

Management of border zone forests in transmission line corridors

TEEMU POIKOLAINEN¹ AND JUKKA MALINEN^{2*}

¹ Karelwood oy, Niskatie 44, 81200 Eno, Finland; e-mail: teemu.poikolainen@karelwood.com

² University of Eastern Finland, Faculty of Science and Forestry, School of Forest Sciences, P.O. Box 111, 80101 Joensuu, Finland

* Corresponding author: jukka.malinen@uef.fi

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Abstract

The resilience of power transmission has been required in Finland by the electricity market act since 2013. As a consequence, Finnish electricity companies began to manage border zone forests of transmission lines more extensively. Five years later, the experiences of experts representing different interest groups in border zone forest management projects along medium-voltage (MV) and high-voltage (HV) transmission lines were summed and analysed in this study utilising argument Delphi method. The first-round interview included 13 experts, and the second-round survey included 33 experts representing electricity companies, forest management associations, forest companies and forest machine operators.

According to the results, landowners' knowledge of border zone forest management should be increased by video clips linked to electricity companies' web-pages, project-specific work demonstrations and demonstrations in exhibitions and other events. Increased knowledge and activation of landowners is crucial when a new MV transmission line corridor is being built. This could offer cost-efficient possibilities to extend joint harvestings in the vicinity forests.

Planning of border zone forest operations and marking estate borders, border zone forests and dangerous spots were found helpful and increase the safety and productivity of harvesting operators. Harvestings by cut-to-length harvesters in the vicinity of transmission lines require calm and experienced harvester operators.

According to the experts, on MV transmission lines, the corridor should be utilised in harvesting operation if possible. If a strip road is needed, it should be placed next to the transmission line corridor, enabling felling away from the transmission line. In HV transmission line border forest operations, the closest strip road to transmission line should be placed on the border zone. Strip road planning of individual thinning nearby transmission lines should consider the need for strip road in the border zone as well.

As a conclusion, information exchange between interest groups of border zone forest management projects and guidance for landowners is crucial for successful border zone forest management projects and needs to be further enhanced.

Keywords: border zone forest; operation models; Delphi-method; right-of-way

Introduction

Storm damages Asta, Veera, Lahja and Sylvi, in July and August 2010, caused extensive electric power transmission failures in Finland. Over 35,000 kilometres of overhead transmission lines were destroyed or damaged by falling trees, nearly 9,000 substations were left without electricity, clearing and repairing of networks amounted nearly 200,000 hours and over 480,000 customers were affected (Onnettomuustutkintakeskus 2010). Power cuts complicated the everyday lives of thousands of citizens, causing obstacles in commuting, trade, housing, daily chores, maintaining contact and receiving help. Similar damages were reported a few years earlier from Sweden,

as Gudrun (2005) and Per (2007) storms hit Scandinavia (Gardiner et al. 2010).

As a consequence of storm damages, the electricity market act was introduced and entered into force in Finland on the 1st of September 2013 (FinLex 2013). The act requires electricity companies to plan, construct and maintain power transmission grids so that it is as reliable as possible. In practice, electricity companies are allowed to fell and remove trees near overhead transmission lines without permission from the landowner, if this is necessary to prevent interruptions in power transmission.

Long-distance electricity transmission lines can be divided into medium-voltage (MV) (< 1 kV–36 kV) and high-voltage (HV) (> 36 kV) transmission lines (de Kock

and Strauss 2004). Nationwide HV transmission from power plants to a primary substation and heavy industry utilises 400 kilovolt (kV), 220 kV and 110 kV lines. The length of the HV transmission lines in the main grid of Finland is over 15 000 km, and the grid is managed by Fingrid (Fingrid 2018), Finland's transmission system operator. Primary substations are connected to secondary substations near residential areas and light industry by MV transmission lines, which typically are 1–20 kV overhead powerlines.

HV transmission lines are constructed as far from inhabited areas as possible, usually on forest land in Finland, where forests cover 86% of land area (Luke statistics 2018) and 56.4% of MV transmission lines are in the forests (Ranta 2013), resulting in annual clearing of 6 000 hectares of transmission line corridors from vegetation. Overhead HV transmission line corridors in the forested area vary according to voltage, being 26–30 metres in 110 kV lines, 32–38 metres in 220 kV lines and 36–42 metres in 400 kV lines, border zone being 10 metres on both sides (Tapio 2016). Border zone trees are limited to 10 metres height on the edge of the corridor and 20 metres on the forest side of the border zone forest (Figure 1). Overhead MV transmission line corridors are usually 10 metres wide and border zones reach from 10 to 20 metres from the edge of the transmission line corridor (Ranta and Niemelä 2016) (Figure 2).

Management of border zone forest along a HV overhead transmission line aims to tree-secure continuous

power transmission, and therefore, all the trees that are able to reach the overhead lines in case they bend or fall, are removed. On the contrary, MV overhead transmission lines are not built tree-secure and they are prone to storm damages and snow-induced problems. A single tree toppling or bending onto the line may hinder the power transmission. The aim in the management of the border zone forest of a MV transmission line is to have forest with a structure that will withstand snow and storm-related strains better than an unmanaged forest.

Finnish forest organisations that is forest management associations, wood procurement organisations owned by the Finnish forest industry, forest service enterprises and The Finnish Forest Centre offer border zone forest management projects as a service. A border zone forest management project includes contacting landowners by letter or by phone, contacting timber buyers and organising timber transactions, planning the operation, making the forest markings and performing the harvesting and clearing operation. In a border zone forest management project, if possible, a joint felling and sale of trees are arranged to ensure a competitive price for the timber. Landowner approval for participation in a joint sale is requested, but participation is not compulsory. Also, a collaboration model, where landowners are encouraged to expand harvestings in the forests that are in the immediate vicinity of the transmission line, is utilised.

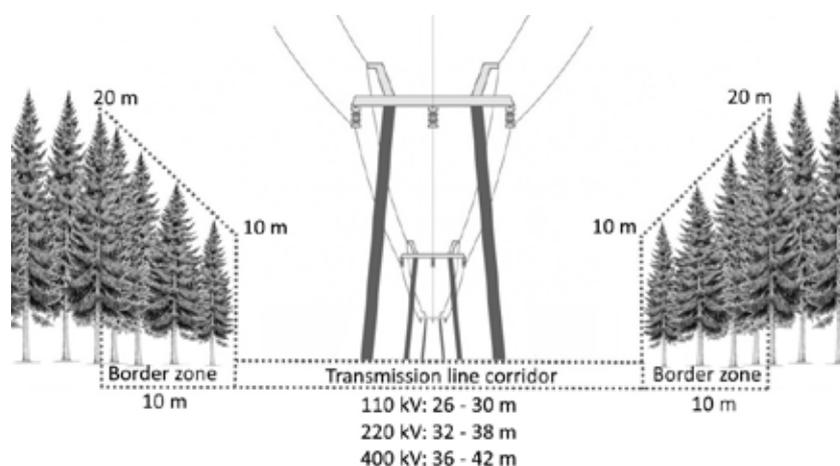


Figure 1. Transmission line corridor and border zones of a high-voltage overhead power line

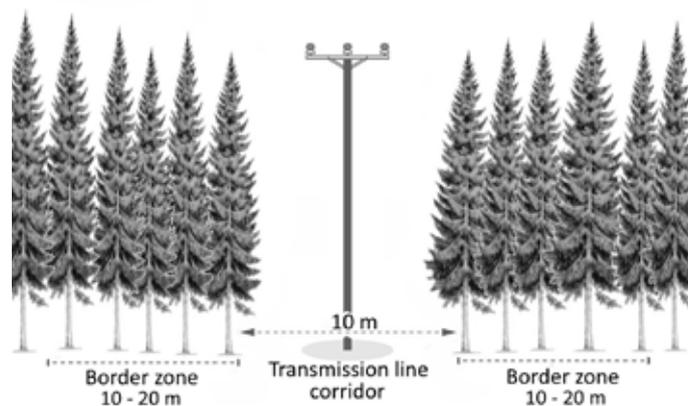


Figure 2. Transmission line corridor and border zones of a medium-voltage overhead power line

Despite the generally accepted border zone forest management guidance practices vary between Finnish electricity companies. For example, according to Tuovinen (2018), electricity company 'Pohjois-Karjalan Sähkö' conducts annually border zone forest management along and around 500 kilometres of MV transmission line in the region of North Karelia. They aim tree-secure power transmission by utilising 10-metre transmission line corridors and 15-metre wide border zone forest. Average harvesting recovery varies between 60 and 200 m³/km. On the other hand, northern neighbouring electricity company Loiste, in Kainuu region, clears annually around 1400–1600 kilometres of MV transmission line corridors (Loiste 2018), but considers border zone forest management as a landowners' responsibility, distributing guidance for landowners through their web pages (Energiateollisuus 2018).

Harvesting and forwarding operations in the vicinity of powered transmission lines are dangerous and require experienced machine operators. Harsh and varying northern weather conditions increase the risks of operations and hinder relocations of machines and transportation of timber (Malinen et al. 2014). The minimum distance between the machine and overhead transmission lines depends on the transmission line voltage. On a one kV transmission line, the distance is two metres both below and side of the line, and on a 400 kV line, the distances are five metres, respectively (Tukes 2010). On HV overhead transmission lines, Fingrid (2018) requires trees to be felled away from the line and proceeding in a manner that the trees closest to the line are felled last. In a border zone forest of a MV overhead transmission line, Ranta and Niemelä (2013) suggest felling trees away from the line, if possible, using the transmission line corridor or its close vicinity. Harvested logs are placed on the border zone and on the corridor. If a border zone forest is wider than the typical reach of a harvester, 10 metres, a strip road has to be opened to the border zone forest. Harvested roundwood must not be stored under a transmission line in any case, the minimum distance from the line should be five metres (Ranta and Niemelä 2013).

The storm damages 2010 and the electricity market act 2013 necessitate guidance for better border zone forest management. These guides were introduced by Tapio, a state-funded provider of forest management related advisory and consulting services in Finland. The guide for border zone forest management of MV transmission lines was published 2013 and the guide for HV transmission lines 2016 (Ranta and Niemelä 2013, Tapio 2016). The guidance was based on experiences from piloting projects conducted by electric companies and Finnish forest management associations. By the Forest Management Association Act (No 534/1998), the task of the forest management association is to provide services needed by forest owners in forestry activities and to organise professional assistance to forest owners in their own territories. Since

publishing the guidance, forest management associations, wood procurement organisations owned by the Finnish forest industry, forestry service enterprises, The Finnish Forest Centre and landowners have gained experience, new piloting projects have been conducted and new operating models have been presented (Tuovinen 2017, Vääntinen 2017, Hiltunen 2018). A few theses based on practical experiences of border zone forest management have been published. These theses indicate the need to improve the safety of operations (Syrjä 2016), use of remote sensing technology in monitoring of vegetation (Kilpeläinen 2016, Jämsén 2017), guidance for silvicultural management and increased productivity of border zone forests (Syrjä 2016), need for larger project entities accompanied by joint harvestings in vicinity forests (Syrjä 2016, Jämsén 2017).

Globally, methods used in vegetation harvesting from a transmission line corridor or a border zone forest follow harvesting methods and traditions of a region (NERC 2011, LIFE Elia-RTE 2017). Harvesting cycles and management distances are derived from growing conditions and species; faster growth requires more attention. In addition to harvestings, vegetation in utility corridors can be controlled by planting management and tree growth regulation by chemicals (Rancea 2014). Species selection aims to low-growing trees, which are adapted to local conditions (altitude, soil, humidity, exposure) (Rancea 2014, LIFE Elia-RTE 2017). Tree growth regulators are currently used mainly for yard trees by utilising soil drench, soil injection or trunk injection method (Rancea 2014). Despite the vast number of transmission corridor and border zone forest management guidances located in electricity companies' web pages, there is a shortage of studies regarding the operational point of view. The existing international literature includes the siting of transmission line corridors (e.g. Luken et al. 1991), incorporating ecosystem management (e.g. Nowak and Ballard 2005), vegetation inventory along transmission lines (Matikainen et al. 2016) and productivity and profitability of bioenergy harvesting at transmission line corridors (Fernandez-Lacruz et al. 2013).

The aim of the study was to examine current operation models for the management of border zone forest of overhead transmission line corridors in Finland applying Delphi methodology. According to current management guidance and expert interviews, a schematic flow chart was created. The challenges and bottlenecks of border zone management projects presented by the experts were aggregated as claims, and agreement or disagreement with the claims was surveyed by the extended expert group utilizing a five-point Likert scale. In the study, both high-voltage (> 36 kV) and medium-voltage (1 kV–36 kV) power transmission lines were considered. The overarching aim was to increase the reliability of electric power transmissions and increase the awareness and acceptance of border zone forest management along transmission line corridors.

Materials and methods

Delphi method

Delphi is a method that utilises “structured communication”: 1) initial individual contributions of information and knowledge, 2) assessment and summary of the initial information, 3) opportunity for individuals to revise views, and 4) analysing and concluding the results (Lindstone and Turoff 2002). Delphi method also relies on the anonymity of the individual responses. Traditionally, the use of the Delphi method has aimed at interactive forecasting, but later Delphi has been used in decision making. In this study, the principles of argument Delphi method were applied (Kuusi 1993). In the argument Delphi method, the first-round questionnaire is usually replaced by interviews, where the researcher presents and reflects different views and solutions. The aim of the interviews is to search for different options and viewpoints. As the first-round interviews were conducted and combined, second-round studies overall view of the group.

Initial information of border zone forest management

The basis for the initial information in the first phase of Delphi process included the electricity market act (FinLex 2013) and border zone forest management guidance of Tapio (Ranta and Niemelä 2013, Tapio 2016). A variety of management practices were examined through external and internal guidelines of Finnish electricity companies and forest management associations. Initial bottlenecks and development need of border zone forest management for the expert interviews were acquired from recent studies (Kilpeläinen 2016, Syrjä 2016, Jämsén 2017), international literature and experiences from practice.

The background information was utilised in the themed semi-structured interviews, where the framework of the themes was pre-defined, but without exact questions. The advantage of the semi-structured interview to enable open dialogue between interviewer and interviewed, where focused follow-up questions are possible and the interviewed person may affect discussed topics as well.

The expert group consisted of 13 experts, from which five were from electricity companies, two from forest management associations, three forest officials management projects, two harvester operators and one forest worker operating manually by a chain saw. The expert group was subjectively selected together with stakeholder groups to consist of persons that are highly experienced in border zone forest management. The interviews took place between September 2017 and May 2018, and they were documented by notes.

Assessment of initial information and survey of bottlenecks and development needs

The initial information, that is literature and interviews, were assessed and a flow chart of relationships and critical issues in a border zone forest management project

was created. Utilising flow chart, current operation models, bottlenecks and development needs raised up in the interviews, a survey consisting of claims regarding border zone forest management projects was created. The survey was based on five-level Likert scale, 1 = “strongly disagree”, 2 = “somewhat disagree”, 3 = “neither agree nor disagree”, 4 = “somewhat agree” and 5 = “strongly agree”.

For the second-round survey, the expert group was extended by 20 experts on border zone forest management. The extended expert group included nine representatives from electricity companies, five from forest management associations, 10 forest officials from enterprises offering border zone forest management and nine forest machine operators including the forest worker operating manually by chain saw. A total of 33 selected and invited experts received a link to the e-questionnaire and all experts returned answers.

Analysing the results

The experts responding to the survey were classified as representatives of a) electricity companies (EC), b) forest management associations (FMA), c) forest companies (FC) and d) forest machine operators (FMO). The groups were compared utilising the Kruskal-Wallis test. If the test showed statistically significant differences between groups, the Mann-Whitey U test was used to compare individual groups between each other. The statistical significance level $p < 0.05$ was used. Statistical tests were calculated using IBM SPSS Statistic 23 software.

Results

The operational environment of the border zone forest management

According to the expert interviews, a schematic flow chart depicting critical issues concerning the success of the management process of border zone forest along the transmission line was created (Figure 3). In the management process, four main interest groups involved were electricity companies, forest organisations, landowners and forest machine operators.

From electricity companies' point of view, the main concerns are the reliability of power transmissions and the cost efficiency of transmission line management, including vegetation management on transmission line corridors and border zone forests. To ensure power transmission, border zone forest management projects are established and forest organisations, such as forest management associations, wood procurement organisations, forestry service companies or The Finnish Forest Centre, are included in the project.

Border zone forest characteristics are influenced by geographical location. It has an influence on tree species, growth and height of trees. Geographical location has also influence on probability and magnitude of severe weather conditions, such as wind and storm and high accumulation of snow. Border zone forest's ability to withstand wind,

storms and high snowfall is also defined by the structure of the tree stock, that is, species, size and spatial distribution, which is affected by a silvicultural regime.

In the management of border zone forests, the landowners' acceptance is crucial. Although legislation gives rights for management of transmission line corridors, successful and cost-efficient management of border zone forests requires co-operation and mutual understanding between Electricity Company, forest organisation and landowner. For mutual understanding, information on management possibilities given by videos, demonstrations and events has been found helpful. As new transmission lines are planned or constructed, activation of landowners to incorporate silvicultural treatments or harvestings in the vicinity forests at the same time benefit all parties.

A landowner has entitlement and responsibility to select silvicultural regimes for the border zone forest. Electricity companies, governmental advisory and consulting service Tapio and forest management association are willing to give guidance of silvicultural possibilities in border zone forest management.

Forest organisations conducting a border zone forest management project are responsible for the operational planning and participation in the collection of mandate letters from forest owners. In the mandate letter, a landowner is able to define willingness to joint sales of harvested timber, willingness to sell the timber by one's own, willingness to conduct border zone forest management by one's own or deny border zone forest management. In the latter circumstance, the electricity company is legitimated only to remove hazardous trees. For the efficient management of border zone forest projects, the extent of mandates is vital. Timber harvesting on privately owned land is a sensitive subject, and discretion is required when acquiring permission for operations.

Operational planning includes most often field visits, where border zone forest management and harvesting

plan are verified. The timing of operations is affected by operational planning and sequence of harvesting sites, and also by expected weather conditions. Because the vicinity of powered lines increases risks of harvesting operations, careful planning ensures work safety and quality.

In a harvesting operation, forest machine operators are responsible for the quality of the operation, as well as their own safety. Operators should be experienced, and specific calmness and deliberativeness are required. Moreover, it is not uncommon to see private landowners on the harvesting site. Some harvester operators actively call landowners to discuss specific goals regarding harvesting.

Claims regarding border zone forest management

According to the experts, landowners' knowledge of border zone forest management could be increased by general or project-based work demonstrations (Claim 1, Table 1). Some landowners are not able to participate in live demonstrations, and therefore electricity companies should upload videos to their web-pages demonstrating border zone forest management (Claim 2).

In Finland, most of the electricity companies have outsourced the building of new transmission lines. As new transmission lines are built and corridors are opened, it would be mutually beneficial to conduct harvestings in the border zone forests as well. Quite often, however, landowners are not willing to participate, and in the worst cases, a border zone forest management project must be arranged some years later. Consequently, there is an emerging need to activate landowners to participate in the border zone forest management project as the new transmission line is built (Claim 3). Currently, landowners are informed of current border zone forest management projects. However, landowners should be informed also about the forthcoming border zone forest management projects so that they could plan their border zone forest management accordingly (Claim 4).

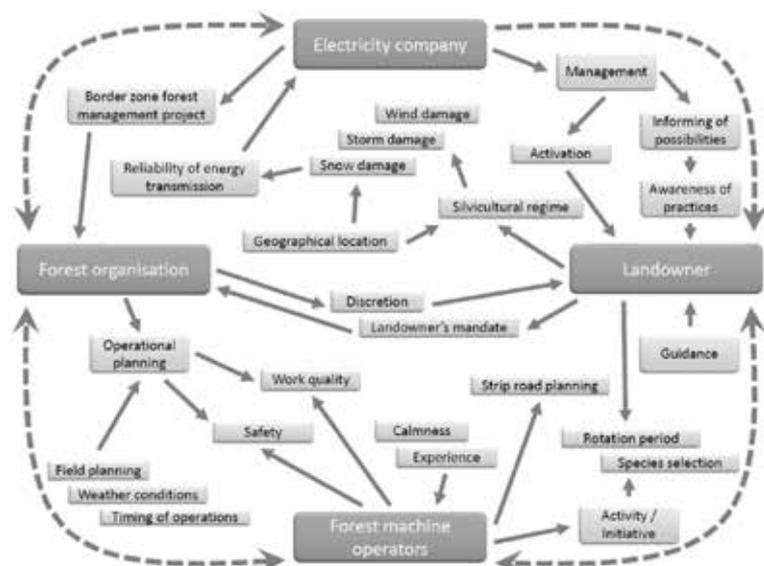


Figure 3. Schematic flow chart of relationships and critical issues concerning border zone forest management project

Table 1. Expert interview-based claims used in the second-round survey

Expert interview-based claims
1. Landowners' knowhow of border zone forest management could be improved by general or project-based work demonstrations.
2. Electricity companies should have videos in their web-pages demonstrating border zone forest management.
3. There is an emerging need to activate landowners to participate in border zone forest management as new MV transmission lines are built.
4. Landowners should be informed in advance about border zone forest management projects so that they could plan their border zone forest management accordingly.
5. There are many landowners in each MV transmission line border zone forest management project, who are surprised by management practices despite the written information.
6. The forest officials are unable to respond to all inquiries presented by the landowners, and therefore, the letter to the landowners should include contact information of the electricity company.
7. Individual landowner's negative attitude towards border zone forest management project may spread among other landowners, hindering the success of the project.
8. Electricity companies should inquire about customer satisfaction of landowners participating in border zone forest management projects.
9. Operational planning, such as marking estate borders, edges of border zones and hazardous locations increases the safety and productivity of harvester operators.
10. The collection of landowners' mandates is the most laborious and time-consuming phase of the border zone forest management project.
11. Harvestings should not be started before all landowners' mandates are collected.
12. In the future (approximately five years) most of the border zone forests will be managed by manual harvestings.
13. In the future, border zone forests of high-voltage transmission lines could be treated by chemical substances to prevent tree growth.
14. When operating border zone forest near to transmission line, the harvester should be heavy-sized as handling of large stems is easier and safer with heavier harvesters.
15. As harvestings take place near to powered transmission lines, the most important characteristic of harvester operator is calmness.
16. Hourly wage is better than wage by production in the harvesting of MV line border zone forest, since it enhances work quality and safety.
17. Border zone forest harvesting is safer and produces better quality when conducted from the MV transmission line corridor than from the border zone forest.
18. Harvesting and forwarding under MV transmission lines is contradictory to Finnish government regulation (749/2001) on safe work, and therefore should not be done.
19. Harvesting from the transmission corridor is unsafe in HV transmission lines if operator delimits and cross-cut trees to the transmission corridor.
20. In a thinning near to the MV transmission line, the closest strip road should be placed on the border zone next to the transmission corridor.
21. In a thinning near to the HV transmission line, the closest strip road should be placed on the border zone.

Although landowners' awareness of border zone forest management has increased during recent years, the expert interviews raised up the opinion that there are still a lot of landowners who are surprised, despite the written information, about harvestings conducted in the border zone forest management project (Claim 5). Although the responsibilities between the electricity company and the forest organisation are unambiguously agreed, the information letter to the landowners may not include any contact information of the electricity company. As the forest officials are unable to respond to all inquiries related to the border zone forest management project, the information letter should always include contact information of the electricity company (Claim 6).

Border zone forest management project generally concerns several landowners. According to the expert interviews, there are individual landowners whose negative attitude towards management project may spread among other landowners (Claim 7). Assessment of project success is an essential part of every project management and in customer service projects the quality of the project is defined by the customer. Landowners, who participate in border zone forest management projects, should be surveyed of customer satisfaction to develop border zone forest management (Claim 8).

Operating a cut-to-length (CTL) harvester close to powered transmission lines is a demanding task. Operational planning including marking estate borders, edges of border zones and hazardous locations increases the safety and productivity of harvesting in border zone forests (Claim 9).

Collection of landowners' mandates for border zone forest management was considered as the slowest phase in a border zone forest management project. The experts' experiences revealed, that on average, only about half of the written mandates in a MV transmission line border zone

forest projects are returned within a given timeframe. The other half must be contacted later by phone. Thus, a collection of mandates is the most laborious and time-consuming phase in a border zone forest management project (Claim 10). Individual border zone forest management projects can include hundreds of landowners, from which some part cannot be reached at all. There is a temptation to start operations before all mandates are collected, but harvestings should not be started before all landowners' mandates are collected (Claim 11).

Quite often some part of trees is outside the reach of, or otherwise impossible to fell by harvester, and manual felling must be utilised. Furthermore, extensive border zone forest management projects might be unnecessary after 2023, as at least 75% of customers must have electricity transmission secured as defined in the electricity marketing act (FinLex 2013). Few experts had an opinion, that manual fellings would mostly replace forest machines in the management of border zone forests, as forest workers could combine silvicultural and harvesting operations (Claim 12). Some part of border zone forests requires special attention due to nearby inhabitation, and one option is to use tree growth regulators, chemicals that suppress the growth of vegetation. These chemicals could be used more widely to control the growth of border zone trees of HV transmission lines (Claim 13).

According to Ranta and Niemelä (2013), when operating in a border zone forests of MV transmission line, harvester should be small or medium-sized. However, during the expert interviews, the opposite opinions were presented, as bigger and heavier harvesters are better in handling large stems safely and effectively (Claim 14). Expert's interviews highlighted the importance of forest machine operator's expertise and caution. The most important characteristic of forest machine operators operating

alongside transmission corridors is calmness (Claim 15). Furthermore, to ensure safe and high-quality work the salary should be based on hourly wage instead of wage by production (Claim 16).

Management of border zone forest by CTL machinery can be conducted by two main alternatives (Ranta and Niemelä 2013), from the transmission corridor or from the border zone forest. The critical zone in the harvesting of border zone forest is located right next to the transmission line corridor, and the easiest and usually the safest alternative is to fell trees away from the line, thus working in the transmission corridor or placing strip road in the edge of transmission line corridor and border zone forest (Claim 17).

Although Finnish government regulation (749/2001) defines minimum distances between powered transmission lines and machinery, the expert interviews revealed that forest machines are occasionally operating closer than the minimum distance in MV transmission lines. The problem is more severe when transmission line corridors are crossing or located side by side. In the study, Claim 18 stated that harvesting and forwarding under MV transmission lines is contradictory to the Finnish government regulation and should not be done. Moreover, if harvesting is conducted from HV transmission line corridor, delimiting stems and cutting logs to the transmission corridor is unsafe (Claim 19).

Every now and then landowners have thinnings next to border zone forest of transmission corridor. In these thinnings, harvester operator does not necessarily consider management of border zone forest, leading to the sub-optimal placing of strip road. If the closest strip road of a MV transmission line corridor is placed on the border zone (max. 8 metres from the edge of the transmission corridor, as the trees have to be felled alongside the transmission line, not against it), the border zone may include trees that are too difficult to fell or are prone to wind damages. Therefore, the closest strip road of a MV transmission line corridor should be placed next to the corridor (Claim 20). In the thinning vicinity of HV transmission line, the closest strip road to the transmission line corridor should be placed on the border zone (Claim 21), as the border zone forest's productivity is hindered due to tree height restrictions.

Responses to the claims

Interview-based claims were entered in e-questionnaire and sent to the amended expert group, classified as a) electricity companies (EC), b) forest management associations (FMA), c) forest companies (FC) and d) forest machine operators (FMO). In each claim, the respondents could respond 1 = "strongly disagree", 2 = "somewhat disagree", 3 = "neither agree nor disagree", 4 = "somewhat agree" and 5 = "strongly agree". Overall, the experts agreed most of the claims, the median being four or five in 16 times of 21 claims.

The experts agreed with the claim that work demonstrations are helpful in the promotion of border zone forest

management (Claim 1, Figure 4). However, there were statistical differences ($p = 0.019$), between EC (median = 4, mode = 4) and FMA (median = 5, mode = 5) as all FMA representatives strongly agreed to the claim. Video links located in electricity companies' web pages (Claim 2) and the emerging need for landowner's activation on a new border zone forest management project (Claim 3) was also strongly agreed without statistical differences between the expert groups. On average, there was strong agreement on the need to inform landowners about forthcoming border zone forest management projects (Claim 4). There was statistical difference ($p = 0.014$) between FC (median = 4, mode = 4) and FMO (median = 5, mode = 5), and also statistical difference ($p = 0.001$) between FC and FMA (median = 5, mode = 5).

On average, the experts had no strong agreement or disagreement (median = 4, mode = 4) against the claim that there are many landowners who are surprised by border zone forest management practices (Claim 5). There was strong agreement against Claims 6, 7 and 8; the electricity company contact information has to be included in landowner letter (median = 5, mode = 5), one individual landowner's negative attitude may spread among other landowners (median = 4, mode = 4) and electricity companies should also conduct satisfaction surveys following border zone forest management project (median = 4, mode = 5).

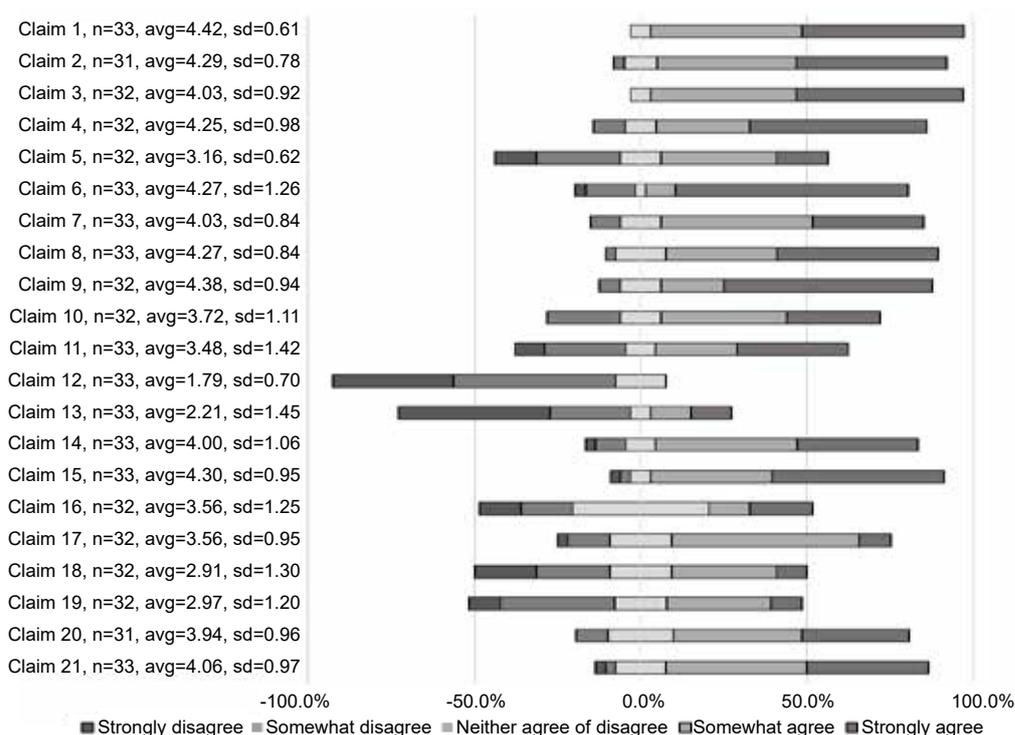
The experts agreed with the claim that operational planning is important (median = 5, mode = 5), as it assists machine operators' work (Claim 9). All FMO strongly agreed with the claim (median = 5, mode = 5), and there was statistical difference ($p = 0.028$) between them and FC (median = 4, mode = 4). The experts also agreed (median = 4, mode = 4) that collecting landowners' mandates are the most laborious and time-consuming task in border zone forest management (Claim 10). However, FMA had most diverging opinion (median = 2, mode = 2), which was statistically different from FC (median = 4, mode = 5) and FMO (median = 4, mode = 4). Also Claim 11, harvestings should not be started before landowners' mandates are collected was agreed (median = 4, mode = 5) without statistical differences between groups, although the mode of the answers was 2, somewhat disagree, for FC and 5, strongly agree, for FMO.

Although manual management of border zone forests was considered advantageous in some expert interviews, Claim 12, "In the future (approximately five years) most of the border zone forest will be managed by manual harvestings", was least agreed, by average value, in the questionnaire (median = 2, mode = 2). Also Claim 13, "In the future, border zone forests of high-voltage transmission lines could be treated by chemical substances to prevent tree growth." was disagreed (median = 2, mode = 1). In the expert interviews, the previous guidance about the use of small or medium-sized harvesters in border zone forest management was questioned, and heavier harvesters

Claim 1, n=33, avg=4.42, sd=0.61
Claim 2, n=31, avg=4.29, sd=0.78
Claim 3, n=32, avg=4.03, sd=0.92
Claim 4, n=32, avg=4.25, sd=0.98
Claim 5, n=32, avg=3.16, sd=0.62
Claim 6, n=33, avg=4.27, sd=1.26
Claim 7, n=33, avg=4.03, sd=0.84
Claim 8, n=33, avg=4.27, sd=0.84
Claim 9, n=32, avg=4.38, sd=0.94
Claim 10, n=32, avg=3.72, sd=1.11
Claim 11, n=33, avg=3.48, sd=1.42
Claim 12, n=33, avg=1.79, sd=0.70
Claim 13, n=33, avg=2.21, sd=1.45
Claim 14, n=33, avg=4.00, sd=1.06
Claim 15, n=33, avg=4.30, sd=0.95
Claim 16, n=32, avg=3.56, sd=1.25
Claim 17, n=32, avg=3.56, sd=0.95
Claim 18, n=32, avg=2.91, sd=1.30
Claim 19, n=32, avg=2.97, sd=1.20
Claim 20, n=31, avg=3.94, sd=0.96
Claim 21, n=33, avg=4.06, sd=0.97

Figure 4. Expert responses to claims concerning border zone forest management

Claims are listed in Table 1. N = number of responses, avg = average and sd = standard deviation.



were suggested (Claim 14). This was also agreed in the survey (median = 4, mode = 4), although there was statistically significant difference ($p = 0.007$) between FMO (median = 5, mode = 5) and FMA (median = 3, mode = 4). FMA opinion was also statistically different ($p = 0.040$) from FC (median = 4, mode = 5), and FMO was statistically different ($p = 0.024$) EC (median = 4, mode = 4).

According to the expert survey, calmness is harvester operator's the most important characteristics when operating near powered transmission lines (median = 5, mode = 5) (Claim 15). EC agreed statistically ($p = 0.043$) more (median = 5, mode = 5) to the claim than FC (median = 4, mode = 4). There was no strong agreement or disagreement for hourly wage being better than wage based on production (median = 3, mode = 3) (Claim 16).

When operating in border zone forest along MV transmission lines, operating from the transmission line was found (median = 4, mode = 4) to produce better quality and productivity (Claim 17). Claim 18, "Harvesting and forwarding under MV transmission lines is contradictory to Finnish government regulation (749/2001) on safe work, and therefore should not be done" divided the expert groups (median = 3, mode = 4). EC strongly disagreed (median = 1, mode = 1) whilst FMO agreed (median = 4, mode = 4) with the claim ($p = 0.002$). EC opinion was also statistically different ($p = 0.019$) to FMA (median = 4, mode = 4). According to the average value and standard deviation, the experts had a very similar opinion of the safeness of delimiting and cross-cutting trees to the corridor of HV transmission line (Claim 19), although the mode (2) was different to claim 18, and there were no statistical differences between expert groups.

Strip road planning effects on safety, the productivity of harvesting operation as well as utilisation of forest land area for wood production. According to the expert survey, in a thinning near to MV transmission line, the closest strip road should be placed on border zone next to transmission corridor (Claim 20) and in a thinning near to HV transmission line, the closest strip road should be placed on a border zone (Claim 21). Median and mode were four in both cases.

Discussion

In the study, the aim was to examine the current operation models for the management of border zone forests of HV and MV overhead transmission line corridors in Finland applying argument Delphi methodology. The initial information of current operation models, bottlenecks and development needs were collected from literature and interviewing border zone forest management professionals utilizing themed semi-structured interviews. Initial information was assessed and a survey of claims regarding border zone forest management was conducted.

Themed interviews allowed flexible and interactive discussions with the experts, which was essential allowing them to raise up bottlenecks and development needs unforeseen by the authors. Selected experts represented different interest groups of border zone forest management projects, and they had wide experience. For practical reasons, most of the experts were from Finnish Lake district (Central Finland, Southern Savonia, Northern Savonia and North Karelia) and Kainuu. However, these areas, and especially forested hill areas in Northern Savonia, North Karelia and Kainuu, are more vulnerable for snow damag-

es along transmission lines due to high snow accumulation in trees on wintertime (LUKE 2018).

The experts were positive about the interview and survey and most often found the study important for the border zone forest management and security of power transmission along overhead transmission lines. Although the experts had the possibility to pass by individual questions, only a few utilized the option. However, as always, there is no certainty that all the questions were correctly understood.

The expert group included experts from the electricity companies, forest management associations, forest company employees and forest machine operators. Private landowners, one of the most important interest group in border zone forest management projects, was not directly included in the expert group. Their viewpoint was thought to be expressed by the experts from the forest management associations. However, forest officials from the forest management associations have two roles: legally, their task is to organise professional assistance to forest owners in their own territories, but they are also selling services, such as border forest management projects for electricity companies.

According to the results, landowners' knowledge of border zone forest management has increased during recent years, but should be further increased by video clips linked to electricity companies' web-pages, project-specific work demonstrations and demonstrations in exhibitions and other events. These actions are considered cost-efficient and would help the management of projects. Jämsén's (2017) conclusions were similar, although the study highlighted the role of forest management associations as a source of information. It should be noted, that Jämsén's study was assigned by the forest management association of Central-Finland.

Increased knowledge and activation of landowners is crucial, when a new MV transmission line corridor is built. The opening of a transmission line corridor and harvestings in the border zone forest could offer cost-efficient possibilities to extend joint harvestings in the vicinity forests. Larger project entities and increased collaboration between stakeholders were suggested also by Syrjä (2016) and Jämsén (2017).

Planning of border zone forest management operations is important to ensure the productivity of the border zone and nearby forests and the safety of operations. According to the experts, on MV transmission lines, the corridor should be utilised in the harvesting operation if possible. Also, Ranta and Niemelä (2013) and Jämsén (2017) suggested that this working method leads to easier and safer operations if the minimum distance requirements are fulfilled (Tukes 2010). If a strip road is needed, it should be placed next to the transmission line corridor, enabling felling away from the transmission line. In HV transmission line border zone forest operations, the closest strip road to transmission line should be placed on the border zone.

In a border zone forest management project, the strip road planning is done by professionals, either by forest by

forest official or by harvester operator while harvesting. However, to ensure maximal productivity of the border zone and vicinity forests, strip road planning of individual thinning nearby transmission lines should consider the need for strip road also in the border zone forest management. Guidance is needed especially for harvester operators, but for landowners and forest officials as well.

Operational planning, including marking estate borders and border zone forest was found helpful and increases the productivity of harvesting operations. Marking of dangerous locations also increases the safety of operations, which is a substantial issue near powered transmission lines. Harvestings by CTL harvesters in the vicinity of transmission lines require calm and experienced harvester operators to guarantee safe and productive operations. The differences between CTL harvester operators' expertise measured as productivity has been found high (Purfürst and Erler 2011), and the expertise is increasing up to 15 years of experience (Malinen et al. 2018).

In the winter of 2017–2018, regions of North Karelia and Kainuu had heavy snowfalls and snow accumulated on trees. Pohjois-Karjalan Sähkö, a local electricity company in North Karelia, conducts border forest management annually around 500 kilometres of MV transmission lines. On the other hand, Loiste, a local electricity company in Kainuu, considers border zone forest management as a responsibility of a landowner (Loiste 2018). As a consequence, in the winter of 2017–2018, Pohjois-Karjalan Sähkö had no severe problems; whereas Loiste had to urgently manage 1,600 kilometres of border zone forests to restore the power transmission through their transmission lines. Landowners were not contacted before the operations. Felled trees were paid but left lying in the forests (Jylhänlehto 2018).

Compensations paid for landowners were not the studied issue, but rose up in the interviews. There is a need to study and clarify sufficient and equal levels of compensations between electricity companies and landowners. The safety of harvesting operations, as well as tree-security of MV transmission line, is greatly affected by the width of the transmission corridor. Currently, there is not enough information on transmission corridors width and its influence on growth and yield of the transmission line area.

This study is based on the operation environment and management practises utilised in Finland. The large number of individual forest owners, electricity companies' responsibility to secure power transmission and high accumulation of snow in wintertime at some parts of the country are characteristics that affect management of border zone forests in Finland. However, the problem with securing power transmission through overhead transmission lines in the vicinity border zone forest and individual trees exists globally. The applicability of these results depends on the local circumstances. These results can be applied at least in similar environments, but the results can help to evaluate border zone forests operation models in other circumstances as well.

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