Working Papers of the Finnish Forest Research Institute 210

http://www.metla.fi/julkaisut/workingpapers/2011/mwp210.htm
ISBN 978-951-40-2322-4 (PDF)
ISBN 978-951-40-2347-7 (paperback)
ISSN 1795-150X

Wood harvesting and logistics in Russia – focus on research and business opportunities

– Final report of the research project

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METLA www.metla.fi

Working Papers of the Finnish Forest Research Institute publishes preliminary research results and conference proceedings.

The papers published in the series are not peer-reviewed.

The papers are published in pdf format on the Internet only.

http://www.metla.fi/julkaisut/workingpapers/
ISSN 1795-150X

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Title
Wood harvesting and logistics in Russia – focus on research and business opportunities

Year	Pages	ISBN	ISSN
2011	157	978-951-40-2322-4 (PDF) 978-951-40-2347-7 (paperback)	1795-150X

Unit / Research programme / Projects
Joensuu / 7337 Wood harvesting and logistics in Russia – focus on research and business opportunities

Accepted by
Karjalainen, Timo, Professor, 24 October 2011

Abstract
The Russian Federation is one of the main trading partners of Finland and the Russian forest sector is an important operational environment for many Finnish forest sector companies. The Russian forest sector is a quickly changing environment that creates both challenges and opportunities for business.

The project had an aim to improve and secure business opportunities and the competitiveness of Finnish forest-related companies and research in the emerging Russian market through international research. New research methods and approaches were built and applied within the project to support successful business operations in the specific Russian conditions.

Opportunities for further improvements were found at many stages of wood harvesting and logistical operations in Northwest Russia. Extensive field and theoretical studies and close cooperation with the logging companies resulted in a set of tools, models and recommendations which could help to realise the discovered opportunities. Field studies showed that the productivity of wood harvesting in some of the companies in Northwest Russia could be increased on average from 10.7 m^3/PMH to 18.0 m^3/PMH. Improvements of the quality of stem processing by harvesters were reached using the project's recommendations on maintenance of delimbing knives. The share of deficient logs (due to unprocessed branches) in the total number of processed stems decreased by 4-6%. A decision support system for optimisation of wood harvesting plans and logistics of logs and energy wood developed and tested in practice demonstrated short and long term positive economic effects. The total run of trucks was decreased by 22% and the fleet utilisation rate was increased by 19% up to 0.89. The positive effect from logistic optimisation can be boosted by proper forest road planning and construction. Investment in construction of forest roads can be economically feasible in the Russian conditions. The project revealed differences in ergonomics and impacts on the environment between different forest machines and harvesting systems applied in Northwest Russia that will help the logging companies to select better machines and methods in the future.

The results of the project are publicly available and widely disseminated. Utilisation of the achieved results in practice would improve productivity of harvesting operations, human and environmental safety. The project's results would facilitate harvesting and use of energy wood in Russia which could result in reduction of greenhouse gas emissions.

Keywords
wood harvesting, energy wood, technology adaptation, logistic optimisation, road planning, road construction

Available at
http://www.metla.fi/julkaisut/workingpapers/2011/mwp210.htm

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1 Introduction

1.1 The importance of the Russian Federation for the Finnish forest sector

The Russian Federation is one of the main trading partners of Finland. In 2008 the volume of trade between the countries was 17.7 billion euro or 13% of Finland's total foreign trade (Metla 2010). Russia was especially important for the Finnish forest sector. Most of Finland's roundwood import in 2007 (66% or 11.8 million m^3) was from Russia. Due to roundwood export fees introduced by Russia in 2007, import of roundwood from Russia to Finland has been decreasing during the last few years. In 2010, Finland imported in total 11.7 million m^3 of roundwood, 58% (6.9 million m^3) of which was imported from Russia (Metla 2011). However, Russia is undoubtedly very important for the Finnish forestry-related business, being the operational environment for an ever-increasing number of enterprises and a growing market especially for machinery manufacturers. To be able to hold their market position and find new business possibilities, enterprises and method developers must be well aware of the current status and future development of the Russian forest sector, and be familiar with the local conditions, which are not similar to Finland.

There is a lack of knowledge related to wood harvesting in earlier unmanaged and deciduous species dominated forests, both of which are very common in Russia, but of which very little is known in Finland. In particular, knowledge related to productivity and prerequisites for machinery and technology for wood harvesting and transportation in such conditions is inevitably needed.

Knowledge of the development of wood harvesting and wood transportation in Russia is important for Finnish companies, since many of them are operating in Russia in these fields. Furthermore, Finnish research and technology developers urgently need this knowledge in order to be competitive and able to provide solutions for the problems faced. This was also the conclusion of the Sitra report (Ollus and Torvalds 2005), which said that Russia research should be directed more at applied research in particular serving the needs of the Finnish business sector and entrepreneurship. This urgently requires proper resources in research and development work, as forestry in Russia is in a fast development phase.

1.2 Wood harvesting and logistics in Russia

In Russia, wood harvesting is conducted using three methods: full-tree, tree-length and cut-to-length logging methods (Karvinen et al. 2006). Although lack of appropriate machinery is hindering implementation of the cut-to-length method, it is becoming increasingly popular in Russia, for example due to its better usability also for thinnings, efficiency and smaller environmental impacts. Its share in the Republic of Karelia was 93% of the harvested wood in 2009 (MFC RK 2010), whereas in the other regions of Russia it is considerably smaller, on the whole federation level approximately 30%.

The majority of the machines that are used in the full-tree and tree-length methods are of domestic origin. With regard to the cut-to-length method, the quality of Russian machinery is inferior to western technology and thus its production is small. As a result, big logging companies and forest industry corporations are purchasing ever more western technology suitable for full-tree and cut-to-length logging methods.

Methods of wood transportation depend on the logging methods used, and wood is transported either directly to the end user from the roadside or via intermediate storage or central processing yards (Karvinen et al. 2006). Currently, railway transportation is the most important way to deliver wood and annual volumes are constantly increasing. Furthermore, the average transportation distance is increasing. There have, however, been problems with the availability of wood cargo wagons, and some companies have even purchased private wagons or have established transport companies.

Wood trucks are used for transporting small amounts of wood on short and medium transportation distances (<140 kilometres). In comparison to other means of transportation, truck haulage is relatively expensive due to the low carrying capacity of the trucks and poor condition of the road network. Utilization of long-distance truck transportation is decreasing and is carried out only if no other feasible means of transportation is available. Both Russian and foreign vehicles are used. Along the inland water-ways, wood is transported by shipping or by floating in bundles. The volume of water-way transportation is decreasing, which is mainly due to a reduction in the use of floating.

Typical logging companies are small in terms of turnover. During the past few years, the profitability of wood harvesting has been low. As the prices of fuel and energy as well as the stumpage prices are increasing, returns for the logging industry are getting smaller still. New forest legislation aims at intensifying forest use through a move towards the Nordic way of forest management. Forest leasers are expected to take more and more responsibilities on forest management, thus increasing costs, but also providing the possibility to control the results and success of the implemented measures. Nordic forest industry companies are used to these responsibilities in their home countries, but for many Russian companies these are new challenges. When expanding obligations for forest leasers have to be met in the logging companies, safety and productivity requirements are causing an increasing need for modern technology, signifying even bigger demand for investment. These financial considerations along the entire production chain mean that wood harvesting, wood transportation and logistics operations must be efficiently planned and implemented.

The main problem in wood harvesting is the poor condition of the road network system and especially the lack of all-season roads. This has been experienced in the last few winters, with substantial difficulties in wood deliveries.

Reasons for the low annual yield in wood harvesting include, among others, neglected thinnings, but also the outdated technologies the logging companies are using. Machinery is often worn out and obsolete, and only logging companies belonging to large forest industry corporations can afford to purchase new technology. Furthermore, because low wages and physically demanding work do not attract young people to the logging industry, it has been difficult to recruit educated and motivated labour. Accidents have been very common in wood harvesting and transportation. Education, training, and better attention to safety and use of modern technology would improve the situation. Also environmental impacts could be decreased at the same time.

Analyses of logging companies in the Republic of Karelia show that bigger companies are in a better position to solve the challenges wood harvesting is facing (Gerasimov et al. 2005). Nevertheless traditional harvesting methods will be used in the future and can be supported with effective western machinery. Wood harvesting costs in Russia are high and sometimes even exceed the harvesting costs in Finland, due to the low productivity of labour in companies using traditional Russian machinery. Analysis also showed that implementation of commercial thinning operations and use of the cut-to-length method would improve the availability of wood for markets. Also, careful modernization and introduction of new methods and technology could improve the status of forest work and help to attract more motivated and skilled employees to companies.

One of the issues developing in the coming years in Russia will be energy wood harvesting. There is plenty of woody biomass available for energy production purposes (Gerasimov & Karjalainen 2011), but currently the subsidized price of natural gas and oil makes it difficult for woody biomass to compete. As energy wood harvesting methods develop and the market situation and competition become real, increasing demand for energy wood will be likely. In this respect the need to develop suitable energy wood harvesting methods and chains, as well as markets for energy wood harvesting technology, will be growing in the coming years.

1.3 Aims of the project

The general aim of this project was to improve and secure business opportunities and the competitiveness of Finnish forestry-related companies and research in the emerging Russian market through international research.

The specific goal was to build and apply new research methods and approaches for improving the Finnish know-how on wood harvesting technology, wood energy and logistics in Northwest Russia.

Finnish organisations and companies can benefit from the results when developing business operations in Russia and adapting forest technology for Russian conditions. Related to this, another aim was to provide know-how about the possibilities for further development of technology for industrial and energy wood harvesting, transportation and logistics, i.e., what could be used, what is the potential, what are the specific requirements for technology appropriate to Russian conditions, in particular in the unmanaged and deciduous species dominating forests, where our knowledge is limited.

The secondary objective of the project was to intensify the existing network between Finnish, Russian and Swedish organisations in wood harvesting and transport operations research.

1.4 Participants

The project consortium was formed by research, business and funding organisations. The Finnish Funding Agency for Technology and Innovation covered 85% of the project budget through the European Regional Development Fund. The Finnish Forest Research Institute (Metla) was responsible for overall coordination of the project and, together with the University of Helsinki (UH), the Petrozavodsk State University (PetrGU) and the Swedish University of Agricultural Science (SLU), carried out research activities within the project. Companies John Deere Forestry Oy, Kesla Oyj, Mantsinen Oyj, Metsäliitto Osuuskunta, Ponsse Oyj, Sisu Auto Oy, Stora Enso Oyj and UPM-Kymmene Metsä covered 15 % of the project's budget and provided necessary data and supported field studies.

1.5 Project implementation

The project started in November 2008 and lasted 3 years. The project consisted of three work packages. Metla coordinated research activities in work packages which covered issues related to harvesting of industrial and energy wood in Northwest Russia. UH coordinated the work package which was devoted to wood transportation and logistics in Northwest Russia.

When implementing the project, special attention was paid to the practical value of all project outputs. The companies supporting the project were its end-beneficiaries, therefore all services and products were elaborated in close cooperation with the companies. Most of them were tested in practice using actual data provided by the companies. When it was needed, the products and services were further improved by following comments and suggestions from the companies.

1.6 Project outputs

The project was designed to provide adequate information about the current status of the forest sector in Northwest Russia and to offer solutions which will in practice increase the competitiveness of the Finnish companies in the Russian market.
The project delivered an informational package consisting of:

- Recommendations on adaptation of Finnish forest machinery to the specific conditions in Russia
- Scientific articles describing methods to improve the efficiency of wood harvesting and transportation
- Reports containing information about the actual state and future development of the Russian forest sector
- Reports on the productivity of Finnish machinery in the specific conditions of Russia
- Recommendations on costs calculations, road construction and selection of supply chains in Russian conditions

Within the project a set of tools and models was elaborated in close cooperation with the participating companies:

- Cost calculators for wood harvesting and transportation
- Cost-effective procurement models for industrial and energy wood harvesting in Russia using the Nordic forest technology
- Tools for optimisation of wood harvesting plans and transportation chains
- A system for planning of forest road networks

Utilisation of the achieved results in practice by the companies participating in the project would improve the productivity of harvesting operations, human and environmental safety. The project's results would facilitate harvesting and use of energy wood in Russia, which could result in reduction of greenhouse gas emissions.

The results of the project are publicly available and widely disseminated through publications, seminars and the internet (www.idanmetsatieto.info), which ensures easy and permanent access to the results. List of publications can be found in Appendix 1.

References

Gerasimov, Y. & Karjalainen, T. 2011. Energy wood resources in Northwest Russia. Biomass and Bioenergy 35 (5): 1655-1662

Gerasimov, Y., Syunev, V., Chikulaev, P., Pechorin, V., Dyakonov, V., Komkov, V., Sikanen, L. & Karjalainen, T. 2005. An analysis of logging companies in the Republic of Karelia. Working Papers of the Finnish Forest Research Institute 16. 39 p. Available at: http://www.metla.fi/julkaisut/workingpapers/2005/mwp016.htm

Karvinen, S., Välkky, E., Torniainen, T. & Gerasimov, Y. 2006. Northwest Russian forestry in a nutshell. Working Papers of the Finnish Forest Research Institute 30. 98 p. Available at: http://www.metla.fi/julkaisut/workingpapers/2006/mwp030.htm

MFC RK. 2010. Shares of logging methods in the total volume of wood fellings in the Republic of Karelia. The Ministry of the Forest Complex of the Republic of Karelia, Petrozavodsk, Russia.

Ollus, S-E. and N. Torvalds (eds.) 2005. From Trade to Partnership. Finland's economic strategy for Russia. Sitra report 58. Helsinki, Finland. 58 p.

Metla. 2010. Metsätilastollinen vuosikirja 2010 [Finnish Statistical Yearbook of Forestry]. Metsäntutkimuslaitos, Vantaan toimipaikka. 472 p.

Metla. 2011. Finnish Forest Research Institute. Statistical service Metinfo. Available at: http://www.metla.fi/metinfo/tilasto.

2 Current status of the forest sector in the Northwest Russia

Northwest Russia, including the regions of Karelia (*Respublika Kareliya*), Komi (*Respublika Komi*), Arkhangelsk (*Arkhangelskaya oblast*), Vologda (*Vologodskaya oblast*), Leningrad (*Leningradskaya oblast*), Novgorod (*Novgorodskaya oblast*), and Pskov (*Pskovskaya oblast*), plays a key role in the Russian forest sector and has been well developed in comparison with the rest of Russia. In 2008, the region produced 36% of the total industrial roundwood of Russia, 53% of its pulp, paper, and cardboard, 36% of its plywood, and 28% of its sawnwood (Rosstat 2009). In contrast, Northwest Russia has only 10% of the forest land and 12% of the growing stock of the whole of Russia. Nevertheless, the forest resources of the region have supplied not only the domestic forest industry but also the industrial roundwood export market. In fact, Northwest Russia has been the most important industrial roundwood supplier to Europe, particularly for the Nordic countries. Finland has traditionally been one of the key importers of Russian roundwood originating mostly from Northwest Russia. Roundwood exports from Russia to Finland increased steadily until 2005, after which they started to decrease. This was due to increasing export duties on roundwood, introduced in 2007. The aim of the Russian authorities is to decrease the export of industrial roundwood and increase wood processing in Russia. Russia has renewed forest legislation aiming at clarification of responsibilities and rights between the state (forest owner) and private business (forest user), and also between the federation and the regions.

The latest detailed information on the forest sector of Northwest Russia is presented in Karvinen et al. (2011).

References

Karvinen, S., Välkky, E., Gerasimov, Y. & Dobrovolsky, A. 2011. Northwest Russian Forest Sector in a Nutshell. Finnish Forest Research Institute. Joensuu. 144 p.

Rosstat. 2009. The Federal Statistics Service. On-line database. Available at: www.gks.ru. Accessed 3.8.2011

2.1 Finnish-Russian wood trade

Introduction

This chapter presents the results of a study recently published in Finnish (Tolonen, T., and M. Koponen 2011).

Imported wood from Russia to Finland has constituted a remarkable share of wood for the Finnish forest industry. Companies' strategy to increase the share of wood imported from Russia can be seen in the growing volumes between the end of the 1990s and 2005, when a record of 17 million cubic metres was achieved. After that, imports from Russia began to decline, and in 2009 it ended up being some 6.1 million cubic metres (Figure 2.1). Declining imports are a result of export duties introduced for roundwood in Russia and the decreased demand for imported raw material in Finnish forest industries. The share from Russia has decreased from 80% to about 65% of all imported roundwood to Finland, and from 20% to 10% of wood procurement in the forest industry (Finnish Statistical Yearbook of Forestry 2010, Viitanen & Karvinen 2010, Pirhonen et al. 2008). Birch pulpwood has been the dominant timber assortment, but volumes of coniferous saw logs have been increasing since the devaluation of the Russian rouble in August 1998 (Mutanen & Toppinen 2007, Holopainen et al. 2006). The amount of imported woodchips outstripped birch pulpwood as a major timber assortment in 2009 (Finnish Statistical Yearbook of Forestry 2010). In recent years the share of coniferous wood has varied from 30% to 50% of all imported Russian roundwood.

Together with the import of wood, there exists a threat that foreign plant pests may invade the recipient country. For coniferous wood, the wood nematode *Bursaphelenchus xylophilus* is one of the most crucial because of its ability to cause severe damage to coniferous forests. Import of coniferous wood from Russia to Finland is regulated by legislation in the European Union and Finland. Since the beginning of March 2005, all coniferous wood imported from Russia to Finland has to be labelled with a phytosanitary certificate given by the Russian plant health authorities,

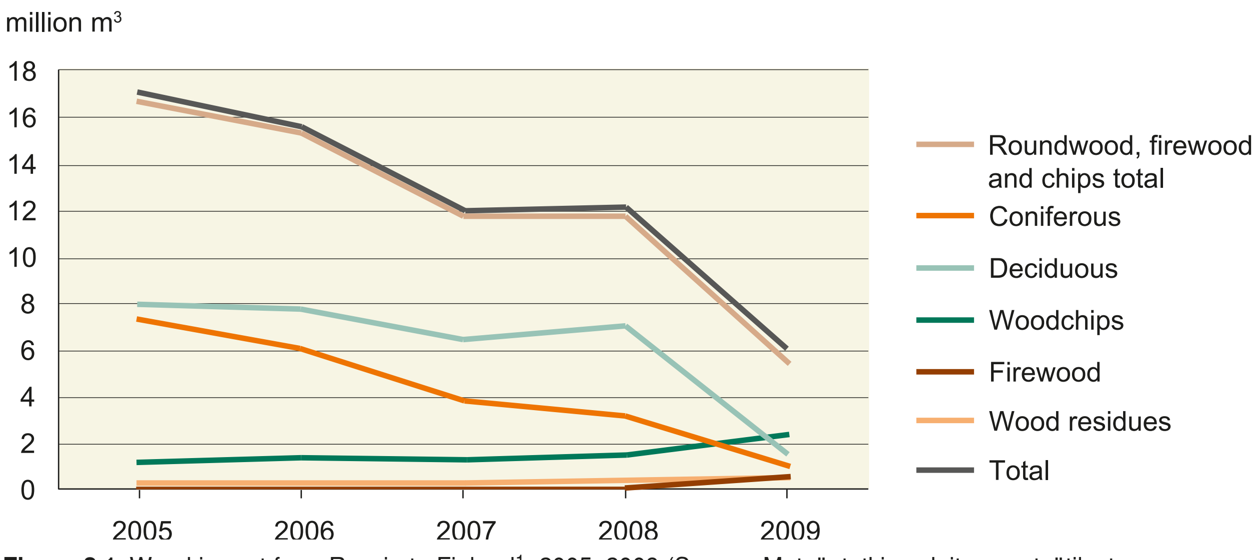


Figure 2.1. Wood import from Russia to Finland[1], 2005–2009 (Source: Metsäntutkimuslaitos, metsätilastotiedotteet).

1 – Wood chips include both industrial and energy wood chips and sawdust.

and certain parts of consignments have been subjected to physical plant health examinations. The demand for certificates and physical checks had already existed for coniferous wood from the Asian part of Russia and for all the larch (*Larix spp*) species (2000/29/EC). This new directive (2004/102/EC) caused fear in the forest industry in Finland and Sweden because most raw wood imported to Finland comes from the European part of Russia, especially its northwest part. Physical plant health checking and its organisation at border crossing points was expected to cause trouble by slowing down the import and increasing bureaucracy and import costs. On the other hand, the threat caused by wood import from nearby Russian regions for Finnish forests was expected to be small according to research results. During the preparation phase of the directive, the EU gave its member countries the possibility to apply for a reduction of physical checking (2004/1756/EC). Finland and Sweden received permission to check only 1% of incoming coniferous wood from the European part of Russia from 2005–2009. Since the beginning of 2010, 3% of imported wood is checked.

Beginning in 2006, Russia increased export duties for coniferous roundwood. Until 2008 the duty was raised step-by-step from 2.5 to 15 €/ m^3. The last duty increase consisted also of birch roundwood with a top diameter over 15 cm. The principal goal was to make roundwood exports from Russia unprofitable, to create value added by processing the wood within the country, and to encourage foreign investments to Russia (Pirhonen et al. 2008, BoF Online 2007, Mutanen & Toppinen 2007). Since the beginning of 2009 there was a threat that the export duty would be raised to 50 €/ m^3. The Russian government postponed the decision twice at the end of 2008 and 2009, and at the end of 2010 confirmed a decree (29.12.2010 № 1190) in which it preserved export duty at the level of 2008.

Aim of the study

The overall economic development in recent years has also strongly influenced the forest sector in Finland and Russia. This study analyses the import of coniferous wood from Russia to Finland and changes within it during the period 2005–2009. The study is based on material collected by the Finnish Food Safety Authority Evira. The study focuses on the whole import chain from Russia to Finland, that is, coniferous wood export done by the various Russian forest industry companies from different Russian regions via different border crossing points and by different means of conveyance to numerous Finnish importers.

Material and methods

Imported coniferous consignment and import documents are checked by Finnish Customs at the border. The Finnish Food Safety Authority Evira (former Plant Production Inspection Centre KTTK) takes care of physical plant health inspection either on the border or at the destination. *After checking, phytosanitary certificates are delivered and stored at the Finnish Food Safety Authority Evira office based in Lappeenranta, Finland, where local officials collect checked certificates by sampling and save the data to a Microsoft Access database.*

The database consists of certificates from different parts of Russia, from different exporters, means of conveyance, border crossing points, tree species, and timber assortments and their volumes delivered to Finnish importers. This way the share of Russian exporters and Finnish importers within the research material, that is, the imported amount of certificates and volumes, equates as well as possible with the real stream of coniferous timber. Almost all certificates from vessel shipments have been stored to the database.

During the period 2005–2009 over half a million coniferous consignments were imported to Finland. This means more than 25 million cubic metres of coniferous wood. The coverage of the sample is approximately one fourth of the number of certificates and some 40% of the imported coniferous timber assortments (Table 2.1). The material has been divided into variables, which illustrate the operational environment and changes within it.

Table 2.1. Import of coniferous consignments and sample material

Year	Total amount of certificates	Total volume of coniferous wood, m^3	Sample amount of certificates	Volume of wood in the sample amount, m^3
2005	150 000 (est.)	7 000 000 (est.)	27 657 (18.5%)	2 196 541 (31.4%)
2006	154 046	6 880 551	35 200 (22.9%)	2 370 304 (34.4%)
2007	108 879	3 909 669	33 737 (31%)	2 083 656 (53.3%)
2008	108 140	4 254 103	34 643 (32%)	2 008 247 (47.2%)
2009	65 542	3 400 000 (est.)	24 764 (37.8%)	1 321 969 (38.9%)
Total	586 625	25 444 323	156 001 (26.6%)	9 980 717 (39.2%)

Import of coniferous wood to Finland

Timber assortments and import volumes

Roundwood remained the dominant import assortment until 2009, when it was replaced by woodchips (including sawdust). In Russia woodchips have been categorised as processed product. Export duty consists of only 5% of customs value. The amount of sawnwood increases during the period, but it stays below the amounts of woodchips and roundwood. Traditionally, imports of firewood have been quite low. During 2009, they increased and followed the tendency of woodchips and sawnwood. The import volume of the fraction “other,” which includes packing material, buildings, and roundwood without bark, remains the smallest import assortment (Figure 2.2).

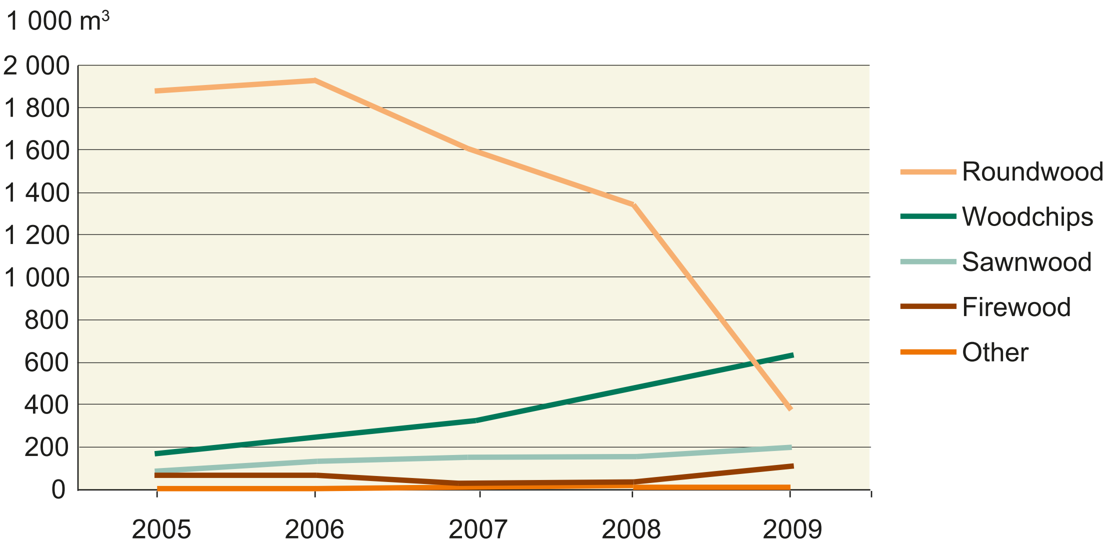


Figure 2.2. Volumes of coniferous timber assortments in research material.

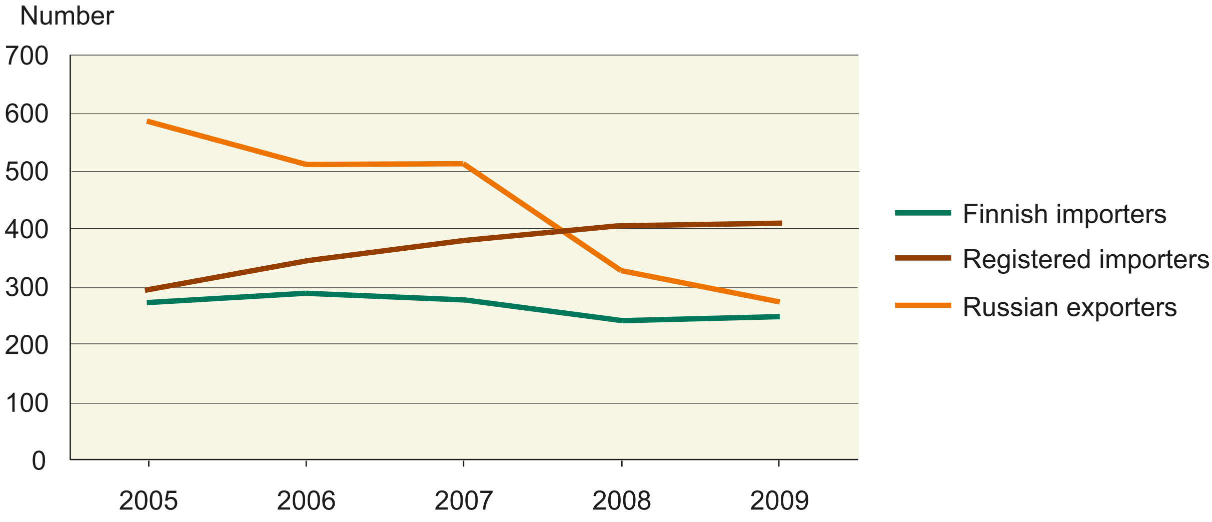


Figure 2.3. The amount of exporters and importers.

The number of exporters and importers

The amount of Russian exporters decreased during the period (Figure 2.3). After the second export duty increase in 2007, the decrease seemed to accelerate. The number of active Finnish importers has remained stable, while the number of importers who have registered themselves to the Finnish Food Safety Authority Evira register has increased. This kind of development probably reflects belief in the future among Finnish entrepreneurs, that is, they want to be ready if some kind of business opportunities exist.

Export from Russia

Export from Russia has been studied as the number of export consignments and delivered volumes in cubic metres. According to the number of export consignments, companies have been roughly divided into large-scale, small, medium-sized, and so-called micro companies. The number of enterprises exporting more than 100 and 1000 consignments annually remains quite constant,

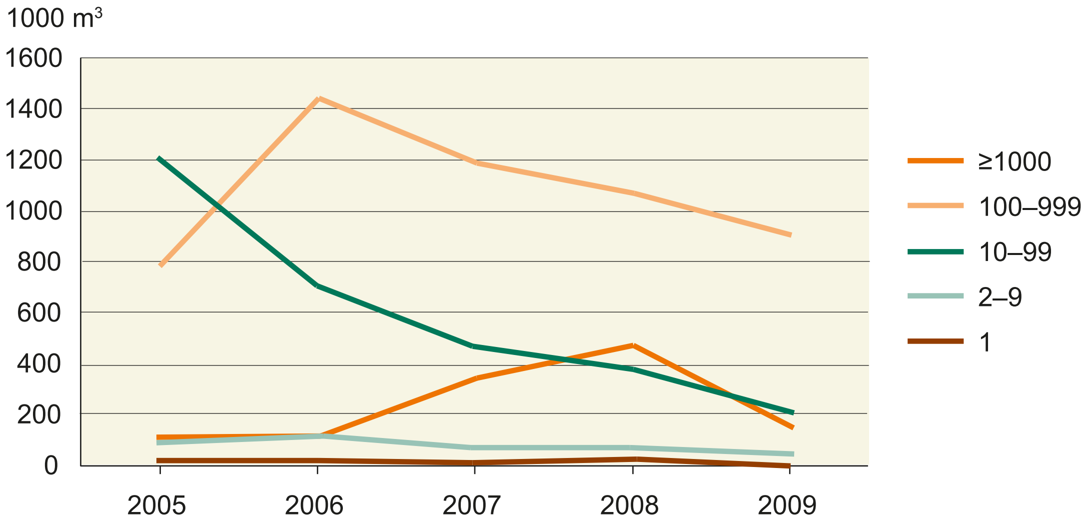


Figure 2.4. Exported volumes from Russia according to export consignments.

while the number of companies exporting less than 100 consignments per year has decreased. Small and medium-sized enterprises dominate in volumes, although the tendency is decreasing. The export volume of large-scale companies reaches a peak in 2008, after which it starts to decrease (Figure 2.4).

Import to Finland

Import to Finland was handled by a few large-scale forest industry companies until the year 2008 (Figure 2.5). After that, the decrease in imports was explained by the fact that companies were obliged to adapt their operations to a changing operational environment in Russia and to a larger extent in the global market. The number of companies importing over 100 consignments annually remains quite constant. A clear hiccup in imports can be seen during 2007–2008, but it revived during 2009. The most numerous group was formed by companies importing fewer than 100 consignments per year. Despite the number, volumes remain below the amount of large and small and medium-sized enterprises.

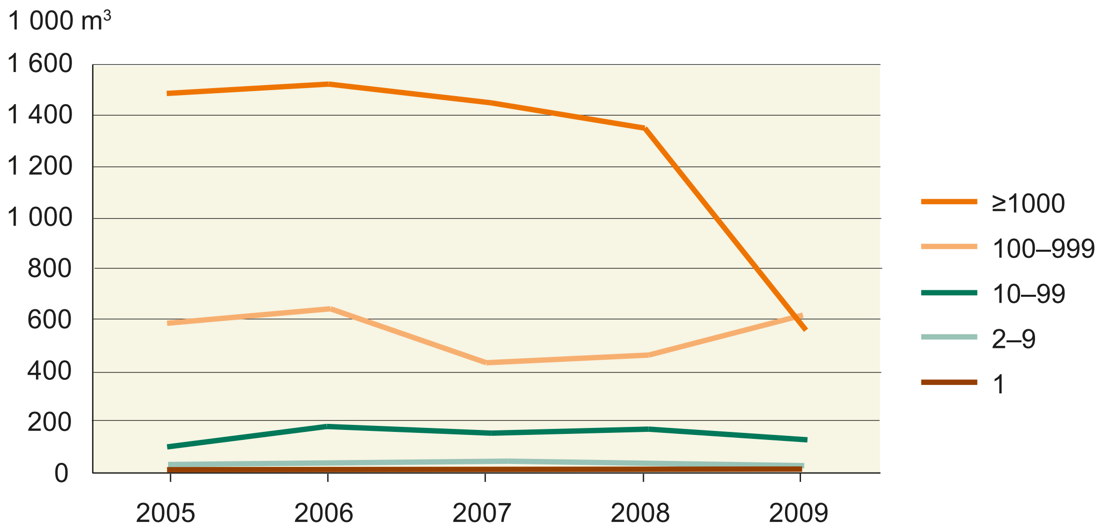


Figure 2.5. Imported volumes to Finland according to import consignments.

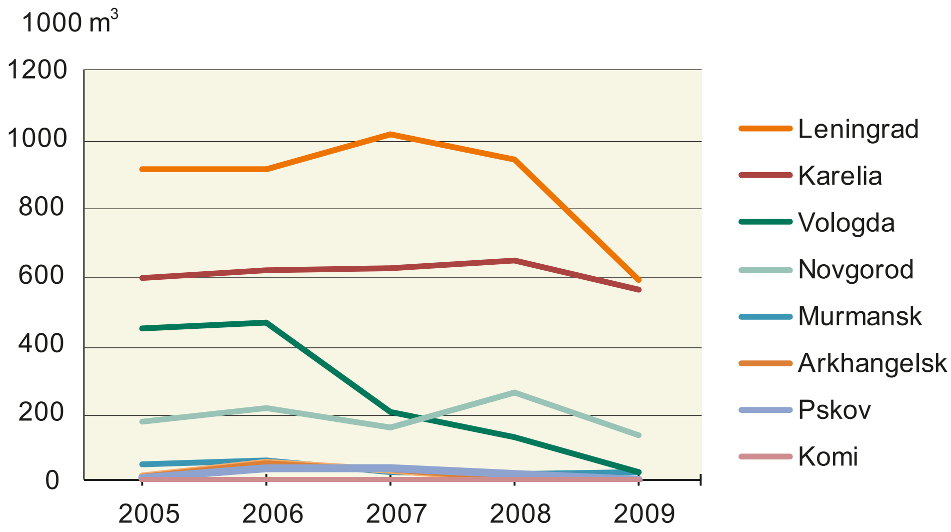


Figure 2.6. Export volumes according to north-west Russian regions.

Origin of wood

Northwest Russia is the main district for coniferous wood imports to Finland. Within the district, the Leningrad and Karelia regions dominate (Figure 2.6). The export volume of Vologda region starts to decrease right after the year 2006, which reflects the reducing effect of increasing export duties and transport distance to delivery. The Novgorod region displaced Vologda in 2007. This was mainly because of woodchip delivery from local sawmills to Finland. In the Murmansk region, the low annual cut and long distances to mills explain the small export volumes. The geographical distance from the border and the regions' own forest industries are probably the main reasons for the small export volumes of Arkhangelsk and Komi regions.

In other Russian districts export volumes have remained below the volumes in Northwest Russia (Figure 2.7). In the Central district the development of Tver and Kostroma regions reflects their geographical location, because exports from Kostroma nearly ended in 2007, while exports from Tver oblast accelerated. In Volga district the Kirov region dominates until the end of 2007. Export from the regions of Perm and Nizhny Novgorod existed during the whole period, although the volume decreased. Export from regions east of the Urals – Krasnojarsk, Sverdlovsk, and Irkutsk – remains in practice occasional consignments only.

Means of transport

Truck transportation seems to be the most dominant means of transport for coniferous wood, while volumes of train and vessel transportation remain less (Figure 2.8). Truck transport has been economically connected to the border areas, which can also be seen in the dominant position of Leningrad and Karelia regions in the origin of the wood. In Eastern Finland, for example, local small and medium-sized saw mills have used saw logs from Russia to complete wood procurement, and these saw logs have mainly been delivered by trucks from nearby Russian regions. According to Gerasimov and Karjalainen (2009), the cheapest way to deliver energy wood is by truck directly from nearby regions to the border crossing point.

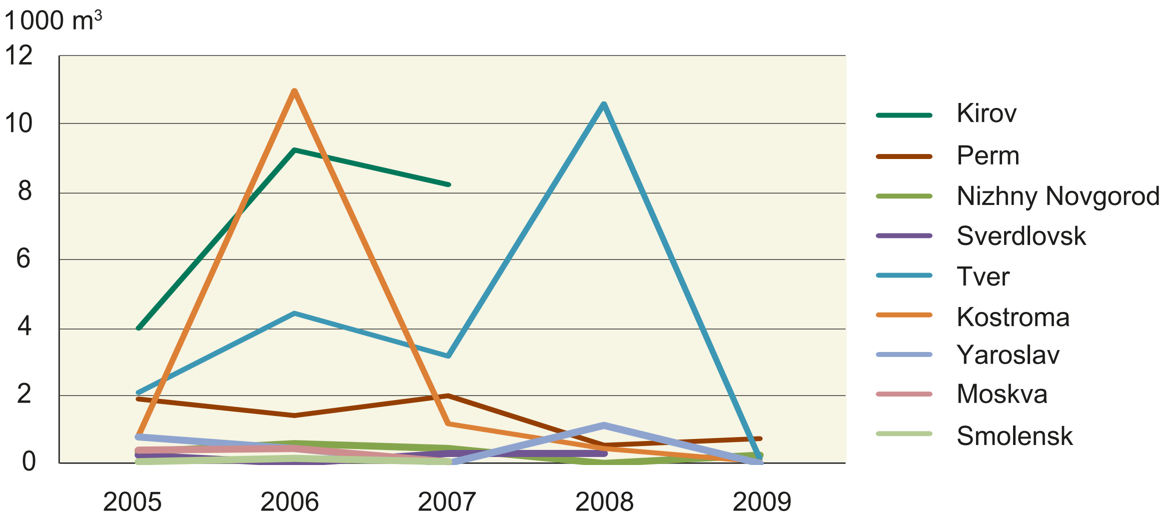


Figure 2.7. Export volumes according to Russian regions.

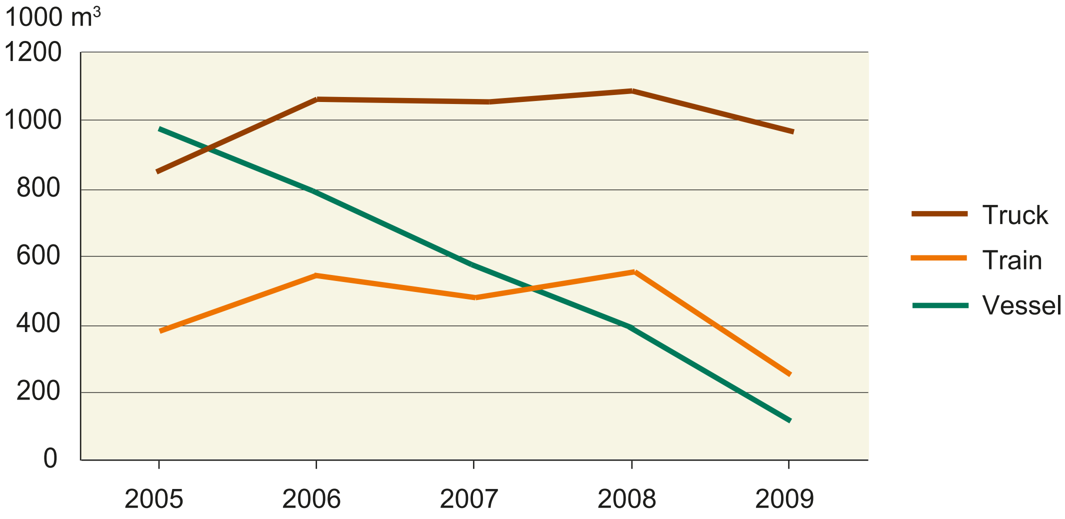


Figure 2.8. Mean of transport.

Border crossing points and coastal harbours

Wood import has been concentrated in the international border crossing points at Nuijamaa, Imatra, Vaalimaa, Vainikkala, and Niirala in Southeast Finland. Imports through the Vartius border crossing points increase during 2008 and 2009, while in Kuusamo the volumes decrease during the last three years. This is mainly due to different kinds of development within companies located in nearby Russian regions. The development in Kuusamo was also affected by the closure of a pulp mill in Kemijärvi. At the northern border crossing points – Salla and Raja-Jooseppi – volumes remained quite small but steady during the period (Figure 2.9).

Temporary border crossing points at Parikkala, Inari (in Lieksa), and Ruhovaara seem to be the busiest ones (Figure 2.10). The decrease, seasonality, fluctuation between years, and even total ending of imports has created pressure to cut down functions in the smallest border crossing points. Coniferous wood shipments have mainly concentrated on the ports of Kotka, Rauma, Hamina, and Kemi, that is, ports (Kotka and Hamina) with good transport connections to inland forest industry concentrations or next to raw material consuming paper mills (Rauma and Kemi) (Figure 2.11).

Discussion

Threats and uncertainty in the forest industry for the future of coniferous wood imports caused by phytosanitary certificates and physical checking did not seem to be realised. This is mainly because of more powerful changes in the operational environment. The current study shows that while the import volumes of coniferous timber have decreased, the export duty for coniferous roundwood has diverted the import from roundwood to processed wood and by-products and even to wood residue. Woodchips, sawdust, and different kinds of wood residue are usable raw material for the forest industry and they have replaced more expensive roundwood as a raw material.

In Finland the import of coniferous timber has been taken care of by large-scale forest industry enterprises, with the exception of 2009, when companies were obliged to adapt their operations to changing operational environments in Russia and to a larger extent in global markets. At this point imports decreased. In Russia, large-scale enterprises have started to take care of forestry

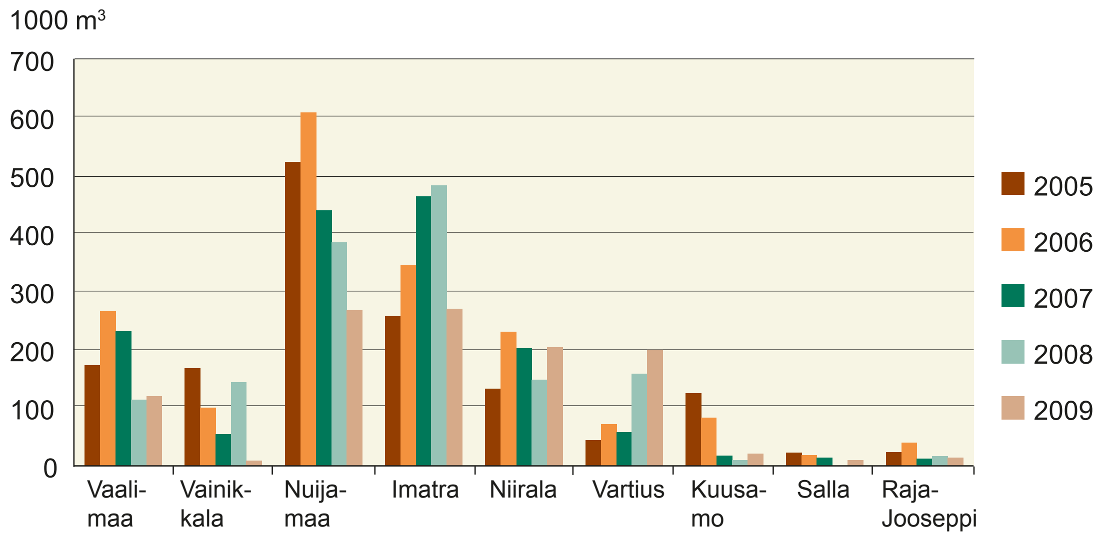


Figure 2.9. Coniferous wood transport through international border crossing points.

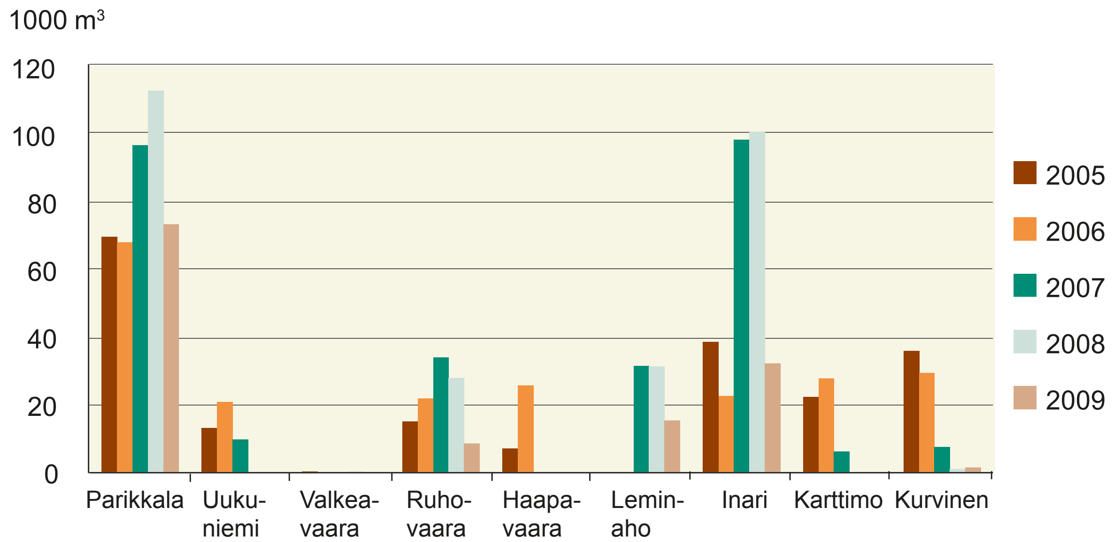


Figure 2.10. Coniferous wood transport through temporary border crossing points.

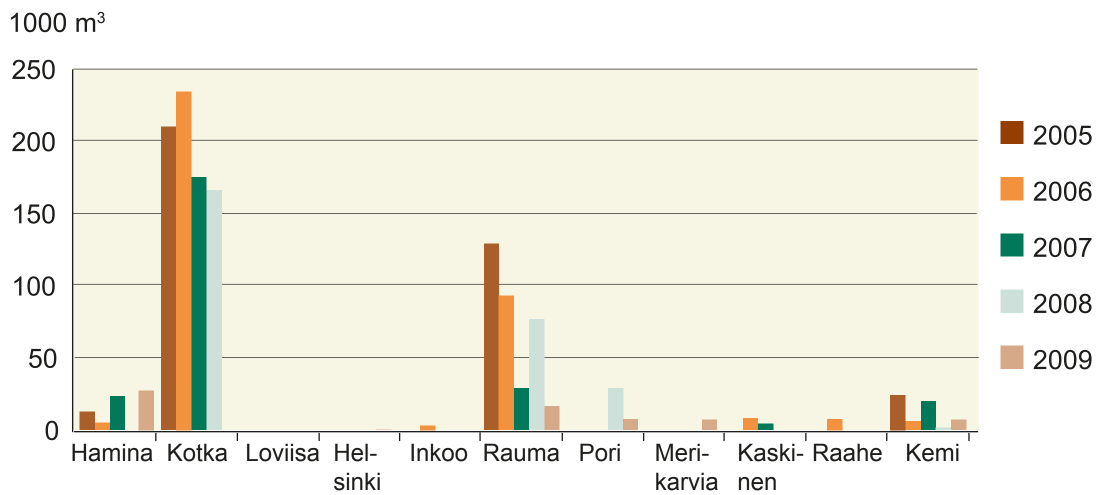


Figure 2.11. Coniferous wood shipment through coastal ports.

operations, and small and middle-sized enterprises, in particular, have descended into trouble. Even if the number of Russian exports has decreased substantially during the last years, their amount is still bigger than the amount of Finnish imports, because imports have been more clustered.

Although Northwest Russia has been the predominant wood procurement area for the Finnish forest industry, increasing import costs have directed wood procurement even closer to the Northwest district and, within it, next to the Finnish-Russian border. This probably explains the domination of truck transportation, smaller volumes of train use, and decreasing volumes of vessel transportation during the study period.

International border crossing points have been the dominant coniferous timber import locations from Russia to Finland. Temporary border crossing points have evened out the stream of coniferous goods and have relieved the load on international border crossing points. Without the temporary border crossing points, import from cross-border areas would have been economically unprofitable because of long transport distances and more expensive transport costs.

References

Elintarviketurvallisuusvirasto Evira, kasvinsuojeluyksikkö 2007. Kasvinsuojeluyksikön valvontaraportti 2006. Osa I b. Tuontipuutavara Venäjältä. 3.4.2007. Dnro 2622/504/2007. 10 s. + liitteet.

Elintarviketurvallisuusvirasto Evira 2007. Ohjeita venäläisen havupuutavaran maahantuojalle. Tuontivaatimukset ja maahantuojan velvollisuudet. Evira, kasvinsuojeluyksikkö, Helsinki 2007. 11 s. + liitteet.

Elintarviketurvallisuusvirasto Evira, kasvinsuojeluyksikkö 2008. Kasvinsuojelun valvontaraportti vuodelta 2007. Osa I b, Venäjän tuontipuu. 31.3.2008. Dnro 2327/504/2008. 9 s.

Elintarviketurvallisuusvirasto Evira 2009. Kasvinterveysyksikön valvontaraportti 2008. Osa I Kasvinterveys ja taimiaineisto. 31.3.2009. Dnro 2196/0411/2009. 21 s. + liitteet.

Elintarviketurvallisuusvirasto Evira 2010. Kasvinterveysyksikön valvontaraportti 2009. Osa I Kasvinterveys ja taimiaineisto. 30.3.2010. Dnro 1480/0411/2010. 19 s. + liitteet.

Forsman, P., Railavo, J., Rantala, A., & Simola, H. 2007. Venäjän raakapuun vientitullien korotusten kokonaistaloudelliset vaikutukset Suomessa. BoF Online. 2007. No 14. [Verkkodokumentti]. Saatavissa: http://www.suomenpankki.fi/fi/julkaisut/selvitykset_ja_raportit/bof_online/Documents/BoF_Online_14_2007_Forsman-Railavo-Rantala-Simola.pdf

Gerasimov, Y. & Karjalainen, T. 2009. Estimation of supply and delivery cost of energy wood from Northwest Russia. Metla working papers 123. http://www.metla.fi/julkaisut/workingpapers/2009/mwp123.htm

Gerasimov, Y., Karvinen, S. & Leinonen, T. 2009. Atlas of the forest sector in Northwest Russia. Metla working papers 131 http://www.metla.fi/julkaisut/workingpapers/2009/mwp131.htm

Gerasimov, Y. & Karjalainen, T. 2006. Development of wood procurement in Northwest Russia: roundwood balance and unreported flows. European Journal of Forest Research, 125: 189-199.

Helsingin Sanomat 21.7.2009. Venäjä haluaa ajaa alas tilapäiset rajanylityspaikat. [Verkkodokumentti]. Saatavissa: http://www.hs.fi/kotimaa/artikkeli/Ven%C3%A4j%C3%A4+haluaa+ajaa+alas+tilap%C3%A4iset+rajanylityspaikat/1135247820959 .

Holopainen, P., Ollonqvist, P. & Viitanen, J. 2006. Factors affecting investments in Northwest Russian forest sector and industry. Metla working papers 32. http://www.metla.fi/julkaisut/workingpapers/2006/mwp032.htm

Jutila, L. 2009. Suomen ja Venäjän välisen metsäsektorin kaupan rakenne ja kehitys vuosina 1997–2007. Metlan työraportteja 140. http://www.metla.fi/julkaisut/workingpapers/2009/mwp140.htm

Lasse, J. 2010. Metsäpolitiikan vaikutus metsävarojen käyttöön ja metsäteollisuuden investointeihin Venäjällä. Metlan työraportteja 162. http://www.metla.fi/julkaisut/workingpapers/2010/mwp162.htm

Jutila, L., Karvinen, S., Leinonen, T. & Välkky, E. 2010. Venäjän tullipolitiikan vaikutuksista Suomen ja Venäjän väliseen metsäsektorin kauppaan. Metlan työraportteja 155. http://www.metla.fi/julkaisut/workingpapers/2010/mwp155.htm

Kasvintuotannon tarkastuskeskus, kasvinsuojeluosasto 2006. Valvontaraportti 2005. Osa I b. Tuontipuun tarkastusyksikkö/ tuontipuutavara Venäjältä 27.3.2006. Dnro 3/406/2006. 10 s.

Karjalainen, T., Ollonqvist, P., Saastamoinen, O. & Viitanen, J. (toim.). 2007. Kohti edistyvää metsäsektoria Luoteis-Venäjällä – tutkimushankkeen loppuraportti. Metlan työraportteja 62. http://www.metla.fi/julkaisut/workingpapers/2007/mwp062.htm

Komission direktiivi (2004/102/EY) kasveille ja kasvituotteille haitallisten organismien yhteisöön kulkeutumisen ja siellä leviämisen estämiseen liittyvistä suojatoimenpiteistä annetun neuvoston direktiivin 2000/29/EY liiteiden II, III, IV ja V muuttamisesta. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:309:0009:0025:FI:PDF

Kriisivalmiussuunnitelma: Mäntyankeroinen. 2006. KTTK:n kasvinsuojeluosasto. [Verkkodokumentti]. Saatavissa: http://www.evira.fi/attachments/kasvintuotanto_ja_rehut/kasvintarkastus/ajankohtaista/kriisivalmiussuunnitelma_mantyankeroinen.pdf. 36 s.

The Finnish Statistical Yearbook of Forestry 2010. Metsäntutkimuslaitos.Vammalan kirjapaino Oy, Sastamala 2010. 472 s.

Metsäntutkimuslaitos. Idän metsätieto-palvelu. Puukauppa. Puuntuonti. Puun tuonti Venäjältä 1997 – 2003. [Verkkodokumentti]. Saatavissa: http://www.idanmetsatieto.info/fi/cfmldocs/?ID=509 .

Mutanen, A. & Toppinen, A. 2007. Price dynamics in the Russian-Finnish roundwood trade. Scandinavian Journal of Forest Research, 22: 71-80.

Mäntyankeroinen ei sovi kauppapolitiikan välineeksi. Artikkeli Maaseudun tulevaisuudessa 13.2.1997.

Ohjeita venäläisen havupuutavaran maahantuojalle. Tuontivaatimukset ja maahantuojan velvollisuudet. Eviran ohje 14405/2. Kasvinterveysyksikkö 12.4.2010. 18 s.

Pirhonen, I., Ollonqvist, P., Viitanen, J., Toropainen, M. & Bungov, V. 2008. Income and employment effects of change of roundwood use in Eastern Finland and the Republic of Karelia. Metla working papers 70. http://www.metla.fi/julkaisut/workingpapers/2008/mwp070.htm

Puun tuonti Venäjältä kallistunut – yksityiset venäläisfirmat rahastavat terveystodistuksilla. www.suomeneurooppaliike.fi/eurometri/2eurometri2005/sivu22.pdf

Skarpaas, O. & Økland, B. 2009. Timber import and the risk of forest pest introduction. Journal of Applied Ecology, 46: 55–63.

Suomen ja Venäjän välillä on nyt kuusi tilapäistä rajanylityspaikkaa. Rajavartiolaitoksen tiedote 01.12.2010. http://www.raja.fi/rvl/bulletin.nsf/PFBD/C5EEB6F067C391F1C22577EC004CB0CE?opendocument

Tomminen, J. & Nuorteva, M. 1987. Mäntyankeroinen. Helsingin yliopisto. Maatalous- ja metsäeläintieteenlaitos. Julkaisuja 11. 18 s.

Tuontipuun terveystarkastukset alkoivat. Karjalan Maa, 22.3.2005, nro 33. http//karjalanmaa.fi/tarkennus.php?lehti=613&id=3260

Valtioneuvoston asetus rajanylityspaikoista sekä rajatarkastustehtävien jakamisesta niillä. 652/2005. 25.8.2005. http://www.finlex.fi/fi/laki/alkup/2005/20050652

Viitanen, J. & Karvinen S. 2010. Review on Russian roundwood imports into Northern Europe 1993-2008. Working Papers of the Finnish Forest Research Institute 148. http://www.metla.fi/julkaisut/workingpapers/2010/mwp148.htm

2.2 Forest machinery market of the Northwest Russia

This chapter presents the most important findings of the study by Jutila et al. (2010) published in Finnish.

There is expected to be a remarkable growth in Russian forest machine markets in the long run, mainly because of a need for renewal of current logging machines and because of a huge cutting potential within Russian forests. The development of sharing among different logging methods, such as cut-to-length (CTL), full-tree (FT), and tree length (TL) is going to have a significant influence on the division between market shares in Russian forest machine markets.

The machine-based CTL method became general in nearby regions along the Finnish border in the 1990s mainly because of Finnish entrepreneurs and forest machines from Finland arriving in the region. The CTL method has become even more common in the 2000s, together with an increase in imports of harvesters and forwarders. The share of CTL methods has increased especially in Northwest Russia, and in the Republic of Karelia; more than 90% of the harvested wood is already logged with the CTL method. Domestic production of harvesters is quite low in Russia, whereas companies in Finland are major CTL machine producers in global markets.

Import duty on harvesters has been quite low (5%) in Russia. At the beginning of 2007 harvesters were freed from import duty, but at the end of 2009 they were restored to 5%. The import duty on forwarders has been higher (15%) than that of harvesters. At the beginning of 2009 import duty was raised to 25%, which is seen as a measure to protect domestic production. The aim was also to redirect foreign manufacturers to transfer part of their production to Russia.

Export of harvesters from Finland to Russia increased substantially during 2002–2008 (Figure 2.12). The development of export amounts on a monthly basis during 2002–2009 is shown in

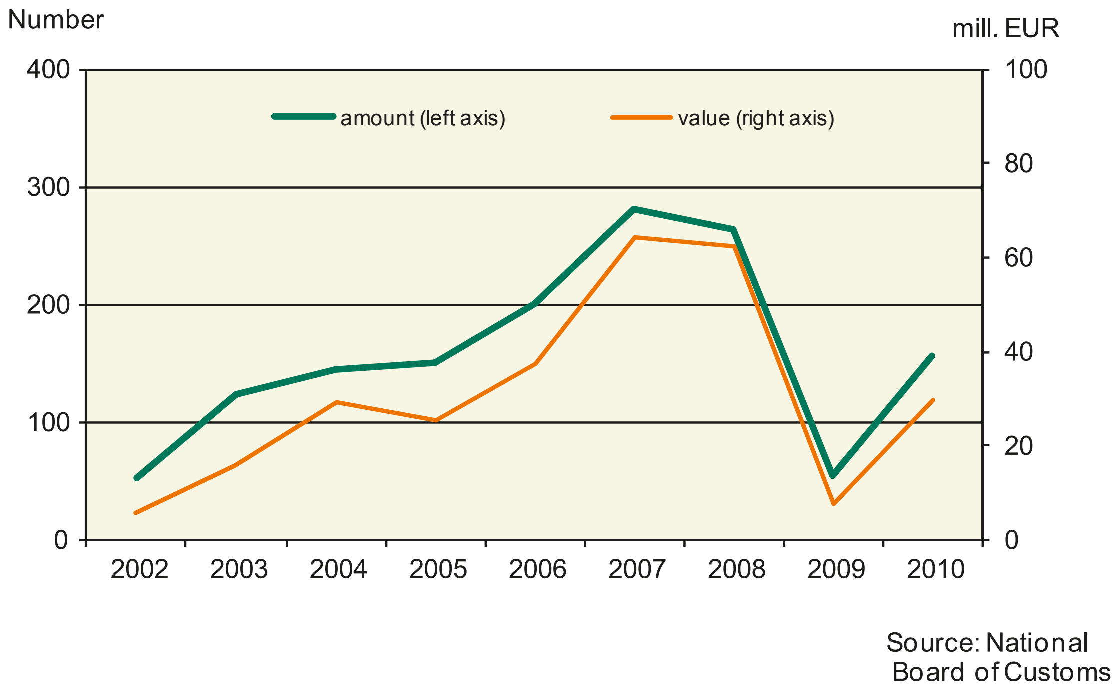


Figure 2.12. Export of harvesters from Finland to Russia during 2002–2010.

Figure 2.13. The record of over 50 exported harvesters to Russia in one month was achieved in November 2007. At the end of 2008 export amounts decreased sharply, and in the beginning of 2009 export ended almost totally.

The export of forwarders from Finland to Russia also increased substantially during 2002–2008 when measured in export value (Figure 2.14). The number of exported machines has remained constant, but export has focused on heavy machines (total weight over 20 t) instead of light ones (total weight under 20 t). According to statistics from Finnish Customs in 2009, the export of heavy machines decreased from 373 to 34 compared to the previous year. Within the group of light machines, exports decreased from 259 to 95 tractors. Export of harvesters and forwarders started to increase during 2010.

Figure 2.15 and Figure 2.16 show the development of the export of light (total weight 5–20 t) and heavy (total weight over 20 t) vehicles during 2002–2010. At the beginning of the period the export of light machines was bigger in amount than the export of heavy machines. Since 2004 the share of heavy machines has grown above the light ones. The share of new machines has also grown since 2004. Export of both groups decreased in the year 2008–2009, together with an increase in Russian import duties. The recovery of the export of small harvesters at the end of 2009 predicted temporary effects of the duty increase. Export of both vehicle groups remained small and steady in amount during 2010.

Reference

Jutila, L., Karvinen,S., Leinonen, T. & Välkky, E. 2010. Venäjän tullipolitiikan vaikutuksista Suomen ja Venäjän väliseen metsäsektorin kauppaan. Metlan työraportteja 155. http://www.metla.fi/julkaisut/workingpapers/2010/mwp155.htm

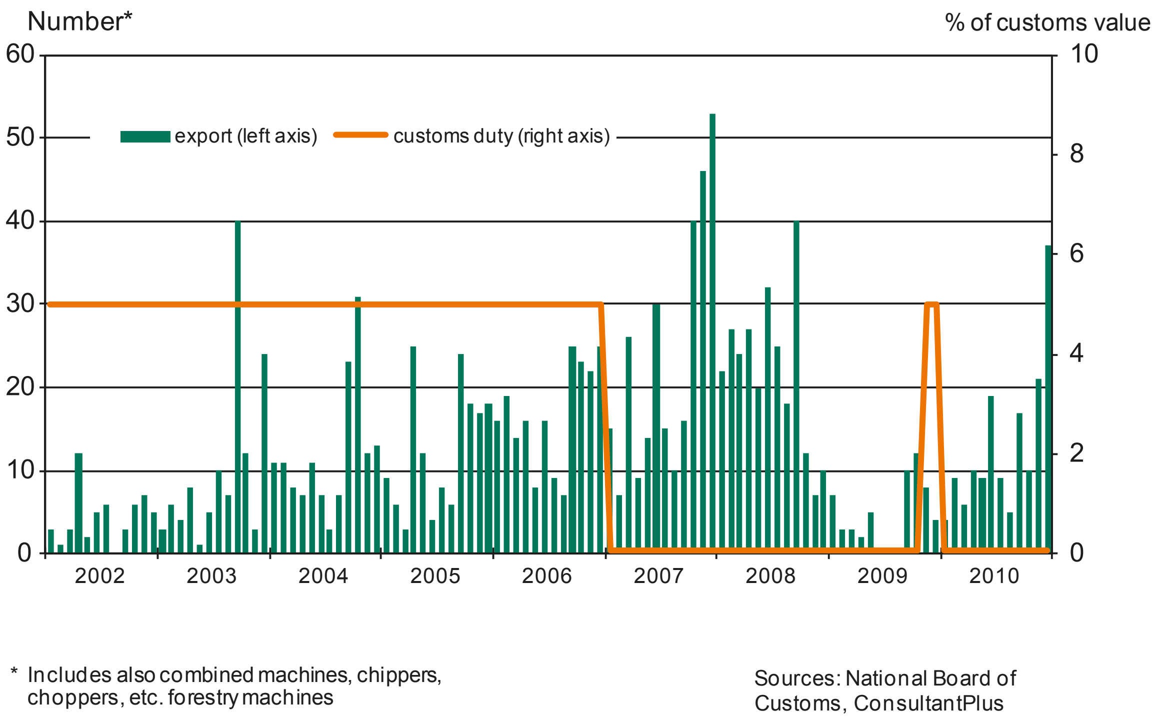


Figure 2.13. Monthly export of harvesters from Finland to Russia and Russian import duty during 2002–2010.

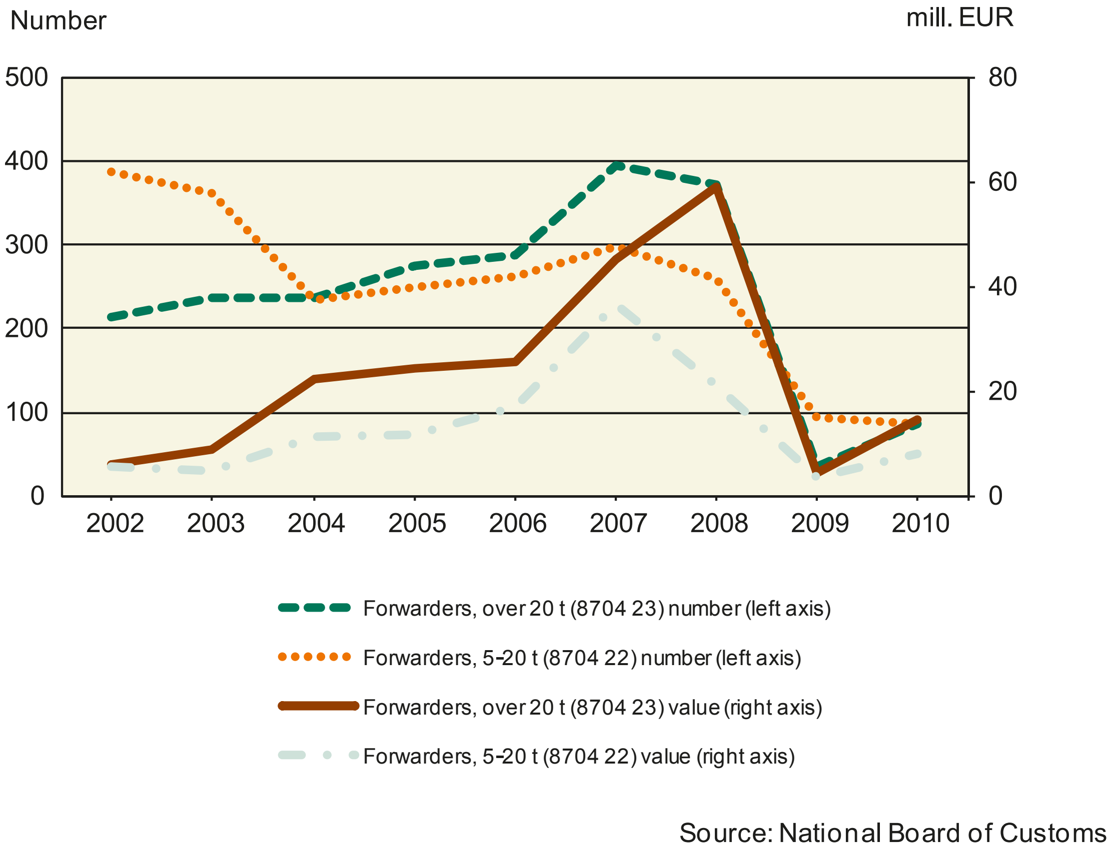


Figure 2.14. Export of forwarders from Finland to Russia during 2002–2010.

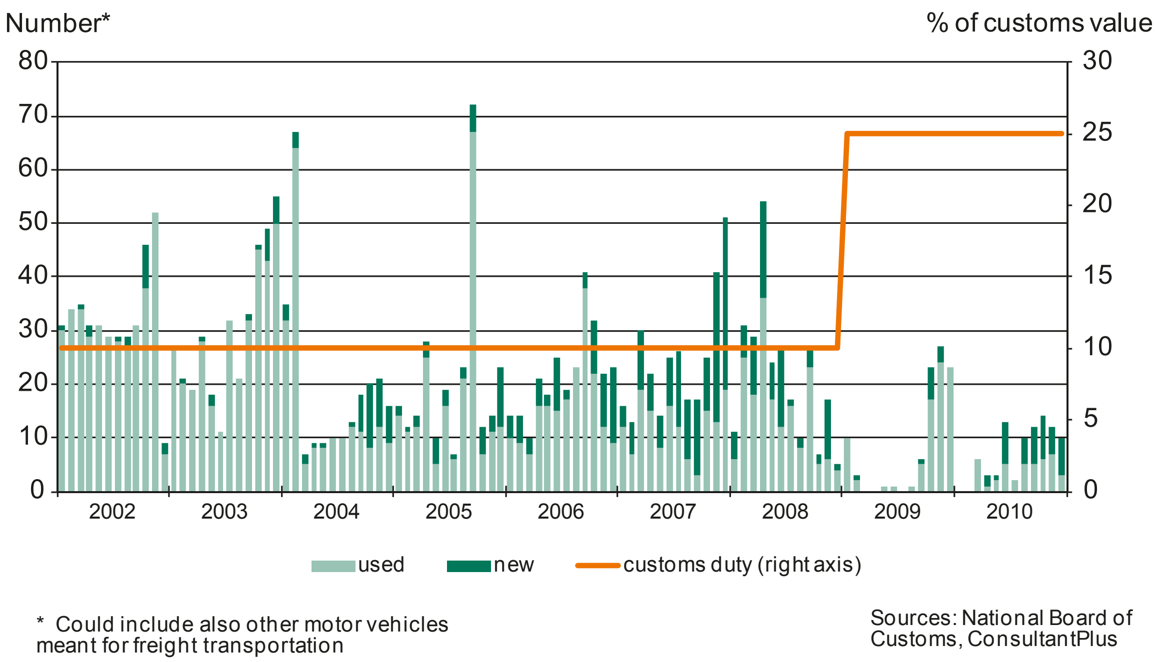


Figure 2.15. Monthly export of light vehicles (total weight under 20 t), including forwarders and trucks, from Finland to Russia and Russian import duty in 2002–2010.

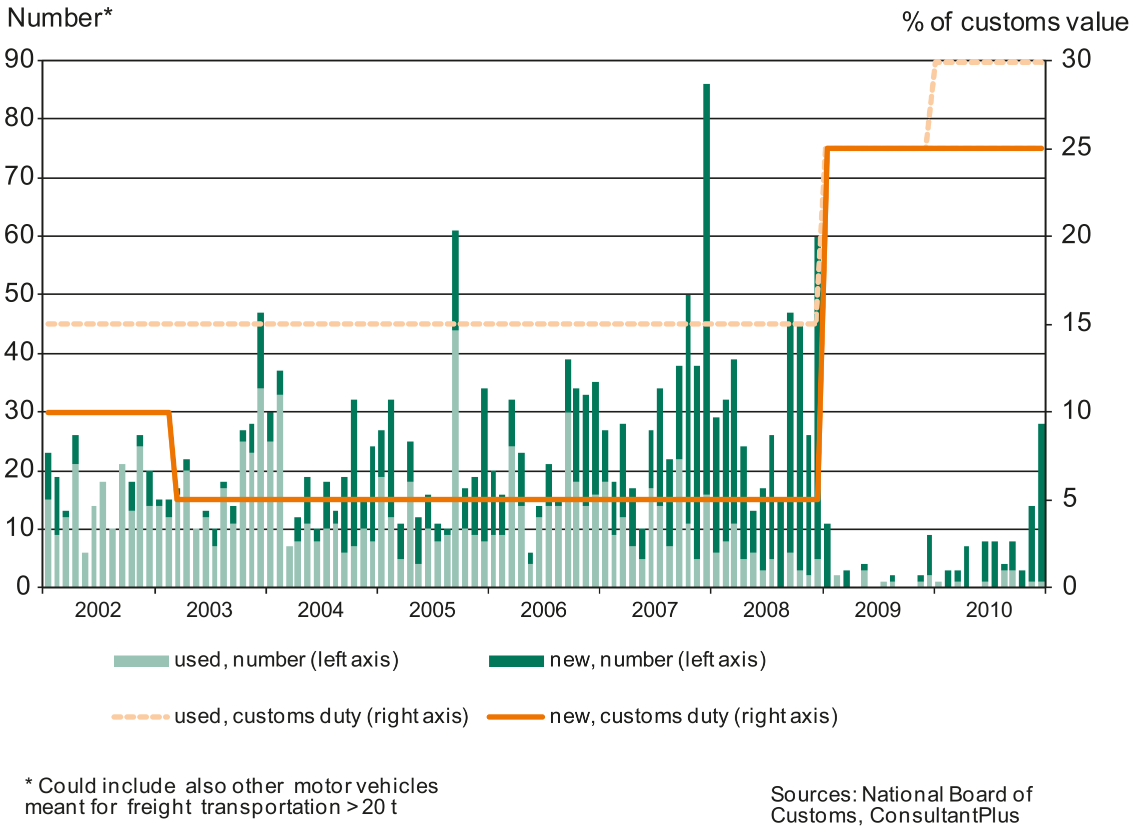


Figure 2.16. Monthly export of heavy vehicles (total weight over 20 t), including forwarders and trucks, from Finland to Russia and Russian import duty in 2002–2010.

2.3 Energy wood resources of Northwest Russia and their delivery costs at the Finnish-Russian border

Introduction

This chapter presents the results of the study described by Gerasimov and Karjalainen (2009 and 2009a).

Russia is the world's biggest producer and exporter of energy, but a major disadvantage is that vast fossil-fuel resources are in Siberia, far from population, industry and export markets. In addition, Northwest Russia uses significant amounts of fossil energy: 19.7 Mtoe of natural gas, 10.8 Mtoe of oil, 1.4 Mtoe of coal, altogether 31.9 Mtoe or 364 TWh (Russia Energy Survey 2002). There is a risk of being too dependent on high fossil-fuel prices and high transport costs from Siberia. In addition, emissions from burning fossil fuels are a major source of greenhouse gas emissions, and thus a significant contributor to global warming. Reduction of greenhouse gas emissions is an essential national and international goal to meet the commitments on mitigating climate change (IPCC 2007). Efficient use of energy wood as a renewable energy resource could help to replace non-renewable and imported energy sources.

The use of fossil fuels dominates the energy consumption in Northwest Russia (Arabkin 2003), while renewables and wood have a minor role:

- natural gas – about 44%
- liquid and fossil fuels – about 36%
- nuclear and hydropower – about 18%
- wood and other sources – about 2%.

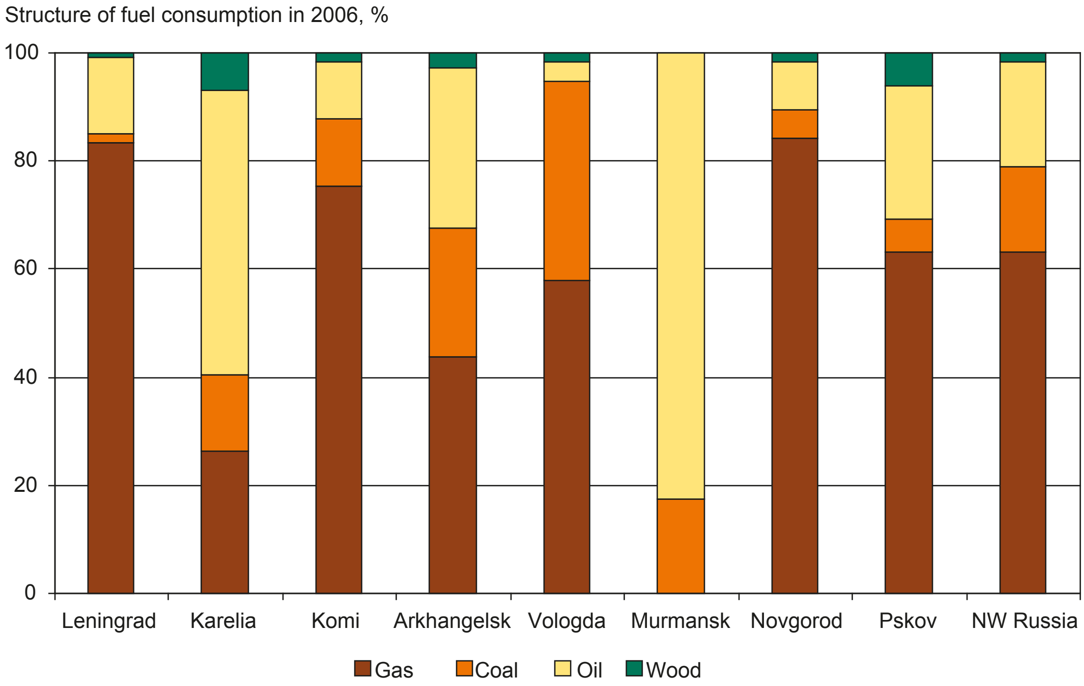


Figure 2.17 Fuel consumption in Northwest Russia, share of the total consumption in 2006.

Currently, wood provides a visible energy supply only in the Karelia and Pskov regions, as shown in Figure 2.17 (Grigoryev 2007).

Almost all energy wood is converted by combustion to provide heat energy. The wood-processing industry is the major consumer of forest biomass, and the other significant users are residential wood burners/district heating plants.

Reasons often cited for the low use of wood by-products for energy are the availability of energy wood and their supplies, and the uncertainty concerning the cost of this supply.

The type and size of sawmills and plywood mills within the study area have an impact on the by-products available for bioenergy. The conversion efficiency from roundwood to different wood products varies. Many sawmills already use a large proportion of their by-products for heat. These by-products compete with energy wood and therefore have an opportunity cost associated with them if the by-products are utilized for bioenergy.

Objectives

The main objective of this study was to estimate the availability and delivery cost of energy wood from harvesting and mechanical wood processing in Northwest Russia.

Data and method for estimating the delivery costs of energy wood

The delivery cost for energy wood depends on the means of transport, transport distance to the bioenergy plant, state of the road network, distribution of forest resources, etc. Scattered geographical distribution of energy wood supply potential has raised interest in using the Geographical Information System (GIS) for analyses. GIS has been used in a number of studies for evaluating energy wood supply and estimation of delivery cost to the power plant (e.g. Nord-

Larsen and Talbot 2004; Voivontas et al. 2001). The GIS approach was applied in this study when estimating the cost of energy wood delivered to the border-crossing points in Finland for three different energy wood transport streams: by railway, by road and by waterway. As a result, cost supply curves for each of the three energy wood transport streams were created.

Results

The study area in Northwest Russia covers eight administrative regions: the Republics of Karelia and Komi, and the Arkhangelsk, Leningrad, Murmansk, Novgorod, Pskov and Vologda regions. There are altogether 200 forest units in the study area. Figure 2.18 shows the location of forest units, sawmills, plywood mills, and potential border-crossing points for energy wood export along the Finnish border. Altogether approximately 30.5 million m^3 of energy wood is available in the study area.

Energy wood supply

Energy wood supply was estimated for the two sources of energy wood: harvesting and mechanical wood processing. The distribution of potential energy wood from harvesting, sawmilling and plywood production in the Northwest Russian regions based on the actual production in 2006 (Gerasimov & Karjalainen 2009a) is presented by the type of by-products in Figure 2.19.

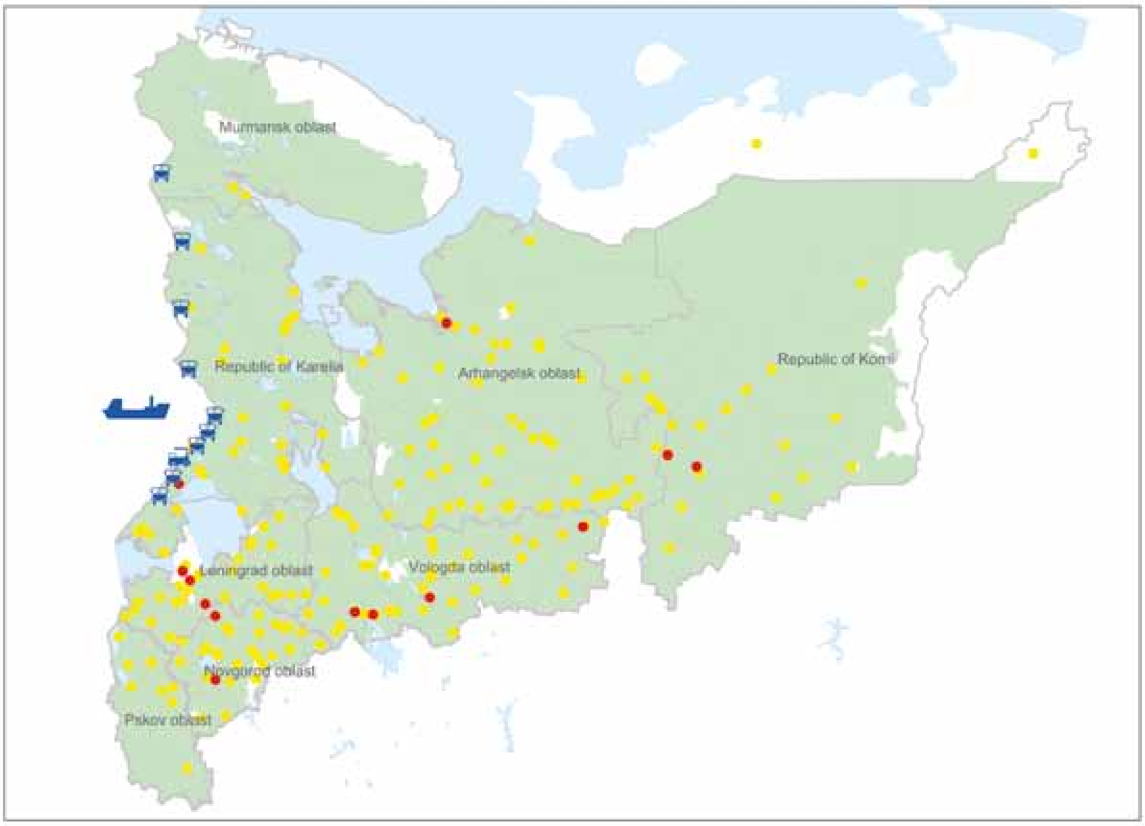


Figure 2.18. Location of the forest units (green), sawmills (yellow), plywood mills (red) and potential border-crossing points (blue).

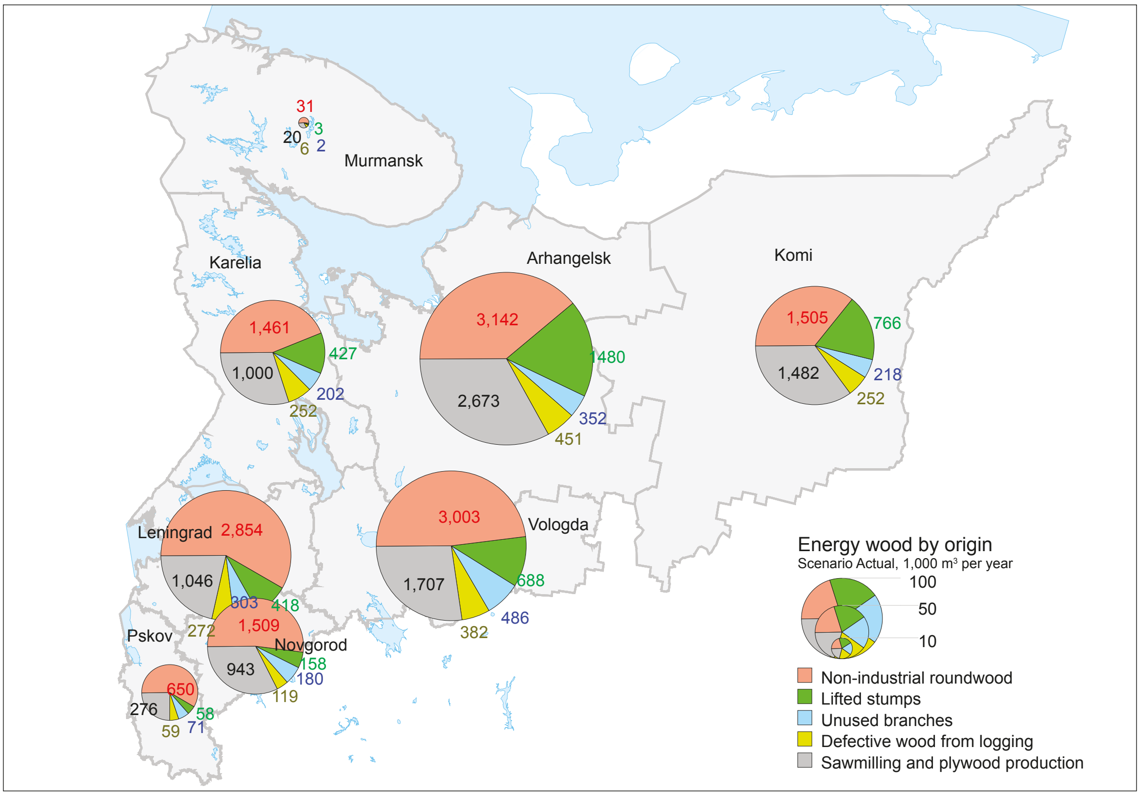


Figure 2.19 Distribution of potential energy wood from harvesting, sawmilling and plywood production in the Northwest Russian regions based on the actual production in 2006 presented by the type of by-products.

Energy wood supply from harvesting

Results from the harvesting survey indicated that the total amount of energy wood generated is about 20.5 million m^3/yr. This is presented for each region in Figure 2.20 by the distance to the border-crossing points, and variation in supply is due to logging capacity, tree species distribution, etc. About 65% of the energy wood is non-industrial roundwood, 16% logging residues and 19% spruce stumps.

Energy wood supply from mechanical wood processing

Results from the wood processing survey indicated that the total amount of energy wood generated is about 9.8 million m^3/yr. This is presented for each region in Figure 2.21 by the distance to the border-crossing points, and variation in supply is due to sawnwood and plywood production. There is a substantial volume of energy wood available from a distance of 1100–1200 km, and this is due to several big sawmills in the neighbourhood of the city of Arkhangelsk. About half of the residues are chips, 30% sawdust and 20% bark (Devyatkin 1999).

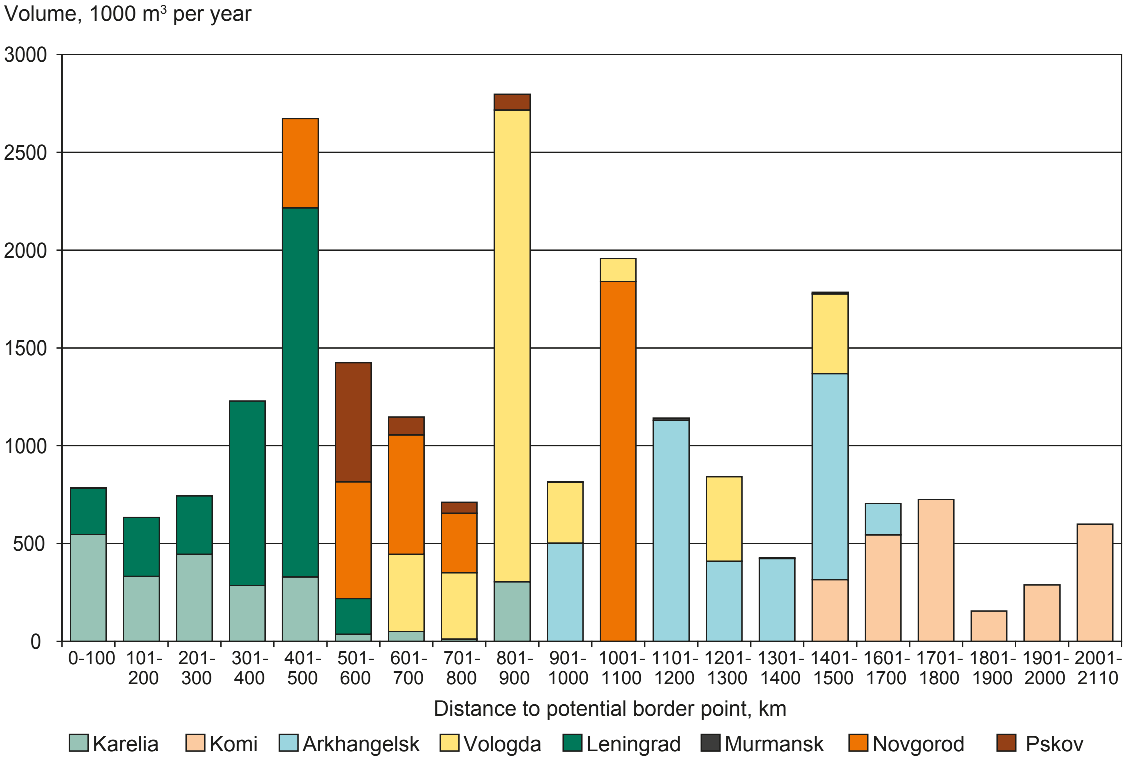


Figure 2.20 Energy wood supply from harvesting by transportation distance to the potential border-crossing point.

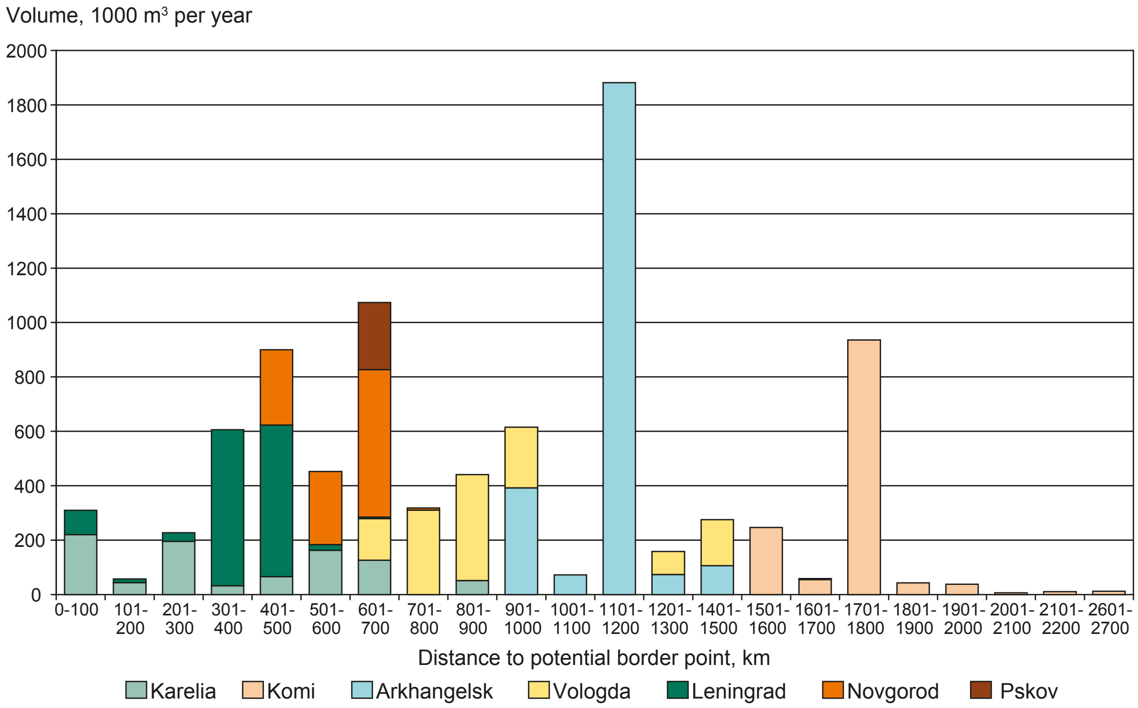


Figure 2.21 Energy wood supply from mechanical wood processing by transportation distance to the potential border-crossing point.

Delivery costs of the energy wood at the Finnish-Russian border

The delivery cost of the energy wood was estimated for each means of transportation, i.e., by railway, road and waterway (Table 2.2).

Table 2.2 Energy-wood supply by source and means of transport in 2006, 1 000 m^3.

Means of transport	Harvesting	Sawmills and plywood mills	Total
Railway	19 479	8 309	27 788
Road	268	1 339	1 607
Water	764	164	928
Total	20 511	9 812	30 323

Delivery costs of the energy wood from harvesting

The cost of energy wood by means of transport from each forest unit is calculated, and then a running average is estimated, from low cost to high cost, to provide the cumulative average delivery cost. The total amount of energy wood varies by year and delivery cost varies by border-crossing point. Estimated average delivery cost of the total energy wood supply varies from 15.8 to 57.5 €/m^3. This is presented for each means of transport, and variation in supply is due to location of the procurement site, i.e., transportation distance. The delivery cost for energy wood supply to the Värtsilä/Niirala border-crossing point by railway varies from 27.2 to 57.5 €/m^3, with the commutative average delivery cost shown in Figure 2.22. The delivery cost for energy wood

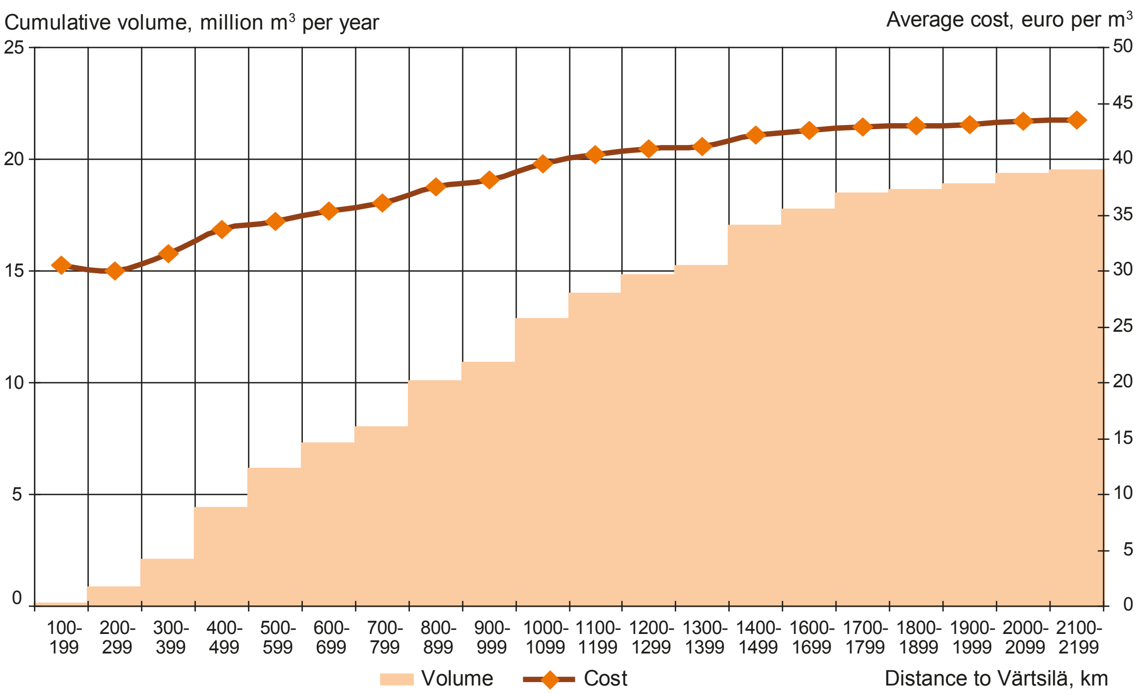


Figure 2.22 Cumulative average delivery cost for energy wood from harvesting to the Värtsilä /Niirala border-crossing point by railway (distance is to Värtsilä railway station on the Russian side).

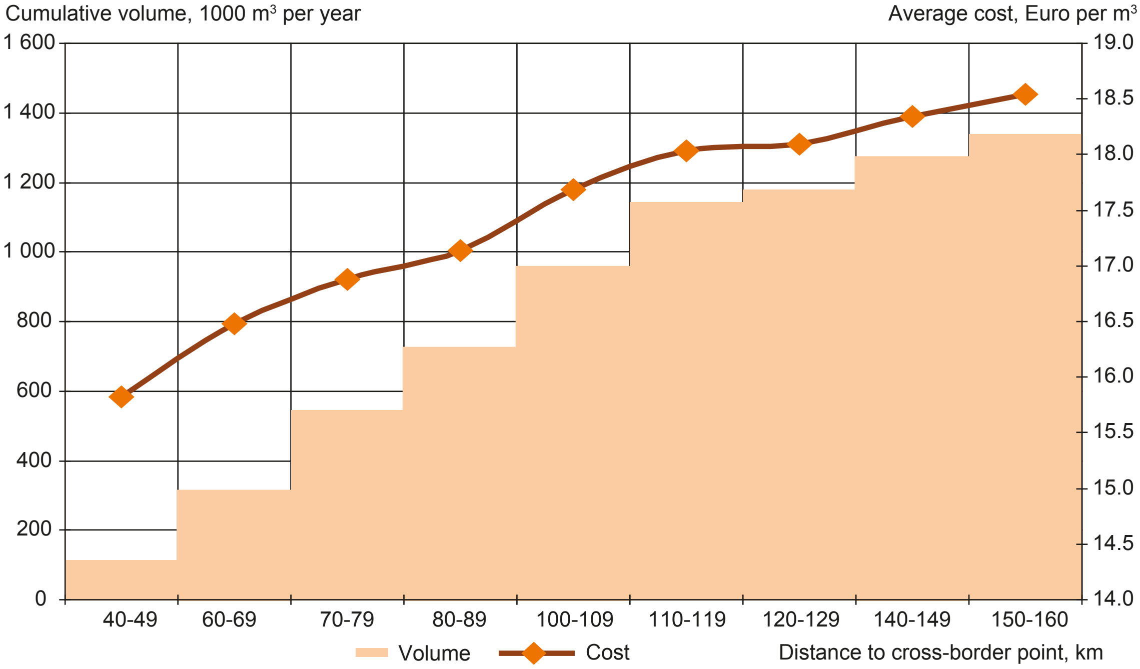


Figure 2.23 Cumulative average delivery cost for energy wood from harvesting to the border-crossing point by road. Note that x-axis is not linear.

supply by road to the border-crossing point varies from 15.8 to 22.2 €/m^3, with the commutative average delivery cost shown in Figure 2.23. The delivery cost for energy wood supply by waterway to the Lake Saimaa area varies from 45.0 to 47.9 €/m^3 from the Lake Onego area.

The cumulative average cost indicates the average cost for a particular amount of energy wood. For example, if a bioenergy power plant needs 5 million m^3 of energy wood, Figure 2.22 indicates that the average cost for this amount of energy wood is about 36 €/m^3 with a maximum distance of 532 km by railway.

The delivery cost of energy wood by means of transport varies, since means of transport have different profiles for the delivery cost. Figure 2.23 shows the average cost of energy wood collection/chipping at the cutting area and direct transport to the border-crossing points. Delivery of chips by road directly to the border-crossing points was the cheapest option to deliver energy wood. Figure 2.22 shows the average cost of energy wood collection/chipping at the cutting area, road transport to the terminal at the railway station and the cost of railway transport to the border-crossing point. The collection/chipping and the opportunity cost is the same for each means of transporting energy wood, but the transport costs vary with the location of the cutting area, i.e., transportation distance to the terminal at the railway station and transportation distance to the border-crossing point.

Delivery costs of the energy wood from mechanical wood processing

The delivery cost of energy wood by means of transport from sawmills and plywood mills is first calculated, and then a running average is estimated, from low cost to high cost, to provide the cumulative average delivery cost. The total amount of energy wood varies by year, and the delivery cost varies by the border-crossing points. The estimated average delivery cost of the total energy-wood supply varies from 9.6 to 47.3 €/m^3. This is presented for each means of transport (Figure 2.24 and Figure 2.25), and variation in supply is due to production of the mills.

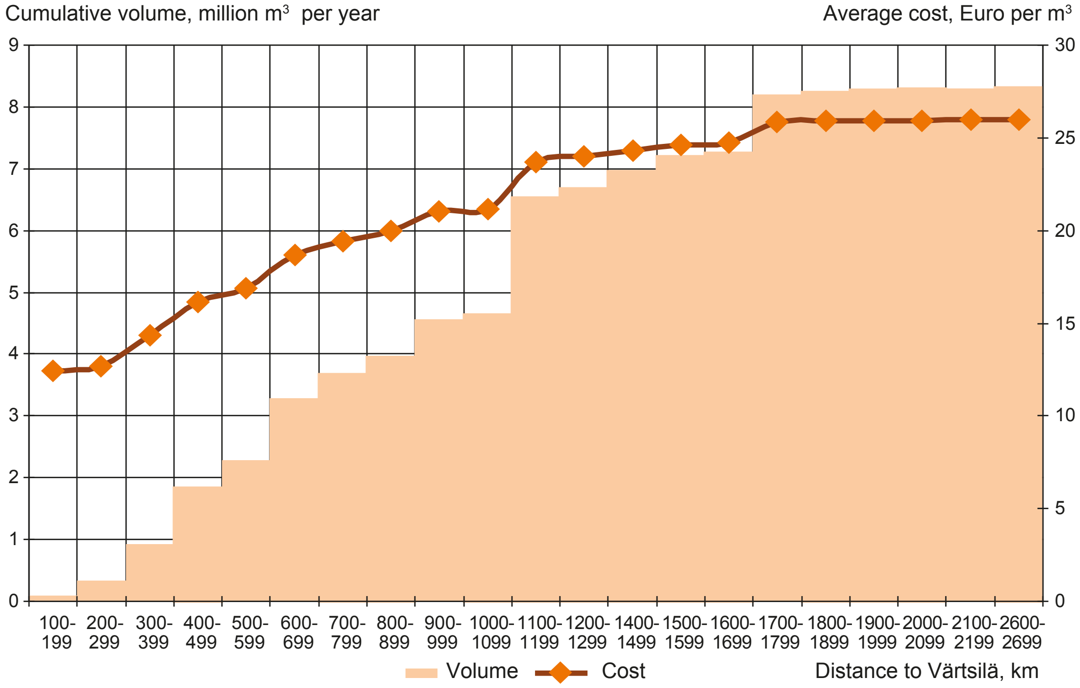


Figure 2.24 Cumulative average delivery cost for energy wood from saw and plywood mills to the Värtsilä/Niirala border-crossing point by railway. Note that x-axis is not linear.

The delivery cost of energy wood to the Värtsilä/Niirala border-crossing point by railway varies from 11.7 to 47.3 €/m^3, with the commutative average delivery costs shown in Figure 2.24. The delivery cost of energy wood to the border-crossing point by road varies from 9.6 to 15.4 €/m^3, with the commutative average delivery costs shown in Figure 2.25. The delivery cost of energy wood by waterway to the Lake Saimaa area is around 28 €/m^3 from the Lake Onego area.

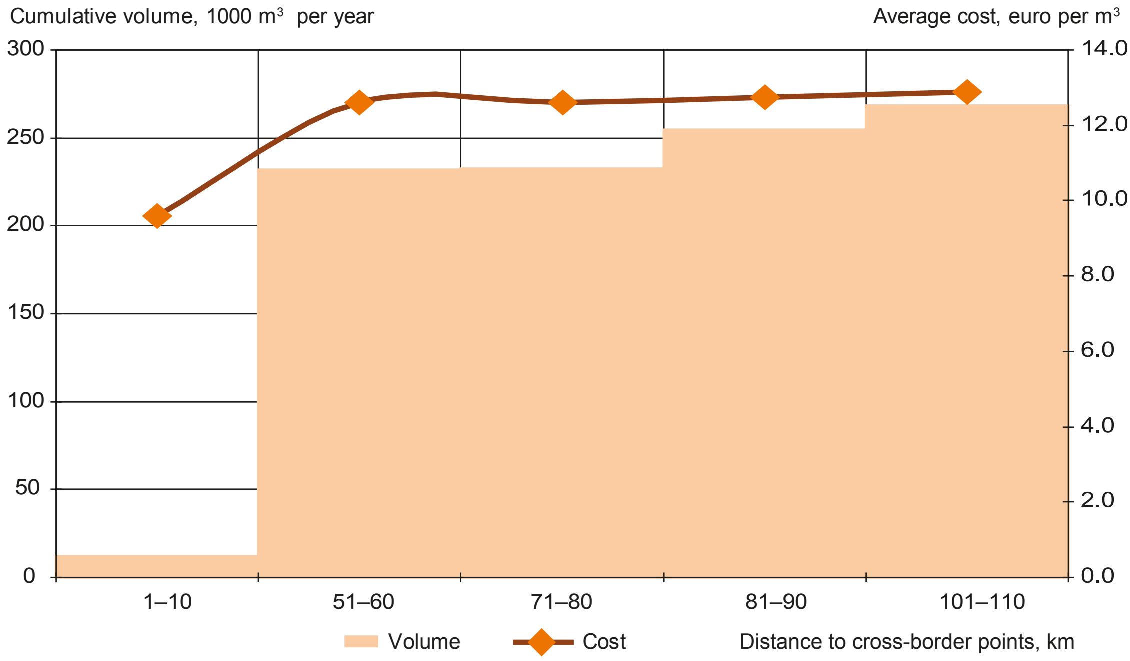


Figure 2.25 Cumulative average delivery cost for energy wood from saw and plywood mills to the border-crossing point by road. Note that x-axis is not linear.

The cumulative average delivery cost indicates the average cost for a particular amount of energy wood from saw and plywood mills. For example, if the potential bioenergy power plant needs 4 million m^3 of energy wood, Figure 2.24 shows that the average cost for this amount of energy wood is about 20 €/m^3 with a maximum distance of 900 km by railway.

The delivery cost of energy wood by means of transport varies. Each means of transport of energy wood has a different profile for the delivery cost. Figure 2.25 shows the average cost of collection/chipping at the mills, road transport to the terminal at the railway station if necessary and the cost of railway transport to the border-crossing point. Delivery of chips by road to the border- crossing points was the cheapest option to deliver energy wood. Figure 2.24 shows the average cost of collection/chipping at the mills, road transport to the terminal at the railway station if necessary and the cost of railway transport to the border-crossing point. Also, for this source of energy wood the chipping and opportunity costs were the same for each means of transporting energy wood, but the transport costs vary due to the location of the mill, i.e., transport distance to the border-crossing point.

Conclusions

The main purpose of this study was to estimate the availability (gross supply possibility) and delivery costs of energy wood from harvesting and mechanical wood processing in Northwest Russia. A developed model provided a framework for estimating the delivery cost of energy wood available for potential bioenergy plants in Finland, and how the cost of collection/chipping, opportunity costs and transport costs vary. It should be emphasized that we have estimated supply and delivery costs, not prices which are defined at the market, based on supply and demand.

Several assumptions had to be made, mainly due of lack of data, but more detailed studies and analyses could provide better results:

- The annual average transport distance from the cutting area to the terminal at the railway station provided by logging companies and forest districts was used. A better option would be to include company data at stand level for all forests, but in some cases this may not be possible.
- The cost of transporting energy wood is based on data received from a logging company in 2007–2008. Changes in fuel prices and other costs influence the supply and delivery costs.
- The same transport cost per kilometre regardless of the type of road surface was applied. In practice, the cost may vary with road surface.
- Collection and chipping cost. The available data relate to particular systems used in the Republic of Karelia and the Leningrad region. More research is required to ascertain these costs and if these costs can be reduced.
- There is no published data for the opportunity costs associated with sawdust, bark and chips. The data used was very good for the particular regions of interest, as they were based on real local information, but they may not be applicable to other regions, thus region-specific information on the opportunity costs would be necessary.

The energy-wood supply possibilities and delivery costs for the eight regions of Northwest Russia were assessed. By-products from harvesting and mechanical wood processing were considered for energy production based on actual harvesting, sawmill and plywood production in 2006 and were estimated at 30.7 million m^3. Nearly 30.5 million m^3 of the energy wood could be transported, and the rest of the energy wood was inaccessible due to the lack of a road infrastructure in the Republic of Komi and the Arkhangelsk region. About 70% of the energy wood was from harvesting, i.e., non-industrial roundwood, unused branches and tops, defective wood resulting from logging, spruce stumps removed after final felling, and 30% from sawmills and plywood mills, i.e., chips, sawdust and bark. The delivery cost of energy wood to the potential border-crossing points in Finland was analyzed for three means of transport. The delivery cost of energy wood to the Värtsilä/Niirala border-crossing point by railway varied from 28.9 to 43.5 €/m^3. The estimated volume was 27.8 million m^3, and the maximum distance was 2110 km to the border station. The cheapest option to deliver energy wood to the border-crossing point was by road. The delivery cost of energy wood by road varied from 15.8 to 18.5 €/m^3. However, the volume was limited to a 200-km belt along the border between Russia and Finland and was 1.6 million m^3. The most expensive means to deliver energy wood to the Lake Saimaa area was by waterway. The delivery cost of energy wood by waterway varied from 45.0 to 47.9 €/m^3. The volume was estimated at 0.8 million m^3 from remote areas without feasible access to a railway in the Lake Onego area.

Results of this study could/may be used by those who are planning delivery of energy wood from Northwest Russia to Finland. The developed model, however, could/may be applied for planning of energy wood delivery in Russia and also to other export destinations than Finland. This was a preliminary study and a more thorough study should be carried out for practical applications.

References

Arabkin, V. 2003. Жизнь за счет ресурсов [Life at the expense of resources]. Expert Northwest Russia 19 (128). (In Russian). Available at: http://www.expert.ru/printissues/northwest/2003/19/19no-seco2/

Devyatkin, V. (ed.-in-chief). 1999. Сборник удельных показателей образования отходов производства и потребления [Collection of waste generation indexes in production and consumption]. Moscow. State Committee of Russian Federation for Environment. 65 p. (In Russian).

Gerasimov, Y., and T. Karjalainen. 2009. "Estimation of supply and delivery cost of energy wood from Northwest Russia". Working Papers of the Finnish Forest Research Institute 123. 21 p. Available at: http://www.metla.fi/julkaisut/workingpapers/2009/mwp123.htm.

Gerasimov, Y. & Karjalainen, T. 2009a. Assessment of energy wood resources in Northwest Russia. Working Papers of the Finnish Forest Research Institute 108. 52 p.

Grigoryev, M. 2007. Повышение роли местных топливно-энергетических ресурсов в обеспечении энергетической безопасности Северо-Запада России [Increasing of the role of domestic fuel-energy resources for energy security in Northwest Russia]. Gas Business, July-August 2007: 28–34. (In Russian).

IPCC 2007. Climate change 2007. Mitigation of climate change. Working group III contribution to the fourth assessment report of the Intergovernmental Panel on Climate Change. [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA., 851 pp.

Nord-Larsen, T. & Talbot, B. 2004. Assessment of forest-fuel resources in Denmark: technical and economic availability. Biomass and Bioenergy 27: 97–109.

Russia Energy Survey. 2002. International Energy Agency, Paris; 2002. 278 p.

Tolonen, T. & Koponen, M. 2011. Havupuun tuonti Venäjältä Suomeen ja tuontihavupuun kasvinterveys-tarkastukset vuosina 2005–2009 [Import of coniferous roundwood into Finland from Russia and phytosanitary inspections during 2005–2009] . Working Papers of the Finnish Forest Research Institute 197. 32 p. (In Finnish). Available at: http://www.metla.fi/julkaisut/workingpapers/2011/mwp197.htm.

Voivontas, D., Assimacopoulos, D. & Koukios, E.G. 2001. Assessment of biomass potential for power production: a GIS based method. Biomass and Bioenergy 20: 101–112.

3 Industrial and energy wood harvesting

3.1 Productivity and costs

3.1.1 Productivity of harvesters in clear cuttings in the northern European part of Russia

Introduction

This chapter presents the results of the field study by Gerasimov, Senkin, and Väätäinen (2011). The fully mechanised cut-to-length (CTL) wood harvesting system based on a single-grip harvester has become widely used by the forest industry in temperate and boreal forests, particularly Nordic countries. Today, almost 100% of loggings in Sweden and Finland are carried out by the harvester-forwarder system (Statistical Yearbook 2009; Asikainen et al. 2009). Many developments have also been made towards CTL and its mechanisation in Russia over the past decade, particularly in the northern European part of Russia (NEPR). The CTL harvesting system reduces labour needs, work safety risks, environmental damage, and landing areas compared with the traditional tree-length and full-tree (FT) systems (Gellerstedt and Dahlin 1999). In fact, a fully mechanised FT harvesting system based on a feller-buncher, a skidder, and a delimber or processor is still more productive than is the CTL one based on a single-grip harvester and forwarder mainly because specific tasks are assigned to each machine (Gingras 1994; Yaoxiang et al. 2006; Adebayo et al. 2007; Syunev et al. 2009). According to previous studies, the costs of CTL harvesting are around 8% to 33% more expensive than FT harvesting (Gingras 1994; Yaoxiang et al. 2006; Adebayo et al. 2007). However, the higher productivity of the FT harvesting system does not result in lower harvesting costs compared with CTL in NEPR (Syunev et al. 2009). Nevertheless, it is essential to keep in mind that most previous comparisons of the FT and CTL methods have been accomplished in conditions where CTL has been the introduced, relatively new method, whereas FT has been the present, used method. Moreover, the logging sites of studies have been clear cuttings where no previous harvesting (thinnings) have occurred. Taking into account that the fully mechanised CTL wood harvesting system is still being introduced in Russia, while the fully mechanised FT system was developed in the USSR era and remains widely utilised, the further development of the productivity of the CTL system in Russia will improve the economic performances of harvesting operations in Russia. Currently, the share of FT loggings in the total harvested volume in Russia is about 50%, with approximately 30% to CTL and 20% to the tree-length method. The share of CTL loggings has been rapidly increasing. In some regions of NEPR, for example in Karelia and Leningrad, over 70% of loggings are still carried out using the harvester-forwarder system (Gerasimov and Sokolov 2008).

The productivity of the harvester depends on many factors, such as the forest stand composition, site, and operational factors such as ground conditions, slope, operator's motivation and skills, branchiness, operational layout, tree size, tree species, number of log assortments, numbers of trees per unit area, undergrowth density, and machine design (Jiroušek et al. 2007; Kärhä et al. 2004; Spinelli et al. 2002; Ward 2002; Bulley 1999; Makkonen 1991; Richardson 1989). In particular, harvester productivity is closely related to stem volume and tree species distribution (Gellerstedt and Dahlin 1999; Bulley 1999; Makkonen 1991; Richardson 1989; Lageson 1997). Available productivity models for single-grip harvesters (Väätäinen et al. 2005; Kuitto et al. 1994; Nurminen et al. 2006; Jiroušek et al. 2007; Ryynänen and Rönkkö 2001; Spinelli et al. 2002; McNeel and Rutherford 1994; Adebayo et al. 2007; Puttock et al. 2005; Kärhä et al. 2004) have mainly focused on managed boreal forests or plantations and coniferous tree species. Only a few studies, where the productivity of single-grip harvesters has been studied, have been carried out in unmanaged boreal forests in Russia (Syunev et al. 2009; Gerasimov et al. 2009). The objective of this study is therefore to develop a harvester productivity model of the CTL harvesting of unthinned mixed forest stands in NEPR as a function of the tree species and stem volume distribution of felled trees. With such a model, prospective users of CTL harvesting technology may evaluate the inherent operation costs under different conditions and assess the competitiveness of traditional FT harvesting systems. It is also intended to facilitate the adaptation of CTL harvesting for unthinned mixed forest stands, especially in those areas where worn-down domestic machines are still available and where cheap labour prevents investment in purpose-built forestry machines.

Materials and methods

The experiments were carried out in typical working conditions in NEPR in 2008–2009 (Figure 3.1).

A mid-sized wheeled John Deere 1270D harvester with an engine output power of 160 kW and operating weight of 17 tons was used in all study sites. All studied harvesters were equipped with a JD 758 HD harvester head. In the harvesting operations, 38 harvesters were studied in 2008–2009, of which nine were in Karelia, eight in Vologda and Arkhangelsk, 16 in Komi, two in Leningrad, two in Tver, and one in Kirov. The cutting volume of all harvesters was 1.4 million m^3 u.b. (under bark) and the total number of trees to be cut was 4.3 million. Harvested stands were not managed or thinned before the final felling. A typical study stand was mixed in terms of tree age and species. The tree species composition included spruce (48% on average), pine (19%),

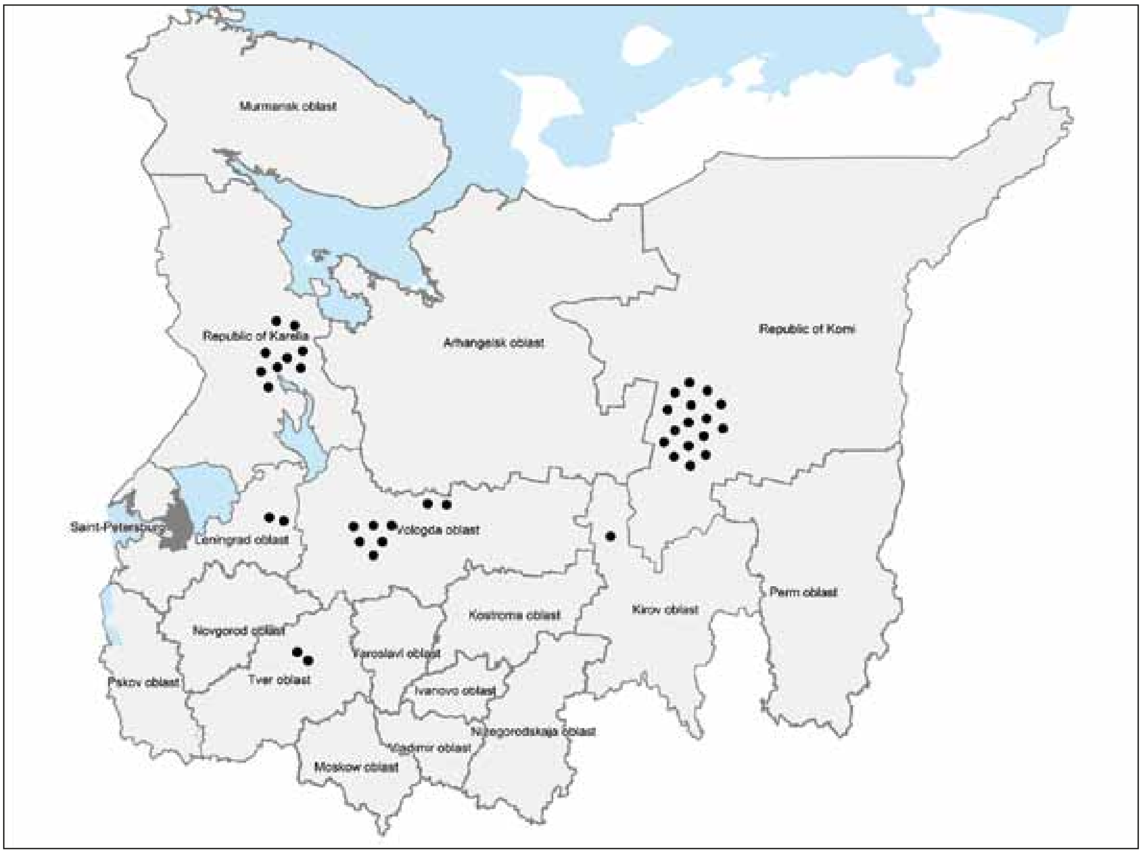


Figure 3.1 Map of NEPR. Locations of studied harvesters are indicated

birch (22%), and aspen (11%). The average stem volumes of the harvesting sites varied between 0.13 and 0.53 m^3 u.b. with an average value 0.31 m^3 u.b. The growing stock of stands varied between 100 and 300 m^3 per ha (note: this is the commercially utilised stand volume and not the total volume including, e.g., undergrowth). The average growing stock of stands in the studied regions was 152 m^3 per ha with a tree density of approximately 490 trees per ha. The typical soils in the test areas were loam, clay loam, and sandy loam. The basis of stem volumes and tree species distribution in NEPR is presented in Table 3.1.

Table 3.1 Distribution of harvested trees by tree species (*P*) and average stem volume (*v*), under bark

Region	Harvested volume, 1000 m^3	Average stem volume, m^3	Pine		Spruce		Birch		Aspen	
			P, %	*v*, m^3	*P*, %	*v*, m^3	*P*, %	*v*, m^3	*P*, %	*v*, m^3
Karelia	236	0.28	40	0.41	45	0.22	11	0.30	4	0.42
Vologda	298	0.31	6	0.58	55	0.27	28	0.34	11	0.46
Komi	685	0.32	16	0.33	50	0.30	22	0.32	12	0.49
Leningrad	52	0.34	5	0.42	37	0.25	27	0.38	31	0.45
Tver	70	0.38	43	0.41	28	0.32	16	0.36	13	0.42
Kirov	30	0.38	7	0.75	62	0.32	27	0.48	4	0.88
NEPR	1371	0.31	19	0.38	48	0.27	22	0.33	11	0.47

The harvesters were scheduled to work seven days per week, 24 hours per day in double (day and night) shift schedules. The number of log assortments usually varied between eight and 10, representing spruce, pine, and birch sawlogs/pulpwood, spruce/pine small-sized sawlogs, aspen pulpwood, and energy logs (Gerasimov and Seliverstov 2010).

The performance of each harvester was automatically monitored during normal operation on a harvesting site. A new version of the John Deere's machine performance and condition monitoring system (TimberLink 2.0) was used for collecting data on cutting productivity and following up cutting conditions (tree sizes and species). Productivity and follow-up data were transferred from the harvester to the office with the help of a USB memory stick. The data collection procedure consisted of preliminary information, such as date, working time, processing time, movement time, stem volume, tree species and number of trees, process productivity, fuel consumption, and some additional information. The additional information included contractor, machine type, harvester head type, and location.

The harvesting operation of studied harvesters was split into two distinct time elements, which were recorded with the TimberLink system. Time elements were stem selection and stem processing (i.e. delimbing and cross-cutting). The stem selection stage covers everything from driving the machine onto the stand and operating the boom to sawing the stem. TimberLink measures the time required for each step of the stem selection process: drive time, boom time, and other time. The stem processing stage includes felling the stem, moving the stem, and delimbing and cross-cutting the stem. TimberLink monitors the time required for the different stages of stem processing when processing different sized stems.

A harvester head measurement system was used to measure the sectional diameters and lengths of each tree to determine stem volume. Machine productivity was determined in cubic metres u.b. both per productive machine hour (*PMH*) and per stem processing machine hour (*SprocMH*).

PMH represents the time during which the machine performs harvesting operations where breakdowns (i.e. mechanical and non-mechanical delays) are excluded. It is the time spent by a machine performing its primary task as well as that spent on support tasks. Short delays that cannot be easily separated from production activities are lumped into productive time.

SprocMH represents the time during which the machine actually performs felling and stem processing (tree felling, delimbing, cross-cutting, harvesting head movement). The proportion of *SprocMH* in *PMH* was expressed as the stem processing time ratio (*SprocR*). All study data were filtered into different categories using an Excel program and the productivity curves were analysed using SPSS 15.0 for Windows.

Results

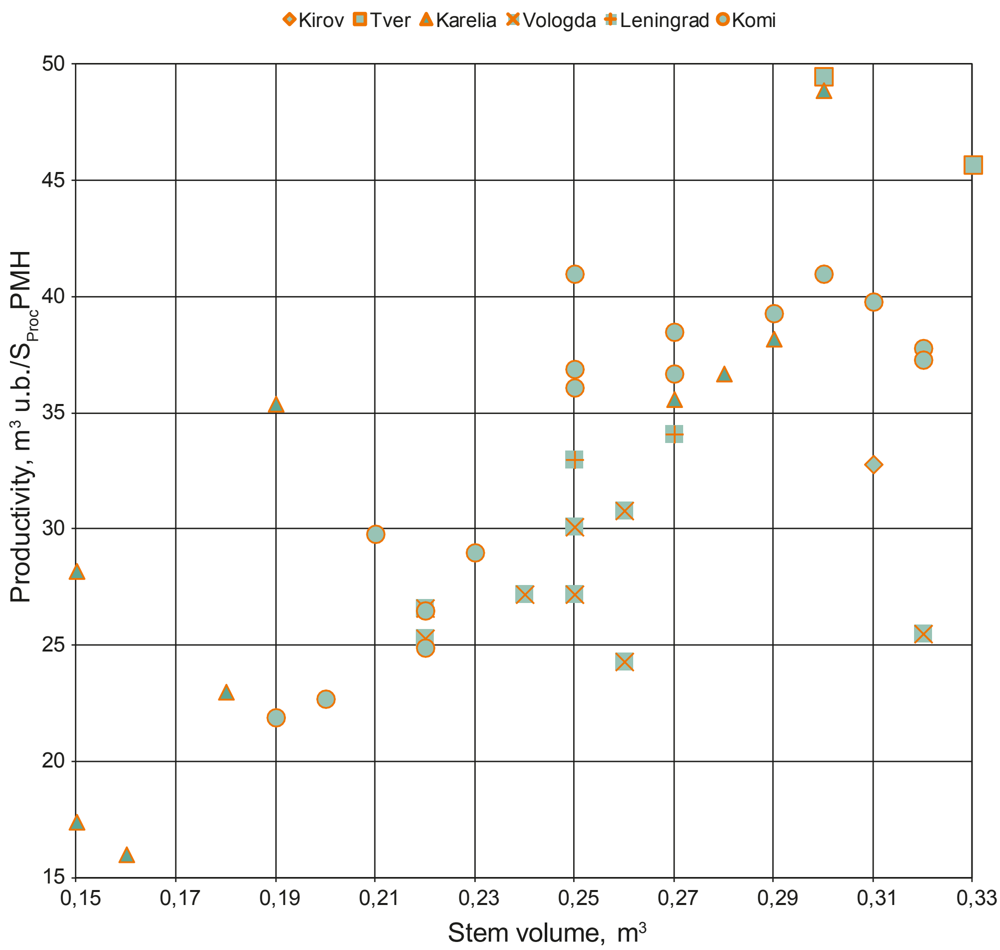


Figure 3.2 Plotted values of the relationship between stem volume and productivity of tested harvesters

The *SprocR* for each harvester varied widely from 0.17 to 0.45 with an average value of 0.34 (Table 3.2).

Table 3.2 The *SprocR values* by region

Region	Stem processing time ratio $S_{proc}R$		
	minimum	maximum	average
Karelia	0.23	0.43	0.30
Vologda	0.19	0.45	0.39
Komi	0.30	0.41	0.35
Tver, Leningrad, Kirov	0.17	0.34	0.25
NEPR	0.17	0.45	0.34

In the regions of Tver, Leningrad, and Kirov, the average *SprocR* value was 38% smaller than it was in Vologda. Stem processing productivity varied from 15 to 60 m^3 u.b. per *SprocMH* between harvesters (Figure 3.2).

The relationship between average machine productivity in cubic metres u.b. per *SprocMH* and the average stem volume per each harvester by NEPR region is presented in Table 3.3.

Table 3.3 Average machine productivity according to the average stem volume by key NEPR region

i	Stem volume group, m^3 u.b.	Average harvester productivity, m^3 u.b./ *SprocMH*			
		Karelia	Vologda	Komi	NEPR
1	2.71–3.20	111.6	114.0	119.8	118.6
2	2.21–2.70	109.5	102.3	114.2	111.1
3	1.71–2.20	101.4	95.0	109.1	104.9
4	1.21–1.70	95.1	83.6	94.5	92.7
5	0.81–1.20	75.0	71.2	78.9	77.1
6	0.51–0.80	59.4	56.5	62.9	61.5
7	0.31–0.50	43.8	42.1	47.4	46.1
8	0.16–0.30	29.6	28.5	32.7	31.3
9	≤0.15	13.7	13.8	15.8	14.9

Tree size and tree species were found to be factors affecting productivity in the most significant way.

A productivity trend curve based on the data of all harvesters investigated in the study for processing machine hour was constructed using a Power regression model with an R-square value of 0.9:

$$\boldsymbol{P_1 = b_0 \times v^{b_1}}$$

where,
P_1 is harvester productivity per processing machine hour (m^3 u.b./*SprocMH*),
v is the stem volume (m^3 u.b.),
b_0 and b_1 are factors and exponents in the regression function for each tree species and NEPR region is presented in Table 3.4.

Table 3.4 Coefficients of the Power regression model by species and region

s	Species	Coefficients of the Power regression model							
		Karelia		Vologda		Komi		NEPR	
		b_0	b_1	b_0	b_1	b_0	b_1	b_0	b_1
1	Pine	69.638	0.595	66.068	0.565	74.223	0.575	71.844	0.582
2	Spruce	65.959	0.627	63.486	0.574	72.260	0.556	69.061	0.576
3	Birch	69.248	0.655	59.091	0.559	72.229	0.557	68.451	0.581
4	Aspen	71.895	0.520	72.980	0.579	75.089	0.556	74.719	0.552

Figure 3.3 shows the function between stem volume and productivity (on the y-axis) by tree species by NEPR.

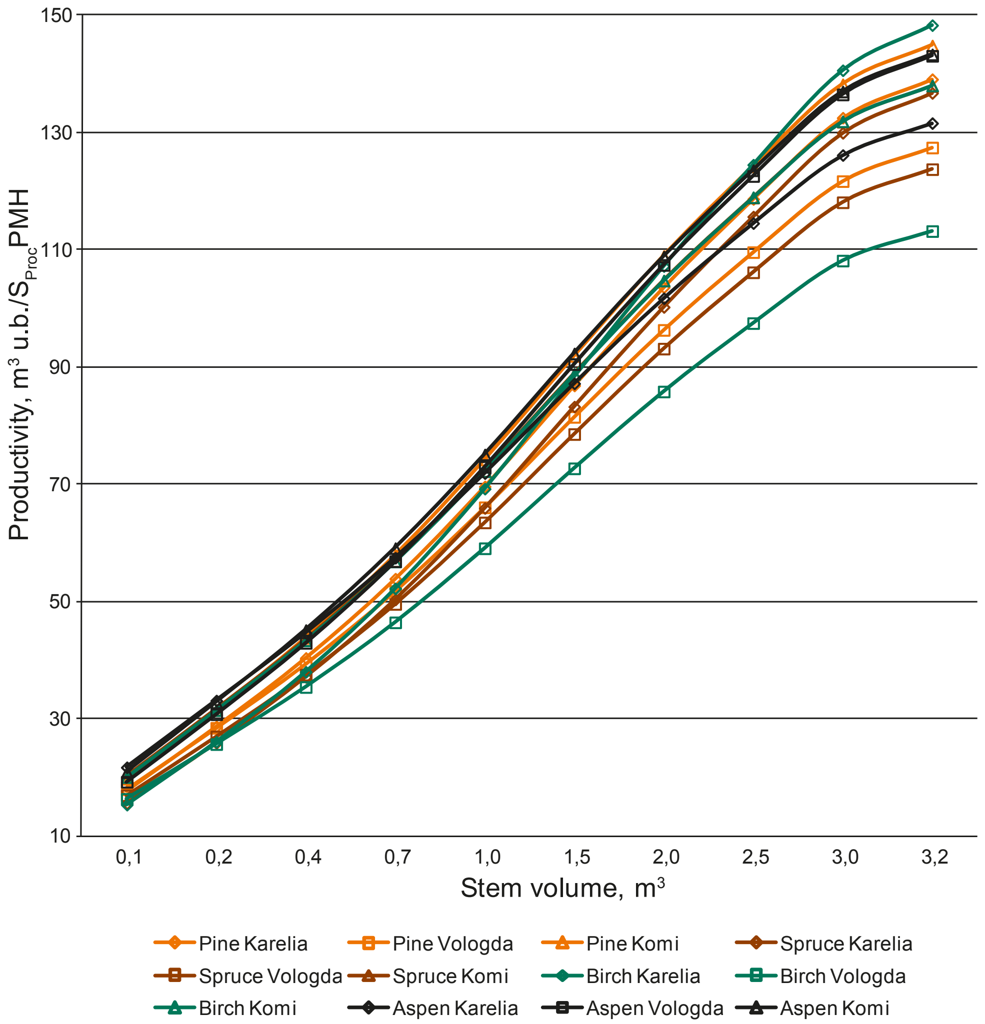


Figure 3.3 The function between stem volume and productivity by tree species and NEPR region

The distribution of harvested trees by stem volume and tree species is presented in Table 3.5.

Table 3.5 Distribution of harvested trees by stem volume group and tree species in all studied NEPR regions

i	Stem volume group, m^3 u.b.	Number of harvested trees	Share of harvested trees by stem volume group, %			
			Pine	Spruce	Birch	Aspen
1	2.71–3.20	1,585	0.04	0.06	0.01	0.04
2	2.21–2.70	7,016	0.16	0.25	0.07	0.12
3	1.71–2.20	23,282	0.53	0.79	0.27	0.34
4	1.21–1.70	73,843	1.70	2.34	1.05	1.47
5	0.81–1.20	200,888	4.62	6.26	3.37	5.15
6	0.51–0.80	457,038	10.50	14.18	8.60	12.12
7	0.31–0.50	699,412	16.07	19.53	14.60	17.87
8	0.16–0.30	1019,159	23.42	23.53	23.10	25.51
9	≤0.15	1868,974	42.95	33.00	48.92	37.35
	Grand total	4351,197	100.0	100.0	100.0	100.0

The harvesting productivity of single-grip harvester in cubic metres u.b. per *PMH* in NEPR conditions can be estimated based on the formula given below and Tables 3.3-3.6 using the following relationship:

$$\boldsymbol{P_2 = S_{proc}R \times \sum_{s} P_s\, b_0 \sum_{i} D_i\, v_i^{b_1}}$$

where,
P_2 is the harvester productivity per productive machine hour (m^3 u.b./PMH),
$S_{proc}R$ is the stem processing time ratio,
v is the stem volume (m^3 u.b.),
s is the tree species (1=pine, 2=spruce, 3=birch, 4=aspen),
P_s is the share of each tree species harvested volume in the total harvested volume,
i is the stem volume group (i = 1–9 in NEPR conditions),
D_i is the proportion of each stem volume group in the total volume, and
b_0 and b_1 for each tree species and NEPR region is presented in Table 3.4.

The results of the harvester productivity calculations for Karelia, Vologda, Komi, and general NEPR conditions are presented in Table 3.6. The stem processing time ratios ($S_{proc}R$) were assumed to be in the range 0.25–0.55 with values presented for each increase of 0.05. The average harvester productivity values per *PMH* (R = 0.35) are 10.6 m^3 u.b./h in Karelia (average stem volume v = 0.28 m^3 u.b.), 10.8 m^3 u.b./h in Vologda (v = 0.31 m^3 u.b.), 12.5 m^3 u.b./h in Komi (v = 0.32 m^3 u.b.), and 11.7 m^3 u.b./h in NEPR (v = 0.31 m^3 u.b.). When comparing the harvester productivity within NEPR regions for the average stem size and tree species distribution in NEPR, productivity did not differ remarkably between regions subject to the same $S_{proc}R$ ratio.

Table 3.6 The calculated productivity in cubic metres u.b. per *PMH* with possible stem processing time ratios ($S_{proc}R$) by region and tree species

Ratio $S_{proc}R$	*Karelia*					*Vologda*					*Komi*					*NEPR*				
	P	S	B	A	T	P	S	B	A	T	P	S	B	A	T	P	S	B	A	T
0.25	9.5	5.8	7.1	10.5	7.6	11.3	6.8	7.5	10.6	7.7	8.9	8.4	8.7	11.2	8.9	9.3	7.5	8.3	11.0	8.4
0.3	11.3	7.0	8.5	12.6	9.1	13.5	8.2	9.1	12.7	9.2	10.7	10.1	10.5	13.4	10.7	11.2	9.0	9.9	13.2	10.1
0.35	13.2	8.2	10.0	14.7	10.6	15.8	9.5	10.6	14.8	10.8	12.4	11.8	12.2	15.7	12.5	13.1	10.5	11.6	15.4	11.7
0.4	15.1	9.3	11.4	16.8	12.2	18.0	10.9	12.1	16.9	12.3	14.2	13.5	14.0	17.9	14.3	14.9	12.0	13.2	17.6	13.4
0.45	17.0	10.5	12.8	18.9	13.7	20.3	12.3	13.6	19.0	13.9	16.0	15.2	15.7	20.2	16.0	16.8	13.5	14.9	19.8	15.1
0.5	18.9	11.6	14.2	21.0	15.2	22.5	13.6	15.1	21.1	15.4	17.8	16.9	17.5	22.4	17.8	18.7	15.0	16.5	22.0	16.8
0.55	20.8	12.8	15.7	23.1	16.7	24.8	15.0	16.6	23.3	17.0	19.5	18.6	19.2	24.6	19.6	20.5	16.5	18.2	24.2	18.5

P-pine, S-spruce, B-birch, A-aspen, T-average composition in the region

Discussion

The material of the study was extensive. Productivity data were collected for 38 harvesters from six of the most forest-covered regions in the European part of Russia. The study was based on 4.3 million felled trees and 1.4 million m^3 u.b. of processed wood, which covered 11% of the total annual actual cut in Komi (0.69 million m^3 u.b.), 4% in Karelia (0.24 million m^3 u.b.), and 4% in Vologda (0.30 million m^3 u.b.).

Overall, productivity per *PMH* varied widely between studied harvesters from 4.3 to 14.9 m^3 u.b. with an average of 10.7 m^3 u.b. The lowest average productivity in NEPR was recorded in Karelia at 9.6 m^3/*PMH* and the highest in Komi at 11.6 m^3 u.b./*PMH*. The average stem volumes were 0.28 and 0.32 m^3 u.b., respectively. Stem processing productivity per *SprocMH* varied widely between studied harvesters from 16.0 to 49.5 m^3 u.b. with an average value of 32.4 m^3 u.b. The lowest average stem processing productivity in NEPR regions was recorded in Vologda at 27.1 m^3 u.b./*SprocMH* and the highest in Komi at 33.7 m^3 u.b./*SprocMH*.

The productivity of harvesters did not differ much from that obtained from Russian logging companies in Russia (Gerasimov et al. 2009; Syunev et al. 2009). However, harvester productivity on final fellings in Finland seems to be remarkably higher than it is in NEPR using the same stem size. According to Väätäinen et al. (2007), the average productivity of conventional single-grip harvesters in Finnish logging conditions for an average stem volume of 0.3 m^3 u.b. was about 18 m^3 u.b./*PMH* on final fellings (higher by 7 m^3 u.b./*PMH*). The volume share of bark from the total stem volume with the bark cover was estimated to be 10%, which was used to convert Finnish productivity figures as comparable values (m^3 o.b. (over bark) to m^3 u.b.).

There are a number of possible explanations for the differences between Russia and Finland. Earlier studies have shown that operator skills have a remarkable influence on productivity in harvesting operations (Syunev et al. 2009; Väätäinen et al. 2005; Sirén and Aaltio 2003). Moreover, the lower productivity in Russia is also the result of divergent distributions of stem volume and stem quality in Russia and Finland because of different forest management traditions in these countries. Stands in Finland are more or less regularly managed and thinned, while in Russia stands are rarely managed and thinned before final felling. These distributions are an important factor associated with harvesting productivity.

The *SprocR* values for the studied harvesters were indeed very low and they changed considerably from 0.17 to 0.45. The set of harvesters in Komi shows the best proportion, with an average ratio *SprocR* = 0.35. In comparison, the Nordic countries stem processing time typically accounts for 25% in first thinnings and up to 55% in final fellings of the productive machine time (Väätäinen et al. 2005, Nurminen et al. 2006, Kariniemi 2006). Stem size has a distinct direct correlation on *SprocR*. In particular, while average stem size increases, *SprocR* increases also. From an operational viewpoint, Russian harvesting companies very much need to improve the evaluation of machine performance because the average utilisation rates of studied harvesters varied from 0.40 to 0.84 with an average value of 0.60. They still have a great potential in machinery utilisation, and the possibility of increasing the share of stem processing machine hours in order to reduce harvesting cost should be explored. The machine's hourly productivity can be boosted by increasing this percentage using improved working techniques. Based on both the results of this study and those of earlier studies (Syunev et al. 2009), harvester productivity per *PMH* could even be doubled in some harvesting companies in NEPR. In its entirety, productivity could be increased up to 16.7 m^3 u.b./*PMH* in Karelia, 17.0 m^3 u.b./*PMH* in Vologda, 19.6 m^3 u.b./*PMH* in Komi, and

18.5 m^3 u.b./*PMH* in NEPR in general if the stem processing time ratio *SprocR* could be increased up to the Nordic countries' level of 0.55. Under this condition, the average productivity of conventional harvesters in NEPR reaches the Finnish level of 18 m^3 u.b./PMH. Once the harvester productivity model for NEPR conditions is available, further research is suggested to improve the developed predictor models and to predict harvester-forwarder system performance over a broad range of stand and site conditions. Different scenarios can be simulated in order to select the best economic use of machinery for each set of conditions in Russia and the other former USSR countries. Prospective users of harvesters may then evaluate the inherent operation costs under different conditions and assess the competitiveness of these alternative options. This could also facilitate the adaptation of fully mechanised CTL harvesting for naturally growing forests, especially in those countries where obsolete domestic machinery is still available and where cheap labour hinders investment in purpose-built forestry machines.

References

Adebayo AB., Han HS., Johnson L. 2007. Productivity and cost of cut-to-length and whole-tree harvesting in a mixed-conifer stand. Forest Product Journal 57(5):59–69.

Asikainen A., Leskinen L., Pasanen K., Väätäinen K., Anttila A. and Tahvanainen T. 2009 Metsäkonesektorin nykytila ja tulevaisuus. Metlan työraportteja 125 (in Finnish). 48 p.

Bulley B. 1999. Effect of tree size and stand density on harvester and forwarder productivity in commercial thinning. FERIC Technical Note TN-292, July 1999.

Gellerstedt S, Dahlin B. 1999. Cut-to-length in the next decade. J For Eng 10(2):17–25

Gerasimov Y (2004) Cut-to-length method in the wood procurement of Russia: SWOT analysis. Proc NSR Conf Forest Operations 2004. Silva Carelica 45:338–344.

Gerasimov Y., Seliverstov A. 2010. Industrial round-wood losses associated with the harvesting systems in Russia. Croatian Journal of Forest Engineering 31(2): 111–126.

Gerasimov Y., Senkin V. and Väätäinen, K. 2011. Productivity of single-grip harvesters in clear-cutting operations in the northern European part of Russia. European Journal of Forest Research. Published online 03 July 2011. Available at: http://www.springerlink.com/content/m452062127908225/fulltext.pdf.

Gerasimov Y., Sibiryakov K., Moshkov S., Välkky E., Karvinen S. 2009. Cost calculation of timber harvesting machines. Metsäntutkimuslaitos, Joensuu. 44 p (in Russian).

Gerasimov Y., Sokolov A. 2008. GIS-based decision-support program for planning and analyzing short-wood transport in Russia. Croatian Journal of Forest Engineering 29(2): 163–175

Gingras JF. 1994. A comparison of full-tree versus cut-to-length systems in the Manitoba model forest. SR-92. Forest Eng. Inst. of Canada, Pointe-Claire, Quebec, Canada. 16 pp. International Journal of Forest Engineering 14(1):39–48.

Jiroušek R., Klvač R., Skoupy A. 2007. Productivity and costs of the mechanised cut-to-length wood harvesting system in clear-felling operations. Journal of Forest Science 53(10):476–482.

John Deere 2009. TimberLink. Quick guide. 16 p.

Kariniemi A. 2006. Kuljettajakeskeinen hakkuukonetyön malli – työn suorituksen kognitiivinen tarkastelu. Helsingin yliopiston metsävarojen käytön latoksen jukaisuja 38. p.126. (In Finnish)

Kellog LD, Bettinger P. 1994. Thinning productivity and cost for mechanized cut-to-length system in the Northwest Pacific coast region of the USA. Journal of Forest Engineering 5(2):43–52.

Kuitto PJ., Keskinen S., Lindroos J., Oijala T., Rajamäki J., Räsänen T., Terävä J. 1994. Puutavaran koneellinen hakku ja metsäkuljetus. Metsätehon tiedotus 410. 38 p. (In Finnish)

Kärhä K., Rönkkö E., Gumse S. 2004. Productivity and cutting costs of thinning harvesters. Journal of Forest Engineering 15(2):43–56.

Lageson H. 1997. Effects of thinning type on the harvester productivity and on the residual stand. Journal of Forest Engineering 8(2):7–13.

Makkonen I. 1991. Silver Streak single-grip harvester in Nova Scotia. FERRIC, Pointe Claire, Que. Field Note No.TR-94: 18.

McNeel JF., Rutherford D. 1994. Modelling harvester-forwarder system performance in a selection harvest. Journal of Forest Engineering 6(1):7–14.

Nurminen T,. Korpunen H,. Uusitalo J. 2006. Time consumption analysis of the mechanized cut-to-length harvesting system. Silva Fennica 40(2):335–363.

Puttock D., Spinelli R., Hartsough BR. 2005. Operational trials of cut-to-length harvesting of poplar in a mixed wood stand. Journal of Forest Engineering 16(2):17–25.

Richardson R. 1989. Evaluation of five processors and harvesters. Forestry Engineering Research Institute of Canada. Pointe Claire, PQ. Technical Report No. TR-94:18.

Ryynänen S., Rönkkö E. 2001. Harvennusharvestereiden tuottavuus ja kustannukset. Helsinki. Työtehoseuran julkaisuja 381. 67 p. (In Finnish)

Sirén M. 1998. Hakkuukonetyö, sen korjuujälki ja puustovaurioiden ennustaminen. Väitöskirja. Metsäntutkimuslaitoksen tiedonantoja 694. 179 p. (In Finnish)

Sirén M. and Aaltio H. 2003. Productivity of costs of thinning harvesters and harvester-forwarders.

Spinelli R., Owende PMO., Ward S. 2002. Productivity and cost of CTL harvesting of *Eucalyptus globulus* stands using excavator-based harvesters. Forest Product Journal 52:67–77.

Statistical Yearbook of Finnish Forestry 2009. Finnish Forest Research Institute.

Syunev VS., Sokolov AP., Konovalov AP., Katarov VK., Seliverstov AA., Gerasimov YY., Karvinen S., Valkky E. 2009. Comparison of wood harvesting methods in logging companies of the Republic of Karelia. Working Papers of the Finnish Forest Research Institute 120. 117 p.

Tufts RA. 1997. Productivity and cost of the Ponsse 15-series, cut-to-length harvesting system in southern pine plantations. Forest Products Journal 47(10):39–46

Uusitalo J. 2004. Metsäteknologian perusteet. FEG, Joensuu, 228 p. (In Finnish)

Ward SM. 2002. Productivity and cost of CTL harvesting of *Eucalyptus globulus* stands using excavator-based harvesters. Forest Products Journal 52(1):67–77.

Väätäinen K., Liiri H., Asikainen A., Sikanen L., Jylhä P., Rieppo K., Nuutinen Y., Ala-Fossi A. 2007. Korjureiden ja korjuuketjun simulointi ainespuun korjuussa. Metlan työraportteja 48. 78 p. (In Finnish)

Väätäinen K., Ovaskainen H., Ranta P., Ala-Fossi A. 2005. Hakkuukoneenkuljettajan hiljaisen tiedon merkitys hakkuutulokseen työpistetasolla. Metsäntutkimuslaitoksen tiedonantoja 937. 90 p. (In Finnish)

Yaoxiang L., Wang J., Miller G., McNeel J. 2006. Production economics of harvesting small diameter hardwood stands in central Appalachia. Forest Products Journal 56(3):81–86.

3.1.2 The system for the estimation of the economic efficiency of a forest chip supply system

The efficient production of forest chips from logging residues requires up-to-date high-capacity machines. Such machinery is expensive and its procurement should be justified. Another problem is that prices for forest chips remain quite low, and the costs of the collection and forwarding of residues, as well as transporting to the consumer, are high. Therefore, a need emerges to calculate the possible economic effects of chipping logging residues.

When solving the issue of the profitability of collecting and chipping residues, it is necessary to account for the possibility and distance of transporting chips to the customer, the availability and technical features of machinery for collecting and chipping logging residues, the characteristics of the stand, and the prices for forest products in the region.

To solve this problem, it is suggested to use a decision support system, which – depending on the input data – allows for the evaluation of several alternatives for systems of machines, comparing the results of different options, and helping answer the following questions:

- What machines are more profitable for collecting and chipping logging residues in given conditions?
- What is the minimal price for chips that should be offered to make the collection of logging residues and chip production economically viable?

The decision support system includes an imitation model of a harvesting site and working conditions, which imitates models for the operation of forest machines, and a program that allows for the evaluation of the profitability of collecting logging residues and producing forest chips under given conditions. The system is special because the collection of logging residues is considered together with harvesting operations.

The key input data for the program calculating economic viability are the results of the simulation of forest machine operations when collecting and processing logging residues. The program accounts for the volume of logging residues and round energy wood collected as well as the working hours of the machine. In addition, the user must enter the data necessary to calculate the fixed and variable costs of the machine, set prices for the products in the forest industry, and give costs for cleaning the harvesting site.

Imitational models and the program for calculating economic viability allow for the computation of four alternatives:
- The baseline alternative does not include the collection of logging residues, and thus the costs for cleaning the site together with the costs for felling, forwarding, and transporting will influence the cost-effectiveness of harvesting. The logger will gain income from selling merchantable roundwood and round energy wood (non-industrial logs).
- The first alternative includes the collection of logging residues, their forwarding to a loading site with a forwarder, chipping, and transportation on a chip truck. In this case, there are additional costs compared with the baseline alternative for collecting, forwarding, and chipping logging residues and transporting forest chips to the customer. The income includes the sales of merchantable roundwood, round energy wood, and forest chips and the reduction in costs for site cleaning after harvesting operation.
- The second alternative examines the use of a bundler for collecting logging residues. In this case, the customer receives tightly tied bundles of logging residues instead of chips. The costs included are felling trees, forwarding and transporting logs, operating the bundling machine, transporting bundles with a forwarder, and furthering their transportation to customers on trucks. Income is generated from the sales of merchantable roundwood and bales of residues and reduced by the costs for site cleaning after harvesting operation.
- The third alternative is based on a mobile chipper mounted on a forwarder with a container. The costs are felling trees, forwarding and transporting logs, operating the mobile chipper, and transporting the chips on chip trucks. The income consists of the sales of merchantable roundwood, round energy wood, and forest chips and the reduction in costs for site cleaning after harvesting operation.

When alternative computations are compared, a conclusion can be made about the profitability of producing chips from logging residues, and the optimal system can be chosen for the given conditions. By varying the input data, one can identify the boundaries for using certain alternatives and expose the weaknesses of the systems of machines.

When choosing a system of machines, it is necessary to analyse the strong and weak points of each alternative. If the first alternative is applied, the positive element is the need to buy comparatively inexpensive special machinery. The cost of a chipper driven by a power take-off shaft and an agricultural tractor is cheaper compared with special bundlers and mobile chippers based on forwarders. Logging residues can be collected with the same forwarder, which forwards logs. At the same time, one should not forget that forest operations in Russia are strictly seasonal. Major harvesting is carried out in winter (FSSS 2011); in summer, the ratio of using forwarders might drop to 0.6 or lower. The use of forwarders at harvesting sites in summer for collecting logging residues can, on one hand, increase the rate of using machinery but, on the other hand, it can reduce the prime cost of producing chips by reducing the fixed costs of operating the machine. When reducing the price for chips or increasing the costs of chipping, forwarders can be used for harvesting merchantable roundwood and chippers can be used for chipping only round energy wood.

The second alternative is special because it uses an expensive and high-capacity machine for bundling logging residues. In order to pay the bundler back and gain profits, its capacity should be used at its maximum; therefore, larger volumes of harvesting are required. In addition, the demand for bundles of logging residues should be stable. The positive feature of this technology is the possibility of transporting bundles by conventional log trucks. In addition, it is possible to drive on roads that are impassable for medium- and large-sized chip trucks if off-road log trucks are used.

The third alternative also requires expensive special machinery, which implies the need for a permanent demand for chips and large wood harvesting volumes. A positive feature is the minimisation of the units of machinery in the chain: only a mobile chipper and a chip truck are needed. Taking into account the small volumes of containers on the machine when wood is chipped, it is more effective to forward round energy wood by a forwarder together with merchantable roundwood and to further chip it with a mobile chipper at the loading site. When solving the issue of the profitability of collecting logging residues and their processing into chips, it is necessary to take into account that because of the low load-bearing capacity of the soil at some sites, the collection of logging residues is impossible. During the collection and transportation of logging residues, the number of trips via strip roads increases. On soft soils, logging residues are required to strengthen strip roads. In addition, logging residues from strip roads cannot be used for producing chips as they are contaminated with sand, mud, and stones, which will not only increase the ash contents of the chips but can also damage the knives of the chipper. Furthermore, one should remember that because of transporting logging residues from the harvesting site, forest roads have to withstand more of a burden when chip trucks drive and machinery is delivered to the site. Therefore, when defining the possible volumes of chips from logging residues, it is necessary to exclude their volumes from the sites with soft soils and from the areas where forest roads cannot withstand the delivery of chips to customers. In addition, one should not collect logging residues at sites with poor soils and a lack of nutrients (Chernikhovskii and Alexeev 2009). It is desirable to leave branches at such sites.

At present, imitational models are being tested for adequacy. As a result of preliminary computations, the diagrams of the cost structures of chips produced from logging residues (Figure 3.4 and Figure 3.5) and the dependence of the cost on the distance to the customer

(Figure 3.6 and Figure 3.7) were obtained for different alternatives. For a better orientation, a price of 18.13 €/m³ is marked red on the diagrams as the average contract price for forest chips from softwood in Karelia in 2010 (MEDRK 2011).

Preliminary calculations were made for two sites. The first stand had 70% of spruce and 30% of birch, age 80 years, growth class 4, and stock 170 m³ per hectare. The second stand had the same tree species composition, age 100 years, growth class 3, and stock 260 m³ per hectare. The average forwarding distance was about 200 meters.

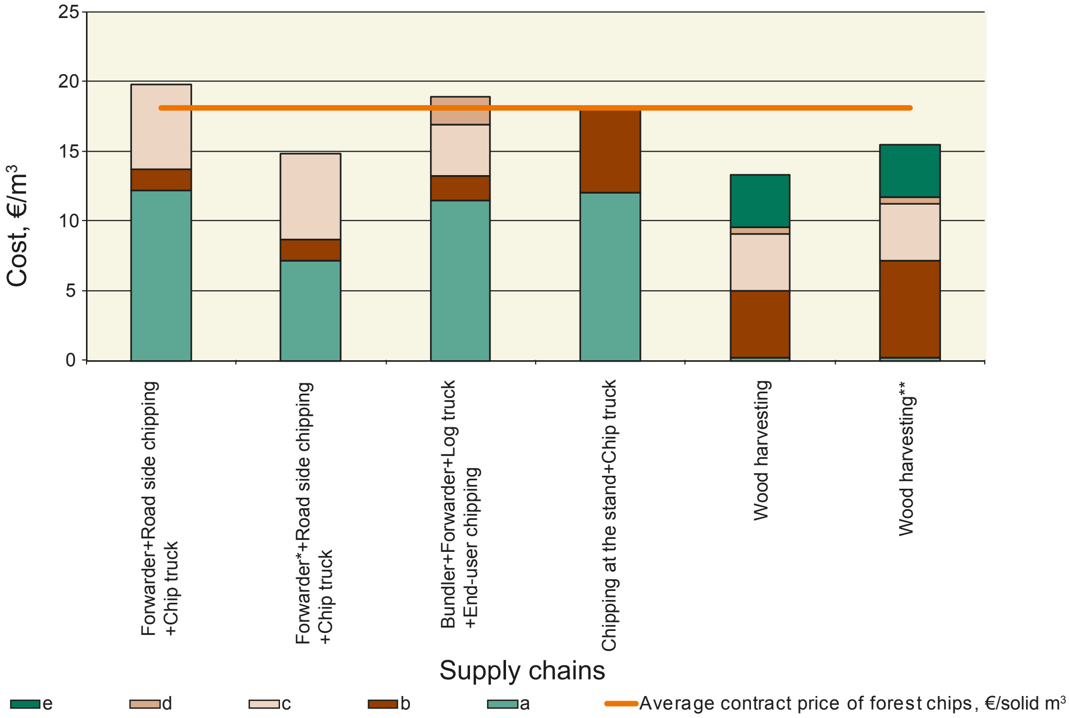


Figure 3.4 Cost structure of one solid m³ of chips given the distance of 50 km. (First stand; * – with no fixed part of the forwarding cost).

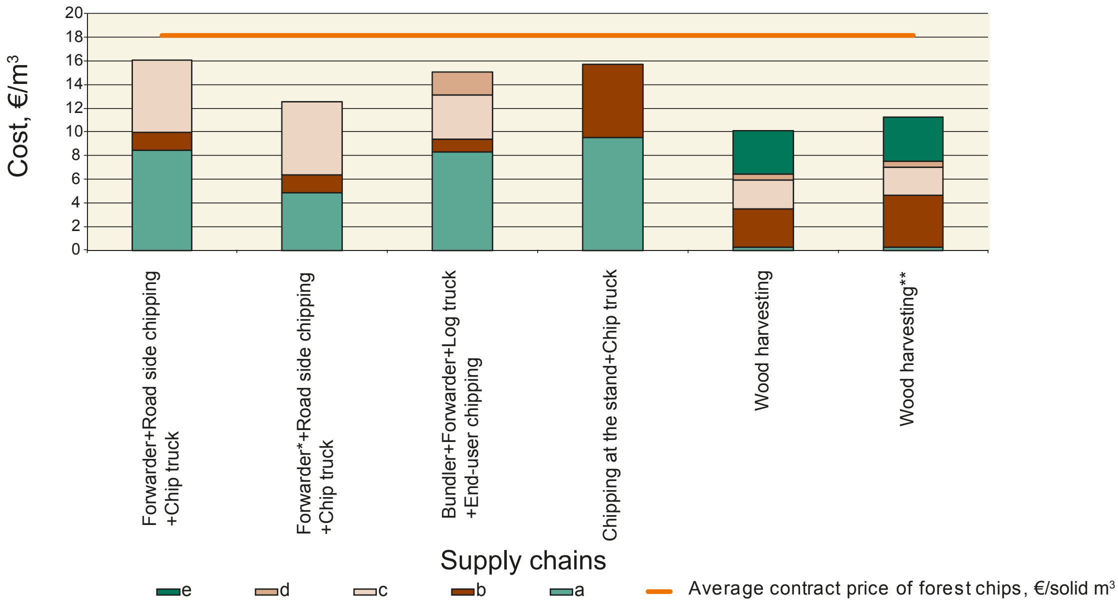


Figure 3.5 Cost structure of one solid m³ of chips given the distance of 50 km. (Second stand; * – with no fixed part of the cost for forwarder operation)

Clarifications to Figure 3.4 and Figure 3.5:

Alternative 1 (Forwarder, chipper at the loading site, chip truck).
a — costs for forwarder operations when collecting logging residues;
b — costs for chipping logging residues;
c — costs for transporting chips to the customer on a chip truck.

The first alternative (with no fixed part of the cost for forwarder operation).
a — costs for forwarder operations without the fixed component;
b — costs for chipping of logging residues;
c — costs for delivery on a chip truck to the client.

The second alternative (bundler, forwarder, short log truck, chipping at the customer's site).
a — costs for the bundling machine;
b — costs for forwarding bundles with a forwarder;
c — costs for transporting bundles to the customer;
d — costs of the client for chipping bundles of logging residues.

The third alternative (mobile chipper at the harvesting site, chip truck).
a — costs for the operations of the mobile chipper mounted on forwarder.
b — costs for transporting on a chip truck to the customer.

Wood harvesting – forest chips are not produced, only the costs of roundwood harvest are shown.
a — costs for marking strip roads and preparing the loading site:
b — costs for harvester operations;
c — costs for forwarder operations;
d — costs for cleaning the site;
e — costs for delivering logs to the customer.

Wood harvesting** – forest chips are produced, forwarders are used also to forward logging residues. Only the costs of roundwood harvest are shown.
a — costs for marking strip roads and cleaning the loading site:
b — costs for harvester operations with the account for the workload of the forwarder;
c — costs for forwarder operations;
d — costs for cleaning the harvesting site;
e — costs for delivering logs to the customer.

By modelling the operations of the machines, we succeeded in calculating the impact of a selected alternative on the number of trips of machines along the same section of a strip road when collecting and forwarding logging residues. The number of trips via the strip road was calculated every 0.25 m.

When considering the impact of the alternative on the number of trips via the main strip road, it was identified that the lowest number of trips for collecting logging residues was necessary for the alternative with a chipper mounted on a forwarder and with a bundler. For the option with the forwarder, 17% more trips were required because of the low density of the logging residues.
When considering the alternative in terms of the number of trips via strip roads, the lowest number of trips was required for the option with a chipper based on a forwarder and when collecting the residues with a forwarder. For the alternative with the bundler, 20% more trips were required because of using a forwarder to collect residue logs after the bundler.

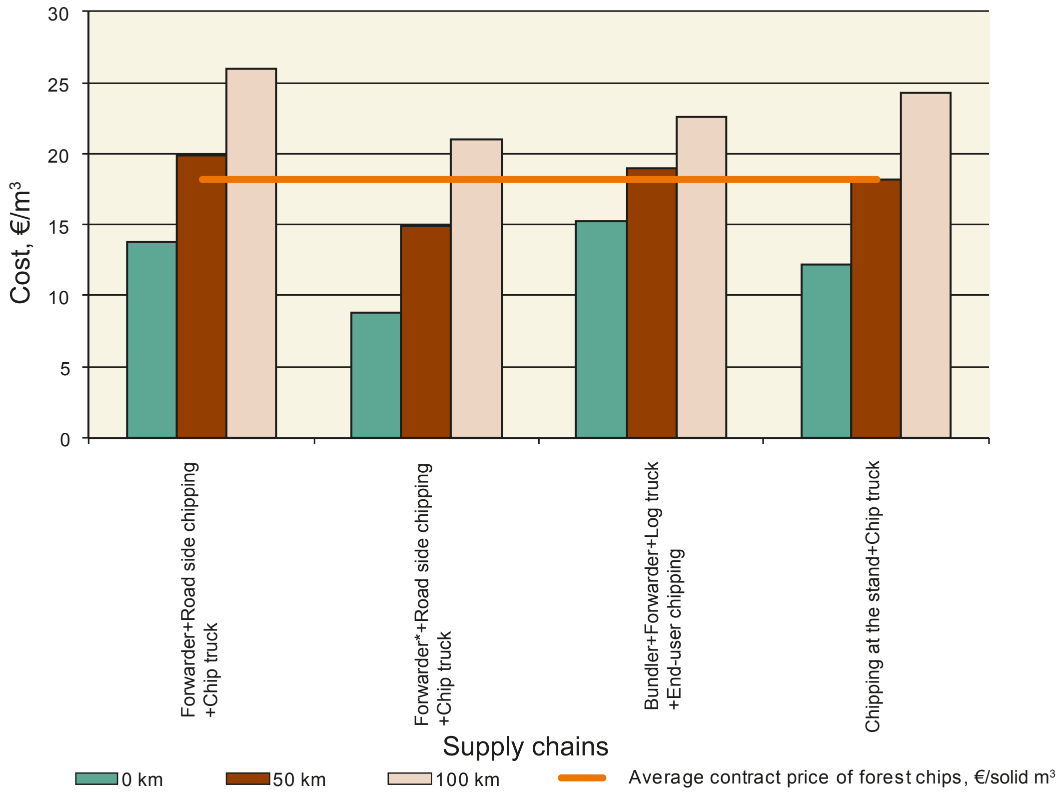


Figure 3.6 Dependence of the cost of one solid m^3 of chips on the distance to the customer. (First stand; * – with no fixed part of the cost for forwarder operation)

When using round energy wood as a raw material, it is necessary to solve the issue of where to produce the chips. One of the possibilities is to process round energy wood at the roadside and to transport forest chips to the customer on chip trucks. The second option is to transport energy wood in the forms of logs to consumers using short log trucks and to chip wood with a stationary chipper at the customers' premises. Based on the results of the preliminary calculations for the

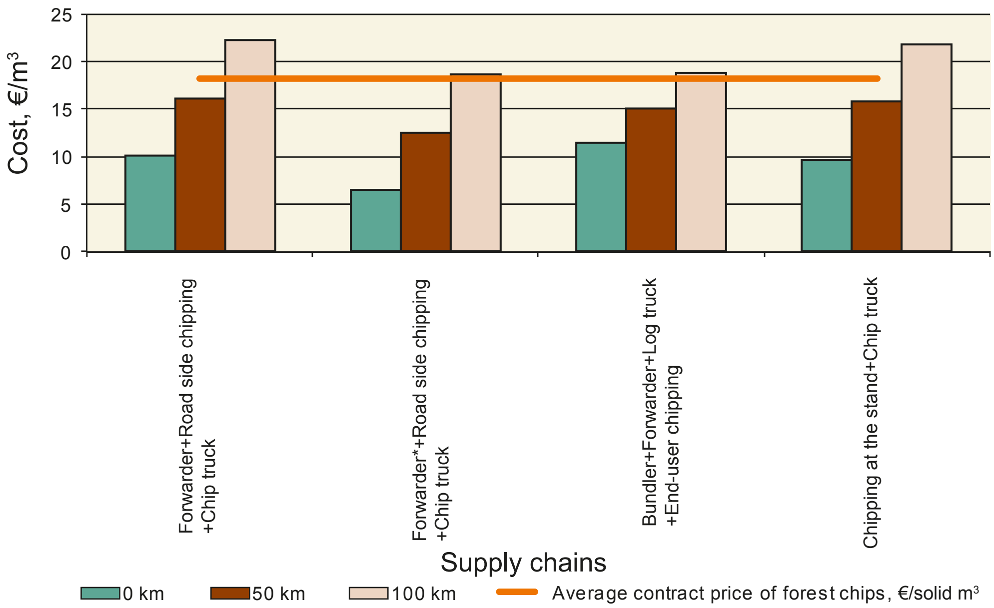


Figure 3.7 Dependence of the cost of one solid m^3 of chips on the distance to the customer. (Second stand; * – with no fixed part of the cost for forwarder operation)

second stand and for two of the alternatives in question, a diagram of the cost structure was drawn for the cost of the chips produced from round energy wood (Figure 3.8). The dependence of the cost of these chips on the distance to the customer was also studied (Figure 3.9).

Clarifications to the figure 3.8:

Alternative one (chipping energy wood at the loading site).
a — costs for forwarder operations for forwarding energy wood ;
b — costs for chipping energy wood ;
c — costs for transporting chips on a chip truck to the customer.

Alternative two (chipping energy wood at the site of the customer).
a — costs for forwarder operations for forwarding energy wood ;
b — costs for transporting energy wood to the customer;
c — costs of the end-user chipping.

The following conclusions can be drawn upon the results of tentative calculations:

1) Given current costs, the collection of logging residues for chipping is cost-effective if the distance to the customer is less than 50 km. If the distance exceeds 50 km, transportation costs are too high regardless of the alternative (Figure 3.6 and Figure 3.7). The use of round energy wood for the production of forest chips compared with the use of logging residues is more economically feasible. In this case, forest chips can be transported up to 150 km (Figure 3.9).
2) If small volumes of chips are produced from logging residues, then the lowest costs occur when using forwarders, but only if they are not taken away from harvesting merchantable roundwood. This can be possible during the summer because of the seasonality of harvesting. Here, one may not consider the fixed costs for forwarder maintenance (Figure 3.4 and Figure 3.5, alternative "Forwarder + chipper + chip truck"). This alternative also does not require the procurement of an expensive bundler or a mobile chipper based on a forwarder.
3) The large-scale production of chips from logging residues is possible only in the case of permanent and high demand for chips. According to the calculations, when considerable volumes of logging residues are used for chipping, a forwarder is not the optimal solution for collecting them (Figure 3.6 and Figure 3.7, alternative "Forwarder + chipper + chip truck"). If the distance to the customer is over 50 km, the optimal solution is a bundler that packs

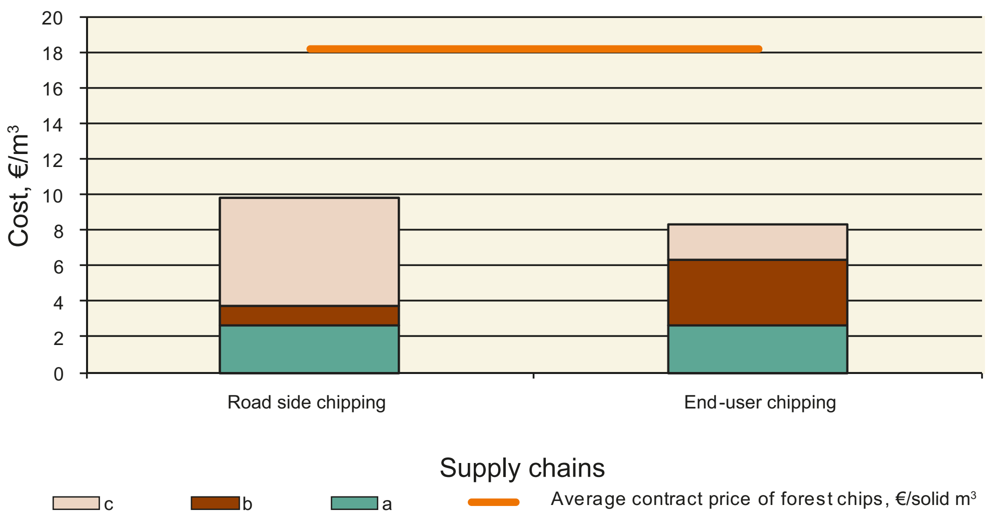


Figure 3.8 Cost structure in the cost of one solid m^3 of chips given the distance of 50 km.

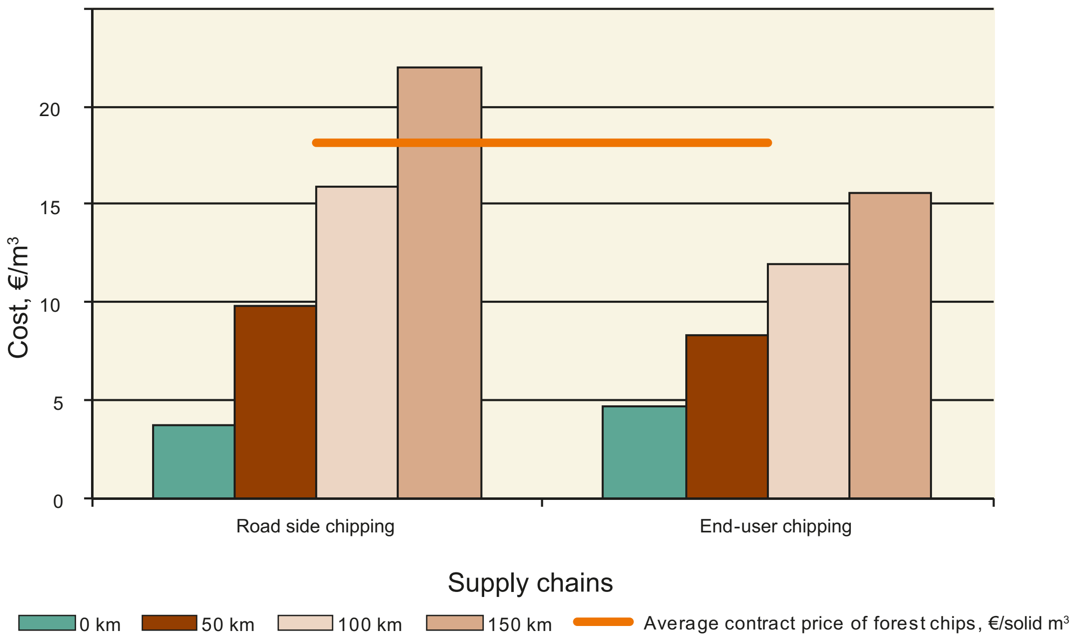


Figure 3.9 Dependence of the cost of one solid m^3 of chips produced from round energy wood on the distance to the customer.

residues into bundles (Figure 3.6 and Figure 3.7, alternative "Bundler + forwarder + log truck + end user's chipper"). The use of log trucks for transporting bundles is significantly cheaper than that for transporting chips on chip trucks. If the price for chips is higher than 19 €/m^3 for a solid m^3, then the transportation of distances over 50 km is cost-effective. However, when choosing this alternative one should take into account that the price of a bundler is high and that it will pay back only if the volume of work is large and allows working in several shifts.

4) The prime cost of producing chips increases when the growing stock of wood reduces (Figure 3.4 and Figure 3.5). This should be accounted for when the decision to produce chips is made at the site.
5) The availability of logging residues largely depends on the load-bearing capacity of the soil at harvesting sites. In the case of soft soils, one should refrain from chipping logging residues, because they should be used to strengthen strip roads.
6) Concerning the best site for chipping logging residues, the best solution is chipping at end-user facilities because it is cheaper to deliver round energy wood than it is to deliver chips.

References

Chernikhovskii D. and Alexeev A. 2009. Comparison of approaches to assessing potential fuel wood resources produced as a result of forestry operations. Report at an international research and practice conference "Bioenergy and biotechnology – effective use of harvesting and woodworking wastes". St. Petersburg Forest Technical Academy.

FSSS. 2011. Proizvodstvo delovoi drevesiny v Rossiiskoi Federatsii. Online database of the Federal State Statistics Service. Available at: http://www.gks.ru/free_doc/new_site/business/sx/leszag.htm (In Russian).

MEDRK. 2011. Average contract prices for major types of products in forest and woodworking industries in the Republic of Karelia in January – December 2010. Ministry of the Economic Development of the Republic of Karelia. Available at: http://gov.karelia.ru/gov/Power/Ministry/Development/Prices/price_wood_1012e.html (In Russian).

3.1.3 Efficiency of the cross-border transportation of forest chips

Introduction

This chapter presents the updated results of the study described by Goltsev et al. (2011). The total forest area of the Republic of Karelia is about 14.9 million ha, with a growing stock of 946 million m^3. Forests cover approximately 53% of the territory (Kareliyastat 2008). The annual allowable cut is 8.8 million m^3, whereas the total actual cut was about 5.7 million m^3 in 2009 (Ministry of the Forest Complex of the Republic of Karelia 2010). Hence, the utilisation rate of the annual allowable cut is about 65%, which is the highest in the Russian Federation.

The Republic of Karelia has a high potential for the intensification of forestry and, as a result, the production of forest chips can also be increased. According to Gerasimov and Karjalainen (2009a), the potential volume of energy wood[1] from harvesting in Karelia is 2.3 million m^3, which includes non-industrial roundwood (IRW) (62%), lifted stumps (18%), unused branches and treetops (9%), and defective wood from logging operations (11%). There are estimations (Regional'naya celevaya programma 2007) showing that it is feasible to harvest about 26% of all logging residues for energy purposes.

Forest chips could be a source of energy for many communities and industries in Russia. However, the domestic use of bioenergy resources is hindered to some extent by the current policy of the expansion of gas pipeline networks to the regions and also by the intensification of energy generation from other renewable sources, mainly hydro energy (Energeticheskaya strategiya 2009).

In Karelia, woody biomass is a relatively new fuel in larger scale municipal and industrial energy production, but in the form of round energy wood, it is a common energy source for households, especially in rural areas. Besides private households, forest industry companies and municipal heat plants are the main users of woody biomass in Karelia (Raitila et al. 2009, Gerasimov and Karjalainen 2009b). Usually, forestry companies work together with municipalities to supply wood fuel to the municipal power plants. The pulp and paper industry has about 30 woody biomass steam boilers in Karelia (Raitila et al. 2009). Existing biofuel power plants use mainly forest chips and sawmill residues.

Sawdust has been increasingly used for pellet production in Northwest Russia and because there has been very little demand on the local market for advanced wood fuels, the Russian biofuel industry has so far been mostly export-oriented (OECD/IEA 2003). However, the domestic consumption of pellets in Russia is growing (Rakitova et al. 2009).

The use of woody biomass for energy production in Karelia contributes 10% of the total energy supply and most of the energy wood is combusted for heat generation (Grigoryev 2007). At the same time, about 54% of all the heat plants in the Republic of Karelia use, at least in part, local biofuels, including round energy wood, forest chips, and peat (Regional'naya celevaya programma 2007, Regional'naya strategiya razvitiya 2010). In some districts of the Republic of Karelia, energy wood is used more widely; in the Kostomukshsky, Muezersky, and Kalevalsky districts, round energy wood consumption is about 23% of primary energy consumption (Raitila et al. 2009).

1 Energy wood – woody biomass used for the production of wood-based fuels.

In addition to the increased use of woody biomass locally, there is the potential to export forest chips from Karelia to Finland. The current weak local demand for low-quality roundwood from final fellings and thinnings in Karelia makes large volumes of raw materials available for chipping at a reasonable cost, while in neighbouring Finland the demand for forest chips and their utilisation is high. In addition, customs duties for forest chips are lower than they are for other assortments, e.g. sawlogs and pulpwood, accounting for only 5% of their export value (Federal Customs Service of Russia 2009).

Figure 3.10 shows the dynamics of forest chip exports from the Republic of Karelia to Finland. As can be seen, the export of forest chips increased substantially in 2009. This can be explained by the high customs duties set for pulpwood. In addition, the demand for energy wood has also increased in Finland, resulting in competitive prices for forest chips.

Table 3.7 shows the average price of forest chips (Free Carrier contract agreement) in the Republic of Karelia (MED 2011) in 2010 and the average cost of forest chips (as received) paid by Finnish power plants (Pöyry 2010) in summer 2010.

Table 3.7 The average contract price of forest chips in the Republic of Karelia and the average cost of forest chips paid by Finnish power plants

Type of chips	Average contract price of forest chips in Russia, €/MWh*	Cost paid by Finnish power plants, €/MWh
Pine forest chips	9.70	17.9–18.2
Birch forest chips	11.00	

* – the ratio 1.85 was used to convert costs per m^3 to costs per MWh (Alakangas 2005).

As can be seen from Table 3.7, there is a big difference between the producer price of forest chips in the Republic of Karelia and the average cost of forest chips paid by Finnish power plants.

Relatively poor preconditions for the domestic utilisation of forest chips and the significant resource potential show good opportunities for the export of forest chips from Karelia to Finland, where the current energy and climate strategies support the use of forest chips for energy generation (Ministry of Trade and Industry 2000). In the past, the use of forest chips on a large

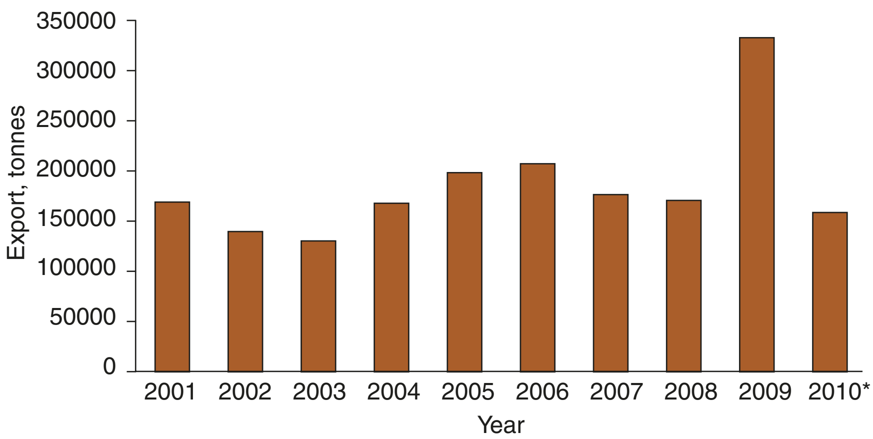


Figure 3.10 Export of coniferous forest chips from the Republic of Karelia to Finland (Kareliyastat 2010).

scale has been less common in Finland (Ranta 2005) and has traditionally been locally oriented (Heinimo 2008). The forest chips boom started in Finland at the end of the 1990s, when the Wood Energy Technology Program 1999–2003, which aimed at the development and commercialisation of the use of forest chips, was launched as one of the government's tools for the implementation of renewable energy sources (Hakkila 2004). As a result of this program, the competitiveness of chips as a fuel significantly improved. The use of forest chips grew from 1.7 million m^3 in 2001 (Hakkila 2004) to 6.1 million m^3 in 2009, and it is expected that 13.5 million m^3 of forest chips will be used in 2020 (Puun energiakäyttö 2009).

In Finland, forest chips for energy purposes are mainly produced from logging residues, and pruned and unpruned small-sized trees (Hakkila 2004), and only a minor share is made from large-sized roundwood, stumps, and roots. On the contrary, in the Republic of Karelia, owing to local features, a better raw material for chipping is large-sized roundwood, which is widely available at a reasonable cost. Therefore, in Karelia logging residues and small-sized trees, raw materials with low bulk density, are not used for chipping. Owing to the higher bulk density of roundwood, its harvesting, transporting, and chipping are more efficient than that of uncompacted logging residues and small-sized trees. In addition, the quality characteristics of chips produced from logging residues or roundwood may differ. For example, forest chips produced from logging residues can be contaminated with soil and stones. The use of different raw materials for chipping makes it difficult to compare the overall productivity of the Finnish and Russian forest chip supply systems.

Therefore, this study focuses on the efficiency of the transportation stage, a parameter that can be compared between the countries irrespective of the raw materials used for chipping. This study analyses the efficiency of forest chip transportation by trucks from Karelia to Finland compared with forest chip transportation within Finland. The studied transportation route for forest chips begins from the Lendery terminal in the Republic of Karelia and ends at the power plant in Finland. The distance from the terminal to the border is 25 km and from the border to the power plant in Lieksa is 57 km, making a total of 82 km.

The specific tasks of the study are:
- The analysis of the efficiency of forest chip transportation by chip trucks from Karelia to Finland based on the results of the case study on the forest chip supply from the Lendery wood terminal in the Republic of Karelia to the power plants in Lieksa in Finland;
- The comparison of the efficiency of cross-border forest chip transportation from Russia to Finland with transportation efficiency within Finland in terms of costs and transported volumes;
- The interviewing of truck drivers to obtain subjective descriptions of factors affecting the efficiency of forest chip transportation and to identify measures to improve it.

Materials and methods

The study focuses on the cross-border transportation of forest chips by trucks. Other types of forest chip transport are not considered here. The cross-border transportation of forest chips is the final stage of the Russian–Finnish forest chip supply chain, which begins in this case from felling sites in the Republic of Karelia and ends at power plants in Finland. In the case study, felling, delimbing, and cross-cutting is carried out by harvester, based on a caterpillar excavator Fiat-Kobelco E135SR with an installed harvesting head Kesla 22RH. The forwarding of assortments to the roadside is carried by the forwarder Timberjack 1010D with a payload capacity of about 15 m^3. Then, logs designated for chipping are transported by Volvo log trucks from the roadside, separately from industrial wood, to the terminal in the Lendery village. Comminution is carried out at the terminal as a reasonable compromise between chipping at a landing and at a power plant in Finland, because Russian export duties for roundwood, including energy wood, are higher than are export duties for forest chips (Federal Customs Service of Russia 2009). At the same time, for chip producers it is important that forest chips from Russia to Finland have higher added value compared with unprocessed roundwood for energy purposes produced in Finland. At the Lendery terminal, the logs are chipped into cone-shaped piles by a chipper Heinola 1310RML installed on a truck.

The core part of the supply chain is the transportation of forest chips by trucks from the terminal in Karelia to the heat plants in Lieksa, Finland. Trucks are loaded at the Lendery terminal by a bucket front-loader. The average loading capacity of a truck is about 100 loose m^3 with trailer and about 40 loose m^3 without trailer. Russian transport norms (Instrukciya po perevozke 1996) strictly limit the maximum allowable payload on one axle of a chip truck. Therefore, the use of a chip truck with more axles is more reasonable because of the bigger allowable payload.

On the given transportation route, chip trucks cross the border at a temporary border crossing point located near to the village of Inari. After crossing the border, the trucks drive about 57 km and unload at the Lieksa power plants using a paddle chain system. One of the heat plants in Lieksa is a company-owned boiler house that was initially used only for heat generation for its own sawmill. However, the boiler house is now also used to provide heat for the Lieksa municipality. The total annual energy output of this heat plant is 200 000 MWh of primary energy. About 90% of the fuel for energy production comes from its own sources and about 10% comes in the form of forest chips from Karelia.

The volumes presented in this report are given in solid m^3 if not otherwise stated. A conversion factor of 0.40 was used to convert loose m^3 to solid m^3 of wood chips (Hakkila 2004). When necessary, volume units (m^3) were converted into energy units (MWh) or vice versa, assuming that wood has about a 50% moisture content and about a 2 MWh/m^3 energy content or 0.77 MWh of energy content per 1 loose m^3. The currency exchange rate of the Central Bank of the Russian Federation at 10 September 2010 was used when it was necessary to convert costs in Roubles into Euros. In the conversion, 39.18 Roubles correspond to one Euro. The efficiency of cross-border forest chip transportation is estimated from the following data:

- transportation distance,
- average driving time,
- loading/unloading operations,
- idle time.

Data were obtained from the tachograph recording system installed in the cabin of the truck and covered six runs (Lendery–Lieksa–Lendery). The six deliveries investigated were made in January and February 2010. A comparative analysis of the transportation costs includes the Russian–Finnish cross-border route as well as transportation within Finland and within Russia.

The costs of cross-border transportation were calculated based on the data collected within the study from a transport company delivering forest chips from Karelia to Finland. The data collected are for 2010 and include the cost of fuel, labour, service, and insurance. It should be noted that according to the findings from the interviews, the trucks are only fuelled with Finnish diesel, even though the price of Russian diesel is half as much. This is so that the transport company avoids the risks of unplanned repairs caused by low fuel quality. Annual payoff, overheads, and amortisation costs were calculated according to Gerasimov et al. (2009b). The costs of cross-border transportation do not include value-added tax (VAT) on fuel because companies working on cross-border transportation outside the EU are not obliged to pay VAT (Palvelujen ulkomaankaupan arvonlisäverotus 2010). For comparison purposes, the costs of forest chip transportation within Russia and within Finland were taken from the literature: the costs within Finland were valid for 2003 (Ranta and Rinne 2006) and the theoretical costs calculated by Ilavsky et al. (2007) for the Tihvin district of the Leningrad region were valid for 2006. Finnish costs were indexed to the cost level of 2010 using a 3% average annual increment of transportation costs in Finland (Tilastokeskus 2010). Russian transportation costs were indexed to the cost level of 2010 using data on the annual growth of cargo transportation tariffs in the Leningrad region of Russia (Federal Service of State Statistics 2010).

The costs of forest chip transportation in the Leningrad region were used for the comparison because no reliable data on the costs of forest chip transportation in the Republic of Karelia were available. In addition, it is appropriate to apply these data to the Republic of Karelia because of similarities in road conditions.

Transportation costs were compared as €/MWh at 10 km intervals within a 100 km distance. In order to determine transportation costs at 10 km intervals, the linear interpolation method was used for the theoretically calculated costs in the Tikhvinsky and Boksitogorsky districts of the Leningrad region, because the published costs referred only to the 20, 60, and 100 km intervals.

The average delivered payload of the chip trucks involved in cross-border transportation was obtained from the company receiving the chips from Russia at its power plants in Finland. Further, this value was compared with the average delivered payload of chip trucks transporting forest chips within Finland. In addition, data on the forest chip flow from one terminal in Russia to Finland were obtained from a company engaged in the cross-border transportation of forest chips.

The interviews with truck drivers aimed to identify the impact of different factors on the productivity of their trucks and consequently on the efficiency of forest chip transportation from Karelia to Finland. They were based on a questionnaire designed to obtain individual responses. This was written in Russian and Finnish (Goltsev et al. 2011) because it was planned to interview drivers from both countries. Respondents were interviewed by direct questioning, via post, and by the phone. In total, 11 respondents were interviewed from four different companies in both Russia and Finland. Drivers of both nationalities were almost equally represented, with five respondents from Finland and six respondents from Russia.

Results

Efficiency of forest chip transportation

The quantitative characteristics of the route, such as the average payload of a truck and total volume of forest chips flow, were obtained from the companies supplying chips from Russia to Finland. Table 3.8 shows the main parameters of the studied route.

Table 3.8 Observed parameters of the transportation route from the Lendery terminal, Russia, to the Lieksa power plant, Finland

Parameter	Value
One-way run, km	82
Average duration of one run, hours	6:38
Average payload, m^3	100
Minimum-average-maximum volume of forest chip flow over eight months, m^3/month	327-2770-5217
Total volume of forest chip flow for eight months, m^3	22157

The average transportation distance from the Lendery terminal to the Inari border crossing point was 25 km and from Inari to the unloading point at the Lieksa district heating power plant was 57 km, making a total distance of 82 km. For comparison, in Russia forest chips are cost-competitive only if the transportation distance is less than 50 km (Goltsev et al. 2010). This is a good illustration of the difference between the costs of forest chips in Russia and Finland. The average driving speeds from the Lendery terminal to the Inari border crossing point and from Inari to the Lieksa power plant are presented in Table 3.9.

Table 3.9 Speed of chip trucks on the transportation route from the Lendery terminal in Russia to the Lieksa power plant in Finland

Route section	Distance, km	Speed, km/h			Average driving time, h
		Average	Maximum	Minimum	
Lendery ↔ Inari	25	34	43	30	0:42
Inari ↔ Lieksa	57	66	76	57	0:52

Table 3.9 shows that the average driving speed on the Russian side between Lendery and Inari is 34 km/h, whereas on the Finnish side between Inari and Lieksa it is 66 km/h. The average driving time is almost the same for the Russian and Finnish parts of the route, despite the big differences between the transportation distances in Russia and Finland. These figures clearly reflect the difference between driving conditions on Russian and Finnish roads. The time taken to load in Lendery and unload in Lieksa, the duration of the run on different sections of the route, and idle time consisting of breaks longer than 15 minutes are shown in Table 3.10.

Table 3.10 Table 5. Duration of main operations on recorded routes

Duration (min)	Average	Maximum	Minimum
Time consumption for driving			
Lendery ↔ Inari	45	50	35
Inari ↔ Lieksa	52	60	45
Time consumption for loading and unloading operations			
Loading (Lendery)*	60	–	–
Unloading (Lieksa)	50	60	30
Idle time			
Border (Inari)	36	105	5
Lunch breaks	43	60	30

*Only average loading time was given by the business contact.

Time consumption was based on the time records provided by the business contact for six runs, amounting to 39 hours 45 minutes of working time altogether. Owing to the short period of observations, time spent on maintenance and repair is not shown in Table 3.10.

Table 3.10 shows that crossing the border on average takes 36 minutes, although the maximum and minimum time spent at the crossing point were 105 and five minutes, respectively. Loading at the Lendery terminal was normally carried out at the end of the truck driver's working shift and the duration of this operation was therefore not recorded by the tachograph system on the six observed runs. The average duration of the loading operation was estimated based on the interviews with the transport companies, but it was not possible to estimate the maximum and minimum duration of loading there. Unloading at the Lieksa power plant on average took 50 minutes, with a maximum unloading time of 60 minutes and a minimum of 30 minutes. Lunch breaks on average took 43 minutes, while the minimum and maximum were 30 and 60 minutes, respectively. The total duration of the six recorded runs was 2385 minutes and the average duration of one run was 398 minutes or 6 hours 38 minutes. Driving takes only 48% of the total time of one run because of the relatively short transportation distance. About 22% of the total run time was spent driving the 25 km on the Russian side, and this was almost the same time needed to drive the 57 km on the Finnish side. The next most time-consuming operation is crossing the border, which takes 18% of the total run time. Loading and unloading operations represent relatively small proportions of the total (15% and 13%, respectively). The smallest proportion, 5% of the total run time, was spent on lunch breaks.

The costs of the cross-border transportation of forest chips were compared with the transportation costs within Finland and within Russia (Figure 3.11). The transportation distance on the cross-border route was 82 km and, therefore, for the cost comparison, 80 km was used as a reference distance. According to Figure 3.11, the transportation costs for cross-border transportation are 3.4 €/loose m^3 or 8.5 €/solid m^3. The total supply costs in the case of the cross-border transportation of forest chips is 28.8 €/m^3, which comprises 10.95 €/m^3 for harvesting and forwarding, 3.7 €/m^3 for transporting logs to the terminal (average transportation distance about 50 km), 6.25 €/m^3 for chipping, and 7.93 €/m^3 for other costs. All expenses are given per solid m^3. Road transportation costs for the studied route are 26% of the total supply costs.

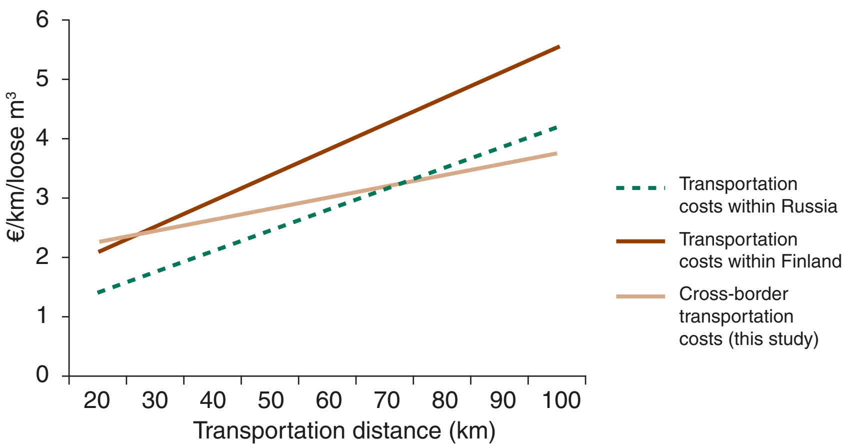


Figure 3.11 Comparative analysis of the costs of the cross-border and the domestic transportation of forest chips.

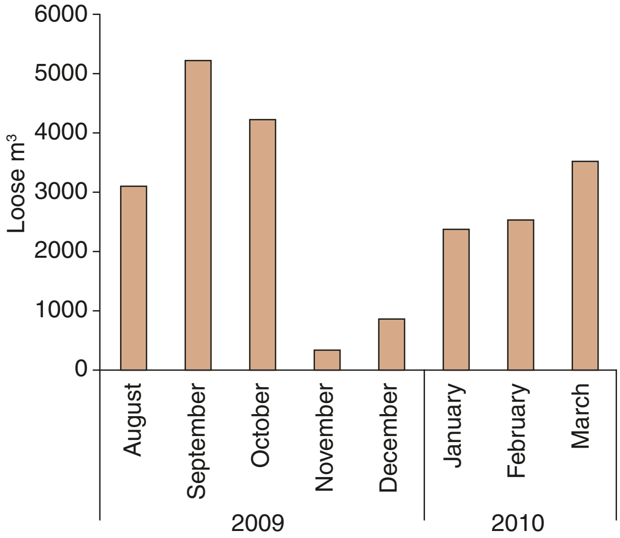


Figure 3.12 Volumes of forest chips transported throughout the year by the business contact.

The productivity of trucks delivering forest chips from Russia to Finland is an important factor affecting transportation efficiency. Based on data provided by the company, the average load of the trucks is 90–110 loose m^3 coming from Karelia and 120–140 loose m^3 coming from Finland to the power plant. The difference is owing to the legislative limitations set in Finland and Russia, where there are differences in the maximum allowable weight of loaded trucks. In Finland, the maximum allowable weight of a truck with six axles is 53 tonnes and for a truck with seven or more axles it is 60 tonnes (Asetus ajoneuvojen käytöstä 1997). In Karelia, the maximum allowable weight of a loaded truck on roads under republic and federal supervision without special permission is 38 tonnes, while with special permission issued by the republic's road authority FGU Uprdor Kola the maximum allowable weight increases on republic roads to 55 tonnes and on federal roads to 44 tonnes (Instrukciya po perevozke 1996). In the case study, on the route from Lendery to Inari the maximum allowable weight can be increased from 38 to 55 tonnes and according to the interviews, drivers receive regularly such permission. The efficiency of supply is also provided by a continuity of forest chip flow. The transport company provided data (Figure 3.12) on the amounts of forest chip supplied throughout the year from Russia to the Lieksa power plant.

As shown in Figure 3.12, the lowest volumes of forest chips were delivered by the business contact in November and December 2009. This was because of the breakdown of the chipper at the Lendery terminal. An inability to quickly change the source of forest chips made this supply chain vulnerable. This is dangerous especially in winter, when the demand for heat is at its highest.

Opinions of forest chip truck drivers

The results obtained regarding respondents' working experiences in the transportation of forest chips, transportation in general, and education indicated high proficiency and long experience in the transportation of forest chips. Most of them had worked in forest transportation for more than five years and all had more than 10 years of working experience in general transportation. In addition, most of them had completed special education and supplementary courses related to forestry and transportation. Therefore, reliable answers to the questions in the specific part of the questionnaire could be expected.

The question regarding the design of trucks used for the transportation of forest chips indicated that 50% of respondents use specially designed trucks, 10% use modified trucks originally designed for other purposes, and 40% did not answer. The drivers saw the importance of personal skills as very strong (18%), strong (28%), moderate (45%), and very low (9%) for the transportation productivity of forest chips. Focus on maximising productivity was very important for 45% of the drivers, important for 19%, and 36% of the respondents did not answer this question. The interviews did not show clearly how important maximising productivity is for the drivers because a relatively large number of respondents did not answer the question. The next question was about the importance of salary as a motivation for the drivers to improve their levels of productivity. Salary was a very important motivation factor for 36% of the interviewed drivers, important for 36%, moderate for 19%, and 9% did not answer the question. These answers are explained by the fact that about 60% of the drivers are on piece-rate wages, fewer than 20% of the drivers have an hourly salary, and about 20% get a combination of hourly and piece-rate wages, depending on workflow and other conditions. Although there was no clear answer to the question about maximising productivity, the answers regarding the payment system clearly illustrate that respondents are highly motivated to increase their levels of productivity.

The interviews revealed that in the given case, the efficiency of the cross-border transportation of forest chips often suffers because of the underloading of the trucks. Of the interviewed drivers, 73% had cases of underloading and only 18% had no cases, while 9% did not answer. Almost half of the drivers felt that underloads have a very strong impact on overall productivity, 27% assumed a strong impact, and 27% a moderate one.

The interview showed that 36% of respondents were forced to carry out unplanned maintenance or to repair their trucks more than five times per year, 45% of the interviewed drivers 2–5 times per year, and only 9% dealt with unplanned maintenance just once a year. For those drivers that answered the question, this means an increase in workload of up to 10% for 30% for respondents, from 10% to 20% for 50% of them, and from 20% to 30% for 20% of them. The drivers pointed out several mechanisms whose breakage strongly affects productivity. About 47% of respondents mentioned the unloading equipment, as medium maintenance 41% indicated the gearbox, and 12% of the drivers mentioned the fuel supply system and transmission. The results on possible causes of truck breakdown are presented in Figure 3.13.

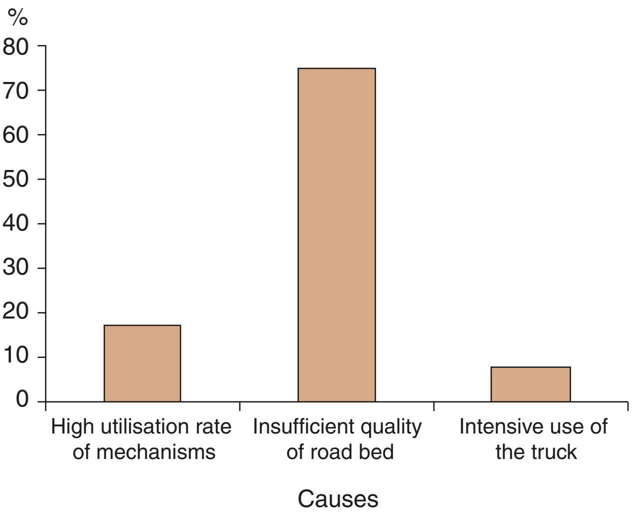


Figure 3.13 Possible causes of truck breakdown.

As shown in Figure 3.13, the insufficient quality of the roadbed is seen as the main cause by 75% of respondents, for 17% the high deterioration of base mechanisms is the main factor, and the intensive use of the truck is the main reason for just 8%. All drivers mentioned that roadbed quality and the development of the road network affect transportation productivity very strongly or strongly.

In drivers' opinions, their productivity depends to some extent on the loading method; 18% consider the relation as very strong, 46% as strong, and 18% as moderate or low. All respondents agree that a front wheel loader is most efficient for loading.

The relation between the unloading method and the overall productivity is not clear for drivers: 27% see a strong correlation, 37% thought it moderate, 9% low, and 27% very low. The commonly used chain unloading system is recognised as the most efficient.

Regarding the return of deliveries to Karelia because of bad quality, 36% of drivers had experienced this, while 64% had not. Idle time at the border was recognised by 64% of the drivers as a very important factor affecting overall productivity, while 36% considered it an important factor.

The majority of drivers indicated idle time during loading/unloading operations as a factor that has a moderate influence on the overall productivity of their trucks. Thus, all these factors affect the productivity of the cross-border transportation of forest chips. The drivers' estimates of the average actual productivity as percentages of the maximum possible productivity are presented in Figure 3.14.

Figure 3.14 shows that, in the drivers' opinions, it is not currently possible to fully utilise the capacities of their trucks. Only 9% estimated that they achieve from 81% to 90% of the maximum possible productivity of their trucks. Most drivers estimated their productivity was between 51% and 80% of the maximum possible. It should be noted that only 9% of the respondents felt their current productivity level was less than 50% of the maximum possible. The drivers pointed out several factors influencing transportation productivity (Figure 3.15).

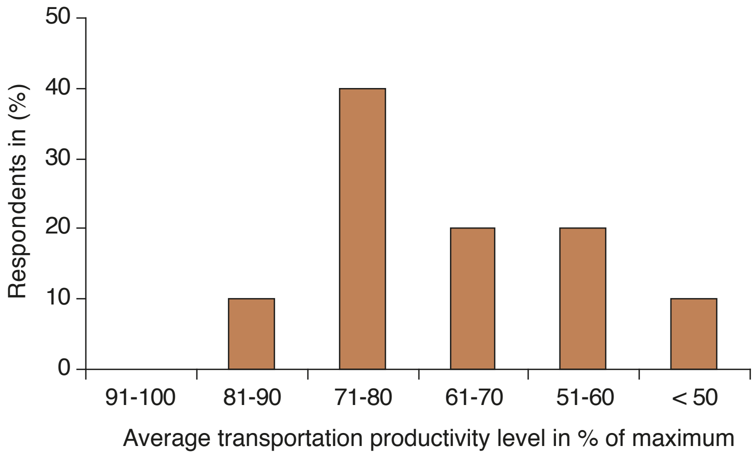


Figure 3.14 The drivers' estimates of the average actual productivity compared with maximum possible productivity.

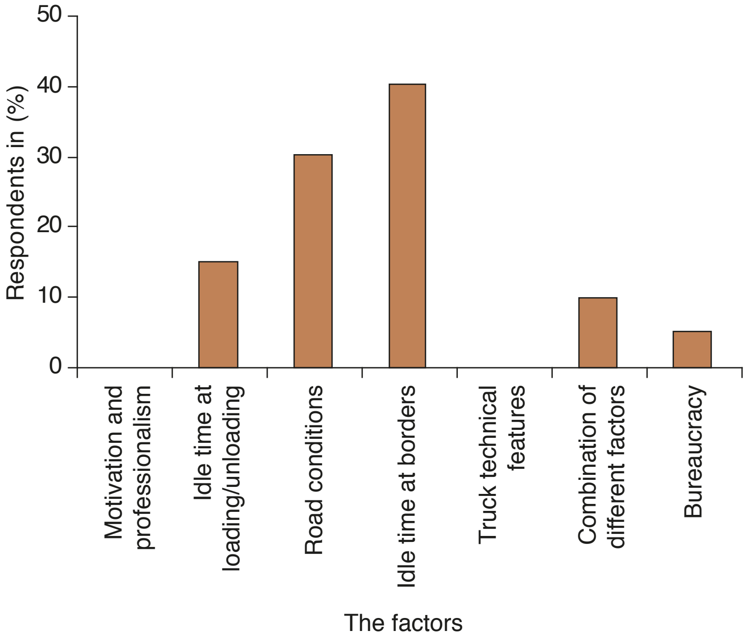


Figure 3.15 The main factors influencing transportation efficiency.

About 40% of respondents underlined idle time at the border as the main factor affecting productivity, while 30% pointed to the road conditions in Russia. Other factors such as idle time during loading/unloading operations, bureaucracy at the border crossing, and a combination of different factors were named as the main issues affecting productivity by 15%, 10%, and 5% of respondents, respectively. Drivers were asked to rank the different factors according to their impacts on transportation productivity (Figure 3.16).

As shown in Figure 3.16, the bad road conditions in Russia and idle time during customs procedures are the most important factors (average ranking 6) affecting transportation efficiency, and those two factors also have the smallest range of deviation among responses. Among the

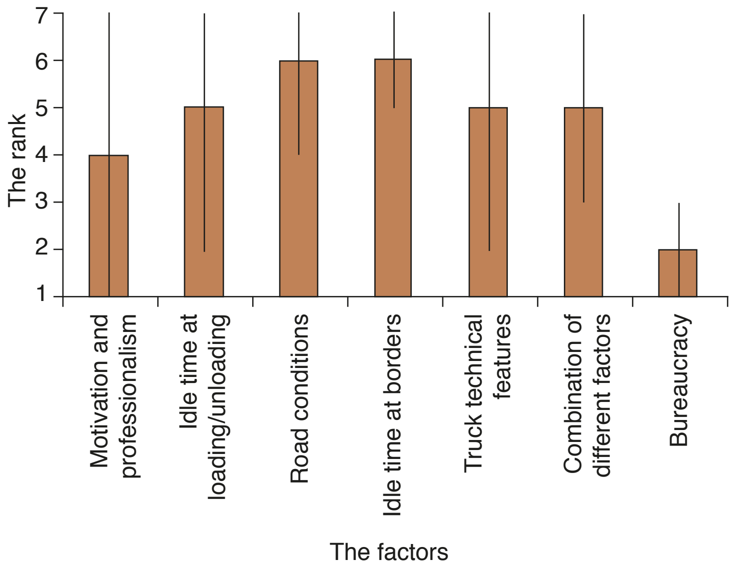


Figure 3.16 Ranking of the main factors affecting transportation efficiency (1 – least important, 7 – most important; the vertical black line on the each bar indicates the deviation of responses).

other factors influencing transportation efficiency are the technical features of the truck and a combination of different factors (average ranking 5). Motivation and professionalism had an average ranking of 4. It is interesting that the drivers ranked differently the apparently related issues of idle time at the border (average ranking 6) and bureaucracy at the crossing point (average ranking 2). This is because idle time at the border is often caused not by bureaucracy but by the excessively large transport flow at the crossing point.

In addition to these factors, the working schedule of the Inari border crossing point was mentioned as a factor affecting the efficiency of forest chip transportation. This subject was not raised during the interviews but appeared later during the discussion with the director of one of the transport companies working on the cross-border route. The current working schedule at the Inari border crossing point is Mondays 15.00 – 20.00, Tuesday to Thursday 7.00 – 19.00, Fridays 7.00 – 17.00, and Saturdays and Sundays it is closed. The current working schedule, in the opinion of the transport company, has a negative impact on the transport flow of forest chips and consequently on its efficiency. As a result, in the case studied the weekly normative plan of 10 round trips to the Lendery terminal was not fulfilled and only eight round trips at most were possible.

On the border between the Republic of Karelia and Finland, there are currently three permanent (Lyttä, Värtsila, and Suoperä) and 12 temporary border crossing points: Korpiselkä, Ristilahti, Kuolismaa, Haapavaara, Voynica, Inari, Mäkijärvi, Rovkuly, Kolvasjärvi, Kokkojärvi, Kivivaara, Syväoro and Hekselä (Federal Agency for Development of the Borders of the Russian Federation 2009). The temporary border crossing points are difficult in terms of their management; some of them work only for roundwood exports and, for many reasons, e.g., road conditions and their remote locations, they can be out of service for uncertain periods of time. According to the interviews, this has a negative impact on cross-border trading. The two permanent border crossing points (Kostomuksha and Värtsilä) are not able to process the traffic flow if the temporary points are closed.

Another factor affecting the cross-border transportation of forest chips is the duration of the slush seasons in Finland and Russia. In the Republic of Karelia, the slush season is one month longer than it is in Finland. During the slush season, the transportation of wood from forests decreases significantly, which can affect the work of chipping terminals if their reserves of wood are not large enough. Moreover, if a terminal is not connected to a road with a hard surface, the transportation of forest chips from the terminal becomes impossible.

Conclusions

The representatives of the transport companies mentioned that the potential to increase productivity is limited by the current working schedule of the Inari border crossing point. According to Decree № 142 from 23.02.1994 with amendments from November 2007 (Article 5, paragraph 3), the supervision and regulatory work of temporary border crossing points should be organised by bilateral agreements, in which local authorities and interested parties should be involved. Currently, there is demand from transport companies to improve the existing situation. However, at the moment it seems that the opinions and suggestions of interested parties, particularly transportation companies, are not adequately taken into account, and communication between the transportation companies and the local authorities is poor. Therefore, certain measures should be taken to improve the operation of the border crossing points. An open discussion process involving all interested parties would help solve the existing problem and find suitable solutions and compromises.

In addition to the infrastructure, there are other ways to improve the efficiency of the cross-border transportation of wood chips. Whereas the minimum reported unloading time was 30 minutes, unloading a modern chip truck with a 100 m^3 load is technically possible in from 30 seconds to 3 minutes, depending on the unloading system used (LIPE 2011). The proper organisation of the unloading process, e.g., decreasing the queuing time, could reduce unloading time.

According to Hakkila (2004), the cost of the road transportation of forest chips accounts for 35% of the total supply cost when using logging residues as a raw material, and 23% for whole-tree chipping. On average, this corresponds to 29% of the total supply cost. At the same time, in Russian conditions the cost of the road transportation of forest chips is 19% of the total supply cost for final felling and 17% on average for the first and second thinnings (Ilavský et al. 2007). It was found that the cost of cross-border transportation is 26% of the total supply cost. Thus, the proportion of transportation costs in the total supply cost is highest for cross-border transportation at 26% compared with 23% and 19% in Finland and Russia, respectively. These costs were compared at a reference distance of 80 km.

The comparison in Figure 12 showed that the transportation costs of forest chips at a 80 km reference distance is the highest within Finland (4.7 €/loose m^3), which is 26% higher than it is within Russia (3.5 €/loose m^3) and 28% higher than cross-border transportation (3.4 €/loose m^3). But the cross-border transportation of forest chips is most expensive on the considered routes when the distance is less than 20 km. When the distance is greater than 20 km, their transportation from Russia to Finland is less expensive than it is within Finland. At a 70 km distance, the costs of cross-border transportation are equal to those in Russia and they are even lower at longer distances. This change in the cost-effectiveness of cross-border transportation can be explained by two factors. With short cross-border routes, the increased proportion of delays related to crossing the border affect the productivity of the trucks and, consequently, the transportation costs. The proportion of fuel costs in the total supply cost increase with distance, but the fuel VAT refund also grows because transport companies engaged in cross-border transportation do not pay VAT. Furthermore, it should be noted that drivers' salaries are lower in Russia.

In addition, transport companies involved in the cross-border transportation of forest chips on this route buy fuel only in Finland to avoid risks related to the poor quality of Russian diesel. Thus, the cost disparity may be explained by the difference between fuel prices, labour costs, and the maximum allowable weight of trucks. The road infrastructure and its condition should also be taken into account, as poor road conditions in Russia may cause additional costs.

The statistics provided by the transport company on the forest chip flow from the Lendery terminal to the Lieksa power plant showed that the supply chain is vulnerable because of its dependence on the availability of raw materials at the terminal or breakdown of the chipper. Russian forest chips supply 10% of the total energy demand at the Lieksa power plant. Storage space at the plant allows for the accumulation of raw materials for a certain period of time and this creates a buffer in supply in order to decrease the risks from any temporary cuts in deliveries.

As an alternative to the transportation of forest chips from Karelia to Finland, deliveries of non-merchantable raw materials (e.g., round energy wood) could be made and chipping could be organised on the Finnish side. However, according to the interviews, such a scheme has already been tested by the companies and presented many challenges. In particular, one of the main problems was the Russian customs classification of round energy wood as IRW. This underlies the difference between customs fees, which for round energy wood are 4 €/m^3 with bark and for

IRW, e.g., pulpwood, are 15 €/m^3 with bark (Federal Customs Service of Russia 2009). Thus, this option is considered risky by the companies because they may be required to pay industrial wood customs fees when transporting round energy wood.

For the cross-border transportation of forest chips, customs fees are the lowest at only 5% of their value, taking into account that Russian forest chips are relatively cheap compared with those of Finnish origin. The price for Russian chips was at its lowest in 2009 when a lot of unclaimed pulpwood was chipped into forest chips on the Russian side and transported to Finland.

According to Ranta (2005), the transportation distance, particularly that of forest chips, will be the main challenge for the efficiency of fuel supply and this is likely to increase in future. As a result, the problems related to transportation cost-efficiency with low-energy intensity will be emphasised. Forest chips are mainly produced from by-products of logging and sawmilling and their procurement operation is often integrated with other forestry operations, such as the procurement of roundwood or industrial wood waste (Asikainen 2001).

The cross-border route studied is 82 km in total, which is within the maximum limit of transportation in Finland. The results of this study have shown that the transportation costs for forest chips delivered from the Lendery terminal in Russia to the Lieksa power plant in Finland are lower than the cost of forest chips transportation within Finland. In the study, it was found that the costs of transportation of forest chips from Russia to Finland are affected by several factors, e.g., the productivity of chip trucks coming from Russia is lower than is that of chip trucks working in Finland, at 90–110 and 120–140 loose m^3, respectively. However, the cost-competitiveness of Russian forest chips in the case considered is supported by lower harvesting costs, lower average salaries in the forest sector, and cheaper fuel for forest machinery. In addition, the relatively weak position of low-quality woody biomass on the Russian domestic market creates a positive precondition for its export to Finland. The limited number of chip producers in Karelia makes the supply chain vulnerable, however, and there are consequent risks related to that. For example, the volume of forest chip flow on the route considered decreased almost ninefold during the two months when the chipper at one of the terminals was broken. At the same time, the development of forest chip production in Russia to a large extent depends on external demand because the local demand for forest chips is low and conventional round energy wood is the predominant type of wood fuel used locally (Raitila et al. 2009).

Respondents indicated that bad road conditions on the Russian side and idle time at the border were among the most important factors influencing cross-border transportation. In addition, other factors affecting transportation productivity, which were not reflected in the questionnaire, were identified during communication with the transport companies. For example, the current working schedules of the Inari border crossing point and the inaccessibility of roads in Russia for at least two months of the year were mentioned by the companies' representatives as factors that have a strong impact on transportation productivity. All these factors together decrease the overall productivity of the cross-border transportation of forest chips. In the case considered, only eight of 10 planned round trips by the chip truck were made during one week. Properly addressed measures can increase overall transportation productivity and reduce transportation costs. Consequently, transportation distances can be expanded to provide large procurement areas for users of Russian forest chips. It is necessary to invest more in the development of the road infrastructure in Russia and improve the customs formalities and legislation at the border crossing.

References

Alakangas, E. 2005. Properties of wood fuels used in Finland, Technical Research Centre of Finland, VTT Processes, Project report PRO2/P2030/05 (Project C5SU00800), Jyväskylä 2005, 90 p. + app. 10 p.

Alakangas, E. 2010. European standard (EN 14961) for wood chips and hog fuel. VTT Technical Research Centre of Finland. Forest Bioenergy 2010 – Book of Proceedings, p. 329–341.

Alakangas, E., Valtanen, J. and Levlin, J.E., 2006. CEN technical specification for solid biofuels – Fuel specification and classes, Biomass and Bioenergy, Volume 30, Issue 11, Standarisation of Solid Biofuels in Europe, Standarisation of Solid Biofuels in Europe, ISSN 0961-9534. doi:10.1016/j.biombioe.2006.06.001.

Asetus ajoneuvojen käytöstä tiellä annetun asetuksen muuttamisesta. §23 Auton ja perävaunun yhdistelmän koko- naismassa. 1997 Available at: http://www.finlex.fi/fi/laki/alkup/1997/19970670.

Asikainen, A. 2001. Design of supply chains for forest fuels. In: Sjöström, K. (ed.). Supply chain management for paper and timber industries. Proceedings of the 2nd World Symposium on Logistics in Forest Sector, 12–15 August 2001, Växjö, Sweden. p. 179–190.

Bing maps. Microsoft Corporation 2010. Available at: http://www.bing.com.

Decree № 142 from 23.02.1994 with amendments from November 2007 (Article 5, paragraph 3). Russian-Finnish bilateral agreement regarding border crossing points (In Russian.) Available at: http://lawrussia.ru/texts/legal_383/doc383a720x887.htm.

Devyatkin, V. (ed.-in-chief). 1999. Sbornik udel'nich pokazateley obrazovaniya otxodov proizvodstva i potrebleniya [Collection of waste generation indexes in production and consumption]. Moscow. State Committee of Russian Federation for Environment. 65 p. (In Russian)

Energeticheskaya strategiya Rossii na period do 2030 goda [Energy strategy of Russian Federation utill 2030]. Utverzdena rasporyazeniem Pravitelstva Rossiyskoy Federacii ot 13 noyabrya 2009 goda № 1715-r. (In Russian)

Eurostat 2009. Demographic Outlook – National reports on the demographic developments in 2007. Luxembourg: Office for Official Publications of the European Communities. 65 p.

Federal Agency for Development of the Borders of the Russian Federation. 2009. Rabochaya gruppa Rosgranici izuchaet opit Finlandii po organizacii I funkcionirovanuyu punktov propuska [The working group of Rosgranitsa is learning the Finnish experience of management of border crossing points]. Avaialble at: http://www.rosgranitsa.ru/node/1301.

Federal Customs Service of Russia 2009. Export statistics. Available at: www.customs.ru

Federal Service of State Statistics. 2010. Indeksi tarifov na gruzoviye perevozki osnovnimi vidami transporta. Procent. Leningradskaya oblast'. Avtomobil'niy. Dekabr'[Federal Department of Statistics. Indexes of main transportation tariffs. Percentage. Leningrad region. Motor-car. December.] (In Russian.) Available at: http://www.gks.ru/ dbscripts/cbsd/dbinet.cgi?pl=1934004.

Gerasimov, Y. and Karjalainen, T. 2009a. Estimation of supply and delivery cost of energy wood from Northwest Russia. Metlan työraportteja / Working Papers of the Finnish Forest Research Institute 123. 21 p. ISBN 978-951-40-2166-4 (PDF). Available at: http://www.metla.fi/julkaisut/workingpapers/2009/mwp123.htm.

Gerasimov, Y. and Karjalainen, T. 2009b. Assessment of Energy Wood Resources in Northwest Russia. Metlan työraportteja / Working Papers of the Finnish Forest Research Institute 108. 52 s. ISBN 978-951-40-2147-3 (PDF). Saatavissa: http://www.metla.fi/julkaisut/workingpapers/2009/ mwp108.htm.

Gerasimov, Y., Karvinen, S. and Leinonen, T. 2009a. Atlas of the forest sector in Northwest Russia 2009. Metlan työraportteja / Working Papers of the Finnish Forest Research Institute 131. 43 p. ISBN 978-951-40-2183-1 (PDF), ISBN 978-951-40-2184-8 (paperback). Available at: http://www.metla.fi/julkaisut/workingpapers/2009/mwp131.htm.

Gerasimov, Y., Sibiryakov, K., Moshkov, S., Välkky, E., Karvinen, S. 2009b. Raschet ekspluatacionnych zatrat lesosechnych mashin. Finnish Forest Research Institute. ISBN 978-951-40-2174-9. Available at: http://www.idanmetsatieto.info/rus/cfmldocs/index.cfm?ID=683andtiedote=viewandtiedote_ID=1799.

Goltsev, V., Ilavský, J., Gerasimov, Y. and Karjalainen, T. 2010. Potential biofuel development in Tikhvin and Boksitogorsk districts of the Leningrad region – The analysis of energy wood supply systems and costs. Forest Policy and Economics 12, no. 4 (2010): 308–316.

Goltsev, V., Trishkin, M. and Tolonen, T. 2011. Efficiency of forest chip transportation from Russian Karelia to Finland”. Working Papers of the Finnish Forest Research Institute 189. Available at: http://www.metla.fi/julkaisut/workingpapers/2011/mwp189.htm.

Google maps. Google, Geocentre Consulting, Tele Atlas 2010. Available at: http://maps.google.com.

Grigoryev, M. 2007. Povishenie roli mestnych toplivo-energeticheskich resursov v obespechenii energeticheskoy bezopasnosti Severo-Zapada Rossii [The increasing role of domestic fuel-energy resources for energy security in Northwest Russia]. Gazovy Business, July-August 2007: 28-34. (In Russian)

Hakkila, P. 2004. Developing technology for large-scale production of forest chips. Wood Energy Technology Programme 1999—2003, Technology Programme Report 6/2004. Final report. Helsinki 2004. 99 p. Available at: www.tekes.fi/english/programm/woodenergy.

Hakkila, P. 2006. Factors driving the development of forest energy in Finland. Biomass and Bioenergy, 30(4), 281-288. Available at: http://linkinghub. elsevier.com/ retrieve/pii/S0961953405001546.

Heinimo, J. 2008. Methodological aspects on international biofuels trade: International streams and trade of solid and liquid biofuels in Finland. Biomass and Bioenergy, 32(8), 702–716. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0961953408000111.

Ilavský, J., Goltsev, V., Karjalainen, T., Gerasimov, Y. and Tahvanainen, T. 2007. Energy Wood Potential, Supply Systems and Costs in Tihvin and Boksitogorsk Districts of the Leningrad Region. Metlan työraportteja / Working Papers of the Finnish Forest Research Institute 64. 37 p. ISBN 978-951-40-2074-2 (PDF). Available at: http://www.metla.fi/julkaisut/workingpapers/2007/mwp064.htm.

Instrukciya po perevozke krupnogabaritnich i tyazelovesnich gruzov avtomobil’nim transportom po dorogam Rossijskoy Federacii. 1996 [Instruction on transportation of large-sized and heavy loads by trucks in Russian Federation] (In Russian).

Kareliyastat 2009. Республика Карелия в цифрах. Население. Численность постоянного населения. [Population in Republic of Karelia]. [Online Document]. Available at: http://krl.gks.ru/digital/region1/DocLib/ dem1.htm.

Kareliyastat 2010. Eksport schepy i toplivnoy drevesini iz Respubliki Karelia. [Export of wood chips and fuel wood from the Republic of Karelia]. 2 p.

Kareliyastat. 2008. Lesopromishlenniy kompleks regionov Severo-Zapadnogo okruga Rossii [Forest sector of the federal regions of Northwest Russia]. Petrozavodsk: Karelian Branch of Federal State Statistics Service (Kareliastat). 201 p. (In Russian).

Kofman, P.D. 2007. Ordering and receiving wood chip fuel, COFORD Connects Note Processing/Products nr 8, Dublin, 2007.

Lindblad, J., Äijälä, O., Koistinen, A. 2008. Energiapuun mittaus. Available at: http://www.metla.fi/metinfo/tietopaketit/mittaus/aineistoja/ energiapuun-mittausopas-2008.pdf

LIPE 2011. Technical specification of the LIPE chip trailers. Available at: http://www.anttiranta.com/pdf/esite/ESITE_LIPE_ENG.pdf.

MED, 2011. Average prices on wood and wood fuels. Petrozavodsk, Russia: The Ministery of Economic Development of the Republic of Karelia, 2011. Petrozavodsk, Russia. Available at: http://www.gov.karelia.ru/ gov/Power/Ministry/Development/Prices/price_wood_1012e.html.

Ministry of the Forest Complex of the Republic of Karelia, 2010. Official request on data obtaining to the Ministry.

Ministry of Trade and Industry, 2000. Action plan for renewable energy sources. Publications 1/2000.

OECD/IEA, 2003. Renewables in Russia – From Opportunity to Reality. International Energy Agency, 2003. ISBN 92-64-105441.

Palvelujen ulkomaankaupan arvonlisäverotus 1.1.2010 alkaen. 2010. Verohallinto. Arvonlisäverotus/Kansainvälinen kauppa. Available at: http://www.vero.fi/?article=2483anddomain=VERO_MAINandpath=5,40andlanguage=FIN.

Puun energiakäyttö 2009. Toimittaja: Esa Ylitalo. Metsähakkeen käyttö nousi yli 6 miljoonan kuutiometrin. Metsäntutkimuslaitos, Metsätilastollinen tietopalvelu. Metsätilastotiedote 16/2010, 28.4.2010.

Pöyry. “Polttoaineiden hintataso.” Bioenergia, no. 4 (2010): 48.

Raitila, J., Virkkunen, M., Flyktman, M., Leinonen, A., Gerasimov, Y. and Karjalainen, T. 2009. The pre-feasibility study of biomass plant in Kostomuksha. Research Report VTT-R-08372-08. 54 p.

Rakitova, O., Ovsyanko, A., Sikkema, R. and Junginger, M. Wood Pellets Production and Trade in Russia, Belarus and Ukraine, 2009. Available at: http://www.forcebioenergy.dk/pelletsatlas_docs/showdoc.asp?id=090520131636andtype=docandpdf=true.

Ranta, T. 2002. Logging residues from regeneration fellings for biofuel production – a GIS-based availability and supply. Thesis for the degree of Doctor of Science. Lappeenranta University of Technology.

Ranta, T. 2005. Logging residues from regeneration fellings for biofuel production–a GIS-based availability analysis in Finland. Biomass and Bioenergy, Volume 28, Issue 2, February 2005, pp. 171–182.

Ranta, T. & Rinne S. 2006. The profitability of transporting uncomminuted raw materials in Finland. Biomass and Bioenergy, vol. 30, no. 3, pp. 231–237.

Regional'naya celevaya programma "Aktivnoe vovlechenie v toplivno-energeticheskiy kompleks Respubliki Karelia mestnich toplivno-energeticheskich resursov na 2007-2010 godi [Regional programme aimed on intensive utilization of local fuels in Republic of Karelia in 2007-2010]. The Republic of Karelia State Government Bodies' Official Web Portal, 2010. Available at: http://www.gov.karelia.ru/gov/News/2010/ 09/0920_02.html.

Regional'naya strategiya razvitiya toplivnoy otrasli Respubliki Karelia na osnove mestnich energeticheskich resursov na 2011-2020 godi [Regional strategy on development of energy sector in Republic of Karelia in 2011-2020]. Official Web Portal of the Government of the Republic of Karelia, 2010. Available at: http://www.gov.karelia.ru/gov/News/2010/09/0920_02.html.

Renewable energy policy review. Finland 2009. In the framework of the EU co –funded project: RES 2020: Monitoring and Evaluation of the RES Directives implementation in EU27 and policy recommendations to 2020.

Roslesinforg. 2008. Svedeniya gosudarstvennogo statisticheskogo nablyudeniya po lesopolzovaniyu za 2007 god [Information about the state statistical monitoring on forest use in 2007]. (In Russian)

Syunev, V., Sokolov, A., Konovalov, A., Katarov, V., Seliverstov, A., Gerasimov, Y., Karvinen, S. and Välkky, E. 2009. Comparison of wood harvesting methods in the Republic of Karelia. Metlan työraportteja / Working Papers of the Finnish Forest Research Institute 120. 117 p. ISBN 978-951-40-2162-6 (PDF). Available at: http://www.metla.fi/julkaisut/workingpapers/2009/mwp120.htm.

The republic of Karelia in brief. The Republic of Karelia State Government Bodies' Official Web Portal. Available at: http://www.gov.karelia.ru/gov/Different /karelia3_e.html.

The Republic of Karelia State Government Bodies' Official Web Portal, 2010. Lesnoy otrasli Karelii udalos' spravitsya s trudnostyami [The forest sector of Karelia has overcome the obstacles] Available at: http://www.gov. karelia.ru/gov/News/2010/02/0218_03.html.

Tilastokeskus, 2010. Kuorma-autoliikenteen kustannukset nousivat vuodessa 2,7 prosenttia. Kuorma-autoliikenteen kustannusindeksi. Available at: http://www.tilastokeskus.fi/til/kalki/2009/12/kalki_2009_12_2010-01-18_tie_001_fi.html.

3.2 Ergonomic characterisation

Introduction

This chapter presents the results of the study described in Gerasimov and Sokolov (2009). In Russia, wood harvesting has been associated with a high risk of fatal accidents because of the low level of mechanisation with deaths estimated at 1.4 per 1 million m^3 of wood cut (Gerasimov and Karjalainen 2008). Recently, special attention has been paid to safe working conditions in harvesting operations (corporate social responsibility). Moreover, comfortable working conditions will make harvesting activities more attractive to young people and thus employment in a harvesting company will become more popular (Syunev et al. 2008).

Owing to the ergonomic feasibility of harvesting operations being a critical element for the development of wood harvesting in Russia, the main objective of this study was to compare the ergonomic performance of harvesting machine operators' work and propose viable solutions to improve the work environment.

Materials and methods

There is a need for a comprehensive approach towards the evaluation of the ergonomic performance of harvesting operations and selection of the most appropriate technology for Russian conditions. To evaluate the efficiency of the harvesting methods currently used in Russia, the authors performed comprehensive field studies. The Republic of Karelia in Northwest Russia was selected as a study region because its territory is representative of the wide range of harvesting machinery used and the fact that nearly all employed harvesting technologies in different natural conditions are typical for Northwest Russia. The study was performed in 2007–2009 and it involved 15 harvesting companies, which provide approximately 40% of the total harvest in Karelia. The selected companies perform harvesting operations across the whole territory of the Republic of Karelia (Figure 3.17) in different natural and production conditions using both Russian and foreign machinery and applying the following logging methods:

- CTL(Harv+Forw) – fully mechanised cut-to-length (CTL) harvesting: felling, delimbing and cross-cutting with a harvester; extracting with a forwarder;
- FT(FB+Skid) – fully mechanised full-tree (FT) harvesting: felling with a feller buncher; extracting with a grapple skidder;
- CTL(ChS+Forw) – partially mechanised CTL harvesting: felling, delimbing and cross-cutting with a chainsaw; extracting with a forwarder;
- TL(ChS+Skid) – partially mechanised tree-length harvesting (traditional): felling with a chainsaw; delimbing with a chainsaw/axe; extracting with a cable skidder;
- FT(ChS+Skid+Delim) – partially mechanised FT harvesting: felling with a chainsaw; extracting with a cable skidder.

A common approach was used for field data collection and processing. Different parameters that affect ergonomics and work conditions were measured directly in the workplaces in actual working conditions. The results were then compared with the effective norms and standards, and the degree of compliance with the stipulated values was determined. The obtained estimates for the degree of compliance for all the measured parameters were integrated into one indicator – the so-called integral work severity rate. This permits the direct comparison of working conditions in different workplaces. A higher severity rate implies harder working conditions. Depending on this value, working conditions were categorised as comfortable, relatively uncomfortable, extreme, or over extreme.

Collection and processing of field data

Field research was carried out at 23 harvesting sites, the locations of which are shown in Figure 3.17.

A total of 25 harvesting machines of 13 models (harvesters, forwarders, feller buncher, cable, and grapple skidders) were studied during the field measurements (Table 3.11).

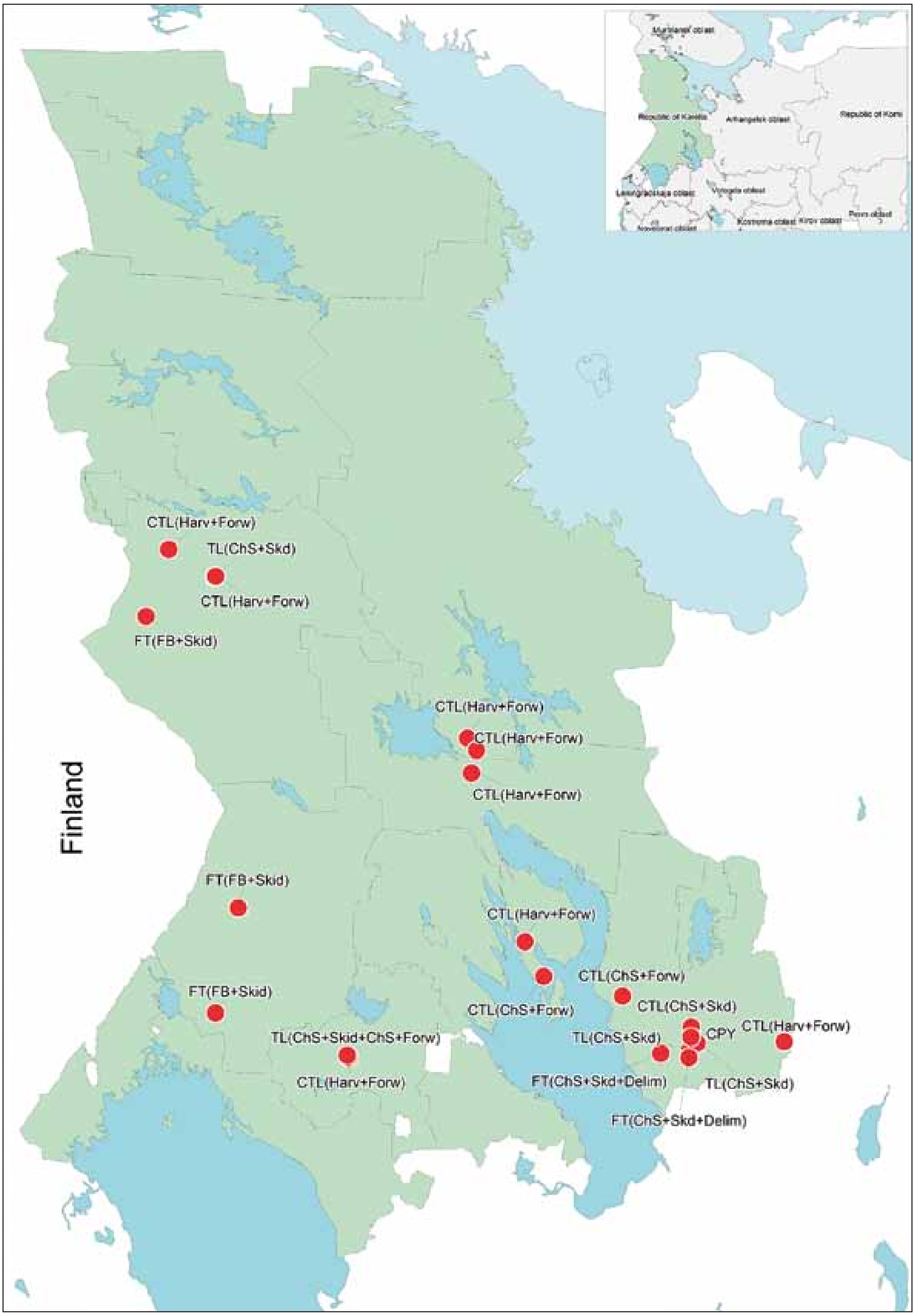


Figure 3.17 Map of the study area

Table 3.11 The studied harvesting machines

Technology	Type of machine	Model	Number
Cut-to-length	Harvester	John Deere 1070D	2
	Harvester	John Deere 1270D	2
	Harvester	Volvo EC210BLC	1
	Harvester	Valmet 901.3	1
	Harvester	Valmet 911.3	1
	Forwarder	Timberjack 1010D	3
	Forwarder	John Deere 1110D	3
	Forwarder	John Deere 1410D	2
	Forwarder	Valmet 840.3	1
Full-tree	Feller buncher	Timberjack 850	1
	Skidder, grapple	Timberjack 460D	3
Tree-length and full-tree	Skidder, cable	TDT-55A	3
	Skidder, cable	TLT-100A	2

Altogether, more than 120 ergonomic parameters listed in the effective Russian and Swedish ergonomic standards and norms were measured in the course of the study, including:

- Geometrical characteristics such as the comfort of the cab layout and seat, location of controls and the operator's body position were measured using a drawing scale, a measuring tape, and a goniometer. Three measurements per parameter were averaged.
- Forces on hand- and foot-operated controls were measured using a laboratory dynamometer. Five measurements per parameter were averaged.
- Parameters of noise and whole-body vibration were measured separately on all operations of the working cycle using a vibrometer and a noise meter. Altogether, 20 measurements per operation within the working cycle, and the weighting according to the operation's share in the working cycle time, were averaged.
- The degree of windshield cleaning was defined using photo images.

The average share of work time during which the operator has to be in an uncomfortable work posture is another important factor that affects the overall comfort of operating the machine. The working cycle was analysed according to Frumkin et al. (1999) and was defined using the coefficients of work repetitiveness and complexity.

Compliance with the effective standards and guidelines

The compliance of these ergonomic characteristics with the effective standards and norms was defined according to Frumkin et al. (1999). The following sources of ergonomic standards and guidelines were taken into account:

- State standards of the Russian Federation (GOST R 51863-2002, GOST 12.2.102-89, GOST 12.1.012-90, GOST 12.1.003-83, GOST 12.2.120-88);
- Ergonomic guidelines by VNIITE (1983);
- Ergonomic guidelines by the Swedish National Institute for Working Life, The Forestry Research Institute of Sweden (SkogForsk) and the Swedish University of Agricultural Sciences (Frumerie 1999);
- Ergonomic guidelines by Peskov (2004) and Frumkin et al. (1999).

The state standards of the Russian Federation were prioritised when deciding between different requirements.

Categorising working conditions

Ergonomic characteristics were grouped as follows:
- Location and course of hand- and foot-operated controls.
- Force required to operate the controls.
- Work posture of the operator.
- Operator's seat.
- Cab and seat position in the cab.
- Repetitiveness and complexity of the work.
- Visibility of working and moving directions and cleanliness of the windshield.
- Noise.
- Whole-body vibration.

The grading of machine sophistication by ergonomic group was then carried out using the integrated indicator shown below:

$$p = \sum_{i=1}^{m} V_i \cdot \alpha_i \quad , (3.1.3.1)$$

where:
V_i – degree of compliance of the i^{th} requirement;
α_i – weight of the i^{th} requirement out of m requirements in the ergonomic group.
Each integrated indicator was valued from 0 to 1. The higher the value, the better the degree of machine sophistication was. Thus, different machines could be compared using particular ergonomic requirements. The total grading of machine sophistication by ergonomics was performed using the work severity rate (Frumkin et al. 1999). The work severity rate can be valued from 0 to 6. A higher value means a higher severity of conditions of work. Thus, different machines can be compared using ergonomic factors.

Results

Machines for the CTL harvesting method

Harvesters

Observations on the work cycles of the harvesters, video filming, and a time study showed the following distribution of the harvesters' working cycles from an ergonomics point of view: processing (delimbing and cross-cutting) 53%; tree felling 16%; travel (movement of the machine to a new position) 4%; and idling (orientation when motionless) 27%.

Regarding uncomfortable work postures, the harvester is a comfortable machine. Valmet and Volvo harvester operators worked almost completely without discomfort in typical conditions. This is because these harvester models have a rotating cab and the operator can always observe the operation process looking directly ahead and without having to turn his or her head at large angles. John Deere harvester cabs do not rotate and, therefore, the time spent in uncomfortable work postures was about 8%. An uncomfortable position mainly meant that the operator had to turn his or her head at significantly large angles in order to monitor cross-cutting and delimbing. Table 3.12 shows the main integrated indicators of the working conditions for the surveyed harvester models. The indicators varied between 0 and 1. The higher the indicator, the better the working conditions were.

Table 3.12 Main integrated indicators of working conditions for logging machine operator's work

Ergonomic characteristics	John Deere 1070D	John Deere 1270D	Volvo EC210BLC	Valmet 901.3	Valmet 911.3	John Deere 1010	Timberjack 1110D	John Deere 1410D	Valmet 840.3	Timberjack 850	Timberjack 460D	TDT-55A	TLT-100
Location and course of controls	0.86	0.86	0.87	0.75	0.75	0.89	0.82	0.84	0.70	0.90	0.73	0.68	0.84
Force required to operate controls	1.00	0.98	0.99	1.00	1.00	0.90	1.00	0.99	1.00	1.00	0.98	0.71	0.70
Hand-operated controls	0.89	0.89	0.88	0.81	0.81	0.87	0.86	0.86	0.84	0.84	0.90	0.50	0.55
Foot-operated controls (pedals)	0.90	0.89	0.91	0.81	0.81	0.87	0.87	0.89	0.77	0.98	0.72	0.80	0.94
Work postures	0.89	0.89	0.89	0.78	0.78	0.90	0.90	0.89	0.75	0.91	0.89	0.87	0.84
Operator's seat	0.86	0.86	0.73	0.75	0.75	0.88	0.86	0.86	0.77	0.70	0.70	0.40	0.55
Cab and seat position	0.74	0.74	0.72	0.71	0.71	0.65	0.71	0.72	0.65	0.75	0.54	0.47	0.66
Noise	0.75	0.74	0.70	0.76	0.71	0.61	0.62	0.70	0.64	0.60	0.33	0.19	0.32
Vibration	1.00	1.00	0.99	1.00	1.00	1.00	0.98	0.99	0.98	0.98	0.69	0.21	0.55
Visibility angles	0.81	0.81	1.00	0.48	0.48	0.99	0.99	0.97	0.98	0.63	0.99	0.97	0.97
Visibility in the operation direction	0.86	0.97	0.99	1.00	1.00	0.95	0.89	0.79	0.85	0.99	0.45	1.00	1.00
Visibility in the moving direction	1.00	0.99	1.00	1.00	1.00	0.98	0.46	0.46	0.46	1.00	0.00	0.99	1.00
Cleanliness of the windshield	0.90	0.90	0.63	0.69	0.69	0.53	0.71	0.71	0.67	1.00	0.56	0.00	0.70
Repetitiveness	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.81	0.31	1.00	1.00
Complexity of work	0.91	0.91	0.91	0.91	0.91	0.98	0.98	0.98	0.98	1.00	1.00	0.91	0.91

Valmet harvesters received lower scores in the "location and course of controls" because they did not comply with three of the Russian norms and standards, namely the diameter of the control handle falls outside the recommended range (49 mm in comparison with the norm of 20–40 mm); the distance between pedals operated with the same foot was too small (40 mm in comparison with the norm of >50 mm); and the pedal stroke distance was too small (50 mm in comparison with the norm of 70–100 mm).

Lower scores in the "work postures" and "operator's seat" indicators for Valmet were caused by the fact that its cabs were considered relatively more cramped compared with John Deere's cabs. This resulted in noncompliance with the Russian norms set for the longitudinal and vertical seat adjustment range and, consequently, a less comfortable body position (in terms of the angles at the body joints). Volvo's seat had too narrow armrests and no adjustable seat backrest.
The noise and vibration parameters of the surveyed harvester models did not differ significantly. The "noise" integrated indicator values were close to 0.7, while "vibration" scored close to 1. The comparatively low visibility angle values for Valmet machines resulted from the fact that the vertical observation angle, which is of particular importance for harvesters, was at the lower limit of the range recommended by Russian standards. The work severity rates for all analysed harvesters based on the measured data were estimated at less than 3.4, namely 3.2–3.4. Thus, for operators of harvesters working conditions can be considered to be "comfortable" (Figure 3.18).

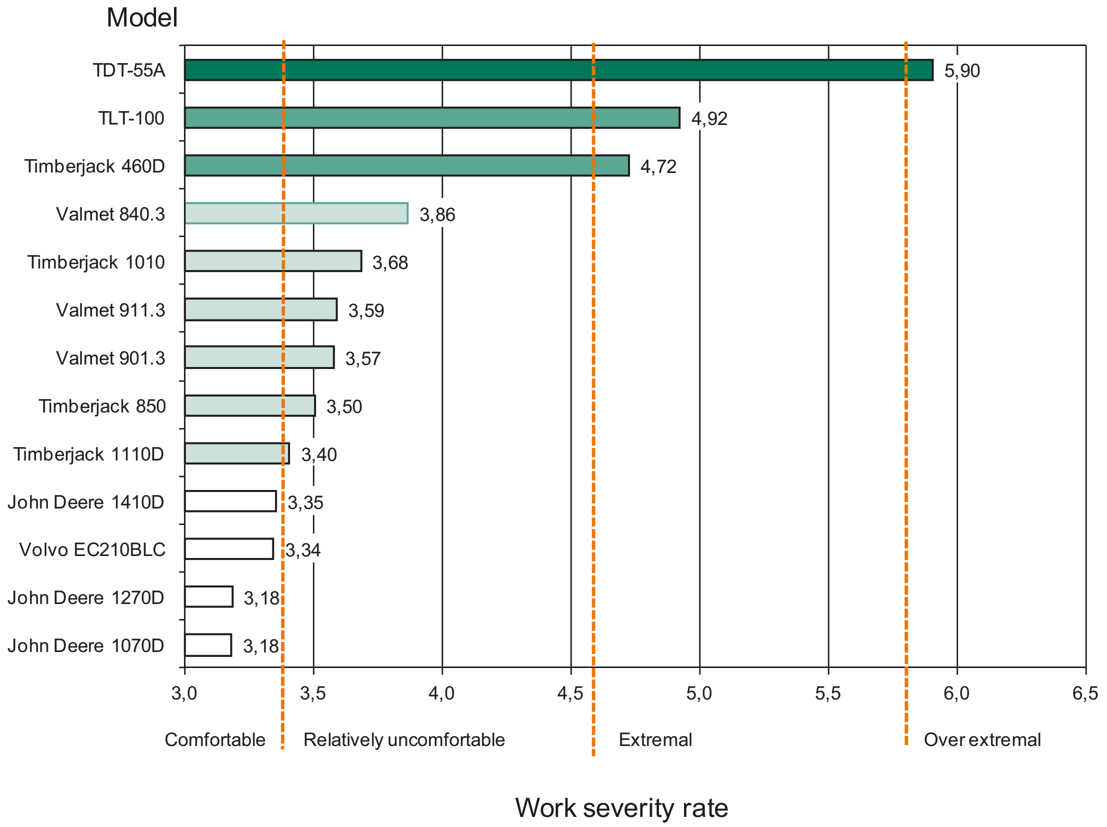


Figure 3.18 Work severity rate on ergonomic performance for harvesting machines operator's work.

Forwarders

A time study showed the following distribution of the forwarder's working cycle from an ergonomics point of view: loading and unloading 73%; travel loaded (forwarding) 16%; travel empty 8%; and idling (motionless when orientation) 3%. According to the time study, forwarder operators spent a considerable amount of time, 23% of the total work time on average, in uncomfortable work postures. Uncomfortable postures involved turning the head and body by large angles during the loading and movement of the machine.

Table 3.12 shows the main indicators describing working conditions for the analysed forwarder models. The Valmet 840.3 forwarder gained the lowest scores for the "location and course of controls" and "foot-operated controls (pedals)". This can mainly be explained by the fact that, similar to the harvesters of the same brand, the distance between the pedals operated with the same foot and the pedal stroke did not comply with the recommended norms. "Work postures" and "operator's seat" indicators were lower because the adjustability of the seat position was at the limits of the recommended range. The "visibility of the moving direction" was substantially higher in a John Deere 1010 forwarder, because it has a much shorter front (a more compact engine room). The "visibility of the operation direction" was somewhat lower in a John Deere 1410D forwarder, mainly because of the overall large dimensions of this model.

Thus, working conditions of the operator were considered to be "comfortable" (I=3.4) for the Timberjack 1110D forwarder and "relatively uncomfortable" (the work severity rate I being between 3.4 and 4.5) for the rest of the models. Similar to harvesters, the difference in the work severity rate was not significant (Figure 3.18).

Machines for the full-tree and tree-length harvesting methods

Feller buncher

Only one feller buncher model was analysed in the course of the study, namely the Timberjack 850. A time study showed the following distribution of feller bunchers' working cycles from an ergonomics point of view: processing (setting the felling head at the tree and bunching) 58%; felling 9%; and travel (movement of the machine to a new position) 33%.

This machine proved to be the best in terms of the majority of the evaluation indicators. Table 3.12 shows the results of the measurements. According to the measurement data, the working conditions of the operators of the Timberjack 850 feller buncher fell into the category of "relatively uncomfortable" because of the value of the work severity rate *I* being between 3.4 and 4.5, namely 3.5 (Figure 3.18).

Skidders

Finally, two models of Russian-made tracked skidders – TDT-55A and TLT-100 manufactured by Onezhsky Tractor Plant – and one model of a wheeled grapple skidder – Timberjack 460D – were analysed. The time study showed the following distribution of a Russian tracked skidder's working cycle from an ergonomics point of view: travel loaded (skidding) 28%; travel empty 38%; loading 15%; and idling (motionless when trees hooking) 19%. The average time during which the operator had to be in uncomfortable work postures was 25% of the total work time. Uncomfortable work postures here were more diverse than they were in the cases of the other machines.

The time study showed the following distribution of the Timberjack 460D grapple skidder's operation time from an ergonomics point of view: travel loaded (skidding) 45%; travel empty 39%; loading 12%; and idling (motionless when orientation) 4%. Owing to the working methods used with the wheeled grapple skidders and the cab design of the analysed skidder, the operator had to spend a considerable amount of time in uncomfortable work postures, namely 31% of the work time. A typical uncomfortable work posture occurred when the operator had to turn his or her head and body at large angles to monitor loading and unloading processes, and also when moving the machine in order to monitor and adjust the grapple and bunch positions.

The results for the skidders are shown in Table 3.12. For the TLT-100 skidder, most indicators were better than they were for the TDT-55A skidder. This is because the TLT-100 is a later model equipped with a more comfortable and spacious cab, a more comfortable spring-mounted seat, and so on. This is why the working environment indicators are two to three times better for the TLT-100 skidder.

The main weaknesses of the Timberjack 460D were a confined cabin, substantially high noise level, and a lack of visibility (visibility of the moving direction does not comply with the recommendations at all, because the forward ground visibility was more than 14 m). In addition, a high level of repetitiveness should be noted. Thus, the working conditions of the TLT-100 skidder operators can be considered to be "extreme" (*I*=4.9, within 4.6–5.8), while with the TDT-55A skidder they were "over extreme" (*I*=5.9) (Figure 3.18). The operators' working conditions with the Timberjack 460D skidder can be considered to be "extreme" (*I*=4.7).

However, there was a significant difference in the measurement-based and personnel survey-based severity rates of work (Sokolov et al. 2008). Naturally, in such conditions only operators that do not perceive the conditions to be over extreme, thanks to their good adaptation skills, stay in the job. Other operators simply quit the work. This can be seen in the presented results, since for this study operators that have substantial work experience with these machines were interviewed.

Discussion and conclusion

The latest models of John Deere and Volvo machines held the leading positions regarding "comfortable" conditions (Figure 3.18). For other machines used in CTL harvesting, the results were almost similar, namely each of these machines was assessed as "relatively uncomfortable". The Valmet 840.3 had somewhat lower results together with the Timberjack 850 feller buncher. These were followed by the significantly worse Timberjack 460D skidder and Russian TLT-100 skidder. They had similar work severity rates and they were assigned to the "extreme" working condition category. The working conditions of the TDT-55A skidder turned out to be totally unacceptable with regard to the present requirements.

The Timberjack 850 feller buncher provided the most ergonomic controls. Altogether, almost all the machines had rather good values for this indicator; however, for the Valmet machines and the Timberjack 460D grapple skidder, these values were somewhat lower than they were for the John Deere machines. Russian tracked skidders, especially the TDT-55A, demonstrated substantially lower levels for this integrated indicator.

John Deere CTL harvesting machines were the leaders based on the ergonomic indicators related to the workplace: cab entrance, cab interior, and operator's seat and controls. For the Valmet and Timberjack 460D machines, these values were somewhat lower. The value of the workplace indicators for the TLT-100 skidders follows them closely. For the TDT-55A, these indicators were considerably lower, even compared with the TLT-100.

The harvesters, forwarders, and tracked skidders showed good results with regard to the repetitiveness and complexity of the work indicators. The feller bunchers' values were slightly lower, and the wheeled skidder's even lower. In both cases, this was because of the high level of repetitiveness (compared with the standards); in other words, the job was monotonous.

Visibility was one of the few indicators where Russian machines gained good results. The TLT-100 skidder even received the best score. However, the results were ambiguous because visibility is impacted by many factors, such as the dimensions of the cab and those of the whole machine, size of the windows, operator's eye position with regard to windows, and so on. The Timberjack 460D skidder had the lowest values in visibility because of its very long engine room, limiting visibility at the front of the machine.

The harvesters achieved better results regarding the noise and vibration characteristics, with forwarders following close behind. The Timberjack 460D skidder and TLT-100 skidder demonstrated poor results (mainly owing to the noise). The TDT-55A skidder was inferior regarding this indicator.

A summary of the evaluation of the machines by ergonomic parameters showed that the best working conditions in terms of ergonomics and occupational safety were provided by the "harvester + forwarder" system in CTL harvesting. Within this combination, the John Deere machine system showed the best results, while the Volvo and Valmet machine systems had lower ergonomic indicators. The “harvester + forwarder” technology was closely followed by the “feller buncher + grapple skidder” in fully mechanised FT harvesting, the difference not being significant. The traditional Russian tree-length harvesting carried out with cable skidders showed the worst results in terms of ergonomics, work severity, and occupational safety. When a partially mechanised harvesting system is used, the use of the TDT-55A skidder should be as limited as possible, because, on the whole, they do not comply with present ergonomics requirements (the “extreme” working conditions score).

References

Cabins and work places for operators of tractors, self-propelled road-construction machines, single-axial haulers, dump-trucks and self-propelled agricultural vehicles. General safety requirements (1988) State standard, GOST 12.2.120-88.

Frumerie, G. (ed.), 1999: Ergonomic guidelines for forest machines, SkogForsk, Uppsala, 88 p.

Frumkin, A.A., Zinchenko, T.P., Vinokurov, L.V., 1999: Methods and means of ergonomics during design. Transport University, Saint-Petersburg, 178 p.

Gerasimov, Y., Karjalainen, T., 2008: Development program for improving wood procurement in north-west Russia based on SWOT analysis. Baltic Forestry 14(1), p. 85–90.

Gerasimov, Y. and Sokolov, A. 2009. Ergonomic characterisation of harvesting work in Karelia. Croatian Journal of Forest Engineering 30 (2): 159–170

Harvesting and floating machines, forestry and silvicultural tractors. Safety requirements, methods for control of safety requirements and occupational safety evaluation (1989) State standard, GOST 12.2.102-89.

Harvesting machines, forestry and silvicultural tractors. Safety requirements (2002) State standard, GOST R 51863-2002.

Machine noise. Methods to determine noise characteristics. General requirements (2002) State standard, GOST 23941-2002.

Methods of noise measurement at work places (1986) State Standard, GOST 12.1.050-86.

Noise. General safety requirements (1983) State standard, GOST 12.1.003-83.

Peskov, V.I. 2004: The basics of ergonomics and design of cars. Technical University, Nizhnii Novgorod, 223 p.

Sokolov, A., Syunev, V.S., Gerasimov, Y.Y., 2008: Comparison of skidders and forwarders in working conditions and work safety, Forest and business 1(41), 56–61.

Syunev, V.S., Sokolov, A.P., Konovalov, A.P., Katarov, V.K., Seliverstov, A.A. Gerasimov, Yu.Yu., Karvinen, S., Valkky, E., 2008: Comparison of wood harvesting methods in logging companies of the Republic of Karelia. Finnish Forest Research Institute, Joensuu, p. 126.

Vibration safety. General requirements (1990) State standard, GOST 12.1.012-90.

VNIITE, 1983: Ergonomics. Principles and recommendations: Methodology guidelines. All-Russian Research Institute of Technical Aesthetics, Moscow, 184 p.

3.3 Forest environment

3.3.1 The impact of wood forwarding on forest soils

Introduction

This chapter presents the results of the study described in Gerasimov and Katarov (2010). The fully mechanised CTL wood harvesting system, based on a single-grip harvester and a wheel forwarder, has become more common in Russia (Gerasimov et al. 2008). Many reasons are given for this statement, including a reduction in labour requirements, work safety risks, environmental damage, and landing areas in comparison with the traditional tree-length and FT systems. In many specific conditions, the CTL system is cost competitive with tree-length harvesting. However, some of the advantages have not been sufficiently defined for specific conditions, particularly related to cross-country ability and ecology.

Mechanised CTL harvesting in thinning and clear felling and extraction are potentially damaging to harvesting sites, as the operations are conducted under all weather conditions involving predominantly heavy machinery (Zeleke et al. 2007). Extreme machine sinkage has a direct influence on productivity, fuel consumption, and the cost of harvesting operations, and leads to site disturbance and soil damage. This is especially true in areas with soft soils in spring and autumn, when specific options are used to improve the operational capability of the existing CTL system, such as “bogie tracks” and “slash reinforcement” (Figure 3.19).

A forwarder equipped with a bogie track has a low average ground pressure on soil in comparison with a conventional wheel with a tyre. Consequently, the external motion resistance on soft terrain is much lower, and drive speed and efficiency are improved. In addition, sinkage and soil compaction are reduced and damage to the ecology (terrain) is minimised (Batelaan 1998).

CTL harvesters spread limbs and tops in their paths as they process stems. Trails covered with slash avoid rut formation, show lower decreases in porosity, and saturate hydraulic conductivity (Eliasson and Wästerlund 2007; McMahon and Evanson 1994; Jakobsen and Moore 1981). The effect of a residue layer in reducing soil compaction is considered to be positive, although a statistically significant influence has not been found (McDonald and Seixas 1997).

Several studies (Bygdén et al. 2003; Šuŝnjar et al. 2006; Sakai et al. 2008; Syunev et al. 2009) have shown an advantage when covering extraction trails with slash or using a bogie track. However, the benefits have not been clearly defined for specific conditions. This research aimed

Figure 3.19 Bogie track and slash reinforcement

to investigate how a bogie track and slash reinforcement influence the sinkage and compaction of prevalent silt loam soil, and how these effects interact with forwarder travel and moisture content.

Methods and data

The first study experiment on the effect of a bogie track was carried out at a cutting area near the town of Medvezhegorsk in the Republic of Karelia. The tests were conducted in late spring 2009. The forwarder used in the study was a Ponsse ELK. The second study experiment on the effect of slash was carried out at a cutting area near the town of Vyshny Volochek in the Tver region, Russia. The tests were conducted in early autumn 2009. The forwarder used in the study was a John Deere 1410. The descriptions of the cutting areas and machinery are shown in Table 3.13.

Table 3.13 Description of harvesting sites and machinery

Region	Cut area	Tree species	Stock	Stem volume	Forwarder	Loading, per test pass
	ha	%	m^3/ha	m^3		
Karelia	16.5	Pine, 30 Spruce, 30 Birch and Aspen, 60	162	0.215	6WD Ponsse ELK Carrying capacity: 13 t Tyres: front – 700/55×34, back – 710/45×26.5, pressure: 350 kPa Ground clearance: 0.67 m Tracks: 700×26.5	13 tons (16 m^3 wood)
Tver	21.2	Spruce, 30 Birch, 20 Aspen, 50	252	0.314	8WD John Deere 1410 Carrying capacity: 14 t Tyres: front and back 710/45×26,5, pressure: 350 kPa Ground clearance: 0.605 m Tracks: "Olofsfors" 700×26.5	13 tons (16 m^3 wood)

The soils in the test areas were silt loams, and moisture contents were 80%, 88%, and 93%. The forwarders were equipped with 710/45 × 26.5 tyres inflated to 350 kPa, and passed over the plots in one direction at about 4 km/h. One pass was defined as one trip of the loaded machine with a loaded weight of 13 tons of wood.

Six linear test plots (30 × 4 m) were installed in cutting areas. On each plot, measurement points were set as follows: left rail, right rail, and cutting strips (monitoring of natural properties). The rut depth was measured in both right and left rails and the average value of the trail depth was calculated. To determine the soil compaction, an organic layer was removed from each measurement point and soil samples were taken using a soil hammer. Soil samples were taken at measurement points according to a standardised methodology (GOST 12071-84) from the surface layer of 0–5 cm in the central zone of the skid trails. The soil samples were delivered to the soil laboratory in airtight packaging and weighed with electronic balances with a resolution of 0.01 g. The bulk density of the soil samples was also determined.

The following six treatments (combination of ground contact devices, surfaces and moisture contents *W*;) with one to 10 passes were assigned to each of the plots within each block:

- forest soil, conventional wheel with tyre, $W = 93\%$, (KW93)
- forest soil, bogie conventional track 700×26.5, $W = 93\%$, (KT93)
- forest soil, conventional wheel with tyre, $W = 80\%$, (KW80)
- forest soil, bogie track, $W = 80\%$, (KT80)
- 15 kg/m^2 slash layer, conventional wheel with tyre, $W = 88\%$, (TW88), and
- 15 kg/m^2 slash layer, bogie combination track 700×26.5, $W = 88\%$, (TT88).

The choice of the number of passes equal to 10 was made based on a previous study that indicated that the most compaction occurs within the first trips (Syunev et al. 2009). The number of rut depth and soil samples for each treatment was 20 and 44, respectively. The choice of the number of soil samples after each pass for each treatment, namely four, was made based on previous experiments and calculations (Redkin 1988).

The slash was collected from a mixed stand in the Tver region (see Table 3.13) that was clear-cut by a harvester. Ten linear test plots (1–1.5 m) were installed along the skid trails. On each plot, the slash was gathered and weighed with spring balances with a resolution of 0.1 kg. The weight of heavy pieces (over 10 kg) was calculated using log diameter, length, and tree species density. Slash densities for these conditions were about 15 kg/m^2, and slash mat thickness varied from 15 to 20 cm, which was comparable to the values in other studies (e.g. Galaktionov et al. 2009). There was a large variation in limb size including 18% of large limbs (more than 10 cm diameter) and 15% of tops remaining after processing.

Soil compaction was analysed using changes in bulk density following traffic. The soil samples for bulk density were collected with a soil hammer with a 4 cm diameter and 4 cm length rings. Oven-dried weight (12 hours at 105°C) was used to express bulk density as weight/unit volume (g/cm^3) and moisture content.

Four samples were taken for bulk density at each of 11 depths in the soil profile (0–5 cm) for a total of 44 from each plot. This sampling regime was applied to both pre-treatments (a total of 20 samples per plot). In addition to changes in soil physical properties, soil disturbance was quantified using measures of rut depth at the midpoint of each plot. All samples were collected after passes, with undisturbed samples collected from the rut centre line.

Soil type was classified according to the Russian soil classification standard (GOST 25100-95) based on the plasticity index and the relative proportions of the various soil separates as described by the classes of soil texture. The name of the textural soil class was adapted to the USDA system using the Glossary of Terms in Soil Science (1976). The data were statistically processed using statistical and regression analyses with SPSS 15.0 for Windows.

Results

Impact of a bogie track

The average soil water contents at the study time were 93% for the wet plots and 80% for the moist plots, without slash reinforcement. In the case of a wheel with a tyre on wet soil (KW93), the initial soil bulk density value was 1.06 g/cm^3. The post-treatment bulk density increased slightly up to 1.15–1.17 g/cm^3 during the first five passes. It was slightly lower by the sixth and seventh passes at 1.11 g/cm^3, and grew again and stabilised by the ninth and 10th passes at 1.14 g/cm^3. The rut depth increased rapidly up to 0.71 m, particularly during the first five passes. The forwarder clearance (0.67 m) was exceeded on the ninth pass.

In the case of a bogie track on wet soil (KT93), the initial soil bulk density was 1.03 g/cm^3. The post-treatment bulk density increased slightly up to 1.17 g/cm^3 within the first six passes. Then, it decreased slightly by the seventh to 10th passes and stabilised at 1.13 g/cm^3. The rut depth increased evenly up to 0.48 m, particularly during the first three passes. The forwarder clearance was not exceeded.

In the case of a wheel with a tyre on moist soil (KW80), the initial soil bulk density was 1.06 g/cm^3. The post-treatment bulk density increased up to 1.33 g/cm^3 within the first four passes. Then, it decreased slightly by the fifth to seventh passes at 1.29 g/cm^3, decreased again, and stabilised by the eighth to 10th passes at 1.24 g/cm^3. The rut depth increased rapidly up to 0.40 m, particularly during the first seven passes. The forwarder clearance was not exceeded.

In the case of a bogie track on moist soil (KT80), the initial soil bulk density was 1.05 g/cm^3. The post-treatment bulk density increased slightly up to 1.33 g/cm^3 within the first six passes. Then it decreased slightly by the seventh to 10th passes and stabilised at 1.30 g/cm^3. The rut depth increased evenly up to 0.22 m. The forwarder clearance was not exceeded.

Impact of a slash layer

The average soil water content during the study time was 88%, and the slash had a density of 15 kg/m^2. The initial soil bulk density was 1.06 g/cm^3. In the case of a conventional wheel (TW88), the post-treatment bulk density increased slightly up to 1.10 g/cm^3 within the first five passes. Then it stabilised by the sixth to 10th passes at 1.11 g/cm^3. Ruts were not detected (less than 0.05 m).

In the case of a bogie track (TT88), the post-treatment bulk density increased slightly up to 1.08 g/cm^3 within the first pass. It then stabilised at 1.10–1.11 g/cm^3. Ruts were not detected (less than 0.05 m). Bulk density and rut depth trend curves based on the obtained data were constructed using a Cubic regression model with R-square values of 0.99 for depths and 0.80–0.99 for density:

$$D = b_0+b_1 \cdot v+b_2 \cdot v^2+b_3 \cdot v^3$$

where:
D rut depth (m) or bulk density (g/cm^3),
v cumulative volume of extracted wood (m^3), b_0, b_1, b_2, b_3 coefficients of equation.

The coefficients of the Cubic model as a function of the treatment conditions (moisture contents, tracks, slash) are presented in Table 3.14.

Table 3.14 Coefficients of the Cubic model as a function of the treatment conditions

No.	Bulk density				Rut depth			
	b0	b1	b2	b3	b0	b1	b2	b3
KW93	1.054	0.004	–5.53E-05	2.02E-07	0.052	0.007	–3.22E-05	7.45E-08
KT93	1.023	0.004	–3.49E-05	8.30E-08	0.020	0.005	–2.457E-05	8.16E-08
KW80	1.046	0.008	–8.20E-05	2.44E-07	0.033	0.003	–2.96E-06	3.088E-08
KT80	1.038	0.005	–2.80E-05	3.65E-08	0.012	0.003	–2.01E-05	7.07E-08
TW88	1.060	0.001	–7.97E-07	-3.32E-09				
TT88	1.064	0.001	–6.15E-06	2.28E-08				

Soil classification

The results of soil classification are presented in Table 3.15.

Table 3.15 Distribution of samples by size of soil particles

	Soil particles percentage						
	Prior	Treatments					
		KW93	KT93	KW93	KT93	TW88	TT88
Sand particles	27	31	32	35	35	30	29
Silt particles	55	53	51	50	50	52	53
Clay particles	18	16	17	15	15	18	18
Plasticity index	11.0	10.3	10.6	9.7	9.5	11.1	11.2
Grain size distribution	Silt loam						

The difference between the initial mass and total mass of samples did not exceed 0.05 g (less than 0.05%). The relative proportions of the various soil separates in the studied soils corresponded to the silt loam class.

Discussion and conclusions

Regarding soil compaction, the CTL system met the ecological requirements for this type of forest soil (1.4 g/cm^3) within the bounds of the experimental design. However, an increase in bulk density was found in all treatments at the silt loam soil surface (0 to 5 cm depth). The magnitude of the increase was a function of the number of passes, the slash/track presence, and the moisture content. In comparison with conventional wheel treatments, bogie track treatments showed that the compaction of wet and moist silt loam held irregularly. The formation of a compacted zone under the traction element, helped by the reinforcement of forest soil roots, took place in the first phase. With an increasing number of passes, the compacted zone deepened and partly collapsed, and there was a lateral bulging of the soil. Then, there was a slight increase in density because of the formation of secondary hardened zones. The results for slash reinforcement treatments indicated that a layer of slash mitigated the effect of a single forwarder pass and subsequent passes. The bulk density did not change considerably. The increased bulk density for the forest soils was nearly 10% of that of slash-covered soils. In addition, the presence of the combination of “slash + track” made no apparent difference within the bounds of the experimental design.

Regarding sinkage, the CTL system with a conventional wheel did not meet the ecological requirements for thinning (rut depth should be less than 0.15 m). Moreover, rut depth reached the forwarder clearance of the machine (0.67 m) on wet soil. The results of bogie track treatments showed that rut depth did not meet the ecological requirements for thinning (0.15 m), particularly on wet soil, but was within the forwarder clearance of the machine. In the slash treatments, rut depth changed only slightly.

All mechanised harvesting systems (tree-length, FT, CTL) applied in Russia cause different kinds of negative environmental impacts. When applied on sandy or sandy loam soils, all mechanised systems demonstrated almost the same impacts on the soil (Syunev et al. 2009). However, the proportion of sandy soils is small in Russian forests in comparison with those of loams and clays. On loams and clays, the tree-length and FT systems, unlike the CTL system, resulted in significant soil compaction, but at the same time formed almost no track. Over 50% of the harvesting sites in Russia are on wet and soft soil (Ananyev et al. 2005). Therefore, the application of the CTL system has to be improved in order to reduce rut formation in most common soils. Hence, the associated CTL machine ground contact devices and slash layer must be suitably adapted for specific harvesting sites, based on terrain classification criteria. The adaptation requires a further study of the effects of the ground contact device (tyre or track) and size of slash layer, the induced ground contact pressure, and the physical characteristics of the slash layer that are affected during soil deformation, which negatively influence the CTL system cross-country ability and environmental impact.

References

Ananyev, V., Asikainen, A., Välkky, E., Gerasimov, Y., Demin, K., Sikanen, L., Syunev, V., Khljustov, V., Tyukina, O., Shirnin, Y., 2005. Thinnings in northwest of Russia. Metla, Joensuu: 150 p.

Batelaan, J., 1998: Development of an all terrain vehicle suspension with an efficient, oval track. Journal of Terramechanics 35(4): 209–223.

Bygdén, G., Eliasson, L., Wästerlund, I., 2003: Rut depth, soil compaction and rolling resistance when using bogie tracks. Journal of Terramechanics 40(3): 179–190.

Eliasson, L., Wästerlund, I., 2007: Effects of slash reinforcement of strip roads on rutting and soil compaction on a moist fine-grained soil. Forest Ecology and Management 252(1–3): 118–123.

Galaktionov, O., Kuznetsov, A., Piskunov, M., 2009: The properties of flooring made of logging waste products and ground condition of skidding road. Proceedings of Petrozavodsk State University. Natural and Engineering Science 101(7): 90–95.

Gerasimov, Y., Katarov, V. 2010. Effect of Bogie Track and Slash Reinforcement on Sinkage and Soil Compaction in Soft Terrains. Croatian Journal of Forest Engineering 31(1): 35–45

Gerasimov, Y., Sokolov, A. 2009. Ergonomic characterisation of harvesting work in Karelia. Croatian Journal of Forest Engineering 30 (2): 159–170

Gerasimov, Y., Sokolov, A., Karjalainen, T., 2008: GIS-based decision-support program for planning and analyzing short-wood transport in Russia. Croatian Journal of Forest Engineering 29(2): 163–175.

Gerasimov, Y., Syunev, V., 1998: Ecological optimisation of logging technology and machinery. University of Joensuu, Joensuu: 170 p.

Glossary of Terms in Soil Science, 1976: Canada Department of Agriculture, Research Branch, Ottawa, Publication 1459: 44 p.

GOST 12071-84, 1984: Soils: sample collection, packing, transportation and storage. State Standard, Moscow.

GOST 25100-95, 1995: Classification of soils. State Standard, Moscow.

Jakobsen, B. F., Moore, G. A., 1981: Effects of two types of skidders and of a slash cover on soil compaction by logging of mountain ash. Australian Journal of Forest Research 11: 247–255.

McDonald, T. P., Seixas, F., 1997: Effect of slash on forwarder soil compaction. International Journal of Forest Engineering 8(2): 15–26.

McMahon, S., Evanson, T., 1994: The effect of slash cover in reducing soil compaction resulting from vehicle passage. LIRO Report 19(1): 1–8.

Redkin, A. K., 1988: Basic foundation of modeling and optimisation of wood harvesting. Moscow, Timber Industry: 256 p.

Sakai, H., Nordfjell, T., Suadicani, K., Talbot B., Bøllehuus, E., 2008: Soil compaction on forest soils from different kinds of tires and tracks and possibility of accurate estimate. Croatian Journal of Forest Engineering 29(1): 15–27.

Ŝuŝnjar, M., Horvat, D., Ŝeŝelj, J., 2006: Soil compaction in timber skidding in winter conditions. Croatian Journal of Forest Engineering 27(1): 3–15.

Syunev, V., Sokolov, A., Konovalov, A., Katarov, V., Seliverstov, A., Gerasimov, Y., Karvinen, S., Välkky, E., 2009: Comparison of wood harvesting methods in the Republic of Karelia. Working Papers of the Finnish Forest Research Institute 120: 117 p.

Zeleke, G., Owende, P. M. O., Kanali, C. L., Ward, S. M., 2007: Predicting the pressure–sinkage characteristics of two forest sites in Ireland using in situ soil mechanical properties. Biosystems Engineering 97(2): 267–281.

3.3.2 Impacts of logging residue harvesting on the forest environment

Harvesting logging residues for energy purposes removes the majority of the forest biomass from harvesting sites, which interrupts the natural lifecycles of stands. The removal of logging residues can result in a reduction in productivity, undesired succession, and the loss of plant and animal biodiversity (Kuusinen and Ilvesniemi 2008). Therefore, when planning to use logging residues one should account for the fact that its removal causes additional impacts on forest ecosystems (Syunev et al. 2008). There are both negative and positive effects of logging residue harvesting on the forest environment. The most important effects and the recommendations on how to mitigate the negative and enhance the positive are given below.

Impact on fertility of forest soils

The removal of logging residues from harvesting sites reduces the fertility of the forest soil because of the leakage of organic matter and microelements. In boreal forests, there are some areas with acidic soils and a weak humus layer, as well as peat lands with low contents of potassium and boron. Harvesting logging residues for energy use should be avoided to maintain the fertility of the soil in infertile forest types (Kallio and Leinonen 2005).

Impact on the soil structure

Logging residues form a natural volumetric cover that hinders the active surface drain of rain and melting water. Therefore, the existence of such a cover is especially important on steep slopes with underdeveloped turf and hauling roads with ruts where the risk of water erosion is the highest. The removal of considerable amounts of logging residues for energy needs reduces the possibilities for reinforcing hauling roads and this causes several impacts on the forest soil.

Wood harvesting in moist conditions or in forests with clay soils often results in the formation of deep ruts and soil compaction. This leads to the reduction of pores and closing pore channels in the soils, which hampers soil air circulation and reduces oxygen content. To secure the active growth of root tips, the oxygen concentration in the soil must be 5–10%, because the roots lose weight considerably if the oxygen concentration falls below 1%. If the soil is not compacted, then root channels, cracks, and other soil cavities facilitate active root development and secure their increment. Soil compaction also results in the drastic reduction of water filtration speed, which affects plants. Furthermore, the tougher the soil composition becomes, the worse the filtration speed reduction is. Therefore, soil compaction on tracks hinders the penetration of water into the soil, which stagnates water in hollows or increases surface drain on slopes. In the latter case, the risk of water erosion emerges. Excess moisture ruins the activities of the soil microorganisms that play an important role in supplying plant roots with available nutrition elements (Gerasimov and Syunev 1998).

Rut formation processes contribute to the devastation of root systems under hauling roads. Ruts can also accumulate moisture that worsen water erosion and hinder reforestation. When root collars are damaged, the risk of a fungal infection grows and as a result, tree productivity and wind resistance may suffer. At the same time, if the soil in the rut is not compacted enough, then the rut soil walls may collapse, which leads to rather successful reforestation on the area around the rut and sometimes in the rut itself. Earlier studies and interviews of practitioners have showed (Katarov 2009) that the probability of this scenario on moist soils is quite high. At the same time, thinnings may result in ruts with damaged and torn roots on the remaining trees.

Impact on fire safety

The removal of logging residues from harvesting sites decreases the risk of forest fires in the future. However, logging residues may be left before harvesting on sites for several months to decrease moisture content in the biomass. This may increase the fire risk during the time of drying. A layer of logging residues can increase the spread of fire over harvesting sites. Therefore, from the point of view of forest fire safety it is better to harvest logging residues right after felling and dry them at the roadside.

Conclusions and recommendations for using logging residues

- A brush mat made from logging residues between forest machines and the soil reduces the negative impact on the soil when forwarding wood. In this case, root damage during thinning decreases. When logging residues decompose, the soil on strip roads becomes less compacted and the biological processes in the root systems thus speed up;
- There is a high concentration of nutrients in needles and leaves as well; therefore, a small fraction of logging residues at harvesting sites contributes to the replenishment of nutrients in the soil;
- It is preferable to dry logging residues for energy purposes, because this will increase the energy contained in each mass unit and reduce the weight of logging residues, which in turn will reduce the load on the soil during transportation. To decrease the risk of forest fire, it is better to dry logging residues at the roadside.
- To prevent soil erosion on slopes, as a rule, transverse ridges should be made from logging residues, and if there is such a technological possibility, they can be matched with strip roads;
- It is recommended to leave about 30% of logging residues in stands on sandy soils (cladina pine stands, vaccinium pine stands; Rozhdestvenskij and Tishler, 2009). This will support fertility and protect the soil on the strip road from compaction. When a forwarder moves on top of a thin layer of residues, the soil mixes with logging residues; thus, the upper part of the soil becomes mineralised, but the surface of the strip road is not subject to erosion. Predominantly, small branches with needles should remain on the harvesting site;

- In the case of an abundance of sandy loam soils (oxalis pine stands etc.) on fresh and moist soils, it is recommended to leave 20–40% of logging residues on the strip road and harvesting sites (50/50) with the aim of preventing soil compaction and supporting fertility. No less than half of logging residues should be left to reinforce the strip roads on wet sandy loam soils;
- Sandy loam soils are sufficiently rich in nutrients, and they are subjected to compaction and deformation. In these conditions (oxalis spruce stands, myrtillus spruce stands, and mixed stands), it is recommended to form a complete branch-and-twig logging residue layer on strip roads. As a rule, about 20–40% of the total volume of logging residues is enough for this purpose. On moist soils, sustainable strip road reinforcement requires no less than 60–70% of logging residues, on wet soils all logging residues should be used to reinforce the strip road, and in lowlands the layer should also include non-IRW;
- The amount of logging residues used to reinforce strip roads on loamy soils (myrtillus pine stands etc.) should be 10–12% bigger compared with the case of sandy loam forests;
- On peaty soils (sphagnum type and the type of the soils near streams), all logging residues should be used to reinforce strip roads. Non-IRW can even be used to reduce the depth of ruts. It should be noted that as a rule, those territories have valuable biotopes in terms of biodiversity conservation that may limit wood harvesting from such sites;
- When operating in late May to early June on all soil types except sandy soils, the majority of logging residues should be used to reinforce strip roads;
- Logging residues should be used in two stages: first, as a reinforcement for strip roads and then as energy; however, the raw material is problematic because of the contamination of logging residues with soil during forwarding;
- A positive effect is reached by reinforcing strip roads and wheels using tracks. In this case, the ground contact area of forwarders is increased, and there is no significant damage to the layer of logging residues (Gerasimov and Katarov 2010). When using tracks on wheels, the volume of logging residues used to reinforce strip roads can be reduced by 10–15%.

References

Gerasimov Y. and Katarov V. 2010. Effect of bogie track and logging residues reinforcement on sinkage and soil compaction in soft terrains. Croatian Journal of Forest Engineering 31: 35–45.

Gerasimov Y. Y. and Syunev V. S. 1998. Ekologicheskaja optimizacija tehnologicheskih mashin dlja lesozagotovok. 178 s.

Kallio, M. and Leinonen, A. 2005. Production technology of forest chips in Finland. Project report. VTT. 97 p.

Katarov V. 2009. Obosnovanie primenimosti tehnologicheskih processov lesosechnih rabot po stepeni vozdeistviya na puti pervichnogo transporta lesa. Avtoreferat dissertacii. PetrGU. 20 p.

Kuusinen, M., Ilvesniemi, H. (toim.) 2008. Energiapuun korjuun ympäristövaikutukset, tutkimusraportti. Tapion ja Metlan julkaisuja. 74 p. Available at: http://www.metsavastaa.net/files/metsavastaa/Energiaseminaari %2020112007/Energiapuun_korjuun_ymparistovaikutukset.pdf.

Rozhdestvenskij S. J. and Tishler O. A. 2009. Landshaftnyj podhod pri lesohozjajstvennom planirovanii: uchebnyj material dlja specialistov lesnogo hozjajstva. 72 s.

Syunev, V. S., Sokolov, A. P., Konovalov, A. P., Katarov, V. K., Seliverstov, A. A., Gerasimov, Y. Y., Karvinen, S., Vjal'kkyu, E. 2008. Sravnenie tehnologij lesosechnyh rabot v lesozagotovitel'nyh kompanijah Respubliki Karelija. 126 s.

3.4 Quality and wood losses

3.4.1 IRW losses associated with harvesting systems in Russia

Introduction

This chapter presents the results of the study described in Gerasimov and Seliverstrov (2010). The use of fully mechanised (FM) systems is increasing in wood harvesting operations globally, which has led to log damage, including butt pull, log splitting during handling, and the bucking and crushing of the log. Damage to a harvested log can occur during the felling, delimbing, bucking, skidding or forwarding, piling, loading, and hauling functions of wood harvesting.

According to Marshall et al. (2006), on average mechanical log-making systems lose 18% of the potential value compared with 11% for motor-manual (MM) systems. However, Connell (2003) and Spinelli et al. (2010) reported that some mechanised harvesting operations have reduced the incidence of log damage by using mechanical handling. In addition, the log damage and value loss associated with tree-length (TL) and full-tree (FT) harvesting systems were reported by Wang et al. (2004).

In these studies, the MM TL system with chainsaws and skidders and the FM FT system with feller-bunchers and skidders were studied. Volume losses of up to 6.1% and 1.1% and value losses of up to 6.0 US $/m^3 and 1.5 US $/m^3 were found when using MM TL and FM FT systems, respectively. The majority of the value loss was caused during the felling function when using an MM TL system.

During the highest quality harvesting operations, mainly carried out in Nordic countries by CTL method, 4–5% of the wood value is lost at harvest (Murphy 2005). However, wood harvesting operations in many countries, such as Russia, using a number of different harvesting systems, such as MM FT, FM FT, MM CTL, FM CTL, and MM TL, have shown losses of 11–18% of the wood value at harvest (Marshall et al. 2006). Certainly, the influence of wood quality on IRW value cannot be ignored when comparing different technologies. This is determined by evaluating it in accordance with the quality specifications in the customer contracts as well as other quality requirements. To remain competitive, logging companies should minimise wood loss at the time of harvest by using more advanced harvesting technologies. The major objective of this study was thus to identify the major sources of damage to IRW arising from applied harvesting systems in Russia in order to minimise this damage loss.

Methods and data

The Republic of Karelia was selected as the study region because its territory is representative of the wide range of harvesting methods, systems, and equipment used – nearly all harvesting technologies are employed in different natural conditions typical of Northwest Russia.

The study was performed in 2007–2009 and it involved 15 logging companies that provide approximately 35% of the total harvesting volume in Karelia (2.2 million m^3 per year). The selected companies perform harvesting operations across the whole territory of Karelia in different conditions and apply MM CTL, FM CTL, MM FT, FM FT, and MM TL harvesting systems using both Russian and foreign machinery (Gerasimov and Sokolov 2008). A common approach was used for field data collection directly on harvesting sites in actual working conditions.

The harvested stands were not managed or thinned before the final felling. A typical study stand was mixed in terms of tree age and species. Tree species composition included spruce (31% on average), pine (35%), birch (28%), and aspen (6%). The average stem volumes of harvesting sites varied between 0.13 and 0.64 m^3 with the average value 0.29 m^3. The average growing stock of stands in the studied regions was 150 m^3 per ha with a tree density of approximately 520 trees per ha. The typical soils in the test areas were silt loam, clay loam, and sandy loam. The harvesting sites were on flat terrains.

According to the methodology used, the required number of logs to be measured was 300 for each species and for each assortment per harvesting site separately in the winter and summer seasons. The total number of observed logs was 23,400 and the number of observed harvesting sites was 17 (seven in winter and 10 in summer).

IRW damage evaluation was based on a number of damage indicators, which are regulated by the relevant national standards and forest industry specifications, as follows:

- mechanical damage, which occurs during skidding, sorting, piling, and transporting wood; this tends to cause the following types of damage: torn and loosened grain, debarked stem, cuts (damage by chainsaw, skidder cable), and gouges made by grapples,
- processing defects, including unprocessed branches and defects caused by improper tree-felling and cross-cutting, namely: log end (butt and top) splits, cracks, log splitting, and snipes,
- contamination with dirt,
- deviation of IRW dimensions, including log-length allowances and tolerances, as well as the grades and the maximum butt and minimum top diameters of assortments.

The results were then compared with the effective quality requirements in a given logging company and the percentage of rejected logs was determined. The obtained estimates for all measured parameters were integrated into one indicator – the so-called reject rate. The quality requirements for IRW of various species, grades, and end-uses (sawlog, pulpwood, etc.) were determined in the contract between the logging company and the IRW buyer, namely the technical specifications. The quality requirements of the measured logs of various species and end uses are shown in Table 3.16 and Table 3.17.

Table 3.16 Quality requirements for sawlogs and veneer logs in domestic and export markets

Damage type	Sawlogs				Birch veneer logs
	Pine		Spruce		
	Export	Domestic	Export	Domestic	Export
1. Mechanical damage	TU 13-2-12-96 Not acceptable	GOST 9463-88	TU 13-2-12-96 Not acceptable	GOST 9463-88	TU 13-2-8-96
2. Processing defects					
Branches	TU 13-2-12-96 *l* < 10/20 mm *d* <50/60 mm	GOST 9463-88	TU 13-2-12-96 *l* < 10 mm *d* <50 mm	GOST 9463-88	TU 13-2-8-96
Log end splits, cracks	Not acceptable	GOST 9463-88	Not acceptable	GOST 9463-88	TU 13-2-8-96
Log end splinters	Not acceptable	Not acceptable	Not acceptable	Not acceptable	Not acceptable
Butt trimming	Not acceptable	GOST 9463-88	Not acceptable	GOST 9463-88	TU 13-2-8-96

Damage type	Sawlogs				Birch veneer logs
	Pine		Spruce		
	Export	Domestic	Export	Domestic	Export
3. Contamination with dirt	Not acceptable	Not acceptable	Not acceptable	Not acceptable	Not acceptable
Maximum diameter of the butt end without bark, cm	55.0* 34.0	75 42.0*	55.0* 40.0* 14.9	75 52.0* 36.0 56.0	65.0* 55.0* 50.0*
Minimum diameter of the butt end without bark, cm	18.0* 15.0 15.0*	16.0 14.0 11.0	18.0* 17.0* 16.0* 12.0	16.0 14.0	25* 18.0*

– Quality requirements in contractual specifications

* – Diameter over bark

l – Max. acceptable branch length

d – branch diameter

Table 3.17 Pulpwood quality requirements for domestic and export markets

Damage type	Pine		Spruce		Birch
	Export	Domestic	Export	Domestic	Export
1. Processing defects	GOST 9463-88; TU 13-2-10-96	GOST 9463-88	GOST 9463-88; TU 13-2-10-96	GOST 9463-88; TU 13-2-10-96	TU 13-2-1-95; TU 13-2-10-96; TU 13-2-11-96. *l* <20 mm
2. Contamination with dirt	Not acceptable	Not acceptable	Not acceptable	Not acceptable	Not acceptable
3. Dimension non-compliance					
Length, m (allowance, cm)	3.0; 4.0; 6.0 (0 / +10)	3.0–6.0 (–20 / +20)	3.0; 4.8. 6.0 (0 / +10)	2.4; 3.6; 4.8; 6.0 (–5/+15); 4.0; 5.5 (–5/+15); 1.2 (–2 /+ 2); 2.4 (–2 /+ 2); 3.6 and 4.8 (–15 / 15); 4.0 and 5.5 (–10 / +10); 2.4 and 3.6 (+3 / +5)	4.0; 5.5 (0 / +10); 3.0; 4.0; 6.0 (–10 / +10)
Maximum diameter of the butt end without bark, cm	60.0	40.0	40.0	60.0; 50.0; 36.0	60.0
Minimum diameter of the butt end without bark, cm	8.0; 6.0	6.0	8.0*	16.0; 6.0	16.0; 6.0

– Quality requirements in contractual specifications

* – Diameter over bark

l – Max. acceptable branch length

If a log complied with both the quality and dimension requirements, it was accepted. If a log did not comply with the abovementioned requirements, it was rejected or transferred to another grade according to its quality: sawlog to pulpwood, pulpwood to fuel wood. IRW damage was analysed in terms of value losses. The losses in IRW value in the context of a logging company and a harvesting system were estimated as follows:

$$L = Rpsl \times Ppsl(Cpsl - Cppw - C') + Rssl \times Pssl \times (Cssl - Cspw - C') + \\ + Rbsl \times Pbsl \times (Cbsl - Cpbw - C') + Rppw \times Ppsl \times (Cppw - Cpfw - C') + \\ + Rspw \times Pspw \times (Cspw - Csfw - C'') + Rpbw \times Pbpw \times (Cpbw - Cbfw - C'') \quad (3.4.1.1)$$

where:
L – value losses owing to IRW damage at harvest, €/m^3
R – average reject rate of the IRW assortment
P – proportion of the assortment production in the total volume of industrial wood at the given logging company
C – average EXW (ex works) price of the IRW assortment at the roadside or central processing yard, €/m^3
C' – additional expenses associated with loading, unloading, and transporting rejected wood, €/m^3
psl, ssl, bsl – indexes for pine, spruce, and birch sawlogs
ppw, spw, bpw – indexes for pine, spruce, and birch pulpwood
fw – index for fuel wood

A log pricing system was developed based on IRW market prices from the Karelia wood market reports (Timber Prices 2010). A monetary value was assigned to the IRW based on its tree species, assortment, and delivery terms.

Results

To summarise, Table 3.18 shows the distribution of reject rates by assortment in 17 studied harvesting sites. The results include all harvesting systems and apply to both the winter and the summer seasons. A rejected log commonly had two or more types of damage. In that case, the log was rejected for several reasons.

Table 3.18 Reject rates of roundwood (% of observed logs) at the studied harvesting sites by harvesting system and season

System	Pine sawlog		Spruce sawlog		Pine pulpwood		Spruce pulpwood		Birch veneer logs		Birch pulpwood	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
MM CTL	4.0	3.7	5.3	4.0	1.0	1.3	1.0	1.3	2.7	3.0	1.7	1.3
FM CTL	2.7	3.3	3.0	3.3	2.0	2.0	1.7	1.7	n/a	n/a	2.0	2.1
MM TL	7.3	9.0	7.0	10.3	2.7	8.3	2.7	8.0	6	8.3	2.3	7.3
MM FT	4.7	7.7	6.3	7.3	2.1	6.0	1.8	6.3	3.3	7.0	1.7	5.0
FM FT	5.3	5.0	5.0	5.3	2.3	2.0	2.7	2.3	n/a	n/a	2.3	2.3

The MM TL system caused the highest reject rate both for sawlogs (7% of observed logs in winter and 9–10% in summer) and for pulpwood (3% in winter and 7–8% in summer). The lowest reject rate for sawlogs was provided by the FM CTL system (3%). The lowest reject rate for pulpwood (2%) was registered by the MM CTL system (Table 3.18).

The study of the quality of IRW harvested with the MM CTL system demonstrated that log end splits and cracks (up to 3% of observed logs), as well as cuts by chainsaws and gouges by forwarders' grapples during loading operations (up to 2%), were the most common types of processing defects (Table 3.19 and

Table 3.21). The reject rate was about 5% in winter and 4% in summer for coniferous sawlogs and about 1% for pulpwood regardless of the harvesting season (Table 3.18).

The FM CTL system, in both winter and summer, was mostly associated with the following types of defects (Table 3.19 and Table 3.21): unprocessed branches (2% of observed logs), log end splits and cracks during felling and bucking (2%), and log surface damage. The latter appeared in the form of damage by the delimbing and feeding mechanisms of the harvester head during delimbing, namely torn and loosened grain (2%). This damage was accompanied by debarked stems or even lost layers of stemwood. Logs damaged by harvester head saws (cuts) or forwarders' grapples were rare (about 1%).

When harvester operators followed all work requirements and instructions, the reject rate was less than 3% for coniferous sawlogs harvested with the FM CTL system and less than 2% for coniferous pulpwood, regardless of the season. The FM CTL system also ensured the efficient cross-cutting of the stems with the required length allowance, normally +(0–4) cm, which maximised the amount of received IRW assortments, unlike the MM CTL system, where the allowance was mostly +(5–10) cm.

For the MM TL and MM FT systems, regardless of the season, the following types of damage were typical (Table 3.19 to Table 3.21): torn and loosened grain (2–3% of observed logs) and cuts in stemwood and gouges made by grapples (2–3%). Less frequent were unprocessed branches (1%) and log end splits and cracks (1%).

Table 3.19 Losses of coniferous sawlogs volume (% of observed logs) at the studied harvesting sites by harvesting system and damage type (PSL – pine, SSL – spruce)

System	Mechanical damage								Processing defect								Contamination with dirt	
	Torn				Cuts, gouges				Unprocessed branches				Splits, cracks					
	Winter		Summer		Winter		Summer		Winter		Summer		Winter		Summer		Summer	
	PSL	SSL	PSL	SSL	PSL	SSL	PSL	SSL	PSL	SSL	PSL	SSL	PSL	SSL	PSL	SSL	PSL	SSL
MM CTL	2.0	2.3	0	0	0	0	1.7	2.0	0	0	0	0	2.3	2.7	2.0	1.3	0	0
FM CTL	0.7	0.7	1.5	1.7	1.3	1.7	1.0	1.0	1.7	2.1	1.7	1.7	1.7	2.1	1.5	1.7	0	0
MM TL	2.0	2.7	2.7	3.0	2.3	2.7	2.0	2.1	0.9	1.0	1.1	1.3	1.0	0.9	1.0	1.3	8.1	7.3
MM FT	2.0	2.7	2.0	2.7	2.3	2.0	1.7	1.7	1.0	1.3	1.1	1.3	1.0	1.1	1.3	1.0	5.0	4.3
FM FT	3.0	3.1	1.7	1.3	1.3	1.7	1.3	1.3	1.3	1.3	1.3	1.7	2.1	1.9	1.7	1.3	0	0

Table 3.20 Losses of birch veneer logs volume (% of observed logs) at the studied harvesting sites by harvesting system and damage type

System	Mechanical damage				Processing defect				Contamination with dirt
	Torn		Cuts, gouges		Unprocessed branches		Splits, cracks		
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Summer
MM CTL	0	0	1.8	1.7	0	0	1.7	1.7	0
MM TL	2.7	3.0	2.7	2.0	1.0	1.1	1.1	1.3	8.3
MM FT	1.7	1.7	2.3	2.0	1.3	1.3	1	1.3	6.0

Table 3.21 Losses of pulpwood volume (% of observed logs) at the studied harvesting sites by harvesting system and damage type (PPW – pine, SPW – spruce, BPW – birch)

System	Unprocessed branches						Contamination with dirt		
	Winter			Summer			Summer		
	PPW	SPW	BPW	PPW	SPW	BPW	PPW	SPW	BPW
MM CTL	0.7	0.7	0.7	0.7	0.7	1.0	0	0	0
FM CTL	1.7	1.3	1.7	1.7	1.7	2.0	0	0	0
MM TL	0.9	1.0	0.9	1.0	1.3	1.0	9.1	8.3	8.0
MM FT	1.0	1.0	0.7	1.0	0.9	0.9	5.0	5.7	4.0
FM FT	1.3	1.7	1.3	1.3	1.7	1.7	0	0	0

In summer, contamination with dirt was also found (up to 9% for the MM TL and 6% for the MM FT). For spruce and pine sawlogs, the following reject rates were registered (Table 3.18): 6–7% for spruce and 5–7% for pine in winter, and 7–10% for spruce and 8–9% for pine in summer. The maximum reject rate was registered for the sawlogs intended for the export market. For birch pulpwood, this figure reached 2% in winter and up to 7% for the TL system and 5% for the MM FT system in summer. For pine and spruce pulpwood, the reject rates were up to 3% and 2% in winter, respectively, and 3% in summer.

FM FT harvesting in both winter and summer was mostly associated with the following types of wood defects (Table 3.19 and Table 3.21): cuts in stemwood and gouges made by grapples (2% of observed logs), log end splits and cracks (2%), torn and loosened grain (2–3%), and unprocessed branches (2%). The reject rate for spruce and pine sawlogs (Table 3.18) was about 5%, regardless of the season. For birch, pine, and spruce pulpwood, this figure was about 3% in winter and up to 2% in summer.

The seasonality of harvesting operations has a negative impact on the quality of harvested wood; this pertains to the MM CTL, MM TL, and MM FT systems. In the 15 studied companies, volume losses of IRW (in terms of the reject rate as a percentage of total IRW on average per year) were found by harvesting system as follows: MM CTL 1.8%; FM CTL 2.3%; MM TL 5.0%; MM FT 4.2%; and FM FT 3.3% (Table 3.22).

Table 3.22 Losses of IRW volume and value at the studied companies by harvesting system

System	Company	Annual harvest, 1000 m^3			Volume loss		Value loss	
		Total	Fuel roundwood	IRW	%	1000 m^3	€/m^3	1000 €
MM CTL	2, 3, 7, 8, 9	363.0	56.2	306.8	1.8	5.64	0.51	156.6
FM CTL	1, 2, 3, 4, 5,6	503.0	64.8	438.2	2.3	9.98	0.65	286.2
MM TL	1, 5, 10, 11, 12 13, 14	935.4	155.6	779.8	5.0	39.14	1.38	1074.9
MM FT	15	67.1	6.7	60.4	4.2	2.52	1.04	62.7
FM FT	1, 14	318.2	31.8	286.4	3.3	9.56	0.86	247.4
Total		2186.7	315.1	1871.6	3.6	66.84	0.98	1827.8

The total average volume loss of IRW in the studied companies was 3.6% or around 67,000 m^3 of IRW per year. Value losses of IRW were found by harvesting system as follows: MM CTL: 0.51 €/m^3; FM CTL 0.65 €/m^3; MM TL 1.38 €/m^3; MM FT 1.04 €/m^3; and FM FT 0.86 €/m^3. The total average value loss of IRW in the studied companies was 0.98 €/m^3 of IRW or around € 1.8 million per year.

Conclusion and recommendations

The analysis of the obtained results indicates that CTL harvesting can ensure the highest quality of harvested wood (reject rate below 3% of observed logs) in all the studied companies, with different species composition. The FT harvesting systems demonstrated acceptable IRW quality (reject rate about 3–5%). The quality of wood in TL harvesting was low (reject rate over 6%), particularly in summer (reject rate up to 10%).

Over 50% of the harvesting sites in Russia are on wet and soft soil terrain and the proportion of sandy soils is small in Russian forests in comparison with loams and clays (Gerasimov and Katarov 2010). The MM TL system causes the highest reject rate because debranched TL logs are bunched and skidded by a cable skidder in this type of terrain, which leads to contamination with dirt and other damage. The MM FT system has the same reason for its high reject rate, particularly in summer, but branches to some extent protect stemwood from damage. The FM FT system is largely free from this disadvantage because of bunching by a feller-buncher and skidding by a grapple skidder. Regardless of the season, the CTL systems show the lowest rejection rates because they use forwarding (roundwood is carried out on a trailer) instead of skidding (logs are dragged out of the forest over soft soils). Therefore, the selection of the harvesting system has to be adapted to the most common soil terrains in order to reduce wood losses.

Mechanical damage (torn and loosened grain, cuts in stemwood, and gouges made by grapples), processing defects (branches, log end splits, and cracks), and contamination with dirt were the most frequent types of damage. On the whole, damage to IRW in terms of volume loss did not differ much from that obtained with FT systems in the US (Wang et al. 2004) and CTL systems in Finland and Russia (Eronen et al. 2000, Syunev and Seliverstov 2006).

Certainly, an improvement of operations is needed to reduce IRW losses even in the same harvest system. Loggers (operators and lumberjacks) need to pay more attention to value rather than volume alone: this could be accomplished by the development of a payment system and harvesting instructions for utilising forest resources better by not damaging valuable logs. Seasonality could also be taken into account: the reject rate is higher for the MM CTL system in winter and for MM TL and MM FT systems in summer. Bed logs under piles should be used for IRW piling at roadside landings, depending on the dirt conditions. Operators need to maintain harvesting machines properly (e.g. adjust the delimbing and feeding mechanisms of harvester heads, sharpen the delimbing knives, clean the rollers to remove bark and wood residue, etc.). A harvester head must match both the base machine and the site conditions (species composition, tree size). The development of new guidelines and corresponding training to minimise IRW damage occurring during wood harvesting is needed as well (Syunev et al. 2008). However, prior to specialising in operating sophisticated machines, such as a harvester, a forwarder, or a feller-buncher, an operator is required to have the relevant vocational education.

The potential improvement in the rejection rate was roughly estimated from the best practices in the studied logging companies in comparison with common practices. If all the discovered shortcomings typical for FM CTL and FM FT harvesting were eliminated, it should be possible to decrease the reject rates by approximately 20% and 25%, respectively. It should be noted that bucking the optimisation of the FM CTL harvesting system allows an increase in the amount of received IRW assortments. Improvements made to the MM CTL system would enable the reject rate to be reduced by approximately 15%. In MM TL and MM FT, the potential reductions in the amount of damaged logs could reach 20% and 15%, respectively.

IRW damage in terms of value loss per unit of volume in the studied companies may not seem important. This is especially true when looking at the lack of difference between FM CTL and MM CTL systems. However, the switch from the traditional MM TL to the CTL system gives an average savings value of 0.8 €/m^3 of industrial wood, or around 100,000 € per year for an average sized logging company. With the initial investment cost in CTL machines of several hundred thousand euros (a forwarder costs over 200,000 €, a harvester over 300,000 €), the switch from MM TL and FT systems to an FM CTL system might be worth it in the long run, but the switch to an MM CTL system might be justified in the medium term. Additional analysis is needed before system selection is made, taking into account that the efficiency of a particular harvesting system depends on a number of criteria. The economic benefits, which are the most applicable in practice, are evaluated by productivity and costs (Adebayo et al. 2007, Konovalov and Seliverstov 2008). Special attention must be paid to comfortable and safe working conditions in felling operations. This will make harvesting work more attractive to young people and employment in a logging company more desirable (Gerasimov and Sokolov 2008). Environmental criteria and terrain conditions include dirt damage, damage to undergrowth or remaining trees, and so on (Syunev et al. 2009).

This study focused on various quality requirements and wood harvesting practices at logging companies in Karelia. This fact might limit the application of the obtained results in other regions in Russia. Moreover, further research is needed to determine the influence of different quality requirements (for the domestic market, export, individual customers) and bucking on IRW volume and value losses. Improper bucking might not damage the log in a physical sense, but it could damage the potential value gained from bucking correctly (Wang et al. 2004; Marshall et al. 2006). Taking into account the natural and production conditions in Russia, it is necessary to improve the design of the harvester head delimbing and feeding mechanism in order to ensure its higher efficiency in the processing of trees with crooked trunks and the tapering of large branches of deciduous trees. More in-depth analysis of birch veneer log degradation in FM CTL and FT systems is also needed because of the substantial increases in the demand for veneer products.

References

Adebayo, A. B., Han, H., Johnson, L. 2007. Productivity and cost of cut-to-length and whole-tree harvesting in a mixed-conifer stand. Forest Products Journal 57(6): 59–69.

Connell, M. J., 2003: Log presentation: log damage arising from mechanical harvesting or processing. CSIRO Forestry and Forest Products. Victoria, 62 p.

Eronen, J., Asikainen, A., Uusitalo, J., Sikanen, L. 2000. Control of log end checks during bucking with a modified single-grip harvester. Forest Products Journal 50(4): 65–70.

Gerasimov, Y., Katarov, V. 2010: Effect of Bogie Track and Slash Reinforcement on Sinkage and Soil Compaction in Soft Terrains. Croatian Journal of Forest Engineering 31(1): 35–45.

Gerasimov, Y. and Seliverstrov, A. 2010. Industrial roundwood losses associated with harvesting systems in Russia. Croatian Journal of Forest Engineering 30 (2): 111–126

Gerasimov, Y., Sokolov, A. 2008. Ergonomic characterization of harvesting work in Karelia. Croatian Journal of Forest Engineering 30(2): 159–170.

GOST 2292-88. 1990. State standard. Roundwood: marking, transportation, methods of measurement and acceptance. Moscow. Gosstandart, 12 p.

GOST 9463-88. 1990. State standard. Roundwood of coniferous species. Moscow. Gosstandart. 14 p.

Konovalov, A. P., Seliverstov, A. A. 2008. Logging technologies: an assessment of techno-economic factors. Forestry Expert 1(2008): 76–81.

Marshall, H., Murphy, G. E., Boston, K. 2006. Evaluation of the economic impacts of length and diameter measurement error on mechanical processors and harvesters operating in pine stands. Canadian Journal of Forest Research 36: 1661–1673.

McNeel, J. F., Czerepinski, F. 1987. Effect of felling head design on shear-related damage in southern yellow pine. Southern Journal of Applied Forestry 11(1): 3–6.

Murphy, G. E. 2005. Technology Aids Value Recovery. Focus on Forestry 18(2): 12.

Murphy, G., Twaddle, A. A. 1985. Techniques for the assessment and control of log value recovery in the New Zealand forest harvesting industry. In: Proceedings of the 9th Annual Meeting of Council on Forest Engineering, Mobile, AL, September 29 – October 2, 1985.

Pickens, J. B., Lee, A., Lyon, G. W. 1992. Optimal bucking of Northern hardwoods. Northern Journal of Applied Forestry. 9(4): 149–152.

Sessions, J. 1988. Making better tree-bucking decisions in the woods. Journal of Forestry (10): 43–45.

Spinelli, R., Magagnotti, N., Nati, C. 2010. Comparison between mechanized and manual log-making in Italian poplar plantations. In: Forest Engineering Meeting the Needs of the Society and the Environment. Proceedings of 43 International Symposium on Forestry Mechanisation, July 11–14, 2010, Padova, Italy, 8 p.

Syunev, V., Seliverstov, A. 2006. The influence of assortment of logging on the quality of wood raw material. In: Actual Problems of Forest Industry. Volume 14. Bryansk, BSETA, 68–71.

Syunev, V., Sokolov, A., Konovalov, A., Katarov, V., Seliverstov, A., Gerasimov, Y., Karvinen, S., Välkky, E. 2009. Comparison of wood harvesting methods in the Republic of Karelia. Working Papers of the Finnish Forest Research Institute 120, 117 p.

Syunev, V., Sokolov, A., Seliverstov, A., Konovalov, A., Katarov, V., Gerasimov, Y., Välkky, E., Karvinen, S. 2008. Training needs analysis for operators of harvesters. Finnish Forest Research Institute, 11 p. <http://www.idanmetsatieto.info/rus/cfmldocs/document.cfm?doc=show&doc_id=1200> (Accessed 1 July 2010).

Timber Prices. 2010. Average contract prices for major products of forest and woodworking industries, established in the Republic of Karelia. Official site of the Government of Karelia <http://www.gov.karelia.ru> (Accessed 1 July 2010).

TU 13-2-12-96. 1996. Technical specifications. Coniferous saw logs delivered to Finland. Khimki. TsNIIME, 20 p.

TU 13-2-1-95. 1995. Technical specifications. Pulpwood delivered to Finland. Khimki. TsNIIME, 15 p.

Wang, J., LeDoux, C., Vanderberg, M., McNeel, J. 2004. Log damage and value loss associated with two ground-based harvesting systems in central Appalachia. International Journal of Forest Engineering 15(1): 61–69.

3.4.2 Improvement in the quality of stem processing by harvesting heads

This chapter presents the results of the study described in Seliverstrov et al. (2010). The experiences of using harvesters by logging companies shows that while machine operators pay due attention to sharpening sawing chains, there are usually problems with maintaining the delimbing unit. As delimbing is carried out at a rather high speed of feeding the stem through the head (up to 5 m/s), there are high quality demands on the delimbing knives in terms of their durability and ability to retain the optimal geometry of the cutting edge and sides of the knife. Blunting the cutting edges and changes in the geometry of their shapes reduce the capacity of the machines and reduce the quality of logs. The knives wear out fastest during snow-free times when the branches carry mineral substances and particles from the soil during harvesting.

The research conducted at seven logging companies in Northwest Russia exposed the fact that most companies did not meet the requirements for sharpening delimbing knives in accordance with the manuals during maintenance. Knives were not sharpened on time, but even worse they were sharpened incorrectly. As a result, even if knives were sharpened, it was not always carried out in line with technical requirements. Table 3.23 gives an example of the sharpening angles for three John Deere 758HD harvester heads, measured at one of the logging companies and compared with the recommendations of the manufacturer (operation manual).

Table 3.23 Sharpening angles of cutting edges.

	Angles of the cutting edges of knives				
	Two moving top knives		Two moving bottom knives	One supporting top knife	
	A	C	C	A	B
Harvester head 1					
Measured	40°	50°	45°	30°	30°
Recommended	35°	40°	40°	35°	30°
Deviation	5°	10°	5°	-5°	0°
Harvester head 2					
Measured	38°	45°	35°	29°	35°
Recommended	35°	40°	40°	35°	30°
Deviation	3°	5°	-5°	-6°	5°
Harvester head 3					
Measured	40°	47°	40°	35°	37°
Recommended	35°	40°	40°	35°	30°
Deviation	5°	7°	0°	0°	7°

A – sector for cutting branches from thin stems, B and C – sectors for cutting branches from thick stems.

As can be seen (measurements were taken after sharpening), the actual angles differ from the recommended ones by up to 10 degrees. Besides the failure to follow the instructions on sharpening angles, sometimes the geometry of sharpening was faulty. For instance, there were some cases when the top supporting knife was additionally sharpened along the lower edge of the upper cutting edge, and thus the necessary clearance was removed (Figure 3.20). With that sort of counter sharpening, a knife would turn away from the surface of the stem, especially when working with deciduous trees, and the branches would be poorly cut.

Figure 3.20 Top supporting knife with counter sharpening along the lower cutting edge

Figure 3.21 Top knife: a – correct angle for cutting branches from thick stems; b – incorrect angle for cutting branches from thick stems

In some harvesting heads investigated, moving top knives (Figure 3.21) had cutting edges (sector C in Table 3.23) that had been increased by 5–10 degrees for delimbing thick stems. The reason for this was that because of wear and tear, the geometry of the cutting edge changed and this was never corrected during the following sharpening process.

The study of delimbing with poorly sharpened knives showed that often such knives cut into the stem or, on the contrary, went off the stem leaving unprocessed branches (Figure 3.22).

In addition to incorrect maintenance, we registered some cases of a failure to observe operational requirements that resulted in mechanical damage to knives. Quite often, when working with a tree, operators allowed the top supporting knife to hit the machine. Such collisions lead to dents on the knife that have to be repaired (Figure 3.23).

Figure 3.22 Unprocessed branches

Figure 3.23 Damaged top supporting knife

In addition to the condition of the knives, the condition of the feed rollers influences the effectiveness and quality of delimbing. Table 3.24 shows the results of measuring the condition of the spikes on the feed rollers.

Table 3.24 Condition of the feed rollers

Average height of the ellipse-shaped spikes on the roller, cm / % of wear				Number of spikes missing on the roller, pieces / %			
side		Support on the frame		side		Support on the frame	
right	left	right	left	right	left	right	left
1.19 21%	1.16 23%	1.3 13%	1.29 14%	8 6%	29 21%	–	3 3%
1.31 13%	1.32 12%	1.39 7%	1.39 7%	4 3%	3 2%	–	–
1.42 6%	1.41 6%	1.44 4%	1.45 3%	10 7%	6 4%	–	–

As the data demonstrate, side feed rollers were most worn out (up to 23% in height and up to 21% sideways). It is clear that the condition of the feed rollers should be under control during maintenance, and that they should be repaired or replaced when needed. One more parameter to be taken care of during the harvesting head maintenance is the power of feed rollers and knives pressing the stem.

It is clear that whereas the replacement of worn out rollers is a rather costly operation, directing spikes on rollers, the periodic check-up of the pressure of feed rollers and knives and its adjustment, and correct sharpening cost relatively little. At the same time, the benefits of those measures are obvious, because faulty functioning rollers also damage stems (Figure 3.24).

In order to evaluate the influence of correctly sharpened knives under different conditions of the rollers and normal pressure on the quality of delimbing, a study was carried out. The quality of logs before and after sharpening knives on three harvesters working in similar stands was evaluated.

Figure 3.24 Stem damaged by feed rollers

In spring after the correct sharpening of the knives (head 1), it was shown that for the most worn out rollers the share of deficient logs (branch stumps over 10 mm) in the total number of sawn logs and pulpwood decreased for pine by 4%, for spruce by 4%, and for birch by 6%, i.e. processing stems with volumes from 0.5 to 1 cubic metres became more efficient.

For worn out rollers in spring (head 2), the share of deficient logs decreased by 2% for pine and by 2% for birch. Almost no change was observed for spruce.

For new feed rollers in summer (head 3), the share of deficient logs decreased by 2% for birch. There were no changes for spruce in both cases. Under the maximum wear of the feed rollers (head 1), the effectiveness of delimbing was worse in comparison with heads 2 and 3.

Most deficient logs of the species described above were found before sharpening delimbing knives and with the most worn out rollers on head 1 (up to 12%), whereas for heads 2 and 3 the figure was no more than 8%. When the knives were sharpened, the quality of the logs improved for all three heads and the share of deficiencies dropped (in terms of branch stumps) by 25–50%. Harvester operators certainly need training in order to fulfil the recommendations listed below, and this is an important factor for increasing the effectiveness of these machines (Syunev et al. 2008). The following is recommended to enhance the effectiveness of harvesters under Russian conditions:

1. To pay more attention to sharpening delimbing knives of the harvesting head in spring, summer, and autumn, which will contribute to upgrading the quality of logs harvested, even when the spikes on feed rollers wear out.
2. To consider the possibility for increasing the durability of the cutting edges of the top supporting delimbing knife (for John Deere 758 HD) (and Kesla head, upon the results of the study of the impact of delimbing and feed unit on the quality of forest materials, head Kesla Foresteri 22RH). For Kesla: to consider the possibility of using a floating top supporting knife instead of a stationary one.
3. To control the condition of the feed rollers during maintenance and to repair and replace them on time.
4. Harvester operators should not only be familiar with the requirements to sharpen knives in accordance with the “Operation and Maintenance Manual” for the harvester head, but they must be obliged to ensure that technical personnel perform high-quality knife sharpening.
5. Manufacturers of harvesting heads should include devices (angle finder) for measuring (controlling) the angle of knife sharpening in the set of equipment going together with the harvester head.
6. The salary of operators should depend on the quality of roundwood.
7. To facilitate a special training system for machine operators for studying the theoretical basics of machines, special operational features, and existing practices. Practical training should be based on up-to-date training simulators.

References

Operation and Maintenance manual for harvester head John Deere 758HD.

Seliverstrov, A., Syunev, V., Gerasimov, A. and Sokolov, A. 2010. Povishenie effektivnosti ispolzovaniya harvesterov. Systems, Methods, Technologies 4(8): 133–139.

Syunev, V. et al. 2008. Analysis of the need in training forest harvesting machines. Publishing office of the Finnish Forest Research Institute Metla. 11 p.

3.5 Recommendations for adapting forest machinery to conditions in Northwest Russia

More than 15 years experience of operating Finnish forest harvesting machines by logging companies in Northwest Russia, and in the Republic of Karelia in particular, have demonstrated their effectiveness regarding better labour conditions in terms of ergonomics and safety and high environmental quality and reliability in combination with convenient operation and maintenance. The productivity of work and the quality of harvested wood can be considered to be acceptable, even though they could be higher (Syunev et al. 2008a).

This chapter presents the results of the study Seliverstrov et al. (2010) published in Russian. When buying the whole harvester or only a harvester head for the available machinery (excavator, for instance), it is necessary to study the technical features of the equipment. Equipment that is not suitable for the operational conditions in question (type of logging, parameters of the stand etc.) will very soon have a negative influence on the effectiveness of its use.

Special attention should be paid to the choice of the equipment if only a harvester head is bought. Its technical specification must meet the parameters of the chosen machine (weight, diameter of trees to be processed, pressure in the hydraulics, feed of pumps, capacity etc.). For example, a low feed of the pump will lead to a situation when it is impossible to combine the operations of the harvester head and the crane. Together with an insufficient capacity of the engine, this reduces the capacity of the machine dramatically.

The right choice of equipment plays a significant but not unique role in the effectiveness of using harvesters. The second factor for success is correct operation and maintenance, which implies the use of the oil and technical liquids recommended by the manufacturer and following the sequence and volume of maintenance operations. Special attention should be paid to the maintenance of the saw and delimbing unit. In particular, it is necessary to correctly adjust and regulate the delimbing and feed unit, sharpen delimbing knives, and clean the rollers from the remains of the bark and wood.

A study conducted on a number of large enterprises in the Republic of Karelia showed that often the companies do not reach a high yield and quality of harvested wood (Seliverstrov et al. 2010; Syunev et al. 2008b). The reason for this may be that forest harvesting machines manufactured in northern Europe cannot adapt to the natural and operational conditions in Russia.

Harvesting machines and processing equipment produced in northern Europe have various geometric, size, and capacity parameters for different functions, which allows harvesting companies (hereafter buyers) to select machines and processing equipment that is suitable for the specific natural and operational conditions. In addition, machines can be delivered to the buyers according to their requirements for the configuration. For instance, the type of cab can be chosen as well as type of crane, automated operation system, measurement system for harvested volume and lengths of logs by computer, harvester head, and equipment additional to the main package (arctic configuration, shape and size of the wood bunks of the forwarder, weighing device etc.). At the same time, Russian buyers when choosing forest machines and equipment do not pay attention to these facts but rather to the following:

1. Price (attractive sales policy of the manufacturer, official representative, or dealer). Machines are procured at the cheapest configuration. At the same time, the machine and/or its processing equipment might be of a size, weight, and capacity that do not allow the achieving of high

productivity and quality under the natural and operational conditions in the forests of the company and under the types of logging used. It is then possible to exceed the load-carrying capacity of the forwarder, use the harvester intended for thinnings at clear cuts, and so on.
2. Warranty and post-guarantee service and logistics for spare parts.

Often, wood bunks are overloaded, which results in their bending and breaking because of forwarder operators' failures to follow the requirements during loading and unloading operations and exceeding the load carrying capacity when hauling wood (even in cases when the machine is suitable for the prevailing natural and operational conditions). In this case, welding is necessary at the point of bending and tearing welding seams (additional strengthening).

The mechanisms for weighing individual logs in the grapple or the whole load space with CTL logs provide for tracing the cases of exceeding the load-carrying capacity and preventing such violations of guidelines by machine operators.

The following parts of the forwarder break down most frequently when these technological requirements are not followed: the chain mechanism of the boom's telescope, hydraulic cylinders of the crane, and attachment part of the grapple at the end of the boom. Whereas the harvester has the following most significant breakdowns: the failure of the hydraulic cylinders of the crane's boom and pillar, cracks at welding seams on the crane boom and handle, and wear of the rotating mechanism.

Wheeled medium and basic size class 6×6 harvesters are the most common in Northwest Russia. (John Deere 1270D and 1470D, Ponsse Ergo and Beaver, and Valmet 911) as are universal 6×6 and 8×8 forwarders such as John Deere 1010D, 1110D, 1410D, Ponsse Wisent and Buffalo, and Valmet 860. Also widely spread are harvesters based on tracked excavators (road construction machines of Volvo, Hitachi, Kobelco, Daewoo etc.) with harvester heads (mainly Finnish or Swedish brands) attached to the booms. In some logging processes, excavator-based harvesters are used as processors at loading sites near forest roads. In these cases, they delimb the stems and cut them to length.

As an example can be mentioned a study of the operation of a harvester based on a FIAT-Kobelco excavator E135SR at a Russian enterprise, which found that quite often the machine does not operate effectively. In particular, the actual hourly productivity of the machine was less than 12 cubic metres with an average stem volume of 0.165 cubic metres. It was found that the capacity of the machine was 63 kW, when a Kesla Foresteri 22RH harvester head that was used requires about 75 kW. In addition, the operation of the head was slowed (delimbing and feed unit) when it was used together with the crane, because the machine had only one hydraulic pump. All this could have been avoided had the company selected the correct machine with hydraulics suitable for the harvester head from the very beginning.

The wide range of the natural and operational conditions in Russia in terms of terrain, nature, climate, and type of logging also have a significant impact on the operation of forest harvesting machines. Machines drive on forest soils that have low carrying capacities and where tree root systems are present. In some regions, the soil contains a lot of stones. In addition, boulders are a serious obstacle for manoeuvres. Therefore, a forest machine should have cross-country ability and manoeuvrability with high tractive force and, at the same time, it should cause minimal damage to the surface layer by forming tracks, pressing the soil, or damaging roots. For instance, the use of articulated machines with six driven wheels secures good manoeuvrability (John Deere 1010D etc.). A double driving system for the rear half-chassis could give additional manoeuvrability to the machine (El-Forest AB). The ground clearance – which is about 600–700 mm as a rule – is sufficient for overcoming obstacles.

The operation of forwarders in hard conditions shows that the following parts are broken most often: the chain system of the bogie, the wheel hubs in the front part of chassis (machines with 6×6 wheel formulas), and the bearings of the middle joint.

In order to improve operational qualities – including work on a slope – most wheeled and tracked harvesters, such as John Deere for instance, have a levelling and rotating cab. Harvesters based on a tracked excavator (road construction machines) predominantly have no cab tilt option. Levelling the cabin of forwarders would also enhance their operational qualities and the effectiveness of technological processes with improved ergonomics of observation (angles, observation in the direction of operations etc., especially if the crane is mounted behind the cab). The John Deere 1510E forwarder is an example of such a machine.

For operations on slopes between 16 to 25 degrees, and from 26 degrees and more (for mountainous regions in Russia), it is feasible to work in dry weather; otherwise, the machine should contain special technical solutions that prevent it from falling or sliding when working upwards and even downwards, namely a prolonged chassis on tracks or eight driving wheels. For slopes exceeding 26 degrees, a synchronically operating winch mounted at the rear is also effective (for example, machine HSM 405HL2 etc.).

The levelling of a harvester on a slope is also possible by means of the hydraulic change of the ground clearance. Several Swedish machines are capable of this. Thus, the centre of mass can be lowered in order to secure maximal stability, and later it can be raised for driving in the forest. However, such a construction makes a machine more sophisticated and heavy; therefore, cab tilting is more effective.

The characteristics of the stand and type of logging have a considerable impact on the choice of the technology, machines and equipment for harvesting. Mixed stands with different defects in wood and abnormalities in stem shape dominate in Russia, which should be accounted for when designing harvester heads (Syunev and Selivesrov 2007); for instance:

- Increase in the feed force for cutting thicker branches (up to 30 kN and higher) (powerful hydraulic motors for driving rollers, increase in the number of rollers, use of tracks, and combined systems: two rollers and a track or two rollers or an extendable boom with a grapple);
- Possibility to process crooked stems (by using a short frame and four-roller or tracked feed system;
- Lighter construction of heads (using new materials)
- Modernisation of steering and operating system.

Powerful harvester heads demonstrate the trend of increasing the width of the gripping arms with feed rollers. This allows the processing of larger trees. One should remember that such heads are feasible for use under certain production conditions, because in stands with small diameter trees to be cut, the surplus of the arms' openings extends the time for gripping a tree and thus decreases productivity.

The following natural and climate conditions influence the parameters of designed and operated machines: air temperature, humidity, wind speed, volume of precipitation, and height of snow cover. The best conditions for the machines are temperatures below zero (up to –15 degrees) with low snow cover (up to 30 cm). In this case, sufficient passability is ensured on all types of soils without causing damage. When the temperature drops and the depth of the snow increases (compared with ground clearance), effectiveness drops as well. For instance, for working in low temperatures in the northwest, a so-called "Arctic configuration" is used (i.e. heaters for warming up fuel and hydraulic oil before starting the engine as well as the possibility of blocking the oil radiator to avoid the forced cooling of hydraulic oil). High outer temperatures in the hot season (above 30 degrees) can also have a negative impact on hydraulics.

Large amounts of precipitation and high levels of humidity reduce passability for machines, especially on moist and wet soils. Machines have a more negative impact on wet soils, on which soils deteriorate faster and lose their carrying capacities. In this case, the use of tracks for wheels is especially urgent (see chapter 3.3.1) and, at the same time, this prolongs the lifetime of the tyres. In the case of increasing the number of wheels (e.g. up to 10; forwarder Ponsse Buffalo 10w), this reduces the pressure on the surface layer and increases load-carrying capacity with somewhat lower manoeuvrability.

For Finnish forest machines, hydrostatic-mechanical transmission has become number one. This allows for smooth change of gears while continuously securing good traction with the soil and carrying out several operations with the machine. Here, we should note that in the case of the long movement of the machine from one harvesting site to another, to avoid the overheating of the transmission it is effective to switch its hydrostatic component off and to use just the mechanical part, as for example John Deere machines do. In Russian conditions, when the sites can be relatively far (about 10 km) from each other, independent trips of forest machines with speeds of up to 30 km/h is plausible from economic and organisational points of view.

References

Seliverstov A.A. Synev V.S. Gerasimov Y.Y. Sokolov A.P. 2010. Povyshenije effectivnosti ispol'zovaniya harvesterov. Systems. Methods. Technologies.: 8(4): 133–139.

Syunev, V.S., Sokolov, A.P., Konovalov, A.P., Katarov, V.K., Seliverstov, A.A., Gerasimov, Y.Y., Karvinen, S., Valkky. E. 2008a. Comparison of harvesting technologies in logging companies of the Republic of Karelia. Finish Forest Research institute. 126 p.

Syunev V.S. Selivesrov A.A. Gerasimov Y.Y. S. Karvinen. 2008b. Vlijanije sortimentnoj mashinizirovannoj tekhnologii na kachestvo zagotavlivajemykh sortimentov // Scientific journal of BGITA [electronic resource]. – Bryansk: BGITA. Available at: http://science-bsea.narod.ru/2008/les_2008/sunev_vlijanie.htm, free. – references from the screen. In Russian.

Syunev V.S. Selivesrov A.A. 2007. Sovremennyje finskije harvestery I harvesternyje golovki v Rossii // V Lesprome. Forest industry Information Portal. Available at: http://www.vlesprome.ru/ (In Russian).

4 Industrial and energy wood logistics and infrastructure

4.1 Current status

Over recent years, the issue of the effectiveness of logistics in wood harvesting has become much more important and timely in Russia. First, this happened because of the accelerated growth in harvesting volumes obtained with cut-to-length (CTL) technology. In many regions, the share of CTL logging has reached 50%, and in some regions – for instance in the Republic of Karelia – it is 93% (MFCRK 2010).

When using the traditional tree-length (TL) method, stems are extracted from the harvesting site to one or two, and more seldom to three, central processing yards. These central processing yards usually accept all types of wood assortments. If a company has several yards, they are usually located at a certain distance, and therefore, it is clear that in most cases the wood is reasonable to deliver to the closest one.

The analysis of the existing approaches to wood transportation plans in the Republic of Karelia and Leningrad region identified two key options. The first option is to reserve for each harvesting site a number of trucks that are sufficient for transporting the harvested volume daily from the site. Therefore, in this case each truck makes the same number of trips daily from the same harvesting site to the processing yard until the site is fully harvested. The second option is based on massive transportation. The wood is not transported immediately and it is stored at the roadside landing (loading site). Then, in one of the three cases:

- When the landing is 100% full,
- When the harvesting at the site has been completed,
- When transportation is possible via seasonal roads,

… the whole fleet of machines, or its considerable part, start transporting wood from the landing site and complete the transportation in the shortest time possible (usually this takes several days). Both options are effective only if the destination for transportation is clear and permanent. The second option is usually applied in regions with long seasonal roads and, in contrast to the first one, this requires roadside landings.

Under other equal conditions, the use of CTL technology considerably complicates the issue of searching for an optimal transportation plan because of the lack of centralised processing yards in the classical scheme and the significant increase in the range of wood assortments. When CTL technology is used, wood assortments are transported directly to the yard of the customer or to a railroad terminal. The total number of customers and terminals can be quite large and, at the same time, the range of products delivered to each customer can be quite small. In addition, the volumes of products needed by different customers can vary greatly.

Therefore, a need often arises to supply products to the same customer from several harvesting sites and to several customers from the same harvesting site. At the same time, there are often other alternatives, namely the same products can be delivered to several clients from the same harvesting site and, conversely, certain products can be delivered to certain clients from several sites. All this results in the fact that standard schemes of organising transportation are ineffective. Therefore, owing to the sophistication of this issue, more effective plans can be produced only with the help of mathematical programming with special applied software.

Among other issues, a lack of acceptable solutions for this matter has seen the emergence of a hybrid approach to transporting logs in Northwest Russia. In the first stage, all logs are delivered from the harvesting sites to the processing yard and then, after secondary sorting, they are transported to the end customers. The yard can significantly increase the costs per one cubic metre of wood transported, because the overall transportation distance from the harvesting site to the processing yard and then from the yard to the customer will always be higher than is the distance from the harvesting site to the client. In addition, one should also add costs for reloading, storing wood, maintenance of the storage, and so on. Therefore, it can be concluded that a reliable and preferably universal algorithm will help logistics experts to find the optimal transportation plan based on the methods of mathematic programming that account for all the special features listed above. This could significantly increase the effectiveness of transporting wood harvesting products.

Reference

MFCRK, 2010. The share of cut-to-length method in the total volume of fellings. Ministry of the Forest Complex of the Republic of Karelia. 1 p.

4.2 Optimisation of wood harvesting and logistics

This chapter presents the GIS-based decision support system for the optimisation of harvesting plans and wood logistics. The development of the system started from the creation of algorithms and software for the optimisation of wood logistics. Later, an algorithm and software for the optimisation of wood harvesting plans were added into the system. A detailed description of the system and its development was presented in Gerasimov et al. (2008) and Sokolov and Gerasimov (2011).

4.2.1 Optimisation of wood logistics

Introduction

In Russia, logging operations are traditionally divided into three stages: harvesting, transport, and work at the central processing yard. Wood harvesting is conducted according to the full-tree, TL, or CTL methods. These methods are different in terms of the applied technology, namely delimbing and cross-cutting taking place at the stump, roadside, or central processing yard (Karvinen et al. 2006). The methods used to transport wood depend on the used harvesting methods: wood is transported either directly to the end user from the roadside storage or via intermediate storages or central processing yards. It is easy to manage logistics issues related to the traditional TL method as all TL wood from cutting areas is transported to one central processing yard. The application of the CTL harvesting method or the use of a processor at a roadside storage require more attention because different wood assortments or shortwood from cutting areas should be delivered directly to several customers: pulp mills, sawmills, wood-based boards mills, wood terminals, and railway stations. Short-wood logistics is complicated and it cannot be realised effectively using current TL approaches (Sikanen et al. 2005). Logistical approaches for shortwood transport are not yet well developed in Russia. The software and tools developed in countries that have a lot of experience of the CTL method and shortwood logistics, namely Finland and Sweden (Andersson et al. 2007; Forsberg et al. 2005; Fjeld and Hedlinger 2005; Uusitalo 2005; Hedlinger et al. 2005; Helstad 2006), are not necessarily applicable in Russian conditions. This is because of the specific organisational structures of Russian logging companies, which include a transport department with its own vehicle fleet, garages, and repair workshops. Russia also has specific requirements regarding the axle loads of trucks, its own standards of roundwood, its own categories of roads, poor road maintenance, seasonality of road availability, and an uneven distribution of logging during the year. Moreover, solutions are usually company-specific, so that tailored programming tools need to be developed for improving the planning and optimisation of wood transport in operational and tactical tasks.

Objectives

The objective was to develop a GIS-based decision support program for planning and analysing shortwood transport for a logging company in Russian conditions. The program should give the logging company comprehensive information about the benefits and limitations of different shortwood transport options. The logging company should get sufficient information to make sound short-term and long-term decisions.

The economic feasibility of logging operations that provide shortwood is a critical element for the development of forestry and wood harvesting in Russia (Karjalainen et al. 2005). The decision support program also acts as a set of guidelines for logging companies since it takes economic aspects into consideration, draws attention to the lack of shortwood trucks, and gives recommendations for the organisational management of logistics (i.e. delivery planning, locations of garages, and temporary wood terminals) when required.

Problem set

The problem in the shortwood transport is to define delivery plans that maximise wood removals and rationalise the usage of the shortwood truck fleet in a logging company. The term delivery plan means an output schedule for the truck fleet for a given time period, including, for example, the places and time for loading and unloading and types of transporting assortments.

Let us formalise the shortwood transport problem. The logging company has several operation units: cutting areas, customers, railway stations, and garages. The following data are known: allowable and actual shortwood storage at roadsides, daily productions in cutting areas by assortments, and their accessibility for wood transport in winter or all-seasons. The company has valid wood trade contracts with some customers and monthly delivery volumes by assortment are known for each customer.

The type of assortment depends on tree species, use (sawlog, pulpwood, energy wood), size or dimensions (diameter and length), and quality of wood (domestic or export requirements). The size of an assortment can be specified by limiting values (minimum, maximum), tree species can be specified directly (pine, spruce, birch, aspen, and other) or given as a general information (coniferous, deciduous, any). Moreover, a customer may accept unsorted roundwood. In such a case, two different assortments in the cutting area can be equal: raw material in the mill and vice versa. Therefore, assortment identification has to distinguish between assortments' nomenclatures in cutting areas and at customer sites.

All cutting areas and customers are connected by road and/or railway. The trans-shipment from trucks to railway wagons is organised in terminals at railway stations. Wood from cutting areas to mills or terminals is delivered by shortwood trucks. The number of trucks and their characteristics (model, carrying capacity, etc.) are established. Each truck registers in a concrete garage. There can be several garages. GIS should be used to locate and connect cutting areas, terminals, customers, and garages.

Program structure

Overall structure of the program

The decision support program was constructed in MapInfo using Map Basics for coding and Microsoft Excel for reporting, i.e. a very common software. The MapInfo environment provides the possibility to build a program with user interfaces and custom dialog boxes with MS Excel. An overview of the program structure and its most important components is presented in Figure 4.1.

- The *Data* module includes information about roads and their quality, locations of logistics management units (i.e. cutting areas, customers, truck garages, and railway stations), and their characteristics. The user can easily manage data with a user-friendly interface.
- The second part of the program is the *Graph* module. In this module, the user can generate a layer of roads including logistics management units. Several sub-modules have been created for the managing graph (construction, editing, deleting, and adding).
- The module of *Optimal Routes* helps the user search for a better variant of shortwood transporting route using a heuristic optimisation method.
- The module of *Optimal Delivery Plan* helps the user optimise the daily tasks for each truck using dynamic programming.
- The *Reporting* module contains reports on the optimal routes and delivery of the shortwood transport for the logging company.

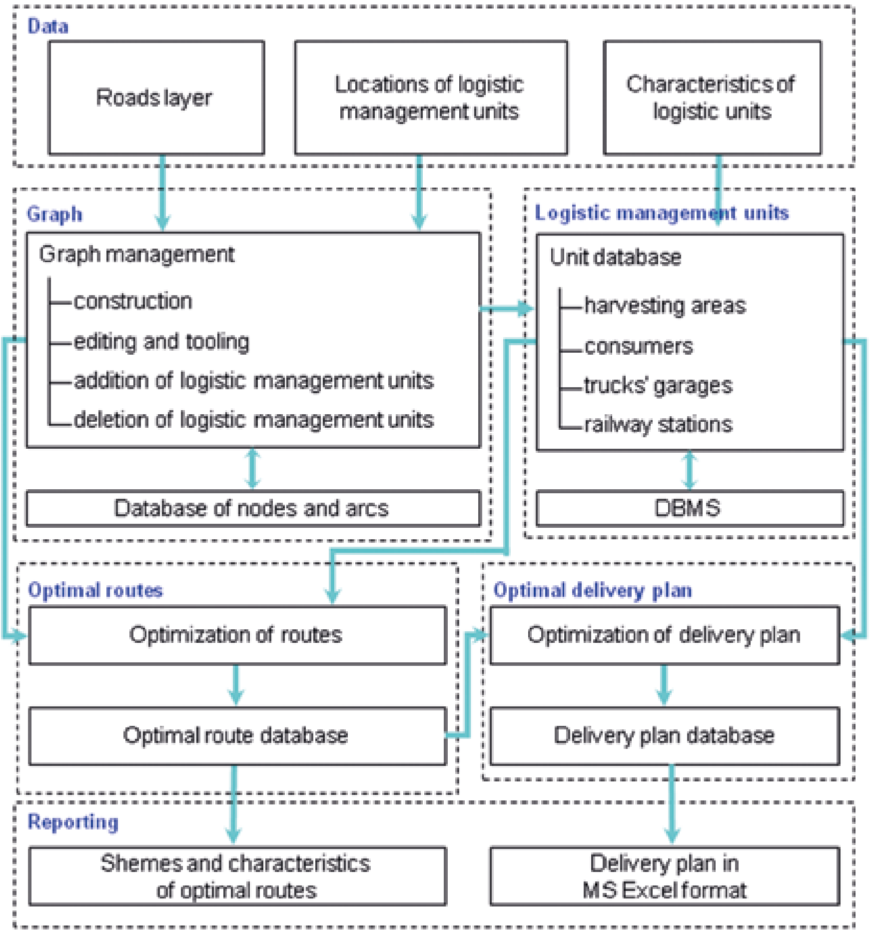
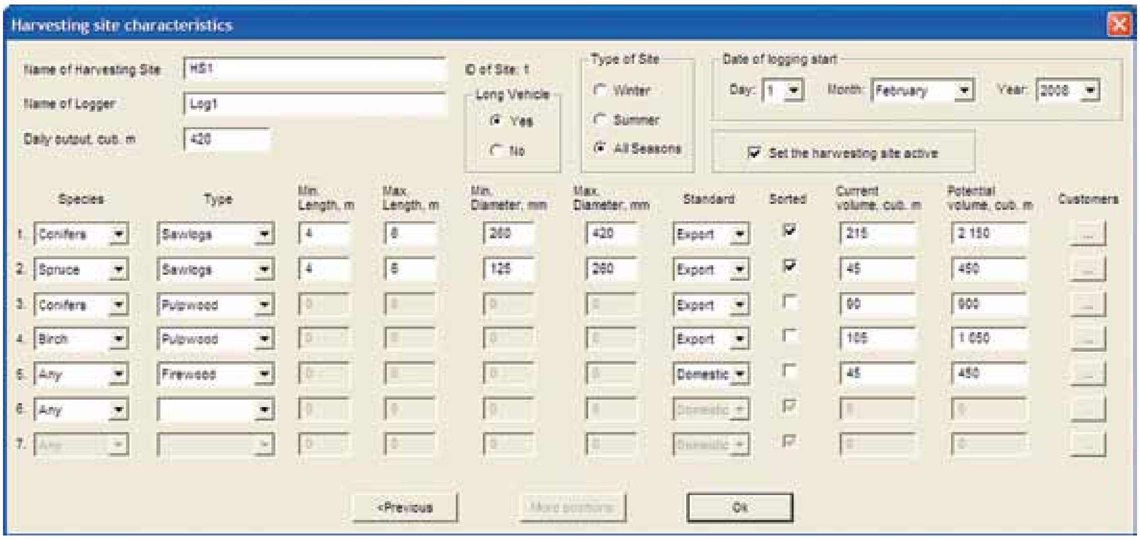


Figure 4.1 An overview of the program structure

Data

Data required for planning and analysing shortwood transport include:

- Road maps in the MapInfo format
- Locations of logistics management units (cutting areas, customers, railway stations, garages)
- Characteristics of logistics management units
- Cutting areas (Figure 4.2): starting date of logging; type of cutting site (winter, summer, the whole year round); type of producible assortments and their characteristics: tree species, size, and quality class; average production of daily logging; growing stock by assortments: actual cut and allowable cut; possibility to use heavy trucks with trailer; possible customers for each assortment.
- Customers (Figure 4.3): type of customer (local customer means that direct delivery by truck is possible, remote customer means that transhipment from trucks to railway wagons is needed); distance from railway station to remote customer; types of used assortments and their characteristics: tree species, size, quality class; monthly contracted deliveries by assortment.
- Garages (Figure 4.4): number of registered trucks; characteristics of each truck: model, trailer, or semi-trailer availability, registration number, carrying capacity, average time for loading and unloading.
- Railway station: name, code; costs of trans-shipment from trucks to wagons via terminal per m.
- Wood transporting costs and trans-shipment costs at terminals are taken into account when searching for optimal routes.



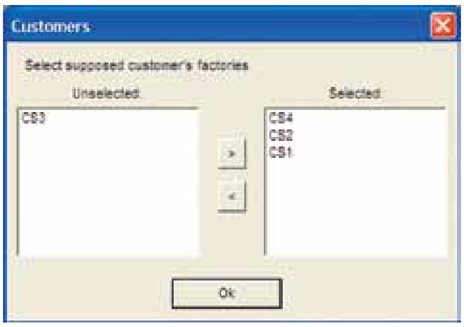


Figure 4.2 Screenshots for a cutting area

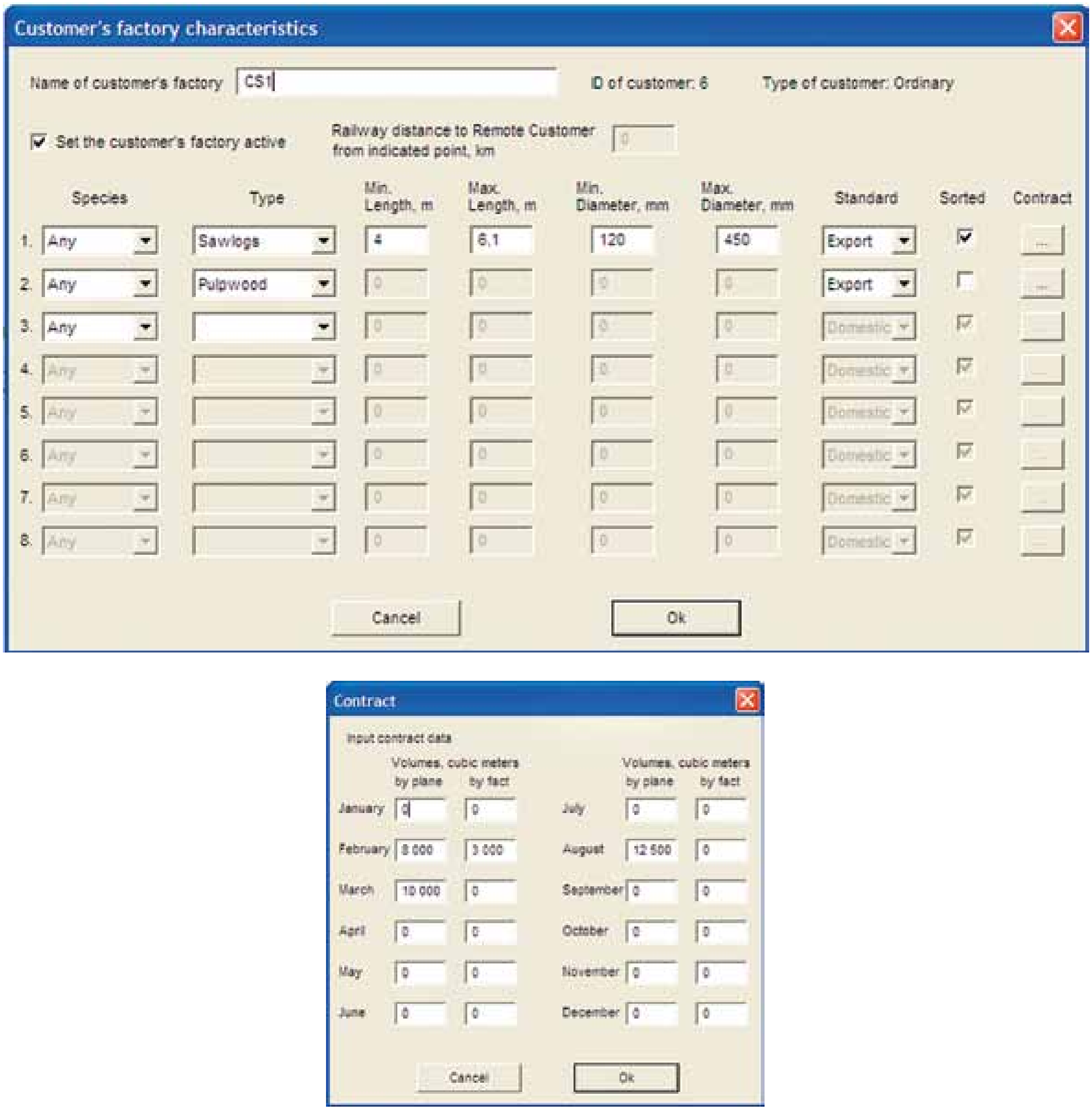


Figure 4.3 Screenshots for a customer

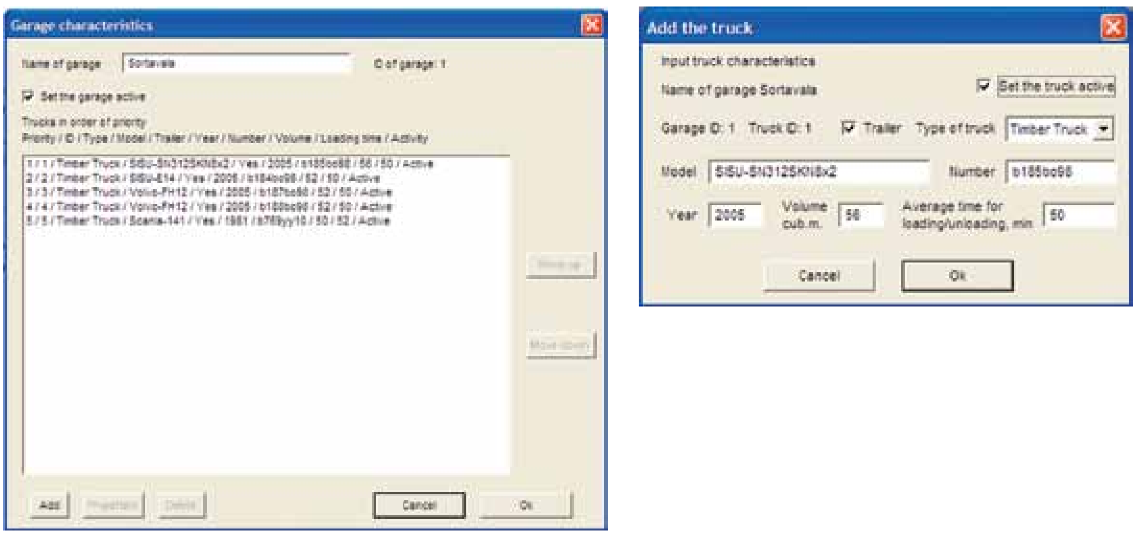


Figure 4.4 Screenshots for a truck garage

Graph

Before searching for optimal routes, the initial layer of roads has to be transferred into the graph. The first step is the creation of the layer of nodes. Nodes are numbered and saved in the database.

The next step is the creation of the layer of arcs – every road is transferred into several independent segments. The starting and the ending points of segments coincide with dotty objects of the layer of nodes.

Type of the road, number of starting and final dots, arc length, and the computed time of moving are entered into the database for each arc. The user has to put down the average speeds of all types of roads for the calculation of moving time.

If the user knows the specific properties of the road sections – their state, complicated turns, and other factors affecting speed – the program has special tools for specifying them. Fig. 1 shows an example of the graph including the logistics management units of a logging company.

Search for optimal routes

The search of optimal routes helps find the route with the lowest transport costs. Relative or absolute wood transport costs per 1 m^3 by different types of roads and trans-shipment costs at the terminals have to be established.

The estimation of moving time and the costs between the logistics management units are important elements for optimisation. Moving time depends on the distance and the average speed of moving along the road under different conditions. Usually, several paths can be used for moving.

For optimal route searching, an original heuristic method based on the Dijkstra algorithm was applied (Dijkstra 1959), allowing the taking into account of all nodes of the graph for every step of the algorithm.

All routes and their characteristics were saved in the database and downloaded from there when queries were repeated. This saved time significantly during calculation of new alternatives for the delivery plan of the same graph.

Search for the optimal delivery plan

The synthesis of the delivery plan cannot be solved by using classical approaches (Andreev and Gerasimov 1999). This problem may be classified as “open” and “without end”. The process of calculating the delivery plan for every truck stops and the procedure for returning to the garage starts because the shift ends, because of a lack of shortwood in cutting areas, or because of obligations of wood trade contracts already performed. The original algorithm based on dynamic programming was developed for these tasks (Sokolov and Gerasimov 2004).

The criterion for the optimisation is wood transport per shift for every truck. The total time of the truck moving is minimised during limited shifts without non-technological stops. The established optimal decision directly corresponds to maximum wood transport per shift, i.e. number of runs. During conditional optimisation, at every step of the dynamic programming and for every current cutting area the customers with minimum total moving time are set in turn. Moving time is calculated from the beginning of the shift to the arrival at the current cutting area.

During unconditional optimisation (from the end to the beginning), the plan with maximum runs is defined. If several alternative plans with the same number of runs are defined, then the plan where the truck returns to garage as late as possible is selected (use of truck is maximised).

The assortment with the highest priority is selected if alternative types of assortments are allocated for transport from the optimal cutting area to the optimal customer. The assortment priority is moved in line with the user's dialog (characteristics of cutting area or customer).

All trucks are included in the total list by garage according to the user's priorities. The truck's priorities are set in line with the user's dialog (characteristics of garage). The first plan is calculated for the first truck in the list, and then for the second one (for undelivered wood), and so on. In the case of several garages, the first plans are calculated for the first trucks of all garages, and then the next plans are calculated for the second trucks of all garages, and so on as long as there is wood to be delivered. The results are saved as Microsoft Excel files; every sheet in the file is a delivery plan for all trucks of a single garage.

Efficiency of delivery plans

Testing

The efficiency of the developed program was tested in the actual logging process. Three delivery plans were compared for a logging company operating in the Republic of Karelia. The company provided forest inventory and infrastructure information and thus the following map layers were created: roads (five types of quality), forest stands, and cutting areas. The "basic" delivery plan (Plan 1) was made in a traditional way without program support. Two delivery plans (Plan 2 and Plan 3) were made with the program. The difference between the second and third delivery plans is that in the third plan the trucks change drivers en route without returning to the garage every shift.

The delivery plans were created for four consecutive working days using two shifts per day to replicate the same conditions of the logistics management units (cutting areas, customers, routes, fleet, etc.). There were five trucks based in one garage, four cutting areas, and four customers (three sawmills and one wood terminal). Capacities for shortwood trucks were 50–52 m^3 depending on the model (Volvo, Scania). Daily outputs in cutting areas were 140–420 m^3 depending on the site; the actual cut per cutting area was 5,000–15,000 m^3. A half of the actual cut was coniferous sawlogs including 9% of small-sized spruce sawlogs, 18% – coniferous pulpwood, 22% – birch pulpwood, 10% – energy wood (Gerasimov et al. 2005).

Performance indexes

Delivery plans were compared using the following performance indexes: total work time (hours), total run (kilometres); total number of runs, total volume of wood transport (m^3), total cargo run (kilometres), required number of trucks, fleet utilisation rate per shift, index of loaded distance; and index of operation work (m^3/km).

The fleet utilisation rate per shift has a somewhat different meaning compared with the standard fleet utilisation rate. This rate shows truck utilisation within a shift, i.e. how effectively trucks are utilised in the delivery plan. If the truck was standing idle during a day, it was excluded from the calculation. The most efficient delivery plan means the least working trucks for the same daily shortwood transport or, vice versa, the biggest shortwood transport for the same number of working trucks. The index of loaded distance means the ratio between the total cargo run and the total run. The operation work shows how much shortwood is delivered per 1 km of the total truck's run.

Results

A comparison of the results between delivery plans when applying the basic method (Plan 1) and the program (Plans 2 and 3) are presented in Table 4.1. The change in the indexes (in percentages compared with the basic Plan 1) is shown in parentheses.

Table 4.1 Comparison between Plans 1, 2, and 3

Plan	Total working time, h	Total run, km	Number of runs	Total volume, m^3	Total cargo run, km	Required number of trucks	Fleet utilisation rate	Index of loaded distance	Operation work, m^3/km
1	307	7382	53	2740	2212	5	0.754	0.300	0.371
2	255 (–17%)	7382 (0%)	58 (+9%)	2996 (+9%)	2697 (+22%)	5 (0%)	0.728 (–4%)	0.365 (+22%)	0.406 (+9%)
3	239 (–22%)	5743 (–22%)	58 (+9%)	3000 (+10%)	2872 (+30%)	4 (–20%)	0.895 (+19%)	0.499 (+66%)	0.526 (+42%)

The optimisation of the schedule using the program with Plan 2 shows that the total delivered wood volume increases from 2740 m^3 to 2997 m^3 (+9%). The total run is the same, but the total working time decreases by 17%. The required fleet is the same, namely five shortwood trucks. The fleet utilisation rate decreases slightly (-4%), the index of loaded distance increases by 22%, and the total volume of transporting roundwood per km increases by 9%.

The optimisation of the schedule using the program with Plan 3 shows that the total delivered wood volume increases from 2740 m^3 to 3000 m^3 (+10%). The total run decreases from 7382 km to 5743 km (-22%), and the total working time decreases from 307 h to 234 h (-22%). This reduces the required fleet from five to four trucks. The fleet utilisation rate increases by 19%, the index of loaded distance increases by 30%, and the total volume of transporting roundwood per km increases by 42%.

Discussion and conclusion

The developed decision support program can be used for the planning and analysis of shortwood transport. One logging company was asked to provide the actual data for testing the program. Different transport options were then presented to the logging company, and feedback was received for the further development of the program.

Testing the program and a comparison of the alternative delivery plans showed that the efficiency of shortwood transport can be increased by 40%. The application of the program allows for the computer-based processing of delivery plans and thus provides possibilities for producing several alternatives and taking into account possible changes both inside and outside the organisation. Most importantly, the program makes it possible to optimise transportation operations.

The program may not be able to find a global optimum in some cases. Testing shows, however, that problems appear only in the case of complicated graphs that have chaotic structures. In reality, forest road networks are not located randomly. They have certain directions, and thus the developed algorithm for searching for optimal routes can be considered to be reliable.

Mathematical programming was used as the main tool for optimisation. Algorithms were coded in a simple Map Basic environment. Obviously, such universal algorithmic languages as C++ or Visual Basic would provide better processing speeds and flexibility.

A review of the existing logistics methods and approaches applied in Russia show that logging companies are using different approaches. These approaches do not provide a basis for economic analysis. Moreover, decision making is strongly based on the experiences of logistics managers rather than on software support. Approaches are suitable for companies that use traditional TL technology and one central processing yard. The introduction of Nordic CTL technology requires more attention to wood transport logistics because roundwood from cutting areas has to be delivered directly to several customers, terminals, and railway stations. GIS-based decision support programs have been developed to assist logging companies make decisions on the planning, utilisation, and optimisation of vehicle fleet. Searching for optimal routes could also be used for other applications, i.e. forest road planning, fuel supply, and seedling transportation.

References

Andersson, G., Flisberg, P., Liden, B., Rönnqvist, M., 2007: RuttOpt – A decision support system for routing of logging trucks. Discussion Papers, Department of Finance and Management Science, Norwegian School of Economics and Business Administration (NHH), No 2007/16, 34 p.

Andreev, V., Gerasimov, Y., 1999: Optimal Decision Making: Theory and Application in Forest Engineering and Forestry. Joensuu University Press. 200 p. (In Russian. Summary in English).

Benkert, M., Wolff, A., Widmann, F., Shirabe, T., 2006: The minimum Manhattan network problem: Approximations and exact solutions. Computational Geometry: Theory and Applications 35(3):188–208.

Dijkstra, E., 1959: A Note on Two Problems in Connexion With Graphs. Numerische Mathematik 1: 269–271.

Fjeld, D., Hedlinger, C., 2005: The Transport Game – A Tool for Teaching Basics of Transport Decision Proficiency. International Journal of Forest Engineering 16(2): 57–64.

Forsberg, M., Frisk, M., Rönnqvisty, M., 2005: FlowOpt – A Decision Support Tool for Strategic and Tactical Transportation Planning in Forestry. International Journal of Forest Engineering 16(2): 101–114.

Gerasimov, Y. Sokolov, A. and Karjalainen, T. 2008. GIS-based decision support program for planning and analysing short-wood transport in Russia. Croatian Journal of Forest Engineering 29(2): 163–175

Gerasimov, Y., Siounev, V., Chikulaev, P., Pechorin, V., Dyakonov, V., Komkov, V., Sikanen, L. Karjalainen, T., 2005: Ananalysis of logging companies in the Republic of Karelia. Working Papers of the Finnish Forest Research Institute 16, 39 p

Hedlinger, C., Nilsson, B., Fjeld, D., 2005: Service Divergence In Swedish Roundwood Transport. International Journal of Forest Engineering 16(2): 153–166.

Helstad, K., 2006: Managing timber procurement in Nordic purchasing sawmills. Acta Wexionensia 93/2006, Växjö University press, 56 p.

Karanta, I., Jokinen, O., Mikkola, T., Savola, J., Bounsaythip, C., 2000: Requirements for a vehicle routing and scheduling system in timber transport. In: Sjöström, K. (ed), Logistics in the forest sector, Timber Logistics Club, Helsinki, 235–251 p.

Karjalainen, T., Mutanen, A., Torniainen, T., Viitanen, J., 2005: Changes and Challenges in the Russian Forest Sector. Finnish Forest Sector Economic Outlook 2005–2005, 50–53.

Karvinen, S., Välkky, E., Torniainen, T., Gerasimov, Y., 2006: Northwest Russian forestry in a nutshell. Working Papers of the Finnish Forest Research Institute 30, 98 p.

Sikanen L., Asikainen, A., Lehikoinen, M., 2005: Transport control of forest fuels by fleet manager, mobile terminals and GPS. Biomass and Bionergy 28: 183–191.

Sokolov, A. and Gerasimov, Y. 2011. Metodika prinyatiya resheniy po optimisacii lesozagotovitelnih planov. Nauchnyi jornal Kubanskogo Gosudarstvennogo Agrarnogo Universiteta 69(5): 320-334

Sokolov, A., Gerasimov, Y., 2004: Corporative information systems for wood procurement development in Karelia. Silva Carelica 45: 166–172.

Uusitalo, J., 2005: A Framework for CTL Method-Based Wood Procurement Logistics. International Journal of Forest Engineering 16(2): 37–46.

4.2.2 Optimisation of wood harvesting plans

Introduction

How to organise logistics is one of the most important issues for the logging industry. The importance of logistics has increased greatly. To a large extent, this has happened because of the introduction of new highly productive machinery in many Russian logging companies and because of the increase in CTL harvesting (Gerasimov et al. 2008, Sokolov and Gerasimov 2009).

To secure effective solutions to a whole range of issues, a computer information system for forest logistics has been developed, which uses GIS as a basis. The description of the system, its interface, problems solved, and applied methods and algorithms are described in detail in several publications (Gerasimov et al. 2008, Sokolov and Gerasimov 2009, Sokolov et al. 2009, Gerasimov et al. 2011, Gerasimov et al. 2008a) (see also chapter 4.2.1). Here, we present only a list of the new functions of the developed system:

1. At the operational level:
   a. Identifying optimal routes for shortwood trucks
   b. Making optimal shift-based transportation plans for each truck with fixed loading and unloading spots and characteristics of the assortments transported (roundwood or wood for bioenergy), times of arrivals and departures, and so on.
2. At the tactical level:
   a. Justification for needed harvesting capacities.
   b. Justification for needed wood transportation capacities.
   c. Making optimal plans for harvesting and transporting fuel wood for bioenergy.
3. At the strategic level:
   a. Justification for comprehensive technical and process solutions related to using forest raw materials (selection of harvesting technology, transportation, road construction, use of intermediate storages etc.)

The system consists of several blocks and subprograms. The main block is for the imitational modelling of wood harvesting. Among other things, the block requires a list of planned harvesting sites and the order of their logging with different machine systems, i.e., harvesters and forwarders or feller-bunchers, skidders and processors etc.

Here, we describe the methods and an algorithm for solving the problem of the allocation of harvesting machinery to harvesting sites to be logged using the latest version of the forest logistics information system described in the previous chapter.

Setting the task

The task of allocating harvesting machinery to harvesting sites can be solved with optimisation. In this case, the task is formulated as follows.

Let there be N sites available for potential harvesting and M harvesting chains of machines. The location of each site and connection to the road network is defined as well as the growing stock by species composition, yield of each type of product (logs and energy wood), and type of site, i.e., all-year-round or winter. Average productivity is known for each chain of machines under the given natural and operational conditions. In addition, the time, as well as average market prices, is known for all wood products FCA (free carrier), the distance, and average speed of the machines moving between each pair of harvesting sites. The task is to identify the sites planned for harvesting, their distribution among the machines, and the order of harvesting in a way that provides for an optimal solution according to the given criteria.

Method of solving the tasks

The given task was solved by modernising the previous forest logistics computer information system. The structure of the modernised system with the new module (the red text) is given in Figure 4.5.

The system allows for the setting, storing, and processing of all necessary information on harvesting sites and machinery. It can calculate the capacity of harvesting machines (harvesters and forwarders) depending on the species composition of the stands, average volume of stems, and average distance of hauling, thereby finding the optimal route for moving among the sites, the distance, speed, and time of movement, as well as defining the yield of products by their types. The possibilities listed above are used for the needs of the given set.

First, it is necessary to identify the criteria for being optimal. Most often, economic criteria are used when solving optimisation issues of production. In this case, it was found by calculating the profitability of harvesting at each potential site. Then, the ones with the highest profitability under the given limitations for machinery and seasonal limitations in a defined period of time were included in the plan.

If the time period contains several seasons, it is suggested to do planning step by step, i.e., for the first season and only for the sites accessible during that season, then for the second season, and for the third one, if necessary. The duration of the time period is limited to one year, because in practice, the necessity of detailed planning for a longer period is less probable. In this way, it is possible to identify the harvesting sites to be included in the logging plan, but not the order in which they will be harvested.

When the sites are known, the order of their harvesting can be defined by minimising the costs for moving the machines between them. In that case, the issue to be solved turns into a “problem of n commercial travellers”. Here we can use the block to identify the optimal transportation routes and the object database of those routes that are already available. Taking into account the

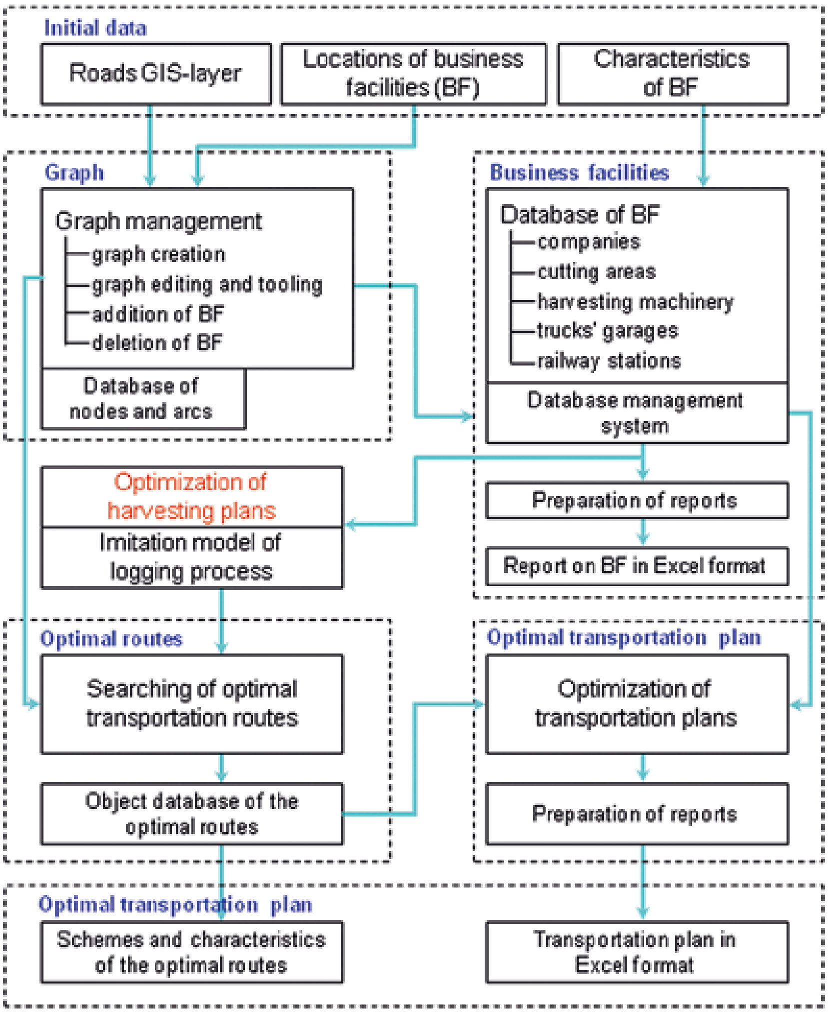


Figure 4.5 Structure of the modified forest logistics computer information system, now including the optimisation of the harvesting plan.

assumption made in the block for identifying optimal routes, namely that transportation costs are directly proportional to the driving time, the driving time from the starting point to the destination is taken as the criterion for the optimal solution. This is computed based on the distances between those spots along the graph of the road network and the average driving speed for each section of the road (graph fragments).

To account for the differences in the productivity of harvesting machines, it is suggested to split the task into two interrelated optimisation tasks. First, the order for covering all the sites included into the harvesting plan is defined without connection to specific harvesting machines. This task is a classical “commercial traveller problem”. The “commercial traveller problem” is solved with the help of the Prima algorithm for defining a minimal spanning tree (Kormen et al. 2005, Prim 1957, Cherition and Tarjan 1976) with the limitation for the number of sections within one peak curve.

The second stage defines the optimal distribution of the harvesting sites among the machines taking into account their concrete productivity. Since the number of harvesting machines chain working simultaneously for an average logging enterprise in Russia seldom exceeds 10, the optimal distribution of sites among the chains can be organised by a complete search of all possible combinations with the help of one of the permutation generation algorithms (Lipskii 1988).

Figure 4.6 The distribution dialogue of logs and prices

Implementation

For the implementation of the given task, programming language C++ was used for the forest logistics computer information system (Sokolov and Gerasimov 2011). A few changes were made in some of the interface dialogues and in the structure of the harvesting site database structure for securing the block functioning. A new field was introduced into the database, which includes the seasonal factor of the site. To set this factor into the main dialogue of entering the site characteristics, a necessary switch to "Cutting season" was added.

In addition, to calculate the profitability of the sites, entering average market prices (FCA) for roundwood was required. For this purpose, changes were made to the dialogue of setting the yields of different assortments and residues by species; thus fields for entering prices were added (Figure 4.6).

A new tool was added to the main dialogue of entering the features of harvesting machines (Figure 4.7). This launches the work of the block for optimising the harvesting plan (marked on Figure 4.7).

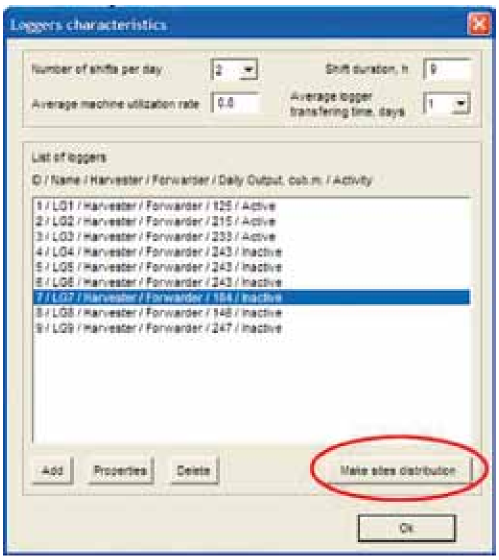


Figure 4.7 Main dialogue of entering the features for harvesting machines

Figure 4.8 Dialogue for entering the time period

After activating the tool, a newly created dialogue appears for entering the time period (Figure 4.8). After entering the time period, the block of harvesting plan optimisation switches on. As a result, the sites identified for harvesting during the time period are automatically distributed among the harvesting machines in the optimal order. Respective changes are also automatically entered into the respective databases, and these can be controlled by the user in the dialogues for entering the site and harvesting machinery characteristics.

The working efficiency of the programme was tested on one large logging company in Northwest Russia. As a result of the testing, the algorithm and software proved to be effective. The number of harvesting sites approved by forestry agencies for the enterprise was 129. Depending on the season, the company operated three to nine chains of harvesting machines. Testing was carried out for different numbers of machine chains (from one to nine) and for different time periods (from one month to a year) covering one to three seasons. For instance, when the sites were distributed among five chains of harvesting machines for half a year consisting of two seasons, the time for processing the algorithm on a PC Intel Core 2 CPU 6300 1.86 GHz 1 GB was about five minutes. In that case, 88 sites were chosen for logging out of a potential 129. Manual calculations would have taken a minimum of one working day. Therefore, upon the results of the work carried out it can be concluded that the techniques developed and the software for its implementation allow reaching the goal in terms of automating the synthesis of optimal harvesting plans, accounting for the special features of the sites, harvesting machines, and their operators, and understanding the availability and conditions of the road network and seasonal limitations.

References

Cherition D., Tarjan R. E. 1976. Finding minimum spanning trees. SIAM Journal on Computing, Vol. 5 (Dec.). 724–741.

Gerasimov Y. Y., Sokolov A. P., Karjalainen T. 2008a. GIS-based Decision-Support Program for Planning and Analyzing Short-Wood Transport in Russia Croatian Journal of Forest Engineering, Vol. 29, Issue 2. Zagreb: University of Zagreb, 163–175.

Gerasimov Y.Y., Sokolov A.P., Katarov V.K. 2011. Razrabotka sistemy optimalnogo proektirovaniya seti lesovoznykh avtomobilnykh dorog. Informatsionnyje tekhnologii, No 1 (68). 39–43.

Gerasimov Y.Y., Sokolov A.P., Syunev V.S. 2008. Logistika lesozagotovok: programma poiska optimalnogo lesotransportnogo plana. Lesnaya Rossiya, No. 5 – 6. pp. 54-61

Kormen, T. Leizerson, C., Rivest, R. and Shtain, K. 2005. Algoritmi: postroenie i analiz, 2 izdanie. 1296 p. (In Russian)

Lipskii V. 1988. Kombinatorika dlya programmistov. 213 p. (In Russian)

Prim R. C. 1957. Shortest connection networks and some generalizations. Bell System Technical Journal, Vol. 36. 1389–1401.

Sokolov A.P., Gerasimov Y.Y. 2009. Geoinformatrionnaya systema dlya resheniya optimisatsionnoj zadachi transportnoj logistiki kruglykh lesomaterialov. Izvestiya vysshikh uchebnykh zavedenij "Lesnoj Zhurnal", No. 3. pp. 78–85.

Sokolov A.P., Gerasimov Y.Y., Seliverstov A.A. 2009. Metodika optimisatsii parka avtomobilei na vyvozke sortimentov na osnove imitatsionnogo modelirovanija v srede GIS. Uchenyje zapiski Petrozavodskogo gosudarstvennogo universiteta, No. 11 (105). pp. 72–77.

Sokolov, A. and Gerasimov, Y. 2011. Metodika prinyatiya resheniy po optimisacii lesozagotovitelnih planov. Nauchnyi jornal Kubanskogo Gosudarstvennogo Agrarnogo Universiteta 69(5): 320–334

5 Forest roads

5.1 Introduction

5.1.1 Background

Accessibility to forests is one of the primary prerequisites for their utilisation. The possibility of gathering resources, in this case wood, and transporting it to a place where it can be processed and further distributed for consumption is essential for any industrial enterprise. As trees and logs are bulky, heavy, and have a low value per volume, this can be a challenge for the forestry industry. In Russia, as well as in Finland and other Nordic countries, horses and water were the two main ways of transporting before WWII. Logs were skidded by horses to the closest waterway, and floated downstream to a processing plant or a terminal. Logging was concentrated to winter conditions as the snow and frozen ground provided superior transport conditions.

In Finland, the development of more efficient truck transportation during the 1950s and 1960s, especially the introduction of hydraulic cranes on trucks, made road transport more competitive. The introduction of mechanised harvesting also called for year round activity in order to decrease the capital cost. In many places, water driving could only be performed during the high waters of spring, and thereby it did not match the more even flow of logs from forests. As a result, the forest road network was heavily expanded, and big investments were made into road-building projects. Today, Finland has all the forest roads it needs, maybe for the exception of some areas in the north; the forest road density being at par or even exceeding what is considered to be optimal.

5.1.2 Russian conditions

In Northwest Russia, development during the past 50 years has been somewhat different compared with Finland. The forest road network is significantly less extensive. Mönkkönen (2008) showed that the forest road density in the Tikhvin area is some three metres per hectare in total, and less than one metre per hectare of roads accessible year round with ordinary trucks. The reasons for the low density may be manifold, but it poses a major problem to introduce more intensive forest and silvicultural practices (Karjalainen et al. 2009).

Figure 5.1 Off-road (6WD) trucks on a forest road in Tikhvin. [Photo P. Mönkkönen]

One reason that makes it hard to build good roads in the area is difficult soil conditions. Silt and similar sediments are in many places the dominating soil texture. This soil has great water-holding capacity and when wet it almost becomes a quagmire. The availability of good gravel is very limited, and the transport of gravel is a very costly operation.

As more than two thirds of the roads are low quality, they serve an important role in the logistics operation. These roads are normally made by a bulldozer or similar equipment. The machine pushes the humus and topsoil to the side of the road, and that is pretty much it. During dry conditions such a road may be accessible to 4WD cars and even to ordinary trucks, but if wet, only specialised machinery may use it.

In Russia, a system of intermediary transport between the terrain transport and the regular road transport can sometimes be seen. This intermediary transport is carried out by six-wheel drive (off-road) trucks with an extremely good ability to cope with bad road conditions (Figure 5.1).

However, this transportation is not free and it has been estimated that the cost is almost as high as for the proceeding highway transport, even if it is only a fraction of the distance (Mönkkönen 2008). The relatively high cost is because of low payloads (~15 tons) and low speeds compared with a normal truck on a good road. The regular calculations of finding the optimal road density (e.g. Sundberg and Silversides 1988) does not include the possibility of intermediary transport. Therefore, there is interest in finding a way to theoretically include this intermediary transport into the calculation. The result is presented in section 5.3.

5.1.3 Study area

We concentrated this research on one study area. Similar conditions can be found in many places in Northwest Russia. The UPM-Kymmene-owned Russian logging company ZAO "Tikhvinsky Komplexnyi Lespromhoz" provided us with the study material. The aim of the company is to efficiently produce high quality wood for its factories in Russia and Finland. The company leases 184,000 ha of forests in the eastern Leningrad region (oblast). The location of the area can be seen in Figure 5.2.

The harvest plan states that the annual maximum allowable cut (sustainably) is 447,000 m^3. Of this, only 350,000 m^3 can be harvested because of the poor forest road network (2007). The majority (85%) of felling and delimbing is carried out by harvester and 15% by motor-manual operations (logger with chainsaw). Terrain transportation is mostly accomplished by forwarders. Transportation from the roadside is typically performed first by off-road trucks on poor forest roads 1–15 km to the nearest good road and then by log trucks up to 100 km to the railway terminal in Tikhvin.

The road network was digitised and the quality of the roads was estimated. The forest map and connecting records were also digitised. Existing and potential sources of gravel for road building in the area were explored and included in the digital map.

To gather manageable data we concentrated our effort even further to one area within the leased forests. The study area consists of 16,900 ha of leased forests. The problems of wood procurement and road construction are similar both in Tikhvin and in many other parts of Northwest Russia. A sparse and poor condition forest road network, expensive road construction, and the high costs of wood transportation are typical problems in Russian forestry (Karvinen et al. 2006).

Figure 5.2 Location of the studied forest area.

5.1.4. Data acquisition

In order to plan well, accurate and precise data on volumes, species compositions, ages, site indexes, and possible times for harvesting, is crucial. Furthermore, data on existing roads, topography, water, soil texture, and moisture are needed to correctly estimate different costs for transportation and road building.

However, data availability and acquisition is a major problem in Russian forestry. In many cases, data are not available digitally and there is much work required to digitise maps and turn paper sheets into databases. The planning authority does provide digital data, but it can be very unclear how to acquire it.

We tried to utilise freely available data for our study and combined this with forest data from the state forest inventory. Kinnunen et al. (2007) showed in a study from the nearby region of Novgorod that official data lack precision and accuracy. To some extent, we can verify data or at least show where the forest data are not accurate.

5.1.5 Planning

Ideally, road planning and harvest planning go hand in hand to minimise costs and maximise revenues. The road network of a forest area is a big investment. It is therefore of great importance that roads are properly allocated and that they can serve different aspects of the forestry industry for many years. Hence, it is essential to have a long-term perspective in the planning process. At the same time, the cost of road building has to be paid by incomes from logging. So, planning roads and harvesting is both a spatial and temporal issue. Dahlin and Sallnäs (1993) showed that the scheduling of harvesting in an area can have a large influence on the total net present value and profitability of a road-building project.

5.1.6 Objectives

The main objective of this project is to improve knowledge about and methods for forest road planning in Northwest Russia. In order to achieve this we want to expand the classical estimation of optimal road density for different road classes. This would provide a theoretical base for more detailed planning.

5.2 Optimal road density

Building an extensive road network is a considerable capital investment, and thus it requires careful planning. A dense road network decreases forest transport costs, but increases capital costs (Figure 5.3). The aim of planning is to minimise total combined costs for road construction and forest transport (Sundberg and Silversides 1988).

In areas where road construction is expensive, ordinary forest roads can be partly replaced with cheaper light forest roads. Ordinary log trucks cannot operate on these low-grade roads, but special high-mobility log trucks can haul the wood from the logging sites to ordinary roads.

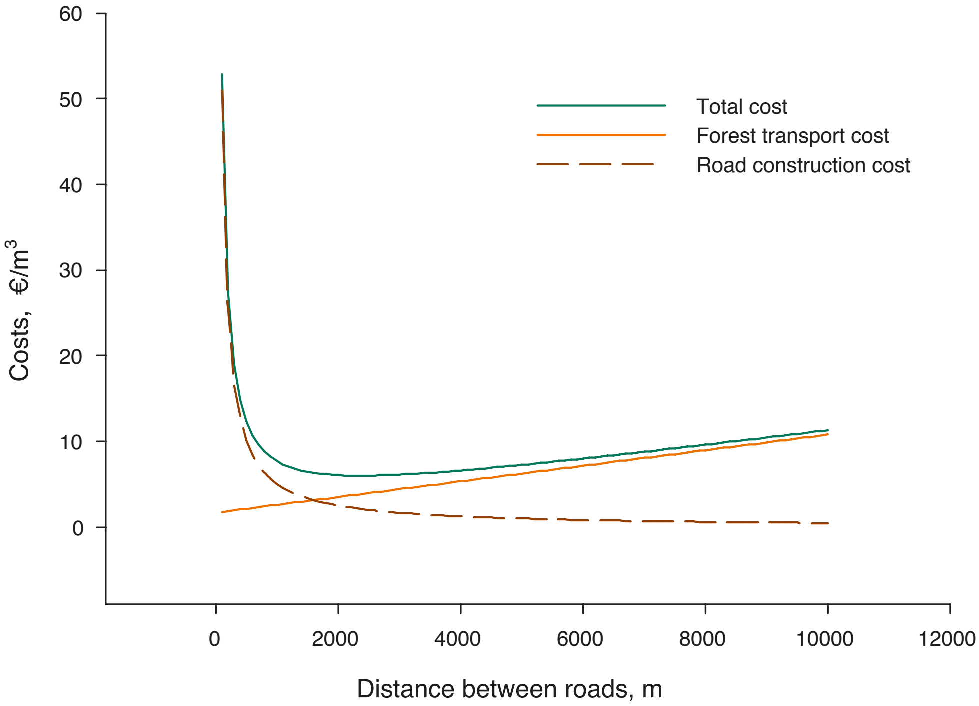


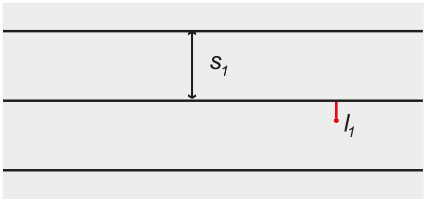
Figure 5.3 Forest transport costs and road construction costs as a function of road distance.

We have developed a road density model that takes into account ordinary and light forest roads. This model can be used to determine the optimal forest road density and forest transport distance. The optimisation method employed can analytically find the minimum point of a cost function by combining road construction and forest transport costs.

Figure 5.4 shows the arrangement of ordinary and light roads in the model. The different road types are perpendicular to each other. From areas near the ordinary roads, logs are transported directly to ordinary roads. From more distant areas, logs are first transported with forwarders to light forest roads, where they are loaded to high-mobility trucks and hauled to ordinary forest roads. The arrangement of roads is somewhat artificial, since it does not fully take into account terrain conditions. However, the effect of terrain is partially brought into the model using terrain correction factors.

This model was applied to a large forest area in Tikhvin. Road construction costs in the area are 30,000 €/km for ordinary forest roads. In Finland, road construction is more affordable, mainly because of more favourable soil conditions. Average road construction costs are in Finland ca. 12,400 €/km (Peltola 2009). Constructing light forest roads in the Tikhvin area provides an economic alternative to ordinary forest roads. Construction costs are 4200 €/km (Mönkkönen 2008).

According to the model, light forest roads and extended forest transport proved to be marginally more economical compared with a road network consisting of only ordinary forest roads (Figure 5.5). The optimal road density was in this case 3.2 m/ha of ordinary roads and 12.9 m/ha of light forest roads. If only ordinary roads were built, the optimal density would be 6.3 m/ha. For a comparison, the optimal forest road density in Finland is 10.5 m/ha (Viitala and Uotila 1999).



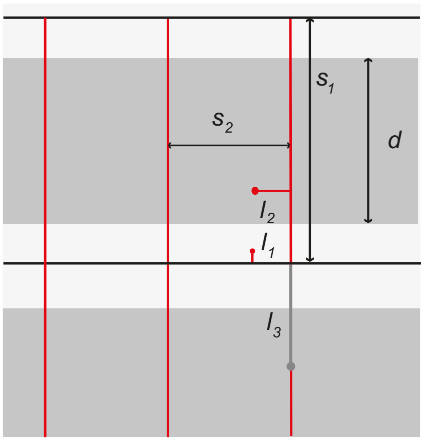


Figure 5.4 a) Schematic illustration of forest transport distance l_1 and distance between ordinary roads S_1. b) Illustration of ordinary and light forest transport network. From the dark grey area, logs are hauled first to light forest roads (red lines), and then to ordinary forest roads (black lines). From the light grey area, logs are transported directly to ordinary forest roads. Term l_1 is the average forest transport distance to an ordinary road, l_2 is the average forest transport distance to a light forest road, and l_3 is the average transport distance along a light forest road. S_1 is the distance between ordinary forest roads and S_2 is the distance between light forest roads. The width of the area where logs are transported to light forest roads is *d*.

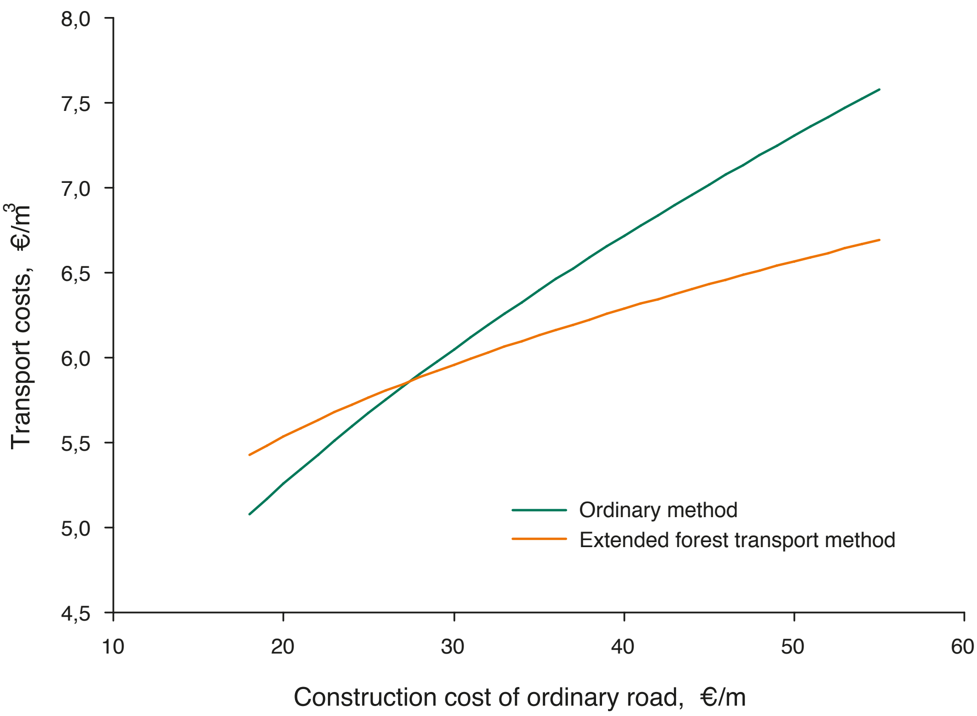


Figure 5.5 The transport costs of the two studied methods. Extended forest transport is slightly more economical in the current situation, but if road construction costs can be lowered by 2000 €/km, ordinary forest transport becomes more economical.

5.3 Data acquisition for operational road planning

5.3.1. Introduction

Operational forestry planning in all countries around the world is based on reliable forest inventory data. All forests located in Russia, including the regions of Archangel, Karelia, Komi, Vologda, Leningrad, Novgorod, and Pskov, produce a considerable amount of wood, which is an important raw material for the development of forest industries and also for socio-economic development. Annually, Northwest Russia produces 35% of all the industrial roundwood of Russia, 63% of its pulp, paper, and cardboard, 39% of its plywood, and 27% of its sawn wood. Moreover, the forestry sector is one of the most important employers in rural areas in the region, with there being approximately 120,000 employees in the industry, and 35,000 in the forestry sector alone (Gerasimov and Karjalainen 2006). Additionally, the forestry and forest industries are the backbones of the economies in many regions of Russia.

To be able to forecast medium-term forest management scenarios reliable multisource forest inventory data are necessary. Accurate and up-to-date information enables the effective and productive utilisation of forest resources. The ocular estimation of stand characteristics is the predominant inventory method in Russia. Detailed inventories are taken in forests that are relatively accessible and where the management is planned. Detailed ground-based surveys cover about 60% of all forests under state forest management (Kukuev et al. 1997). The accuracy of forest inventory data has been tested in several studies, and the volumes of the growing stock have been found to be underestimated by 10% to 30%. The amount of bias depended on the structure, age, and species composition of the stand. Aggregated data at the forest management unit (leshoz) have been found to be biased by 5% to 15%. The study carried out by researchers from the European Forest Institute in the Novgorod region of Russia showed on average an underestimation of growing stock of 13.4% (Kinnunen et al. 2004). The corresponding root mean square error was 32.4% for the material from 179 compartments (Kinnunen et al. 2004).

5.3.2 Materials and methods

The raster maps from the State Forest Inventory that were used in this study covered the leased areas in the Tikhvin region in Russia (Figure 5.6). The inventory was carried out in 2006 using aerial photographs and an ocular assessment of the stands was obtained in 2005. The planning of the construction of new roads started in 2010. Therefore, the growing stock and ages were updated using local growth and yield tables. The mapping scale of the original data set was 1:25,000. The vector polygon data set was produced by digitising original forest inventory maps. These data include information about species-specific tree volumes and ages. However, data were also collected using a simplified survey approach, which is practiced in Russia when a detailed survey is not considered to be necessary. A simplified survey includes a limited amount of ground verification and consists of combined satellite and aerial imagery interpretation (Kukuev et al. 1997). The data set was reprojected from a Transverse Mercator projection into UTM 36 N. One of the most critical parameters for road construction planning is the amount of growing stock. To update the information on actual growing stock we used the Landsat imagery and reference sample plot method. Landsat scenes were acquired by looking through the three main data providers for Landsat images, namely USGS Global VisualisationViewer (http://glovis.usgs.gov), USGS Earth Explorer (http://earthexplorer.usgs.gov), and Global Land Cover Facility, University of Maryland (http://www.landcover.org/portal/geocover/).

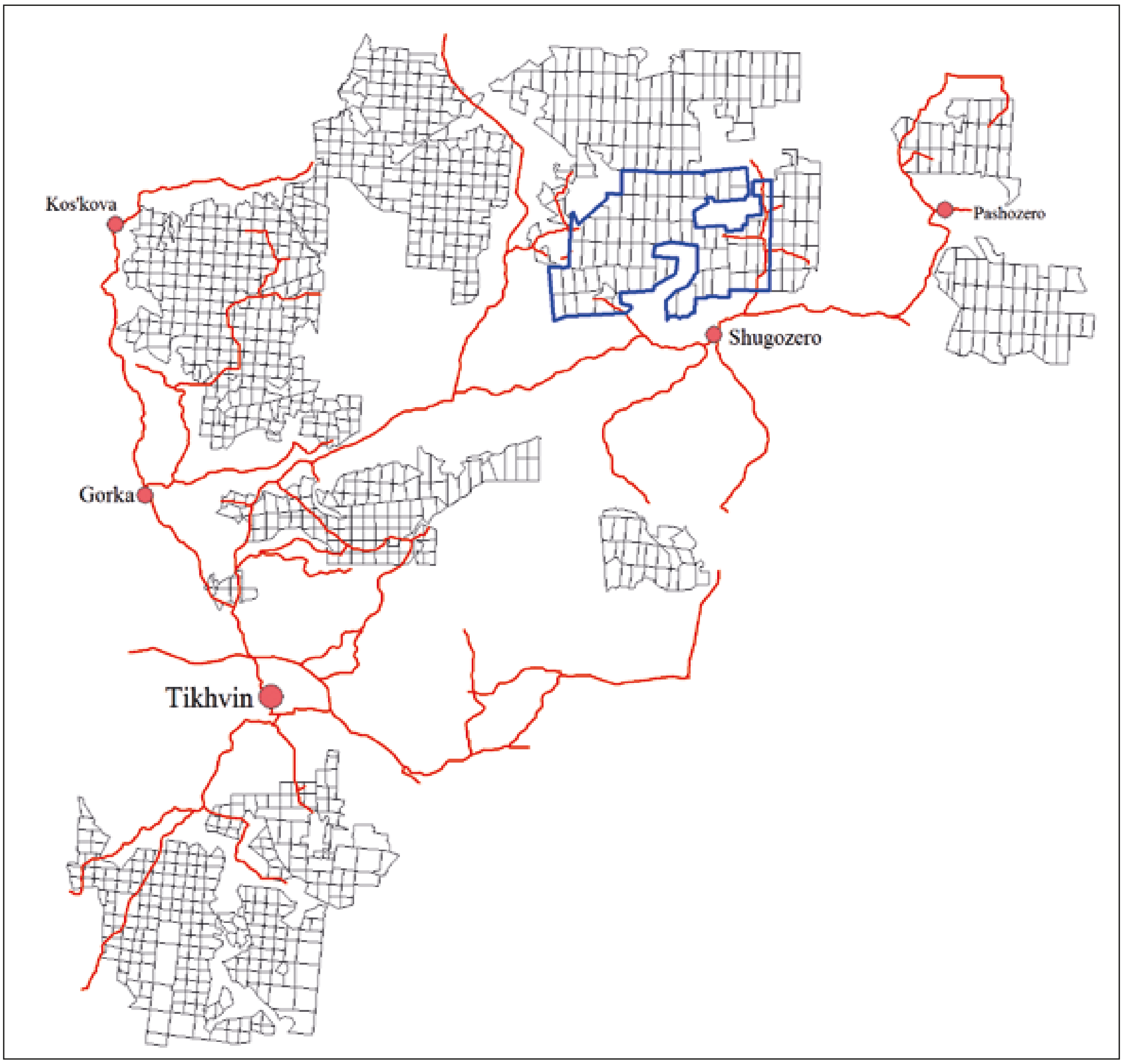


Figure 5.6 Study area in the Tikhvin district.

In fact, there were numerous obtainable scenes but many of them were limited by the excessive presence of clouds or because of poor quality (too much noise). A Landsat TM image from 10.08.2009 was finally used to update the forest inventory data.

Supervised classification was carried out using 200 training sets to assure maximum separation between the classes. Supervised classification is time consuming and it needs expertise, but it is still one of the key methods. A maximum likelihood algorithm was applied with equal probability because of its efficiency when the training sets are well distributed in the images. The training set was selected using high-resolution QuickBird images and other ancillary data. The six bands involved in classification were R, G, B, NIR, MIIR1, and MIIR2. Thermal bands were omitted from the classification.

There were two steps in the classification; firstly, we classified the whole landscape into four classes, namely forest, water bodies, urban lands, and other unclassified type of landscape. The second step was the integration of the three non-forest classes into one class (termed non-forest). For the ground truth data, high resolution QuickBird images in Google Earth™ were used.

5.3.3 Results and discussion

In order to update the growing stock in Russian forest inventory data, we recalculated the map of growing stock distribution and excluded non-forest areas (Figure 5.7). This was carried out using the k-NN estimation method, which is applicable when considerable field data are available. The same method has been used, for example, in the production of Finnish forest inventories (Tomppo et al. 2008).

The reference sample plot method was used for mapping the growing stock and species proportion in each Landsat pixel. This method is a distance-weighted k-NN estimation method, which allows for the simultaneous interpretation of several variables. In it, the k spectrally nearest field plots are considered separately for each unknown pixel and the area height of the unknown pixel is divided as a function of the spectral distances to the nearest plot (Tokola et al. 1996; Tomppo and Halme 2004). The programme REFE (available at: http://www.mm.helsinki.fi/GIS/Refe/index) was used to implement the reference sample plot method in order to produce the growing stock and species proportions for the Landsat image.

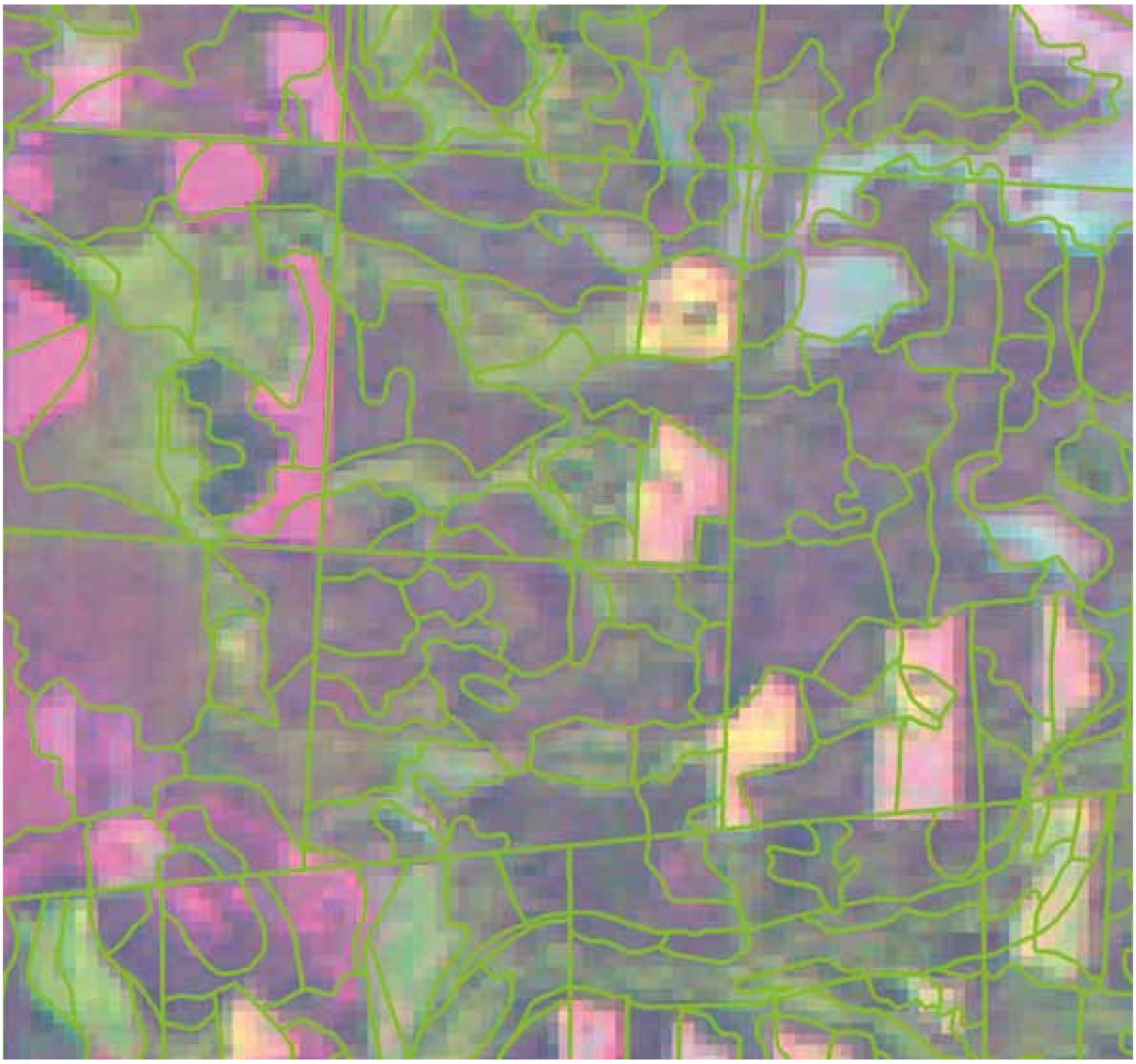


Figure 5.7 Forest stands from 2005 (aerial imagery) overlaying the Landsat image from 10.08.2009. Pink – clear-cuts from 2009, Yellow – clear-cuts from 2007–2008.

From the Russian forest inventory data set, 5433 polygons with the attribute "natural forest" were selected. Using the Landsat land cover map, the polygons with changes since 2005 (clear-cuts and young regenerated forests) were excluded. The centre points of the selected polygons were determined and used as sample pixels for the k-NN estimation of the growing stock and species composition. Tests showed that the accuracy of the calculation could be improved by placing additional plots near the centres. Therefore, the number of points within the polygons was increased by five. The simulated plots were systematically placed around the centre point of the polygon within a distance of 80 m.

Owing to the varying forms of the polygons, some plots were placed over neighbouring polygons. This was considered to be a random process. The attributes of the polygons were transferred to the plots using an overlay analysis. In total, 9087 plots were used as a training set. From these, 2372 polygons were selected as a test set. The predicted values from the reference sample plot method for every pixel were summarised for every polygon of the test set using the overlay analysis. After the growing stock had been estimated by the k-NN method, the polygons from State Forest Inventory data were updated (Figure 5.8).

Detailed topography data were not available for the study area because of their "classified" status in Russia. For planning road construction, the utilisation of the digital elevation model is one of the main ways of avoiding problems with water flow. Freely available data from the Shuttle Radar Topography Mission (SRTM) was used to obtain elevation data to generate the high-resolution digital topographic database of the leased area (Figure 5.9). The SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February 2000. It is an international project spearheaded by the National Geospatial-Intelligence Agency and NASA. Data are available to download free from http://dds.cr.usgs.gov/srtm.

The combination of the updated forest inventory data and SRTM digital elevation model with a raster resolution of 90 metres allowed us to calculate the ridges and water accumulation models. These models were used in road construction planning in order to avoid road erosion.

Over large areas, earth observation data provide practical tools for the mapping and frequent monitoring of land cover (Norjamäki and Tokola 2007). The use of Landsat imagery was appealing because it was free of charge and efficient for updating forest inventory data (Burnett et al. 2003).

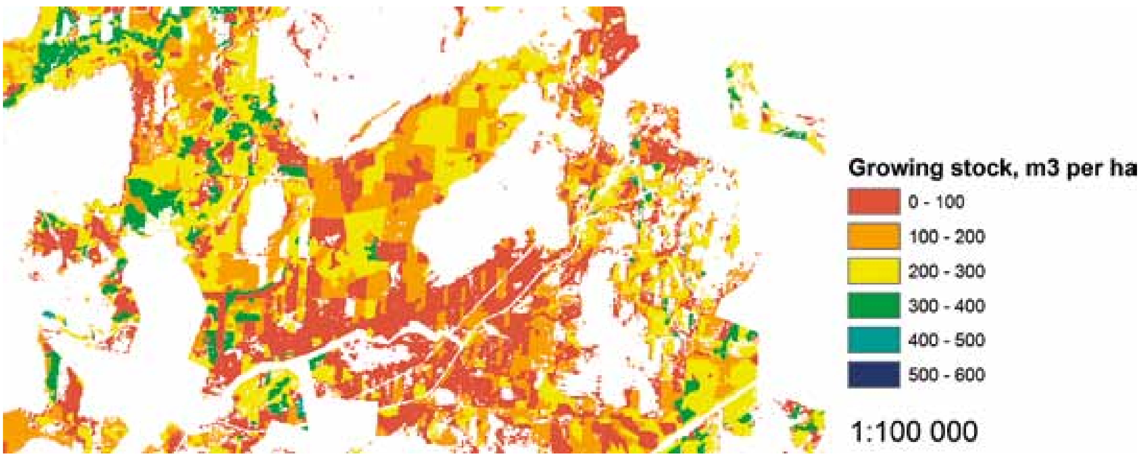


Figure 5.8 Spatial distribution of the growing stock within the subset of the study area.

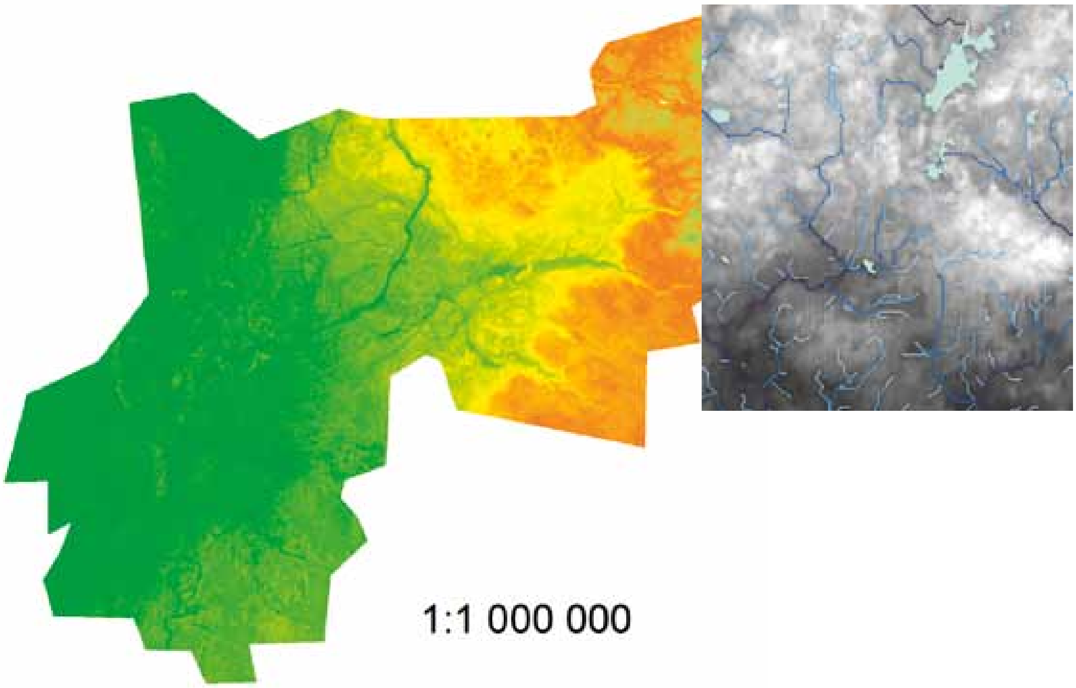


Figure 5.9 Subset of the digital elevation model for the leased area (left) and an example of a water accumulation model using SRTM data (right).

The results show that the existing spatially explicit forest inventory data could be quickly updated using fresh Landsat images. The spectral data from the shortwave infrared (e.g. Landsat band 5) portion of the electromagnetic spectrum was most effective for mapping clear-cuts and forest fires. The analysis of the fresh remote sensing data and update of the Russian forest inventory data allowed us to capture 73% of the uncertainty for wood harvesting planning.

5.4 Road planning system

5.4.1 Introduction

One aim of this study is to clarify which transportation and road construction strategy is more profitable in Northwest Russia. In other words, is it better to develop extended forest transportation or invest into a good quality forest road network? Another aim is to clarify the cost structure and to compare the costs for six forest use scenarios. The third aim of the study is to present tools and methods for tactical forest planning.

5.4.2 Materials and methods

5.4.2.1 Planning system

A GIS-based planning and cost estimation system was constructed. The system assists in the accurate planning of forest roads and estimates transportation and road construction costs in tactical terms. The general outline of the system is illustrated in Figure 5.10.

The system is a process that begins by determining the goals and constraints for each scenario and continues step by step with planning, estimations, and GIS analyses in order to estimate the total costs of each scenario. The basis of the system is data and functions. Data include forest stand data, information about roads, elevation data, and soil data. Functions include forest growth model and cost functions for transportation and road construction. The system uses the ArcGIS, MapInfo, and Microsoft Excel computer programs. The main planning process and all GIS analyses are performed in ArcGIS.

The first phase in the process is to decide on the details of a scenario. This includes determining planning period, interest rate, harvesting volume during the planning period, proportion of summer and winter harvesting sites, and transportation strategy.

The second phase is processing forest data. Potential harvesting sites that are possible to harvest during the planning period are selected from the forest data and divided into summer and winter sites. They are then further divided during the planning period according to the maturity of the forest. Wood volumes are grown in the potential harvesting sites until their potential harvesting periods. Then, volumes are discounted into today's values for the purpose of analysing the current values of future harvesting sites.

The third phase is planning the forest road network and harvesting sites. The basic idea of road planning is to maximise the wood volume of potential summer harvesting sites in the area of road network influence and to minimise road construction costs. Planning the road network optimises both these goals because it concentrates on the harvesting volume available and spatial cost factors of road construction. After planning the road network, summer harvesting sites are defined by the area of road network influence. Outside of the area of road network influence are the winter harvesting sites and these are planned as temporary winter roads. The area of road network influence is the area nearby a forest road, where wood transportation using a forwarder is appropriate.

The fourth phase estimates transportation costs and road construction costs, which correspond to each scenario of forest use. Costs are estimated using cost grids with cell sizes of 30 × 30 metres. The cost of transportation over each grid cell per cubic metre is estimated. Transportation costs over a grid cell vary from expensive forest transportation to cheap wood trucking on asphalt roads. For each harvesting site, the cheapest transportation route is estimated based on the cost grid from the forest to the railway terminal. During the planning period, total transportation costs are estimated by summing the transportation costs of each harvesting site. Road construction costs are estimated on a cost grid, where the costs of potential road construction are defined for each cell. Cost values were copied from grid to road polyline objects. Total road construction costs are the sum of the cost values of road polylines.

The fifth phase of the system collates the results of the forest use scenarios. The results include the amounts and locations of harvesting and road construction and the allocation of costs and values, which lead to the profitability. Average cost is the most important variable for cost comparison between scenarios. By using this system, six different scenarios of forest use were developed. The main result of the study is the comparison of these estimates.

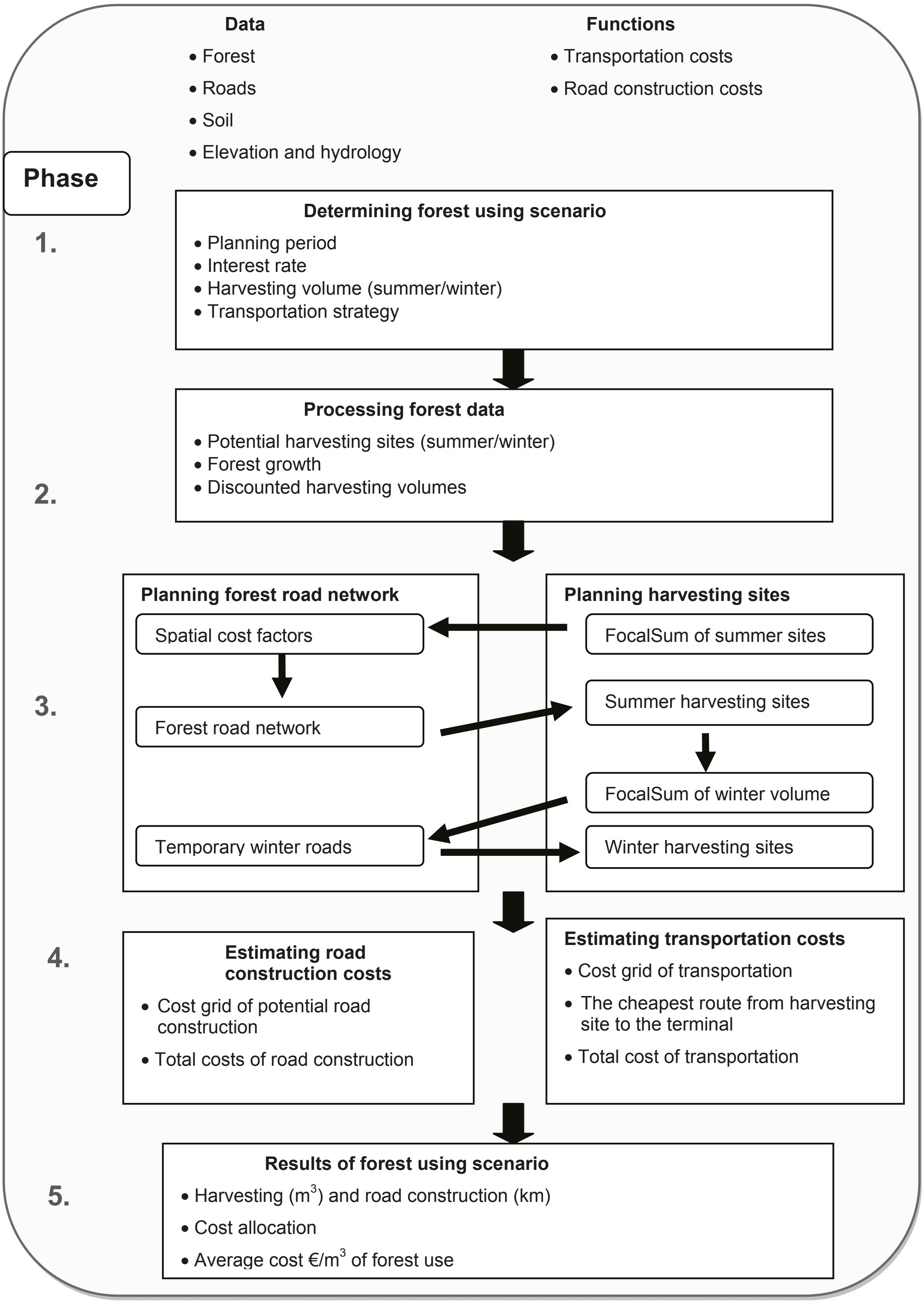


Figure 5.10 Outline of the GIS-based system for planning harvestings and road construction.

5.4.2.2 Soil and hydrology

In the original forest stand data, soil characteristics are presented according to Pogrebnyak's classification, where fertility varies from A to D and moisture from one to five (Pogrebnyak 1955). Together, these factors make 20 combinations. Soil classification was simplified into three soil classes from a road construction point of view. The first class consists of dry and poor sandy soils, which assumes easy and cheap road construction. The second class consists of moist soil types, which are typically silt and difficult for road construction. The third class includes wet soils, which are typically peat lands and wet silt, where road construction is difficult and very expensive.

The altitude differences are rather small in the Tikhvin area and topography is quite flat or gently hilly. There are no steep slopes that hinder road construction or harvesting. Still, information about small differences in altitude is useful for planning forest roads. From a hydrological point of view, the best place for the road is on ridges, where water flows away from road area and depressions can be avoided. Thus, a hydrology model was used to estimate water accumulation. Brooks and rivers were visualised and the cost of a culvert or bridge was estimated in case of road construction over a stream.

5.4.2.3 Cost functions

Transportation

An important part of the study was determining the variable and fixed cost parameters for forest terrain transportation, extended forest transportation, and long distance transportation. An accurate determination of these parameters would require its own study, which, in the case of transportation costs, would involve excessive time. In this study, we cannot dig deeply into these issues. Instead, we have to rely on the existing literature, experiences from practical forestry in the area, and basic cost calculation methods.

For forest terrain transportation by forwarder, the model of Nurminen et al. (2006) was modified for Tikhvin conditions. For long distance transportation by log truck, the study of Nurminen and Heinonen (2007) was used with an adaptation to Northwest Russia, where road conditions are more difficult and average driving speed is lower. Driving time was estimated separately for driving on forest roads and for driving on asphalt roads or on very good quality public gravel roads. The effective machine cost for driving was 59.6 €/h and for loading, unloading, and delays 48.0 €/h. It was assumed that log trucks have a full load of 48.4 m^3.

There are no published time studies for high-mobility trucks. To tackle this problem, we adapted a time consumption function for ordinary log trucks. High-mobility trucks are similar to ordinary log trucks in many ways; the main differences are their smaller payloads, lower purchase prices, and good performances in difficult terrain conditions. The approach is not the perfect one, but it gives reasonable results. In the calculations, the average load for a high-mobility truck was 15 m^3 and effective machine cost was 30 €/h.

Road construction

Forest road construction means building new roads and upgrading old roads. New forest roads are divided into new ordinary forest roads, new light forest roads, and new winter roads. In this study, upgrading refers to rebuilding a light forest road to the standard of an ordinary forest road.

Mönkkönen (2008), which exemplifies the costs of forest road construction in Northwest Russia, was applied to estimate the road building costs. The costs of material and working and the norms of road structure were taken from the same study. The norms of ordinary forest roads were taken from the Finnish norms of forest roads (Metsäteho 2001).

The road norms are represented by soil classes because the structure of a forest road depends on soil conditions. Road construction costs were divided into fixed and variable costs. The fixed costs of ordinary forest roads include work by an excavator and culverts and strengthening the road base. Strengthening the road base is usually carried out using low-price aspen logs. Variable road construction costs are incurred while building the road gravel surface. The costs of gravel surface depend much on the transportation distance from the gravel pit to the road-building site.

The costs of light forest roads were estimated in the similar way but without variable costs because there is no gravel surface. The construction of road base is carried out by bulldozer, not by excavator. Light forest roads are built as cheaply as possible but because of the difficult soil conditions, strengthening the road surface using aspen logs is a necessary and costly operation.

The estimation of road construction costs includes two factors from the water accumulation and ridges models. Winter road construction costs are defined as 3000 €/km everywhere, based on the working costs of bulldozers.

5.4.2.4 Scenarios of forestry strategy

In the planning and cost estimation system, the first phase was to determine the scenarios of forest use. Six realistic scenarios with different strategies were made to compare the costs for road construction and transportation in the study area (Table 5.1). Three scenarios were composed following the current transportation strategy (A), where a large proportion of harvested wood is transported in three steps, by forest transportation, extended forest transportation, and wood trucking chain. The other three scenarios were composed from a transportation strategy (B), where all transportation is carried out in two steps, by forest transportation and by wood trucking chain, eliminating the extended forest transport and thus the need for light forest roads.

These scenarios were built for different intensity levels of forestry. Because of the poor road networks, there is a lack of summer harvesting sites in the study area. Following forest road construction, more sites are available for harvesting in summer and forestry becomes more intensive all year round. The scenarios suppose next summer/winter site proportions: 50%/50% (1), 60%/40% (2), and 70%/30% (3). Thus, by combining transportation strategy (A or B) and summer/winter site proportions (1, 2 or 3) six scenarios of forest use (A1, A2, A3, B1, B2 and B3) were formed.

In addition to transportation strategy and summer/winter site proportions, all other factors that influence the cost estimation were assumed to the same. The planning period was defined as 20 years and the interest rate was 3%. For all scenarios the annual harvesting volume was approximately 85,000 m^3 and an average 5.0 m^3/ha, a in the study area.

Table 5.1 The six scenarios used in the study

SCENARIO	*TRANSPORTATION STRATEGY*	*SUMMER SITES*	*WINTER SITES*
A1	three-step	50%	50%
A2	three-step	60%	40%
A3	three-step	70%	30%
B1	two-step	50%	50%
B2	two-step	60%	40%
B3	two-step	70%	30%

5.4.2.5 Planning harvesting and roads

The planning of the forest road network and harvesting sites was a gradual process beginning by road network planning and defining the summer sites and ending by planning the winter road network and winter sites. The forest road network was planned on the map view, where FocalSum (a MapAlgebra operation that summarises a variable for neighbouring pixels) of potential summer sites and spatial cost factors were visualised (Figure 5.11). In each scenario, forest roads were

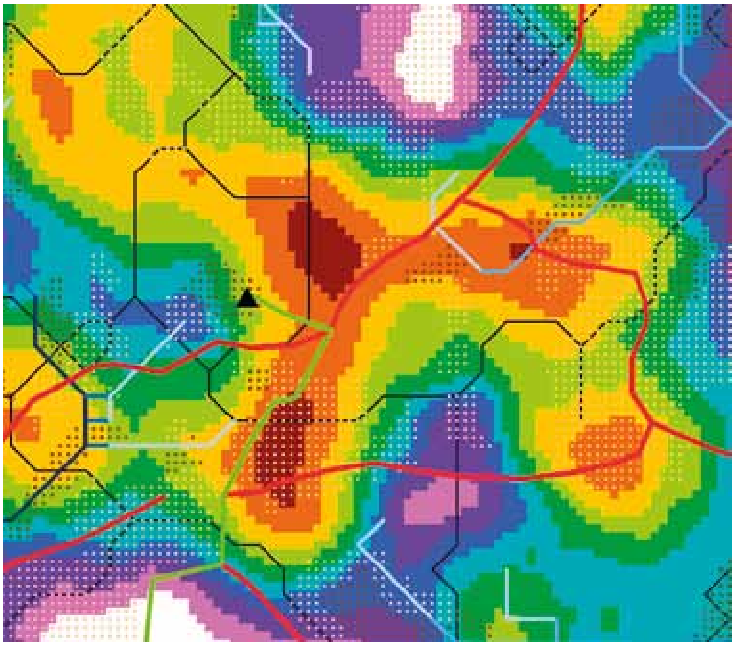


Figure 5.11 Map view of forest road planning. The planning map includes the FocalSum of the volume available for harvesting (high concentrations in brown and yellow colours), existing ordinary forest roads (green lines) and light forest roads (red lines), and spatial cost factors of road construction. Favourable spatial cost factors, which make road construction cheaper, are sand soil (yellow points), ridges (black lines), and short distance to gravel pit (black triangle). Unfavourable cost factors are wet silt or peat soils (brown points) and streams (blue lines).

planned at a quantity in order to fulfil the goal of summer harvesting volumes. Thus, potential summer sites were defined within the area of the planned road network. Then, the rest of potential harvesting sites were accepted as potential winter sites. The FocalSum of potential winter sites was visualised and the winter road network was planned to follow these concentrations of volumes. When planning the winter road network, spatial cost factors were not taken into account because of favourable conditions during a frost period. Real winter stands were selected on the grounds of winter road planning within the area of planned road network influence.

5.4.3 Results and discussion

The main results from the study are shown in Table 5.2. In scenarios A1 and B1, discounted harvesting volume over 20 years is approximately 1.2 million m^3 and in scenarios A2, A3, B2, and B3 approximately 1.3 million m^3. Scenarios A1 to A3 are made for a three-step transportation system and scenarios for B1 to B3 for a two-step transportation system. In scenario A1, there is a minimum of investment in forest roads. In scenarios A2 and A3, both ordinary and light forest roads are planned to be constructed. In the scenarios B1 to B3, only ordinary forest roads are planned. All scenarios include the construction of winter roads.

Table 5.2 Main results for the six studied scenarios.

Scenario	*Summer/ winter sites, %*	*Volume on summer sites, m^3*	*Volume on winter sites, m^3*	*Total harvesting volume, m^3*	*Upgrading forest roads, km*	*New forest roads, km*	*New light roads, km*	*New winter roads, km*
A1	50/50	621 000	598 000	1 219 000	0.0	0.0	0.0	48.4
A2	60/40	811 000	528 000	1 339 000	8.0	4.7	15.4	55.0
A3	70/30	939 000	404 000	1 343 000	8.5	6.8	33.9	42.0
B1	50/50	620 000	617 000	1 237 000	10.4	16.7	0.0	34.5
B2	60/40	809 000	530 000	1 339 000	22.7	31.6	0.0	48.2
B3	70/30	942 000	401 000	1 343 000	27.9	45.0	0.0	37.0

The current density of forest roads (scenario A1) is far from the theoretical optimum density of forest roads in the Tikhvin area. If only ordinary forest roads are built, optimal road density is 6.3 m/ha and if both ordinary and light forest roads are built, then optimal road density is 3.2 m/ha for ordinary and 12.9 m/ha for light forest roads (cf. chapter 5.2). The theoretical optimum forest road density in the Tikhvin area is based on a marginally lower annual cutting rate (4.5 m^3/ha) than that in the study area (5.0 m^3/ha). Thus, only scenario B3 reaches the level of optimum density. In the case of the two-step transportation system (scenarios B1 to B3), light forest roads are used only like winter roads (Table 5.3).

Table 5.3 Road density at the end of the planning period (20 years) for the different scenarios.

Scenario	*Ordinary forest roads, m/ha*	*Light forest roads, m/ha*
A1	2.4	4.0
A2	3.1	4.4
A3	3.3	5.5
B1	4.0	(3.3)
B2	5.6	(2.6)
B3	6.7	(2.3)

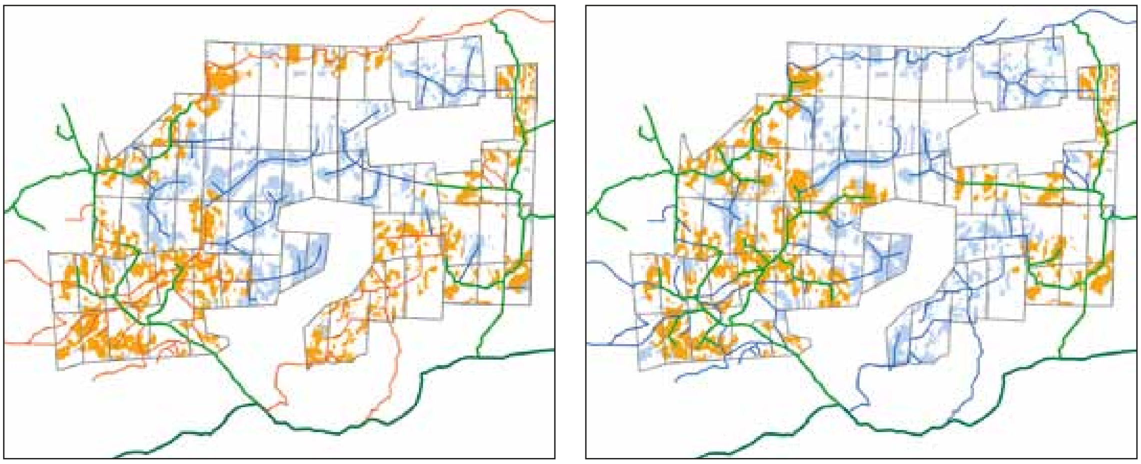


Figure 5.12 Scenarios A1 and B1 with 50% summer (yellow areas) and 50% winter sites (light blue areas). In both scenarios, the discounted harvesting volume over 20 years is 1,200,000 m^3. In scenario A1, wood transportation is carried out using light forest roads (red lines) and ordinary forest roads (green lines), and in winter season winter roads (blue lines) are also used. In scenario B1, the road system includes only ordinary roads and winter roads. The forest road network is connected to common asphalt roads (dark green line).

One result of the study is maps of the planned harvestings and roads. Figure 5.12 exemplifies these results for two scenarios.

The discounted total costs of road construction over 20 years differ much between the scenarios, as can be seen in Figure 5.13. In scenarios B2 and B3, the total costs of road construction are approximately 1,000,000 €. In scenarios A2, A3, and B1, road construction costs are 300,000–400,000 €. In scenario A1, the costs are only 100,000 €. In scenarios B1 to B3, the construction of new forest roads takes the greatest share of costs. In scenarios A1 to A3, most costs come from the construction of winter roads and light forest roads.

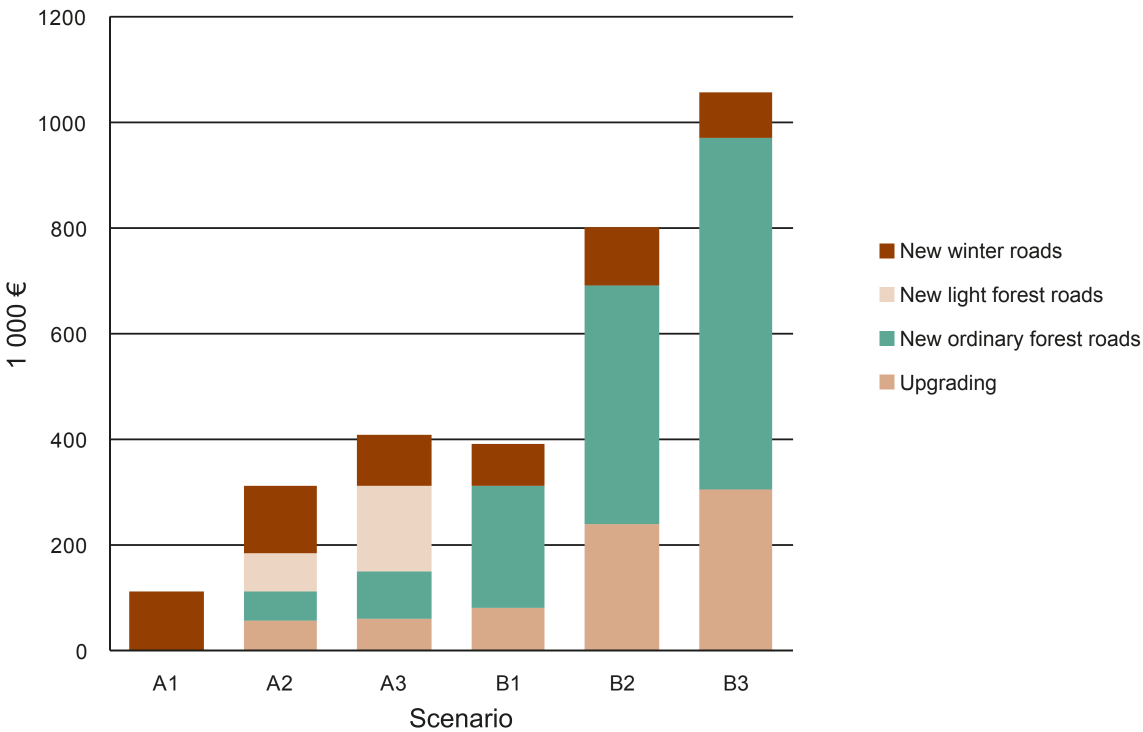


Figure 5.13 Road construction costs for the scenarios during the planning period (20 years).

The average cost of new ordinary forest roads varies between 15,200 and 19,400 €/km and the cost of upgrading is 9000–14,300 €/km depending on the scenario. In scenarios with small road investments, roads are planned mostly to favourable places and this lowers the average cost. The average cost of building light forest roads is 6200 €/km. In each scenario, 3000 €/km was of the cost for a winter road.

Compared with road construction costs, the total costs of wood transportation over 20 years are very high (Figure 5.14). Transportation costs vary between 12,600,000 and 14,600,000 €. These high total costs are caused by the large volume of wood (1.2–1.3 million m^3 depending on scenario), and the transportation of this amount of wood from the forest to the terminal is naturally a very expensive operation. The forest transportation cost is approximately the same in each scenario, because of the same definitions of maximum forest transportation distance (700 m). Differences between the scenarios come from wood trucking (varying between 8.5 and 10.2 million €) and from extended forest transportation (1.3–1.9 million €, in scenarios B1 to B3 this operation does not exist). Extended transportation increases costs in scenarios A1 to A3 but not by very much compared with the combined costs. The relatively low total costs of extended transportation are a small amount of wood that is transported by the three-step system. In scenario A2, only 14% of the harvested wood is transported by the expensive three-step system and the rest of the wood is transported by the two-step system. In scenario A1, 27% and in scenario A3 33% of the harvesting volume is transported by the three-step system.

The average cost per cubic metre is probably the best measure for comparing the scenarios. The results show that there are no major differences between the scenarios (Figure 5.15). In each scenario, the average cost is approximately 11 €/m^3 (varying between 10.5 and 11.2 €/m^3). Compared with transportation costs, road construction costs are rather small (0.1–0.8 €/m^3).

The road maintenance costs are not taken into account in the road construction costs, which underestimates the total costs of the road network to a small degree. Transportation costs are overestimated, however, because most potential harvesting sites are mature already at the beginning of the planning period and mature stands are planned to be harvested in the first harvesting period (2011–2016). This differentiation was made knowing that there is no sense harvesting all mature forests in the first harvesting period, but that all mature stands should be taken into account as

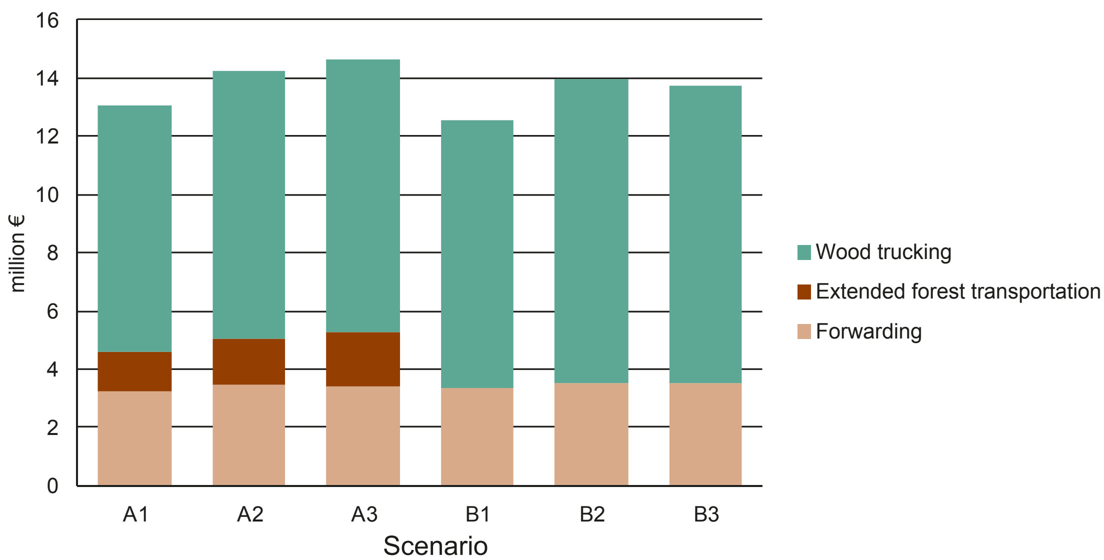


Figure 5.14 Wood transportation costs for the scenarios during the planning period (20 years).

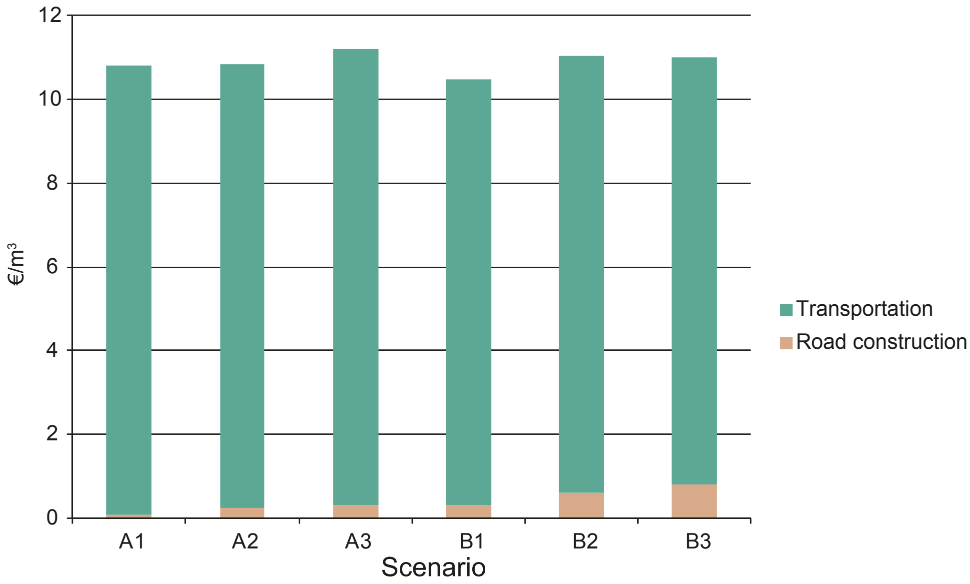


Figure 5.15 Average combined cost for transport and road construction for the scenarios during the planning period (20 years).

"possible stands for the first harvesting period". If harvesting were planned more evenly during the planning period of 20 years, the discounted transportation cost would be lower.

There are no conclusive results from the study to state whether a two-step transportation or a three-step transportation system is better. In any case, if there are no economic reasons to use the three-step transportation system, the two-step system is preferable. Owing to a better road network and using the two-step transportation system, wood flow from forest to terminal is faster and there are fewer risks because of an unsure and complicated logistics chain. Harvesting and silviculture operations are easier and cheaper to conduct close to a good quality road network compared with if the only access is by a light forest road network.

5.5 Discussion and conclusion

According to the results presented here, it should be economically feasible to invest in increasing the density of the forest road network. But to plan well data have to be accurate and precise. This is a big problem as both studies and experiences from the field have shown that the data available are quite unreliable. However, it is possible to increase accuracy by using freely available data from the Internet. Forest data can also be updated and verified from satellite data. An elevation model can thus be obtained to provide information on the hydrological conditions in an area. This is of utmost importance for successfully planning the locations of roads. Operational planning should incorporate costs for harvesting, road construction, and transport in order to minimise total costs. There is no clear evidence from the study which strategy is best. However, the construction of good forest roads should be concentrated on areas with large concentrations of volumes ready for harvesting and where construction costs are relatively less expensive.

The use of extended forest transportation with 6WD trucks on roads of lower quality (light forest roads) will continue to be an important part of the supply chain for a foreseeable future. Nonetheless, it could be profitable to upgrade some of these roads to allow year around access with ordinary trucks. One possible strategy would be to zone the procurement area into different intensity classes. In areas with high volumes and growth that are relatively close to existing good roads, the intensity of silvicultural and harvesting activities should be higher than they are in areas with low volumes that are further away from existing roads. Therefore, light forest roads and winter roads may still be a cost-efficient solution for the time being.

References

Burnett C, Fall A .,Tomppo E. & Kalliola R. 2003. Monitoring current status of and trends in boreal forest land use in Russian Karelia. Conservation ecology. 7 (2) Article Number: 8

Dahlin B. & Sallnäs O. 1993. Harvest scheduling under adjacency constraints – a case study from the Swedish sub-alpine region: Scandinavian Journal of Forest Research. 8: 281–290.

Gerasimov Y. & Karjalainen T. 2006. Development of wood procurement in Northwest Russia: roundwood balance and unreported flows. European Journal of Forest Research 125: 189–199.

Karjalainen T., Leinonen T., Gerasimov Y., Husso M. & Karvinen S. 2009. Intensification of forest management and improvement of wood harvesting in Northwest Russia – Final report of the research project. Working Papers of the Finnish Forest Research Institute 110. Finnish Forest Research Institute.

Karvinen S., Välkky E., Torniainen T. & Gerasimov Y. 2006. Northwest Russian forestry in a nutshell. Metlan työraportteja/Working Papers of the Finnish Forest Research Institute 30. 98 p. Finnish Forest Research Institute.

Kinnunen J., Maltamo M. & Päivinen R. 2004. The Accuracy of Forest Inventory Data in the Novgorod Region in Russia. European Forest Institute Proceedings. 48.

Kinnunen J., Maltamo M. & Päivinen R. 2007. Standing volume estimates of forests in Russia: how accurate is the published data? Forestry 80 (1): 53–64.

Kukuev Y.A., Krankina O. N. &. Harmon M. E 1997. The forest inventory system in Russia. Journal of Forestry 95(9): 15–20.

Metsäteho 2001. Metsätieohjeisto [In Finnish]. Finnish norms of forest roads.

Mönkkönen P. 2008, Planning of forest roads, costs and profitability in the North-West Russia [In Finnish with English abstract], University of Helsinki.

Norjamäki I. & Tokola T. 2007. Comparison of atmospheric correction methods in mapping timber volume with multitemporal landsat images in Kainuu, Finland Photogrammetric engineering and remote sensing. 73 (2): 155–163.

Nurminen T. & Heinonen J. 2007. Characteristics and time consumption of timber trucking in Finland. Silva Fennica 41(3): 471–487.

Nurminen T., Korpunen H. & Uusitalo J. 2006. Time consumption analysis of the mechanized cut-to-length harvesting system. Silva Fennica 40(2): 335–363.

Peltola A. 2009, Finnish Statistical Yearbook of Forestry. Finnish Forest Research Institute, Vantaa.

Pogrebnyak P. S. 1955. Osnovy lesnoi tipologii. 2. Izdanie ispravlennoe I dopolnennoe [In Russian]. Printing house of Academy of Science of Ukrainian SSR. 456 pages.

Sundberg U. & Silversides C.R., 1988, Operational Efficiency in Forestry Volume 1: Analysis: Dordrecht, Kluwer Academic Publishers, 219 p.

Tokola, T. Pitkanen J. & Muinonen E. 1996. Point accuracy of a non-parametric method in estimation of forest characteristics with different satellite materials. International Journal of Remote Sensing. 17 (12): 2333–2351.

Tomppo E & Halme M. 2004. Using coarse scale forest variables as ancillary information and weighting of variables in k-NN estimation: a genetic algorithm approach. Remote Sensing of Environment. 92, (1): 1–20

Tomppo E., Olsson H., Ståhl G., Nilsson M., Hagner O. & Katilaa M. 2008. Combining national forest inventory field plots and remote sensing data for forest databases. Remote Sensing of Environment. 112 (5): 1982–1999.

Viitala, E.-J. & Uotila, E., 1999, Optimaalinen tietiheys yksityismetsätalouden kannalta [In Finnish]: Metsätieteen aikakauskirja, pp. 167–169.

6 Business opportunities in wood harvesting and transportation in Northwest Russia

6.1 Finnish–Russian wood-based trade

There are long traditions between Finland and Russia on wood-based trade and despite the current quiet period of time, this tradition should continue. The main reason for the current situation is most probably the export duty for coniferous roundwood, which Russia introduced in 2006. During the subsequent two years, export duty was raised from 2.5 to 15 Euros per cubic metre. Together with other customs policy measures against roundwood exports and the global market crisis, imports to Finland decreased from 17 million m^3 to 6 million m^3 during the period 2005–2009. Development during the past couple of years has had a strong influence on the forest sector in both Finland and Russia. Forest industry enterprises in Finland have shaped their wood procurement organisations in order to react to these changes. In Russia, large-scale enterprises have started to take care of forestry operations, and small and mid-sized enterprises, in particular, have descended into trouble.

Russia remains an important partner for the Finnish forest sector. The rising economy and abundant energy and forest resources of Russia offer a variety of opportunities in developing far-reaching business. Further investments in the Russian forest industry are only possible if a stable and predictable business environment can be secured. According to the Finnish Forest Industry Federation, export duties of wood, which are comparable to export restrictions, are now triggering a long-term cycle of negative development and this could make it more difficult for both Russian and non-Russian forest industry companies to expand their operations.

The situation in the roundwood market is expected to be normalised with Russia's entry into the World Trade Organization. Together with this membership, export taxes are expected to decrease at least to a level that would allow for the rebuilding of wood procurement organisations and continuing of wood procurement from Russia. If the current export duty on roundwood exists in the near future, there still are possibilities for wood-based trade, however. This is because traditional roundwood trade can at least partly be compensated by the trade in processed products (e.g. woodchips), export duty on which consists of only 5% of customs value and which have already in the past couple of years been the dominant wood assortment.

Global Finnish corporations are not only importers of roundwood, but are also willing to invest in wood processing in Russia, which is evidenced, for example, by the five sawmills owned by Finnish companies. Over the past two decades, Finnish companies have invested about one billion Euros in the Russian forest sector. Companies have also been investigating possibilities for pulp and paper mill investments. These investigations were frozen together with the withdrawal of the companies from Russian markets when the current era of export duty increases started. World Trade Organization membership and the security of investments could reignite such investment projects in foreign companies in Russia.

Despite the difficulties in domestic and foreign markets over the past couple of years, all large-scale Finnish forest enterprises are still in operation. Indeed, the amount of Finnish companies ready to start coniferous wood import from Russia has slightly increased. This kind of development probably reflects the belief of Finnish entrepreneurs in the future, i.e., they want to be ready if business opportunities exist. Even though the number of Russian exporters has decreased substantially during recent years, their amount is still bigger than that of Finnish importers, because imports to Finland have been more clustered.

Finnish companies have traditionally purchased all assortments, including birch and aspen pulpwood, which have no demand in Russia. The financial capabilities of these companies are good and they have reputations as reliable partners. In many cases, the management in Finnish companies is Russian speaking, which makes business even easier.

Exporting wood has been a major provider of jobs in Northwest Russia. For example, the harvesting of the wood supplied to Finland has been estimated to provide direct employment for almost 40,000 people. If indirect impacts are included, this exported wood used to employ nearly 100,000 people in Russian rural areas. Some years ago, Finnish forest industry companies engaged a workforce of almost 7,000 in production and harvesting in Russia. Now, this number of jobs has been cut about by one fifth. In many Russian regions, these companies act as a source of employment and engines for growth.

Forest certification has become more widespread in Russia and the certified area is expected to grow even more in the near future. The FSC-certified forest area in Russia passed the 30 million ha milestone in March 2011, which makes it the second largest FSC-certified forest area in the world after Canada. The importance of certification has grown in the global marketplace, because end users of the product want to know the origins of the wood. Forest certification gives customers the certainty that the wood is originated in legal loggings and from forests that have been managed according to the best practices.

During recent years, the physical wood procurement area has become closer to the Finnish–Russian border. At the same time, the role of Northwest Russia in wood procurement has been even more pronounced. This is mainly because of the cost increase caused by export taxes. If that kind of barrier to international business is removed, the possibility to deliver wood from more remote areas increases.

During the past 10 years, the Russian forest industry has been developing steadily. New investment projects have been launched in order to modernise the industry. Russia's own production has been coniferous-orientated and one of the aims is to increase the use of deciduous species in production. While some wood assortments – mainly deciduous – cannot be processed in Russia, trade with Finland would also benefit Russia.

Despite the fact that Finnish forest resources are growing, the Russian forest resource base is in its own league and provides great opportunities. For example, the annual allowable cut only in Northwest Russia is some 95 million cubic metres. The Russian Federation has the largest unused softwood potential in the world. There is great potential for mutually beneficial cooperation between Finland and Russia in the field of wood-based trade. However, efforts have to be intensified on both sides of the border, if aim is to realise the utilisation of this potential.

6.2 Industrial and energy wood supply

Business opportunities in the Russian forest sector

Nordic CTL harvesting systems, including energy wood technology, have become increasingly common in Russia because of technology transfer from Nordic countries. There are many reasons for the increasing popularity of these CTL systems. There are also some obstacles, such as wood logistics, fibre breakage, cross-country ability, environmental issues, and machinery maintenance. The following issues were identified as being important for further improvements of business. If all the discovered shortcomings typical of Russian harvesting could be eliminated, it would be possible to decrease wood harvesting costs by 2.5 €/m^3, wood transporting costs by 2.5 €/m^3, and the value loss of industrial wood by 0.8 €/m^3.

Opportunities for decreasing costs in the wood supply chain

The logistics approach for CTL operations is poorly developed in Russia. Decision support systems (DSSs) developed in countries with long experiences of CTL harvesting are not necessarily directly applicable to Russian conditions. This is because of the specific organisational structures of Russian logging companies. Russia also has specific requirements for traffic, its own standards for wood, its own categories of roads, and poor road quality and maintenance. Moreover, solutions are usually company-specific, and thus tailored programming tools need to be developed to improve the planning and optimisation of wood procurement for operational and tactical tasks. The developed GIS-based DSS is a tool used to help logging companies make justified decisions on organisational options for CTL harvesting and logistics. The application of the program allows efficiency to be increased when introducing CTL and energy wood operations, wood harvesting and transport costs to be decreased, and the utilisation of the CTL machinery fleet to be improved. This DSS gives the logging company comprehensive information about the benefits and limitations of different CTL options. A logging company gains sufficient information to make sound operational, tactical, and strategic decisions. The improvement of the economic feasibility of CTL and energy wood operations is a critical element in the development of forestry in Russia. Good productivity and thus economics of the whole CTL chain can be further improved in logging companies, since DSS takes economic aspects into consideration, warns of a lack of trucks, and gives recommendations for the organisational management of logistics (i.e. wood harvesting and delivery planning, need for temporary wood terminals). The DSS suits different levels of planning in the wood supply chain, which depend mainly on the planning horizon and tasks. The practical tests of the DSS carried out within the present project showed positive effects of the system application for all levels of the planning of harvesting operations (chapter 4):

- *Operational planning – up to one week*. The total costs of wood supply might be reduced by 0.5–1.6 €/m^3;
- *Tactical planning – up to three months*. Transport costs might be reduced by 1.0 €/m^3 or 250 000 €/yr in a medium sized logging company.
- *Strategic planning – up to one year.* Transport costs might be reduced by 1.5 €/m^3 or about 0.4 million €/yr. This would require infrastructure investments (€1 million), but the positive effect from optimisation would decrease the payback time by over three years.

Opportunities for a reduction in log damage

The increase in the use of mechanised harvesting systems has led to log damage, including butt pull, log splitting during handling, and the bucking and crushing of the log. Damage to a harvested log can occur during the felling, delimbing, bucking, skidding or forwarding, piling, loading, and hauling functions of wood harvesting. The world's best harvesting operations using modern CTL machinery – many of them in Nordic countries – are currently losing 4–5% of wood value at harvest. However, wood harvesting operations in many countries, such as Russia, using a number of different harvesting systems, such as the motor-manual full-tree system (MM FT), fully mechanised FT system (FM FT), MM CTL system, FM CTL system, and motor-manual tree-length (MM TL) system, have shown losses of 11–18% of the wood value at harvest. Certainly, the influence of wood quality on the value of industrial roundwood (IRW) cannot be ignored when comparing different technologies. This is determined by evaluating it in accordance with the quality specifications in the customer contracts as well as other quality requirements. To remain competitive, logging companies should also minimise wood loss at the time of harvest by using more advanced harvesting technologies.

One of the major opportunities of this project was to identify damage to IRW arising from applied harvesting systems in Russia in order to minimise this damage loss. The following volume losses of IRW (in terms of the reject rate as a percentage of total IRW on average per year) were found by the harvesting system: 1.8% in MM CTL; 2.3% in FT CTL; 5.0% in MM TL; 4.2% in MM FT; and 3.3% in FM FT. The total average volume loss of IRW in the studied companies was 3.6% or around 67,000 m^3 of IRW per year. The following value losses of IRW (in terms of value loss per unit volume of IRW) were found by the harvesting system: 0.51 €/m^3 in MM CTL; 0.65 €/m^3 in FT CTL; 1.38 €/m^3 in MM TL; 1.04 €/m^3 in MM FT; and 0.86 €/m^3 in FM FT. The total average value loss of IRW in the studied companies was 0.98 per €/m^3 of IRW or around 1.8 million €/year.

The presented analysis indicates that CTL harvesting can ensure the highest quality of harvested wood (reject rate below 3% of observed logs) in all studied companies, with different species compositions. The FT harvesting systems demonstrated acceptable IRW quality (reject rate about 3–5%). The quality of wood in TL harvesting was low (reject rate over 6%), particularly in summer (reject rate up to 10%). Certainly, an improvement in harvesting operations is needed for a reduction in IRW losses – even in the same harvest system. Loggers (operators and lumberjacks) need to pay more attention to value rather than volume alone, which could be accomplished by the development of a payment system and harvesting instructions for utilising the forest resources better by not damaging valuable logs. The reject rate is higher for the MM CTL system in winter and for the MM TL and MM FT systems in summer, indicating that seasonality should be taken into account.

The potential reduction in the rejection rate was roughly estimated from the best practices in the studied logging companies and common practices. If all the discovered shortcomings typical of FM CTL and FM FT harvesting were eliminated, it should be possible to decrease the reject rates by approximately 20% and 25%, respectively. It should be noted that the bucking optimisation of the FM CTL harvesting system allows for an increase in the amount of received IRW assortments. Improvements made to the MM CTL system would enable the reject rate to be reduced by approximately 15%. In the MM TL and MM FT systems, the potential reductions in the amount of damaged logs could reach 20% and 15%, respectively.

IRW damage in terms of value loss per unit of volume in the studied companies may not seem important. This is especially true when looking at the small differences between the FM CTL and MM CTL systems. However, the switch from the traditional MM TL system to CTL provides an average saving of 0.8 €/m^3 of industrial wood, or around 100,000 € per year for an average sized logging company. With an initial investment in CTL machines of several hundred thousand Euros (a forwarder costs over 200,000 €, a harvester over 300,000 €), the switch from MM TL and FT systems to an FM CTL system might be worthwhile in the long-term, but the switch to an MM CTL system might be justified in the medium term.

Opportunities for increasing machinery productivity

Harvester productivity on final fellings in Finland seems to be remarkably higher than in the northern European part of Russia (NEPR) with the same stem size (chapter 3.1.1). There are a number of possible explanations for the differences between Russia and Finland. Earlier studies have shown that operator skills have a remarkable influence on productivity in harvesting operations. Moreover, the lower productivity in Russia is also the result of divergent distributions of stem volume and stem quality in Russia and Finland because of different forest management traditions in these countries. Stands in Finland are more or less regularly managed and thinned, while in Russia stands are rarely managed and thinned before final felling. These distributions are an important factor associated with harvesting productivity. The proportion of stem processing machine hours in the productive machine hours (SprocR) for the studied harvesters was indeed very low and changed considerably from 0.17 to 0.45. The set of harvesters in Komi shows the best proportion, with an average ratio SprocR of 0.35. In comparison, in Nordic countries stem processing time typically accounts for 25% in first thinnings and up to 55% in the final fellings of productive machine time. Stem size has a distinct direct correlation on the proportion of stem processing machine hours in productive machine hours. In particular, while the average stem size increases, the stem processing ratio SprocR increases also. From an operational viewpoint, Russian harvesting companies very much need to improve machine performance because the average utilisation rates of the studied harvesters varied from 0.40 to 0.84 with an average value of 0.60. They still have great potential in machinery utilisation, and the possibility of increasing the share of stem processing machine hours in order to reduce harvesting cost should be explored. A machine's hourly productivity can be boosted by increasing this percentage using improved working techniques.

Based on both the results of this study and those of earlier studies, it seems that harvester productivity per productive machine hour (PMH) could be even doubled in some harvesting companies in NEPR. In its entirety, productivity could be increased up to 16.7 m^3 u.b./PMH in Karelia, 17.0 m^3 u.b./PMH in Vologda, 19.6 m^3 u.b./PMH in Komi, and 18.5 m^3 u.b./PMH in NEPR in general if the stem processing time ratio SprocR could be increased up to the Nordic countries' level of 0.55. Under this condition, the average productivity of conventional harvesters in NEPR reaches the Finnish level of 18 m^3 u.b./PMH. The economic effect might be up to 2.5 €/m^3.

Opportunities for improvements in working condition and work safety

Recently, special attention has been paid to comfortable and safe working conditions in felling operations. This will make harvesting work more attractive to the youth and employment in a harvesting company more attractive. Fourteen wood harvesting systems, applicable currently, were compared (see chapter 3.2) based on the obtained total average work severity rate of the single harvesting equipment using the Hodge–Leman (HL) criterion. According to the findings, FM CTL harvesting performed with the "harvester + forwarder" technology and FT harvesting with the "feller buncher + wheeled grapple skidder" seemed to provide the best working conditions. MM CTL harvesting with "chainsaw + forwarder" and the combination of overseas feller bunchers and Russian cable skidders were in second place providing "uncomfortable" working conditions. Traditional Russian MM TL harvesting that employs chainsaw and cable skidders and its various modifications had the worst results in terms of ergonomics, work severity, and occupational safety. Thus, when a MM harvesting system is employed, the use of cable skidders should be as limited as possible, because, on the whole, they do not comply with present ergonomics requirements. The results of the measurements obtained on forestry harvesting works may be helpful in the evaluation of ergonomics performance for single machinery within similar harvesting methods and systems. The FM CTL harvesting systems based on the latest John Deere and Volvo machines held the leading position with "comfortable" conditions. For other machines used in CTL harvesting, the results were almost similar; each of these machines was assessed as "relatively uncomfortable". The Valmet 840.3 had somewhat lower results together with the Timberjack 850 feller buncher. These were followed by the significantly worse Timberjack 460D skidder and Russian TLT-100 skidder. They had similar work severity rates and as such these were assigned to the "extreme" working condition category. The working conditions of the TDT-55A skidder, choker setting, and chainsaw turned out to be unacceptable with regard to current requirements.

Opportunities for improvements in cross-country ability and forest environmental issues

Mechanised CTL harvesting in thinning, clear felling, and extraction are potentially damaging harvesting sites, as operations are conducted under all weather conditions involving predominantly heavy machinery. Extreme machine sinkage has a direct influence on productivity, fuel consumption, and the cost of harvesting operations, leads to site disturbance and soil damage. This is especially true in areas with soft soils in spring and autumn, where options are used to improve the operational capability of the existing CTL system, such as "bogie tracks" and "slash reinforcement".

Regarding soil compaction, the CTL system met the ecological requirements for its use on common forest soils in Northwest Russia (see chapter 3.3) within the bounds of this experimental design. However, an increase in bulk density was found in all treatments at the silt loam soil surface (0 to 5 cm depth). The magnitude of the increase was a function of the number of passes, slash/track presence, and moisture content. In comparison with conventional wheel treatments, bogie track treatments showed that the compaction of wet and moist silt loam held irregularly. The formation of a compacted zone under the traction element, helped by the reinforcement of forest soil roots, took place in the first phase. With an increasing number of passes, the compacted zone deepened and partly collapsed, and there was a lateral bulging of the soil. Then, there was a slight increase in density because of the formation of secondary hardened zones. The results for slash reinforcement treatments indicated that a layer of slash mitigated the effect of a single forwarder pass and subsequent passes. The bulk density did not change considerably. The increased bulk density for the forest soils was nearly 10% of that of the slash-covered soils. In addition, the presence of the combination of "slash + track" made no apparent difference within the bounds of the experimental design.

Regarding sinkage, the CTL system with a conventional wheel did not meet the ecological requirements for thinning (rut depth should be less than 0.15 m). Moreover, rut depth reached the forwarder clearance of the machine (0.67 m) on wet soil. The results of bogie track treatments showed that rut depth did not meet the ecological requirements for thinning (0.15 m), particularly on wet soil, but was within the forwarder clearance of the machine. In the slash treatments, rut depth changed only slightly.

All mechanised harvesting systems applied in Russia cause different kinds of negative environmental impacts. When applied on sandy or sandy loam soils, all mechanised systems demonstrated almost the same impacts on the soil. However, the proportion of sandy soils is small in Russian forests in comparison with loams and clays. On loams and clays, the TL and FT systems, unlike the CTL system, resulted in significant soil compaction, but at the same time formed almost no track. Over 50% of the harvesting sites in Russia are on wet and soft soil. Therefore, the application of the CTL system has to be improved in order to reduce rut formation in most common soils. Hence, the associated CTL machine ground contact devices and slash layer must be suitably adapted for specific harvesting sites, based on terrain classification criteria.

Opportunities for improvements in the choice and maintenance of forestry machinery

The wrong choice of equipment negatively affects the efficiency of forestry machines. Particular attention should be paid to the selection of equipment when it comes to buying harvester heads. Technical specifications should meet the chosen base vehicle (mass, diameter of the treated wood, pressure in the hydraulic system, supply of pumps, power, etc.). For example, an inadequate power of hydraulic pumps leads to the impossibility of combining operations with the joint work of the harvesting head and crane. Another example is the improper use of a mobile chipper designed for the chipping of logging residues to chip roundwood that leads to frequent breakages. This, and an inadequate engine power, dramatically reduces the efficiency of the machines.

The correct choice of equipment plays a significant role in ensuring the effectiveness of forest machines. The second factor that contributes to success is proper maintenance. This involves the application of recommended oils and fluids, compliance with regulations, and consistent servicing. Particular attention should be paid to the maintenance of the chainsaw and the delimbing and feeding mechanism. In particular, it is necessary to correctly adjust the delimbing and feeding mechanism, sharpen delimbing knives, and clean the feed rollers of infiltrated residues, bark, and wood.

The operating experience of harvesters in Northwest Russia (see chapter 3.4) shows that if operators do not pay due attention to sharpening chainsaws then the proper functioning of the delimbing mechanism is a problem. Because the process of delimbing by a harvester is a fairly high speed pulling of the stem (up to 5 m/c), delimbing knives have to meet high requirements on durability and ability in order to maintain the optimum cutting geometry of the cutting edges of the knives. Blunting the cutting edges of the knives and violating the geometry of their forms reduce the productivity of the machine and lower the quality of harvested assortments. In particular, the knives intensively wear out during a snowless season when stems can be contaminated with soil. Our studies showed that the proper maintenance of the delimbing knives is rarely performed. It is not carried out timely and, most importantly, knives are sharpened incorrectly. Our studies showed that the proper maintenance of delimbing knives could improve the productivity and quality of stem processing. In order to achieve better productivity and quality we recommend:

1. Paying more attention to sharpening delimbing knives, especially in spring/summer andautumn, which will improve the quality of harvested assortments, including when rolls or spikes have worn out.
2. Controlling the state of dragging rollers, and repairing or replacing them in good time.
3. Making the operators of harvesters aware of the requirements for sharpening knives in accordance with the "Guidelines for the Operation and Maintenance" of harvesting heads and ensuring their job duties include monitoring compliance.
4. Ensuring that the manufacturers of harvester heads include appropriate tools for the measurement of sharpening angles as standard accessories.
5. Associating the wages of operators with the quality of assortments.

The economic effect might be up to 0.22 €/m^3 for an improvement in the quality of logs, 0.03 €/m^3 for a reduction in fuel consumption, and 0.15 €/m^3 for increasing machine productivity.

Opportunities in energy wood supply

Northwest Russia has significant volumes of energy wood of different origins that are available for supply. About 30.5 million m^3 of energy wood, including non-industrial wood, logging residues, stumps, and wood processing residues, are technically accessible and only 0.2 million m^3 cannot be supplied because of the shortage of roads in the Republic of Komi and in the Arkhangelsk region (see chapter 2.3).

Despite abundant energy wood resources in Northwest Russia, wood is not widely used as fuel. Wood, together with other renewable energy sources, provides only 2% of the total energy consumption in Northwest Russia. There are several factors hindering the domestic use of energy wood. First is the fast expansion of the national natural gas pipeline network. In addition, there is a lack of investment in the production and use of wood fuels. In addition, the development of wood-based energy in Russia is affected by national policy. The latest energy strategy of Russia prioritizes the intensification of energy generation from other renewable sources, mainly hydropower.

The supply of energy wood, however, has a commercial potential in many regions of Northwest Russia for two reasons. The growing global demand for wood pellets and the availability of resources have created good preconditions for establishing pellet factories in Northwest Russia. Recently, a pellet factory, which can produce about one million tons of pellets annually, was built close to the Finnish border in Vyborg. This factory was designed to use roundwood as a raw material and would consume about 3.6 million m^3 of roundwood annually when operating in full capacity.

Another reason for increasing the commercial potential of energy wood is the policy measures in some regions of Northwest Russia. Those regions prepare (Arhangelsk region), or already implement (the Republic of Karelia, Novgorod, and Vologda) developmental strategies aimed at the increased use of wood for energy. These development strategies have different targets in different regions. For example, in the Republic of Karelia the target set by the regional development strategy is to switch municipal boiler houses from heavy oil to peat and forest chips. The development strategy of the forest sector in the Vologda region focuses on the production of pellets from low-quality wood. Despite these different targets, these strategies have common features. All of them define the main uses of energy wood: the production of forest chips (the Republic of Karelia), pellets (Vologda region), and pellets and briquettes (Arkhangelsk region), thereby providing logging companies, biofuel producers, and users with a clear statement of the development of the bioenergy sector in the regions. Moreover, the implementation of these strategies should result in growing local demand for energy wood, which can be a raw material for the production of different biofuels. This creates great opportunities for logging companies, which could finally find a market for low-quality wood.

At the same time, abundant resources are the reason why forest chips, one of the most common types of wood fuel produced from energy wood in the region, have a low value in the local market. This complicates the selection of a method for the profitable supply of forest chips. When considering the local market, a production method based on chipping energy wood at the end user facility has the best economic efficiency (see chapter 3.1.2). However, to keep this production method efficient it is necessary to allocate costs of energy wood forwarding to the costs of industrial wood harvested from the same site.

The abundant energy wood resources, small domestic demand, relatively low labour and resource costs, and proximity to Finland creates opportunities for the export of energy wood from the border region to Finland. The costs of forest chip transportation, however, limit supply (see chapter 2.3). A supply method based on chipping roundwood at terminals with a mobile chipper was profitable when exporting forest chips from the Republic of Karelia to Finland (see chapter 3.1.3). However, the efficiency of this supply method depends on many factors (see chapter 3.1.1) including the cost of the transportation of roundwood from the forest to the chipping terminals, the transportation distance of forest chips, and the time needed to pass the Russian–Finnish border.

Opportunities in the forestry machinery markets

The recent development of forestry practices in Northwest Russia includes the fast implementation of CTL harvesting, transfer of technology, introduction of commercial thinnings, and energy wood harvesting. The market size for industrial and energy wood harvesting machinery was assessed for the Leningrad region. The fleet of logging machines was about 700 machines for traditional TL technology and 120 harvesters and forwarders for CTL technology. Because domestic machinery is obsolete, the manufacture of domestic forest machinery has dropped in both quantity and models, and thus imported CTL machinery is replacing domestic TL machinery. Thus, the market for CTL machinery could be 21 harvesters, 32 forwarders, and 26 shortwood trucks per year, which could increase up to 30–40 machines each in the future. The maximum need for machinery in the Leningrad region could be 50–60 harvesters, forwarders, and shortwood trucks per year if allowable cut and commercial thinnings could be fully realised. The market for energy wood harvesting machinery could be four biomass forwarders, 11 mobile chippers, and 13 wood chip trucks per year, which could rise to six and 15–20 machines per year in the future, respectively. The maximum need could be 30–40 biomass forwarders, mobile chippers, and wood chip trucks per year. Only one third of the logging enterprises in the region has enough leased forest resources to apply such high productive mechanised CTL technology. These 41 forest enterprises would need 270 machines, namely 90 harvesters, 100 forwarders, and 80 shortwood trucks. Thirty-seven enterprises would need about 50 biomass forwarders and chippers and 60 wood chip trucks for energy wood harvesting. Sixty percent of forest leasers has enough forest resources and thus they could be users of Nordic CTL technology if allowable cuts could be utilised completely and if commercial thinnings could be fully carried out. These 68 enterprises would need 500 machines, namely 160 harvesters, 190 forwarders, 150 shortwood trucks, 100 biomass forwarders, 100 chippers, and 110 wood chip trucks. In addition, 10 of the largest enterprises would need half of the total fleet.

The economic indexes of technology development in wood harvesting show positive signals, as the renewal rate for harvesting machinery has been increasing since 2005 from 14% (2005) to 36% (2009). This means that logging enterprises are now in better positions to renew machinery and technology than they perhaps were in the past. Furthermore, there are also now better possibilities to finance the purchase of new technology.

6.3 Forest infrastructure and transport

The effectiveness of the logging industry is assumed to be dependent, first of all, on such factors as stable demand and high enough prices for the products, the characteristics of forest stands, technologies used, and prices for fuel. These factors are definitely of key significance. At the same time, logging companies have limited influence on them.

By contrast, a number of possibilities might enhance the effectiveness of the work that, in our opinion, receives insufficient attention from most Russian loggers. We are talking about the optimal organisation of internal business processes. The proper organisation of those processes – in accordance with up-to-date approaches and new techniques – could significantly cut organisational costs and enhance the effectiveness of both production processes and their management.

In this respect, one of the most promising areas is introducing up-to-date logistics methods into logging organisations. This might produce good results when solving such issues as ensuring effective transportation logistics, developing the forest road infrastructure, or optimising harvesting plans.

Searching for effective solutions to the logistics issues of roundwood and residues has become considerably more urgent in Russia over recent years. First, this is determined by the increasing volumes of harvesting with CTL technologies. The Northwest region is the most active in applying this technology, which dramatically complicates searching for an optimal transportation plan because of a lack of central processing yards in the classical scheme and the significant increase in the range of wood assortments at sites. All this leads to the low effectiveness of standard transportation schemes. Owing to the complexity of the task, the production of more effective plans is possible only if modern logistics methods are used with special software.

A hybrid approach came up with a two-stage transportation solution because of the unwillingness to solve the matter as well as for other reasons. In the first stage, all logs are delivered from harvesting sites to a processing yard, and then, after secondary sorting, they are taken to customers. The yard can significantly increase costs for transporting one cubic metre of wood, because the total distance of transportation from the harvesting site to the yard and further from the yard to the customer will always be longer than is the distance of direct transportation from the site to the customer. In addition, there are also costs for reloading and storing wood, maintaining loading depots, and so on. Therefore, usable logistics methods could increase the effectiveness of wood transportation.

The modernisation of the forest road network in Russia is an urgent task. The weakness of the transportation infrastructure is hindering the development of the forest industry, limiting its possibility to fully exploit forests and reducing the economic accessibility of forest resources. In this respect, activities that improve the effectiveness of the construction and use of forest roads are becoming especially important.

One of the areas for increasing the effectiveness of the construction and use of forest roads is the comprehensive justification of the road construction plan and transportation plans, which can be facilitated by new logistics technologies and up-to-date methods for supporting decision-making based on modelling. These methods are different from the traditional ones because they account for different factors and are more precise. In addition, the use of up-to-date tools reduces the costs of design and construction as well as the use of forest roads.

Road construction is known to be a costly process. Therefore, the proper planning of forest road networks at a corporation level can save a lot of resources in logging companies. Namely, the application of logistics methods allows for the harvesting of larger areas of profitable forest stands with a minimum need for constructing new forest roads.

Securing the transport accessibility of forest resources at minimal costs can be considered to be a key goal for designing an optimal forest road network. This can be achieved by developing methods that take into account the spatial locations of the most promising forest stands and natural and production factors, such as the distribution of different types of soils, lakes, swamps, and other impassable barriers, or protected areas where road construction is prohibited for some reason. In addition, possible sources (sand and gravel pits etc.) of materials for road construction should be accounted for as well as the existing road network.

Furthermore, additional benefits could be achieved by optimising harvesting plans. Optimal harvesting planning means providing a procedure for forest harvesting, which would secure the yield of more valuable products with minimal additional production costs. An effective solution should become common practice among the managers of logging companies in Russia in order to ensure cost-efficiency and the sustainable growth of their companies.

List of publications — Appendix 1

International peer-refereed journals

1. **Gerasimov Y., Sokolov A., Fjeld D. 2012.** Improving CTL operations management in Russian logging companies using a new decision support system. *European Journal of Forest Research*. 17 p. Submitted on 2.01.2012.
2. **Gerasimov Y., Sokolov A. 2011.** Ergonomic evaluation and comparison of wood harvesting systems. *International Journal of Industrial Ergonomics*. 18 p. Submitted on 23.08.2011.
3. **Gerasimov Y, Karjalainen T. 2011.** Estimation of machinery market size for industrial and energy wood harvesting in the Leningrad region. *Croatian Journal of Forest Engineering*. 33(1). 13 p.
4. **Gerasimov Y, Karjalainen T. 2011.** Energy wood resources availability and delivery cost in Northwest Russia. *Biomass and Bioenergy*. 18 p. Submitted on 05.07.2011.
5. **Gerasimov Y., Senkin V., Väätäinen K. 2011.** Productivity of single-grip harvesters in clear-cutting operations in the northern European part of Russia. *European Journal of Forest Research* 130. DOI: 10.1007/s10342-011-0538-9. 8 p.
6. **Gerasimov Y, Karjalainen T. 2011.** Energy wood resources in Northwest Russia. *Biomass and Bioenergy* 35 (2011): 1655-1662.
7. **Gerasimov Y., Seliverstov A. 2010.** Industrial round-wood losses associated with the harvesting systems in Russia. *Croatian Journal of Forest Engineering* 31(2): 111-126.
8. **Goltsev, V., Ilavský, J., Karjalainen, T., Gerasimov Y. 2010.** Potential of energy wood resources and technologies for their supply in Tihvin and Boksitogorsk districts of the Leningrad region. *Biomass and Bioenergy* 34(2010): 1440-1448.
9. **Gerasimov Y., Katarov V. 2010.** Effect of bogie track and slash reinforcement on sinkage and soil compaction in soft terrains. *Croatian Journal of Forest Engineering* 31(1): 35-45.
10. **Gerasimov Y., Sokolov A. 2009.** Ergonomic characterization of harvesting work in Karelia. *Croatian Journal of Forest Engineering* 30(2): 159-170.
11. **Goltsev V., Ilavsky J., Gerasimov Y., Karjalainen T. 2010.** Potential for biofuel development in Tihvin and Boksitogorsk districts of the Leningrad region – the analysis of energy wood supply systems and costs. *Forest Policy and Economy* 12(4): 308-316.

Russian peer-refereed journals

12. **Sukhanov Y.V., Gerasimov Y.Y., Seliverstov A.A., Syunev V.S. 2012.** Системы машин для производства топливной щепы из древесной биомассы по технологии заготовки деревьями [Machine systems for production of fuel chips from woody biomass using full-tree harvesting method]. *Tractors and Agro-machinery* 1(2012): 9 p.
13. **Gerasimov Y., Sokolov A., Syunev V. 2011.** Optimization of industrial and fuel wood supply chain associated with cut-to-length harvesting. *Systems Methods Technologies* 3(11): 118-124. (in English)
14. **Gerasimov Y.Y., Syunev V.S., Sokolov A.P., Seliverstov A.A., Katarov V.K., Sukhanov Y.V., Rozhin D.V., Tyurlik I.I., Firsov V.M. 2011.** Рациональное использование древесины и лесосечных отходов в биоэнергетике: оценка потенциалов и технологических подходов [Rational energy use of wood-based biomass: Estimation of potentials]. *Scientific Journal of the Kuban State Agrarian University* 73(9): 576 – 587.
15. **Sukhanov Y.V., Gerasimov Y.Y., Seliverstov A.A., Sokolov A.P. 2011.** Технологические цепочки и системы машин для сбора и переработки древесной биомассы в топливную щепу при сплошносечной заготовке в сортиментах [Technological chains and machine systems for collecting and processing woody biomass into fuel chips in clear-cutting harvesting by cut-to-length]. *Systems Methods Technologies* 4(12): 101-107.

16. **Gerasimov Y.Y., Seliverstov A.A., Sukhanov Y.V., Syunev V.S. 2011.** Основные факторы влияющие на процесс планирования производства древесного топлива из древесной биомассы [Major factors affecting process production planning of wood fuels from woody biomass]. *Proceedings of Petrozavodsk State University. Natural and Engineering Science* 8(121): 77-80.
17. **Sokolov A.P., Gerasimov Y.Y. 2011.** Методика принятия решений по оптимизации лесозаготовительных планов [Methodology of decision-making for wood harvesting optimization]. *Scientific Journal of the Kuban State Agrarian University* 69(5): 320–334.
18. **Gerasimov Y., Sokolov A., Katarov V. 2011.** Разработка системы оптимального проектирования сети лесовозных дорог [Development of a system for optimal design of a forest roads network]. *Information Technology* 1(2011): 39-44.
19. **Seliverstov A., Siounev V., Gerasimov Y., Sokolov A. 2010.** Повышение эффективности использования харвестеров [Improving the efficiency of harvesters]. *Systems Methods Technologies* 4(8): 133-139.
20. **Gerasimov Y., Karjalainen T. 2010.** Ресурсы древесного топлива Северо-Запада России [Energy Wood Resources in Northwest Russia]. *Forest Herald 4(73):* 12-13.
21. **Sokolov A., Gerasimov Y., Seliverstov A. 2009.** Методика оптимизации парка автомобилей на вывозке сортиментов на основе имитационного моделирования в среде ГИС [A method for short-wood trucks fleet optimization based on the simulation modeling in the environment of geographic information system]. *Proceedings of Petrozavodsk State University. Natural and Engineering Science* 11(105): 72-77.
22. **Sokolov A., Gerasimov Y. 2009.** Геоинформационная система для решения оптимизационной задачи логистики круглых лесоматериалов [Geoinformation system for solving optimization problem of transport logistics for round wood]. *Forest Journal* (3): 78-85
23. **Gerasimov Y., Karvinen S., Sjunjev V., Sokolov A., Katarov, V. 2009.** Развитие транспортной инфраструктуры лесной отрасли – опыт Финляндии [Development of wood transport infrastructure – Finnish experience]. *Transport Business in Russia* 7(68): 99-102.

Textbooks and manuals

24. **Syunev, V., Seliverstov A., Gerasimov, Y., Sokolov, A. 2011.** Лесосечные машины в фокусе биоэнергетики: конструкции, проектирование, расчет [Wood harvesting machinery in the focus of bioenergy: constructive solutions, design, engineering calculation]. METLA, Joensuu. 143 p. ISBN 978-951-40-2325-5.
25. **Gerasimov Y., Katarov V. 2009.** Лесные дороги [Forest roads]. METLA, Joensuu. 70 p. ISBN 978-951-40-2194-7.
26. **Gerasimov, Y., Sibiryakov, K., Moshkov, S., Välkky, E., Karvinen, S. 2009.** Расчет эксплуатационных затрат лесосечных машин [Cost calculation of timber harvesting machines]. METLA, Joensuu. 44 p. ISBN 978-951-40-2174-9.

Research papers and reports

27. **Karvinen S., Välkky E., Gerasimov Y., Dobrovolsky A. 2011.** Northwest Russian Forest Sector in a Nutshell. Joensuu. 144 p.
28. **Tolonen, T. & Koponen, M. 2011.** Havupuun tuonti Venäjältä Suomeen ja tuontihavupuun kasvinterveystarkastukset vuosina 2005-2009. *Working papers of the Finnish forest research institute 197*. 32 p.
29. **Goltsev, V., Trishkin, M. & Tolonen, T. 2011.** Efficiency of forest chip transportation from Russian Karelia to Finland. *Working papers of the Finnish forest research institute 189*. 42 p.

30. **Gerasimov Y., Siounev V., Sokolov A. 2010.** Алгоритмы определения оптимальных маршрутов на графах для решения задач управления системами транспортировки древесины для лесопромышленного комплекса и биоэнергетики [Algorithms for determining optimal routes on graphs for solving problems of control systems for the transportation of wood harvesting and bioenergy]. *Research Reports of Forest Engineering faculty of Petrozavodsk State University* 9 (2010): 30-33.
31. **Sokolov A., Gerasimov Y. 2010.** Алгоритм синтеза оптимального транспортного плана в системе поддержки принятия решений для лесопромышленного комплекса и биоэнергетики [The synthesis algorithm of optimal transport plan in the decision support system for wood harvesting and bioenergy]. *Research Reports of Forest Engineering faculty of Petrozavodsk State University* 8(2010): 144-148.
32. **Gerasimov Y., Karvinen S., Leinonen T. 2009.** Atlas of forest sector in Northwest Russia. *Working papers of the Finnish forest research institute* 131. 43 p.
33. **Gerasimov Y., Karjalainen T. 2009.** Estimation of supply and delivery cost of energy wood from Northwest Russia. *Working papers of the Finnish forest research institute 123*. 21 p.
34. **Syunev, V., Sokolov, A., Konovalov, A., Katarov, V., Seliverstov, A., Gerasimov, Y., Karvinen, S., Välkky, E. 2009.** Comparison of wood harvesting methods in the Republic of Karelia. *Working papers of the Finnish forest research institute 120*. 117 p.

International proceedings, symposia and congresses

35. **Gerasimov Y., Sokolov A., Katarov V. 2011.** GIS-based optimization of wood supply chain for a logging company in Russia. *In: Innovations and technologies in forestry. Proceedings of International Scientific and Technical conference. March 22-23, 2011 – Saint-Petersburg, Russia*. Working papers of Saint-Petersburg Forest Research Institute. 24(1): 68-72. ISSN 2079-6080.
36. **Gerasimov Y., Sokolov A. 2011.** Wood supply chain optimization: Case studies of logging companies in Russia. *In: Formec 2011. 44rd International Symposium on Forestry Mechanization. Proceedings. October 9-13, 2011 – Graz, Austria*. 11 p.
37. **Sokolov A., Gerasimov Y. 2011.** Ergonomic characterization of wood harvesting systems in Russia. *In: Formec 2011. 44rd International Symposium on Forestry Mechanization. Proceedings. October 9-13, 2011 – Graz, Austria*. 12 p.
38. **Laitila, J., Väätäinen, K. 2011.** Harvesting alternatives and transportation logistics for wood from young stands. *In: Forest Cluster in North-Western Russia, Finland and Sweden. Proceedings of International Scientific and Technical Conference devoted to the 60th anniversary of Forest Engineering Faculty of PetrSU – Petrozavodsk, Russia, September 20-22, 2011*. Pp. 108-109.
39. **Gerasimov Y. 2011.** Business opportunities in the Forest Sector in Russia. *In: Forest Cluster in North-Western Russia, Finland and Sweden. Proceedings of International Scientific and Technical Conference devoted to the 60th anniversary of Forest Engineering Faculty of PetrSU – Petrozavodsk, Russia, September 20-22, 2011*. Pp. 106-107.
40. **Syunev V., Katarov V., Gerasimov Y. 2011.** Mitigation of the impact of forwarders on forest soils. *In: Forest Cluster in North-Western Russia, Finland and Sweden. Proceedings of International Scientific and Technical Conference devoted to the 60th anniversary of Forest Engineering Faculty of PetrSU – Petrozavodsk, Russia, September 20-22, 2011*. Pp. 117-118.
41. **Gerasimov Y., Syunev V., Sokolov A., Karjalainen T. 2010.** Wood harvesting and logistics in Russia – Nordic business possibilities. *In: Forest operations research in the Nordic Baltic Region. Proceedings of 2010 OSCAR conference – Honne, Norway, October 20-22, 2010*. Pp. 41-42.

42. **Gerasimov Y., Senkin V., Väätäinen K. 2010.** Productivity of harvesters in the northern European part of Russia. *In: Forest operations research in the Nordic Baltic Region. Proceedings of 2010 OSCAR conference – Honne, Norway, October 20-22, 2010*. Pp. 51-52.
43. **Gerasimov Y., Katarov V. 2010.** Effect of Bogie Track and Slash Reinforcement on Sinkage and Soil Compaction in Soft Terrains in Russia. *In: Forest operations research in the Nordic Baltic Region. Proceedings of 2010 OSCAR conference – Honne, Norway, October 20-22, 2010*. Pp. 67-68.
44. **Syunev V., Katarov V., Gerasimov Y. 2010.** Effect of skidding operations on forest soils in the off-season condition. *Eurasian Forests: Materials of the All-Russian conference for young scientists with scientific education supplies, dedicated to the 90 the anniversary from the date of the Moscow State Forest University foundation and to the 170 the anniversary of Prof. M.K. Tursky's birth. September 19-22, Moscow*. MSFU. Pp. 129-132.
45. **Karjalainen T., Gerasimov Y., Kholodkov V. 2010.** Energy wood resources in Northwest Russia and international trade of wood fuels. *In: Forest Bioenergy 2010. Book of Proceedings. Finbio Publications 47, FINBIO – The Bioenergy Association of Finland FINBIO*. Pp. 69-76.
46. **Gerasimov Y., Sokolov A. 2010.** Decision-support system for harvesting planning in Russia. *In: Formec 2010. 43rd International Symposium on Forestry Mechanization. Proceedings. July 11-14, 2010 – Padova, Italy*. 8 p.
47. **Karjalainen T., Gerasimov Y. 2010.** Energy wood resources in Northwest Russia. *In: Bioenergy 2009. Book of Proceedings. Part 2. Finbio Publications 45, FINBIO – The Bioenergy Association of Finland FINBIO*. Pp. 957-959.

Forest professional journals

48. **Syunev V.S., Sokolov A.P., Konovalov A.P., Katarov V.K., Seliverstov A.A. Gerasimov Y.Y., Karvinen S., Valkky E. 2011.** Анализ потребности в обучении операторов лесозаготовительных машин [Analysis of training needs of operators of wood harvesting machines]. *PROLes* (1-2): 1-9.
49. **Gerasimov Y. 2010.** Development of the Normative Base of Sustainable Forest Management at Regional Level Leningrad region. *Forest & Nature in Northwest Russia NWRDP Bulletin* 1(2010): 15-16.
50. **Gerasimov Y., Katarov V., Karvinen S., Valkky E. 2010.** Лесные дороги [Forest roads]. *PROLes* (1-2): 23-53.
51. **Syunev V.S., Sokolov A.P., Konovalov A.P., Katarov V.K., Seliverstov A.A. Gerasimov Y.Y., Karvinen S., Valkky E. 2008.** Сравнение технологий лесосечных работ в лесозаготовительных компаниях Республики Карелия [Comparison of wood harvesting methods in logging companies of the Republic of Karelia]. *PROles* (1): 50-107.