.2 (mode 13 and median 5.5), was much higher than in Finnish timber trucking companies as a whole (Table 1). The material was therefore classified subjectively by the size of the companies, the five with more than 10 truck being classified as large, the six with 4-9 trucks as medium sized and the five with 1-3 trucksas small.

Table 1: Total number, minimum (min), maximum (max), average (Avg), median and standard deviation (SD) of the number of trucks, timber trucks and CTI timber trucks in the companies studied.

	Total	*Min*	*Max*	*Avg*	*Median*	*SD*
Number of trucks	195	1	100	12.2	5.5	23.0
Number of timber trucks	85	1	11	5.3	5.0	3.1
Number of CTI timber trucks	19	1	3	1.2	1	0.5

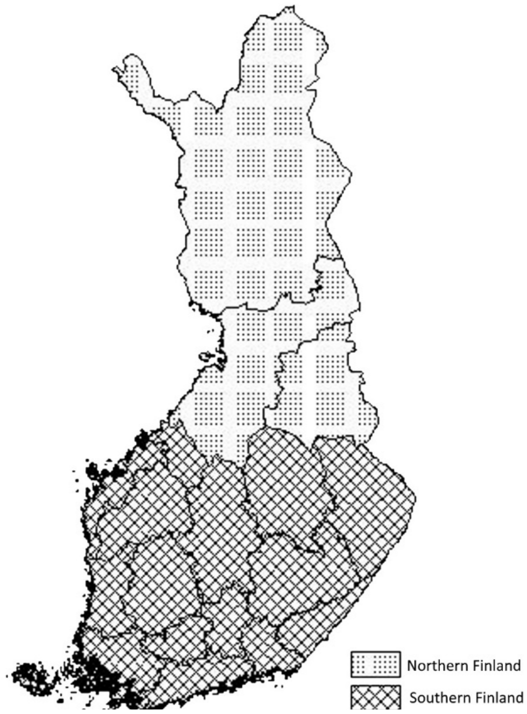

Figure 1: Geographical distribution of the companies in Northern and Southern Finland.

2.4 Statistical analyses

A non-parametric Mann-Whitney U-test was used to analyse the statistical differences between the Likert scale answers given by the northern and southern companies, and a non-parametric Kruskal-Wallis test forthe comparison between large, medium-sized and small enterprises. If the Kruskall-Wallis test showed significant differences between certain groups, Kruskall-Wallis pairwise comparisons were used to assess the statistical differences between the individual groups. $P \leq 0.05$ was accepted as indicating statistical significance. At the end of the questionnaire the respondents had an opportunity to express opinions on matters that had not previously been raised in the survey.

3. Results

3.2 CTI timber trucks in the companies studied

All the companies concerned had a "TIREBOSS" CTI system manufactured by Canadian Tire Pressure Control International Ltd., in addition to which, one also had a CTI system manufactured by the French company Syegon. Out of the total of 19 CTI trucks, the system had been installed when acquiring a new truck in 12 cases and in a truck that was already in use in three cases. In the remaining four cases the system had originally been installed in a new truck and had later been transferred to another truck, or else it had come with a truck that had been purchased. The length of operation ranged from one to eight years, averaging (Avg) 3.37 years with a standard deviation (SD) of 2.01 years (Figure 2). The working life of the systems that came with used trucks was calculated from the date of purchase, not that of the initial installation.

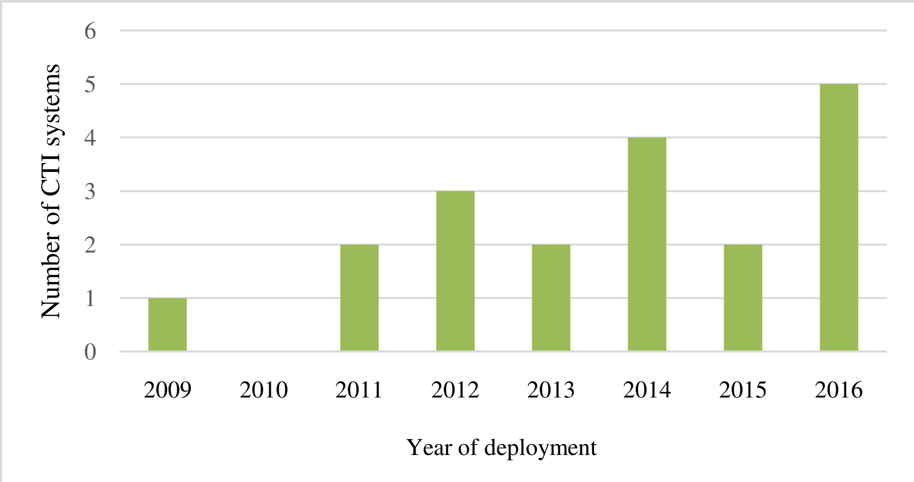

Figure 2: Number of CTI systems by year of deployment.

Most of the vehicle combinations with CTI consisted of a four-axle truck and a five-axle trailer, but other combinations of three or four-axle trucks and four or five-axle trailers were used as well. In all cases the system was installed on all the axles of the trailer, but there was some variation in the number of axles to which is was fitted on the truck. According to Finnish legislation in force since 2013, a front wheel and a single-axle wheel width of 385 mm will qualify as a CTI wheel, and therefore all three-axle trucks deployed in 2013 or earlier had CTI on their front wheels, whereas four-axle trucks did not. The respondents to the survey indicated that the air pipes of the TIREBOSS systems went through the truck externally but were located within the structures of the trailer, while all the air pipes in the Syegon system ran externally. The prices of the system variedin the range EUR 12,000 –40,300 according to the time of installation (new vs. used truck), the type of air supply line (external vs. internal), the purchase of optional accessories and number of axels, with an average price of EUR 25,647. Price information was available for the 15 combinations for which the system was acquired and installed by the owner company.

3.3 CTI experiences

The experiences of companies with regard to the benefits of CTI under difficult driving conditions (snow, slippery surfaces, hills), and the time required when using the CTI system compared with other means of improving transportability (use of chains, sanding) are presented in Figure 3. The evaluation scale for difficult conditions was from 1 = “no effect” to 5 = “major effect”, and that for the time requirement from 1 = “considerably more” to 5 = “considerably less”. The system was considered to be most useful in snowy conditions and on hills, but when averaged over all of the types of conditions mentioned in the survey it was found to provide only a little help (Avg = 2.27 and SD = 1.16). There were no statistically significant differences between geographical locations or company sizes at the $p \leq 0.05$ significance level in the Mann-Whitney or Kruskal-Wallis tests. When answeringthe open question, “Are there any other circumstances in which CTI is beneficial?”, the respondents mentioned situations such as driving on a wet surface in summer, driving on a soft, very fine sand, driving in conditions where a hard ridge of snow is breaking under the tires or where the road surface has been broken up by forest machinery, and driving on a surface composed of coarse aggregate. According to one respondent, lower tire pressures should always be used when driving for the first time on roads that have been levelled in spring, to prevent the sharp stones on the surface from causing tiredamage leading to savings in tire expenses. CTI was not found to reduce the need for sanding or for using chains and nor was it felt to produce obvious savings in time compared with other methods.

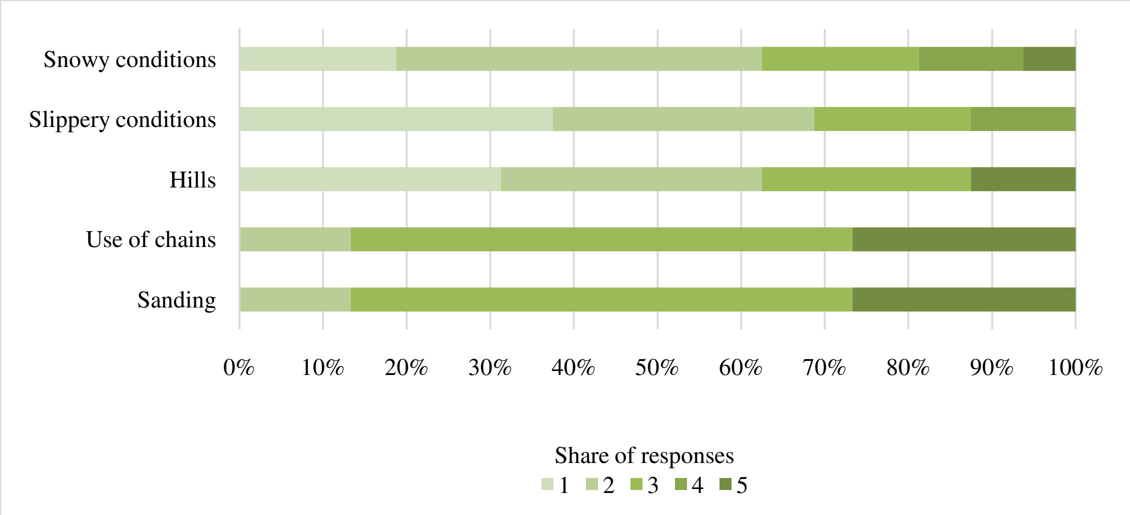

Figure 3: Summary of responses on the benefits of CTI under snowy and slippery condition and on hills, and the time required for CTI use compared with the use of chains or sanding. Likert-scale for snowy conditions, slippery conditions and hills: level 1 = “No effect”, 2 = “Minor effect”, 3 = ”Moderate effect”, 4 = “Significant effect”, 5 = “Major effect”, and for use of chains and sanding: 1 = “considerably more”, 2 = “slightly more”, 3 = “no difference”, 4 = “slightly less” and 5 = “considerably less”.

In Finland, the regional Centres for Economic Development, Transport and the Environment (ELY Centres) can grant permission for weight-restricted roads to be used by CTI trucks during the thawing period, and the company owners were asked whether having CTI-equipped truckshad increases the volume of timber transported at the time of these seasonal restrictions. The responses suggested, however,that the volume transported was only slightly higher during these seasonal bottlenecks, with average values ranging from 2.00 (SD = 1.06) for surface weakening due to autumn rainfall to 2.31 (SD = 1.16) for surface thawing in spring (Figure 4). There were no statistically significant differences between the groups based on geographical location or company size. Five companies reported that the length of the transportation season was no differentwhen using a CTI truck from what is was with a normal truck, and for another two companies the difference was only a matter of a few days. For four companies the transportation season was extended by something between two weeks and two months per year, and in the best case use of the CTI system meant that there were no restrictions at all.

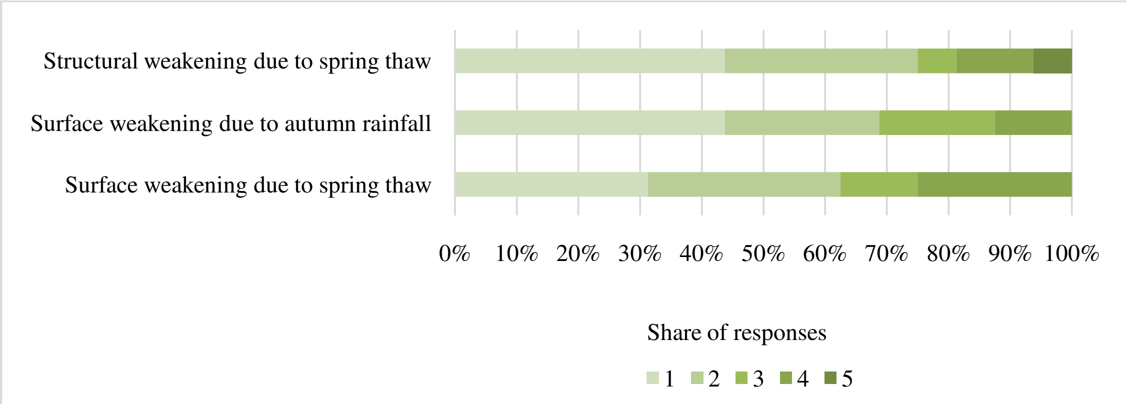

Figure 4: Respondents' experiences of weather CTI increases volumes transported at times of seasonal bottlenecks. Likert-scale is: level 1 = "No effect", 2 = "Minor effect", 3 = "Moderate effect", 4 = "Significant effect", 5 = "Major effect".

The effects of CTI on the ruts left by a timber truck relative to one without CTI were considered minor or moderate on average (Avg = 2.69 and SD = 1.10) (Figure 5). Some of the respondents mentioned that a truck equipped with CTI would not be sent to places that could not be reached with the normal tire pressure unless there was a need to retrieve the logs by a certain deadline. On the other hand, the use of CTI evidently reduced vibration in the vehicle (Avg = 2.94 and SD = 1.25), and one respondent mentioned driving empty as being softer with reduced tire pressures.

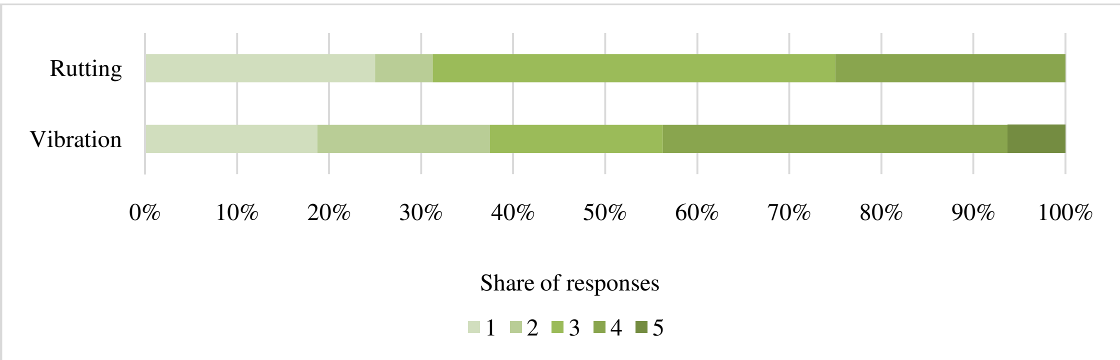

Figure 5: Respondents' experiences of the effect of the CTI system on rutting and vibration. Likert-scale is: level 1 = "No effect", 2 = "Minor effect", 3 = "Moderate effect", 4 = "Significant effect", 5 = "Major effect".

The majority of respondents also controlled tire pressures on roads operable by trucks without CTI (Avg = 3.75 and SD = 1.53 on a Likert scale 1 = "never", 2 = "rarely", 3 = "sometimes", 4 = "usually" and 5 = "always"), and this was the case even outside the thawing period (Avg = 3.44 and SD = 1.41). Trucks operating in Northern Finland in particular used CTI regularly, although there was no statistical difference between the groups according to the Mann-Whitney test ($p = 0.090$).

When the respondents were asked whether CTI has any impact on tirefatigue, tire life or fuel consumption, tirefatigue was considered to be the same with or without CTI (Avg 3.00, SD 1.06) (Figure 6), tire life was thought to be slightly shorter (Avg = 3.4

and SD 1.06) and no effects on fuel consumption were noticed (Avg 2.75, SD 0.43), although many respondents admitted that fuel consumption had not been actively monitored.

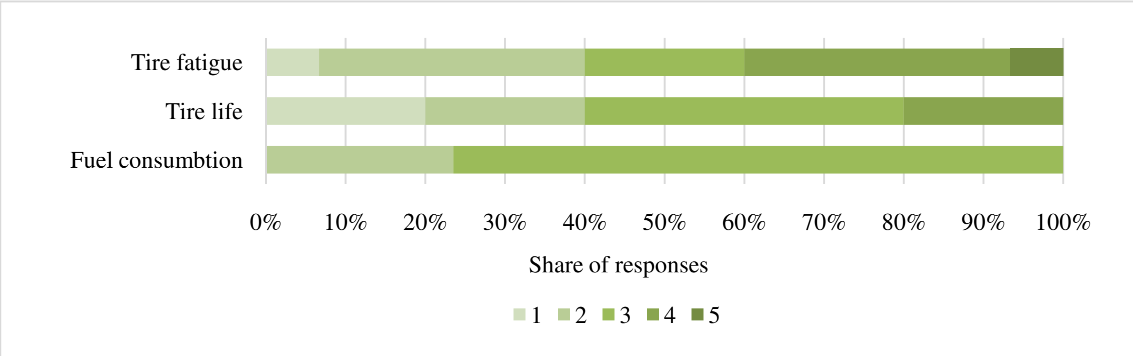

Figure 6:Respondents' experiences of the effect of the CTI system on tire fatigue, tire life and fuel consumption. Likert-scale is: level 1 = “Increases greatly”, 2 = “Increases slightly”, 3 = “No effect”, 4 = “Decreases slightly”, 5 = “Decreases greatly”.

3.4 Costs and benefits of CTI

When the entrepreneurs were asked how much each interest group benefitted from the use of CTI, they replied that CTI was least beneficial to the trucking companies (Avg 1.56 and SD 0.86) and most beneficial to the timber procurement company (Avg 2.25 and SD 1.15) (Figure 7). This led the truckers to demand that the timber procurement company should pay a large share towards the cost of CTI (Avg 4.25 and SD 1.09) and the trucking company less (Avg 1.75 and SD 1.09). Three trucking companies said there were so few CTI-enabled roads in their hauling areas that the matter was of no practical significance, while two companies were operating for the time being in an area where there were no CTI-enabled roads at all. In addition, one mentioned that access to weight-restricted private roads is virtually impossible for CTI trucks, which limits the rate of CTI use in areas with a high proportion of private roads. Using a CTI timber truck was also considered to be a poorer alternative than a regular truck because regular trucks are allowed to travel on good roads while CTI trucks are directed to poorer roads.

The acquisition of contracts had a very large impact on the initial purchase decision (Avg 4.94 and SD 0.2 on Likert scale 1 = “No effect”, and 5 = “Major effect”), while the impact on the utilization rate of the fleet of vehicles was of somewhat more moderate importance (average 2.56 and SD 1.37 on Likert scale 1 = “No importance” and 5 = “Major importance”). According to nine respondents, installation of the system has had no effect on the transport prices, where as five other claimed that prices hadgone up somewhat. Two respondents reported that prices used to be higher for the CTI trucks than for ordinary ones but that nowadays they were all the same. Although the acquisition of contracts had a very large impact on the initial purchase decision, the need to obtain more CTI systems was quite small (Avg 1.75 and SD 0.75). Two owners no longer wanted to buy trucks equipped with CTI, and only one intended to keep the system in the future. For the rest of the truck owners the situation depended on future contracts, so that if the contract required the presence of CTI, this would be acquired, but otherwise there was no inherent desire to have the system available.

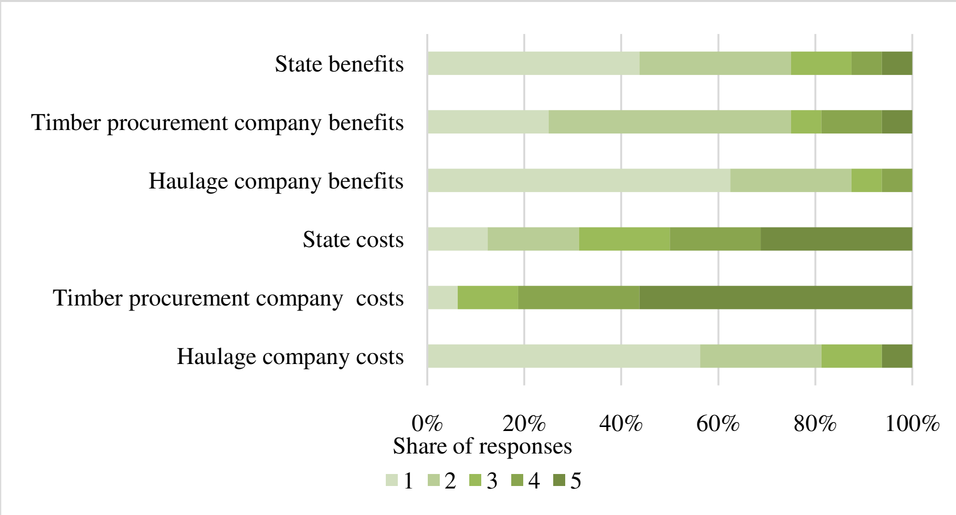

Figure 7: Respondents' perception of who benefits from the CTI system and who should pay its costs. Likert-scales: for benefits, level 1 = "No benefits", 2 = "Minor benefits", 3 = "Moderate benefits", 4 = "Significant benefits", 5 = "Major benefits" and for costs 1 = "Not at all", 2 = "A little", 3 = " Moderately", 4 = "A lot" and 5 = "All".

When given the opportunity to raise issues that were on their mind, one respondent stated that the system pays itself back and generates a little profit over a four-year contract on the strength of lower tire costs, but most of them believed that breaking even would require a clear increase in utilization, which has not been possible so far. Nine entrepreneurs reported that tire manufacturers did not have anything to say about the use of CTI, whereas six other claimed thattire manufacturers do not guarantee tires that are used at reduced pressure. Moreover, a better overall design chain was demanded from timber procurement companies in order for them to consider the existence of CTI trucks in all planning phases and thus increase the utilization rate.

4. Discussion

The results of this attempt to clarify the benefits and shortcomings of Central TireInflation (CTI) systems in operational use in the Finnish timber transportation environment by means of a survey conducted among Finnish timber trucking companies suggested that companies were not very satisfied with the CTI systems, primarily because the benefits of the system did not adequatelyjustify the costs. The initial investment involved is high, and from the trucking company's point of view this means that the system should also generate profits. No surveyof the experiences of CTI users or their companies had been carried out before, but the vehicle owner interviewed in the thesis of Ramén (2014), for example, listed the benefits and disadvantages of the system in a similar manner to that reported here.

According to the respondents, the system was found to be useful on wet, clayed roads and on very fine sand. The performance of the system under slippery conditions was also tested by Vuorimies et al. (2012), who found that tire pressure had an effect in circumstances where the surface under the tires varied between slippery and good traction. Although the aim of that study was mostly to find out about the truck's ability to pull loads on an icy surface, the Finnish timber truckersinvolved also found CTI beneficial in summer. This was not surprising, since CTI systems are also commonlyusedin Australia and New Zealand, where non-icy conditions are normal. Increasing heavy rainfall in Finland in autumn and winter due to climate change (Jylhä et al., 2009) may worsen the roadsand render transportation conditions more challenging, which means that trucks with normal tire pressures will not necessarily be able to operate at the required level in the future.

The profitability of the system is affected by the number of CTI-enabled roads in the hauling area andby the amount of timber deposited beside these roads, which shows how much transportation work is available for CTI-equipped trucks on roadswhere it is not permitted to operate without CTI. As applications for permits in Finland must be submitted to the regional ELY Centres, regional inequalities may arise. It became apparent during the interviews, for instance, that in one area the first permits were received only after the ELY staff had changed. The profitability of CTI could be improved substantially harmonizing these practices across the country, although the number of CTI-enabled roads alone does not yet guarantee sufficient transportation volumes. This result is in line with Brokmeier (2017), where economic advantages in Germany were found only if unrestricted approval for road use can would be received. The trucking companies represented here especially hoped that timber procurement companies would improve their overall planning during the thawing season, when regular trucks are standing idle. Harvesting times beside CTI-enabled roads should be scheduled so that they do not occur all the year round, but rather during the thawing season, which would make the CTI system a real benefit for timber-trucking companies. This would require the development of a design process that involved forest planning, harvesting planning and transportation planning in order to create an opportunity for the use of CTI vehicles.

Rutting was considered by the timber trucking companies to be only slightly reduced by the use of CTI trucks as compared with trucks having constant tire pressures (Figure 5), although earlier studies have found rutting to be significantly reduced by means of CTI (Mabood et al., 2008; Ghaffariyan, 2017). Such comparisons are difficult to make, however, since trucks that do not have a CTI system are generally not used on roadsthat are vulnerable to rutting.

Although it has been claimed that CTI systems reduce medical complaints and driver fatigue, this was not investigated here, since it is very difficult to conclude whether a medical condition or fatigue is caused by any one particular element of the workload. The responses obtained here nevertheless confirmed that vibration is reduced at the lower tire pressures permitted by CTI (Figure 5), and consequently it is possible that the general well-being of truck drivers would also be improved.

According to Ghaffariyan (2017), optimized tire pressures could increase the service life of vehicletires from 27% to 90%, but according to the majority of the present respondents, the reduced tire costs would not bring in revenue to match the investment (Figure 6), for which purpose the rate of utilization of CTI should be higher. The problem, however, was that the CTI system was a requirement in contract negotiations and the associated higher pricing level could easily lead to a loss of the tender even though the quotation might in other respects be competitive.

In general, the cost-benefit studies have focused on the perspective of the timber procurement companies, i.e., the mechanical impacts of CTI trucks on the road surface or the ability to haul timber from a location that would not otherwise be accessible (Ghaffariyan, 2017). According to Ghaffariyan (2017), the estimated savings on road maintenance costs due to optimized tire pressures varies from 33 % to 75 %. At the same time, the costs of having CTI in Canadian log trucks have been estimated to be 2.35 – 5.11 CAD h^{-1} (Jokai and Bradley, 2000), and in Sweden the average cost was estimated about 23 cents per transported tonne over a five-year period and with an average haulage distance of 100 km (Granlund, 2006b).

The perceived problem that having a CTI truck means that loads are hauled on weaker roads,whereas haulage companies without a CTI truck will enjoy better circumstances and therefore have better profitability, bears a certain similarity to the claim thatoften arises regarding harvesting peatland forests: namelythat the acquisition of machines suitable for peatland harvesting is a requirement for Finnish forestry, where about one third of the forestsare on peatlands, but the initial investment insuch special equipment is high and the machines often suffer from use on worse harvesting sites and ones with lower productivity, leading to weaker profitability. To cover the initial investment and lower productivity, the fee should be higher than for forestson mineral soils.

Since the statistical analysis did not show any significant differences between the respondent groups, the trucking companies' experience of CTI are evidently very similar regardless of the geographic location or size of the company. The respondents' negative attitude towards CTI was perhaps stronger than expected, but the critical comments were well-founded and inline with those of almost all comparable entrepreneurs. Moreover, the research method allowed the respondents to express their honest opinions, and it was evident that they were pleased that the CTI system was being studied also from their point of view.

Although the number of respondents was small, the reliability of the results should be reasonable. The sample is also small in relation to all the companies specialized in timber transportation (about 700 according to Venäläinen (2016)). CTI timber trucks are nevertheless still rare in Finlandand all known owners of one were included in the sample. The list of companies was drawn up in consultation with the leading CTI experts in Finland, and the likelihood of there being other companies that possess CTI timber trucks can be considered very small.Five of the companies listed did not answer the telephone or respond to the invitation to call back, and since no data were available oncompanies having a CTI truck other than the bare contact information, it is difficult to estimate the non-response bias.

The companies´ experience of CTI as reflected in these results differs from previous findings in that the benefits of the system are not as unambiguous or as significant as might be expected. The expensive initial investment and the non-existent impact on transportation prices make CTI investment commercially unprofitable. Lowering the cost of CTI or improving the revenue available from the system could lead to the benefits outweighingthe costs, but the high initial cost of investing in CTI may affect whether the benefits of the system are perceived at all, even if they do exist. In order to improve the cost-effectiveness of CTI trucks, the entire timber procurement chain should consider trucks equipped with CTI in its planning, so that the benefits can be exploited as fully as possible. An adequate number of CTI-enabled roads is a prerequisite for the cost-effectiveness of the CTI system.

One important objective for the development of CTI usage is to share the costs between interest groups. The present results show that most companies find it unfair that they should bear all the costs, as the main benefits concern lower road management costs and more balanced year-round roundwood acquisition. Metsähallitus, as the organization responsible for managing the state forests, also manages a large proportion of the forest roads, and therefore bears a major responsibility for the development of CTI-based timber trucking in Finland. Better internal planning processes in Metsähallitus could be the fastest way of improving CTI profitability, although creation of a variety of cost-sharing models and assessment of their functionality will require independent research involving cooperation between all the interest groups benefiting from the CTI system.

5. Conclusions

In conclusion, respondents representing Finnish timber transportation companies found that CTI in timber trucks allowed the transportation of only slightly more timber than with a regular truck and that little assistance wasprovided by CTI under difficult conditions, e.g. on snowy, slippery or hilly roads. The respondents were not content with CTI, because the benefits of the system did not match thecosts. The high investment costsentailed in CTI would require higher prices for timber transport in CTI-equipped vehicles, as the companies owning these consider that they themselves gain the least benefits from CTI and the forest management company the most. The number of CTI-enabled roads within the transportation area affects the profitability of the system, as does the number of stands alongsidesuch roads during frost heave seasons. Better overall planning of the timber procurement chain which takes CTI into account at all stages is therefore necessary in order to maximize the utilization of the system.

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