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Review

Annotated bibliography of the global literature on secondary transportation of raw and comminuted forest products (2000 – 2015)

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Abstract: Secondary transportation of raw and comminuted forest products is a major component in forest harvesting operations in terms of economics, public perception, and safety. Consequently, there is a substantial amount of literature on this topic. The existing literature has dealt with many of the technical aspects of transportation with a majority of them focusing on improving supply chain issues; However, there are only few specific to secondary transportation issues in general. This annotated bibliography will help practitioners, researchers, and stakeholders gain a better understanding of the existing literature from 2000 to 2015. To this end, we began by classifying the selected literature into six themes: cost, roads and routes, trucking, efficiency & safety, other modes of transportation, and supply chain & optimization. Woody biomass for bioenergy production was the most researched forest product with respect to transportation. About one-third of the articles were presented in the context of supply chain modeling and optimization. More than half of the studies originated from Europe while the United States had the most publications for any given country. The most articles (16) were published in 2013. *Biomass and Bioenergy* published the highest number of articles (29) during the timeframe.

Keywords: forest biomass; timber harvest residue; supply chain; trucking; delivery; logging residue

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Abbreviation

BSC – Biomass Supply Chains
CHP – Combined Heat and Power
CJFE – Croatian Journal of Forest Engineering
CTL – Cut-to-length
EU – European Union
GIS- Geographic Information System/ Studies
GT – Green Ton
IJFE – International Journal of Forest Engineering
Km – Kilometer
L – Liter
m – Meter
MPa – Mega Pascals
MW – Mega Watts
ODT – Oven Dry Ton
PMH – Productive Machine Hour
Tg yr^{-1} – Tera-gram per year
TWh – Tera Watt Hour(s)
WPS – Wood Procurement System
WT- Whole-tree
US/ USA- United States of America

1. Introduction

Transportation in forest operations can be broadly divided into two phases. The first phase involves moving wood from the stump to the roadside/landing sites, referred to as primary transportation. The second phase involves the hauling of the processed forest products (sawlog, pulpwood, or energy wood biomass) from the roadside/landing sites to the processing facilities, referred to as secondary transportation [1]. Secondary transportation is considered to be one of the most expensive elements in the harvesting operation, generally accounting for 30–50% of the total cost, depending on the distance travelled and compared to the cost of the primary transportation [2–4]. Therefore, improvements in secondary transportation may yield significant overall cost reductions.

Secondary transportation is predominantly road-based. Various factors influence the cost of secondary transportation including - but not limited to – the road network (road types) and conditions (infrastructure), cost of operating the truck, weight limitations, and hauling distance. Research generally focuses on the transportation problem addressing one or some of these factors, but rarely all at the same time. It cannot be expected that one research activity can look into all of these factors because addressing each topic requires expertise in different domains. Nonetheless, having all informational aspects on transportation integrated will be of great value to stakeholders.

The purpose of this study is to address this gap, by proposing a classification of a collection of scientific literature and addressing several relevant topics in forest products secondary transportation. It provides an overview of the current state of the art, and helps in identifying knowledge gaps that require further attention. To this end, the objective of this article is to list the major findings from these studies and assess the chronological development of forest products secondary transportation research in the past 15 years.

2. Materials and Methods

2.1. Literature Review

The literature was searched using major online databases and library catalogs: CrossRef, Scopus, Google Scholar, and Web of Science. The initial search started in November 2016 with three

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keywords: "forest transportation", "forest trucking", and "wood supply chain", which yielded 71 scientific articles. After careful analysis of those articles, four more keywords, "forest optimization", "biomass', "sawlogs" and "forest roads" were used to gather more literatures. Additionally, the reference section of the previously selected articles was also utilized for more specific search. A total of 169 scientific articles (related to forest products secondary transportation) were identified as relevant to this process. The four major journals with the highest publication frequency of related articles were selected and every issue of those journals from year 2000 to 2015 was searched again (Table 1). These journals were accessed through the University of Maine library resources from January to April 2016. A total of 369 volumes and issues of these four journals were assessed in order to include all information in these four journals related to forest products transportation. A total of 131 articles were chosen as relevant for the purpose of this review. The article search was limited to English-written scientific articles.

Table 1. Peer-reviewed journals that published articles related to forest products secondary transportation from 2000–2015.

Journal	Number of publication
Biomass and Bioenergy	29
Croatian Journal of Forest Engineering	26
International Journal of Forest Engineering (Journal of Forest Engineering before 2001)	25
Renewable and Sustainable Energy Reviews	10
European Journal of Operational Research	3
Forest Policy and Economics	3
Transportation Research: Part A	2
European Journal of Forest Research	2
Canadian Journal of Forest Research	2
Journal of Cleaner Production	2
Western Journal of Applied Forestry	2
European Journal of Forest Engineering	2
Others (Journals with single publication) [1]	23
Total	**131**

[1] Publication details can be accessed from reference section.

2.2. Literature Categorization and Classification

Based on the scope and objectives of articles identified, six major research themes emerged:

I. Cost of transportation
II. Roads and route planning
III. Trucking characteristics
IV. Efficiency and safety
V. Other modes of transportation
VI. Supply chain and optimization.

The classification is intended to facilitate compilation and reporting. Understandably, some of the themes overlapped. For example, there were several software and models which generated results that could be included in Theme II- Roads and route planning and VI - Supply chain and optimizations. Several articles dealt with more than one theme. Additionally, for minimizing ambiguity, no articles in one theme have been repeated in another.

Theme I (Cost) primarily dealt with articles focusing on financial aspects of trucking operations. The theme also included articles related to detailed time studies; strategies to minimize the overall transportation costs; assessing the impacts of transportation distance on final cost of delivered forest products; and evaluating the performance of transportation cost estimating software and models. Theme II (Roads and route planning), focused on every aspect of forest roads including engineering, planning, design, construction, maintenance, spatial modeling, and computer software. Theme III (Trucking characteristics) was specific to road transportation: truck size and configuration, speed at various road conditions, weight limits, payload enhancement measures, trucking performance, and features of trailers. Theme IV (Efficiency and safety) dealt with fuel efficiency, log truck accident analysis, social surveys with related stakeholders, evaluation of fuel consumption capacity, and potential effects of forest road erosion on the supply chain. Theme V (Other modes of transportation) focused on articles dealing with railways and water transportation. Theme VI (Supply chain and optimizations) included modelling supply chain in different regions, geospatial evaluations, linear programming, strategic and tactical planning, optimization of supply chain, decision support tools for wood procurement and management, and simulation of logistics models.

Each article was evaluated for country of study, objectives researched and major findings, resulting in Table 2.

Table 2. Distribution of articles related to forest products secondary transportation based on the geographic location of the study.

Region	Number of articles
Europe	73
North America	43
Asia	8
Australia & New Zealand	3
Africa	2
South America	2

3. Results

Out of the 131 articles reviewed, 127 were published in peer-reviewed scientific journals, three in conference proceedings and one was a cooperative extension article. With more than 22% publications, Biomass and Bioenergy published the highest number of articles related to the field followed by Croatian Journal of Forest Engineering (Table 1). On a regional basis, about 56% of the research articles were published by authors based in Europe followed by 33% from North America (Table 2). However, the United States had the highest number of publications on a per country basis. Several articles were authored by authors from multiple countries.

For the given period, the highest number of articles was published in 2013 (16 articles) followed by 2005 (15) (Figure 1). Hence the interest seems to be growing. On average, eight articles related to forest products transportation and supply chain were published per year from 2000 to 2015. Nearly 33% of the reviews were related to supply chain logistics and optimization (Figure 2).

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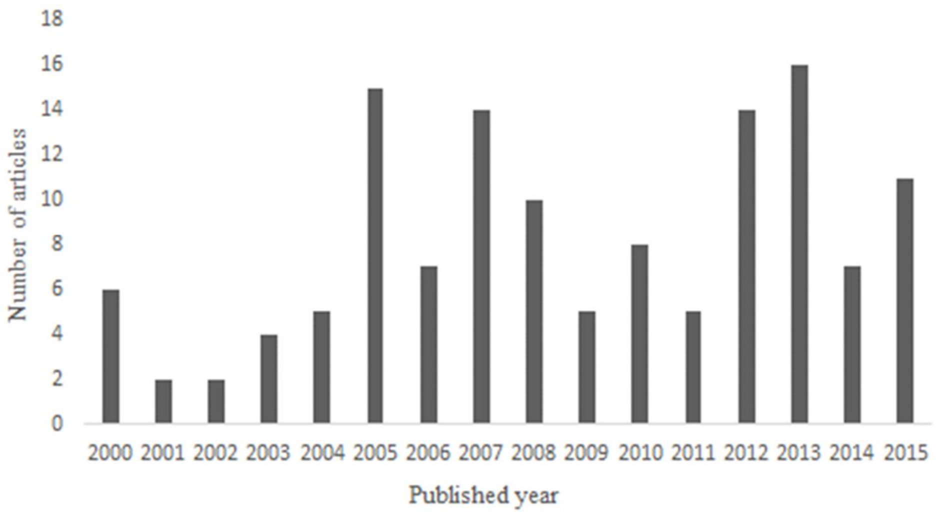

Figure 1. Distribution of articles related to forest products secondary transportation over the years of publication (2000 to 2015).

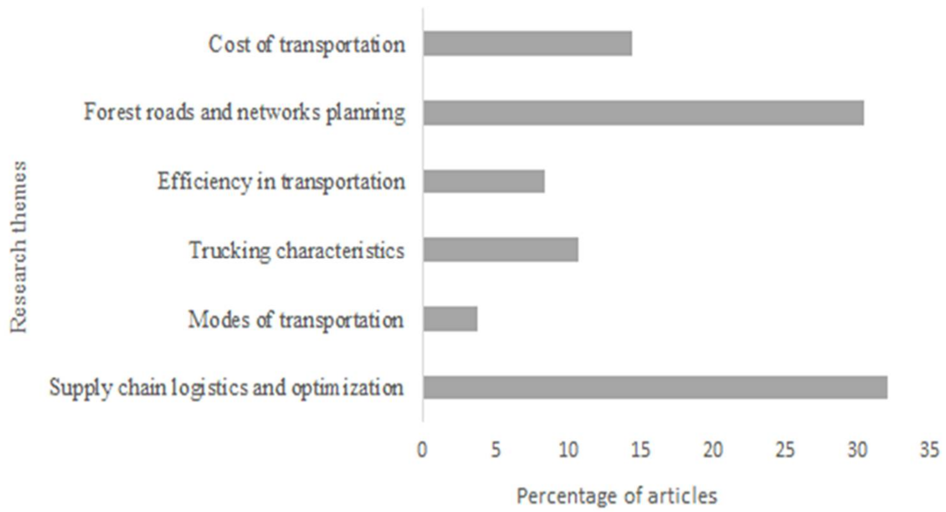

Figure 2. Distribution of articles in forest products secondary transportation based on research themes.

3.1. Theme I – Cost

There were 19 articles in this category, accounting for approximately 15% of the total articles reviewed. An average of a little more than one article per year was published in this category. A majority of the articles (more than 80%) were based on comminuted forest products, mainly wood chips, logging and industrial residues for bioenergy and biofuel production (Table 3). The greatest number of publications (6 articles) were based in the USA, followed by Sweden, Finland and Austria.

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Table 3. Published scientific articles handling the cost of transportation. The cost values mentioned reflects the actual value presented in the article.

Author(s)	Country	Wood products*	Research objective(s)	Major finding(s) and/or suggestions
Acuna et al. [7]	Australia	3	Demonstrated the benefits of adjusting efficiency and cost of trucking	Model predicted a savings of 52% of costs in truck payload and 29% in chipper utilization.
Aksoy et al. [8]	USA	4,5	Assessed economic impacts of four different types of bio-refinery	Average transportation distance was 52 km to the bio-refinery plants. Among different techniques evaluated simultaneous saccharification and fermentation (SSF) and direct spouted bed (DSB) gasification techniques were viable to conduct in terms of economy.
Frisk et al. [9]	Sweden	1,2,3	Used cost allocation method for allocating transportation costs among forest companies	Improved individual company-based planning saved about 5% transportation cost while collaboration between companies saved 14% cost.
Graham et al. [10]	USA	3,4	Estimated potential transportation costs of energy feedstock in eleven US states	Transportation cost was lowest in Iowa, North Dakota and South Dakota the highest was in South Carolina, Missouri, Georgia and Alabama.
Grebner et al. [11]	USA	1,2,3	Excel based program 'Routechaser' to assess the impacts of different variables on transportation cost	This tool was useful for establishing contract rates from timber harvest units to markets.
Johansson et al. [13]	Sweden	4	Analyzed cost of transporting logging residues	Wood bundles for energy (dry) were cheaper to transport than fuel chips. The limiting factor was volume for transporting dry substance. Transportation cost reduced until critical moisture content i.e. below 41% for chips and below 45% for bundles.
Jones et al. [12]	USA	4	Analyzed financial effects of changes in diesel and delivered biomass price on transportation	In case of lowest delivered biomass price ($32 ODT^{-1}) and diesel price ($0.05 L^{-1}), the financially viable volume was 28%; while only 6% was available with highest diesel price ($1.32 L^{-1}).
Junjinger et al. [13]	Sweden	4	Quantified cost savings in primary forest fuel supply chain	In forwarding and chipping major cost savings was obtained for forest fuel supply chain.
Kizha et al. [3]	USA	4,5	Identified potential biomass feedstock available regionally based on transportation cost	Transportation cost zone within $20 ODT^{-1} had the highest potential supply of woody biomass for the region.
Kurka et al. [14]	UK	3	Allocated biomass feedstock supply to bioenergy plants and estimated transportation costs	Ten bioenergy plants could potentially produce 49 MW and 129 MW of electrical and thermal energy respectively. Based on this the transportation cost was calculated at ~$23 million/year.
Möller and Nielsen [15]	Denmark	3	Estimated transportation costs	Large energy plants with optimal road connections had higher costs of fuel supply

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Paolotti et al. [16]	Italy	6	Compared and evaluated economic feasibility of various transportation modes	Road and water transport cost ranged between $19–120 ton^{-1} and $73–88 ton^{-1}, respectively.
Ranta and Rinne [17]	Finland	4	Profitability and possible measures for improving forest residue transportation	Most cost-efficient way to transport raw material was in the form of bundles and most expensive was as loose residues. The difference between options increased with increase in distance.
Rauch and Gronalt [18]	Austria	4	Impacts of increasing energy costs on forest residue procurement costs.	20% increment in energy costs resulted in 7% increment in procurement cost. Reducing the empty trips of trucks and trailers can reduce procurement costs.
Rauch et al. [19]	Austria	4	Cost gap between co-operative and non-co-operative BSC (biomass Supply Chain)	Collaboration between power plants reduced 23% transportation costs and 26% transportation distance.
Spinelli et al. [20]	Italy and USA	1,2	Modelled transportation cost for short rotation plantations	Whole tree (WT) system proved to be cheaper in terms of transportation than Cut-to-length (CTL) system. The pulp chips delivered cost from WT was ~$21 GT^{-1} while it was $27–30 GT^{-1} from CTL.
Tahvanainen and Antilla [21]	Finland	3	Estimated costs of forest chips procurement for long-distance transport	For shorter distances (<60 km), trucking of loose residues and end-facility comminution was most cost-effective while it was roadside chipping with chip truck transportation, for longer distances. For distance range 135–165 km, rail transportation provided lower cost.
Yemshanov et al. [22]	Canada	4	Potential amount and financial costs of forest residue biomass supply	Annual available biomass was about ~19.2–23.3 Tg/yr and 16.5–20.0 Tg/yr. If residue extraction cost was decreased by 35%, the residues availability would have increased by ~5.5 to 5.7 times at $45 ODT^{-1} supply price and ~1.5 to 1.6 times at $60 ODT^{-1} supply price.
Yoshioka et al. [23]	Japan	4	Examined the cost viability of transporting logging residues	Comparison between European countries and Japan showed that there was need of a low-cost timber harvesting, transporting, and comminution techniques in Japan.

*Type of wood products dealt in the article: Sawlogs (1), Pulpwood (2), Wood chips (3), Logging residue (4), Sawmill residue (5), and wood pellets (6)

3.2. Theme II – Roads and route planning

A total of 40 articles (about 31%) were categorized under this theme, averaging 2.5 articles published per year. Similar to the Theme I, the greatest number of publications were from the United States (12 articles) followed by Turkey, Croatia, Slovenia, Sweden, Iran, and Japan (Table 4). Articles related to GIS modeling and linear & mixed integer programming to solve forest road planning problems were included in this theme instead of Theme VI (Supply chain and optimization). Similarly, for articles analyzing costs related to certain aspects of forest roads (i.e. construction) were included in Theme II instead of Theme I (cost).

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Table 4. Published scientific articles handling various aspects related to forest roads. The recommendation/ findings are specific to the research/ region and conditions described in the article.

Authors	Countries	Objective(s)	Major findings and/or suggestions
Abeli et al. [24]	Tanzania	Addressed issues of road alignment and grades on a gravel forest road maintenance costs	Alignment and gradient of roads affected soil loss rate. Grades less than 6% and radius more than 100m provided less maintenance costs.
Akay and Sessions [25]	Turkey	Plan an alternative forest route from a software (TRACER) to predict lowest cost in terms of construction, maintenance and transportation	Unit costs were $46/m and $28/m, respectively for two given stations (A & B). Construction cost was the largest component, followed by maintenance and transportation costs.
Akay et al. [26]	Turkey	Reviewed the evolution of software to design forest roads	Development of modern heuristics techniques such as *Tabu Search, Threshold Accepting, Simulated Annealing, Genetic Algorithm*, and their hybridization with traditional solution techniques into meta-heuristic algorithms can offer opportunities for future research.
Aruga et al. [27]	USA	Optimized road alignments using the Dijkstra shortest path method and cubic spline function	Solution with Spline function was inferior compared to solution without it. Additional investigations using given functions were recommended
Beck and Sessions [28]	USA	Determining access of woods chip trailers in forest roads utilizing Ant Colony optimization and Breakeven analysis	Forest transportation network that can accommodate larger trucks could lower hauling costs. Feasibility of biomass operations were depended on road modification cost, transport volume, and transportation costs.
Beck et al. [29]	USA	Developing a novel algorithm using Aerial LiDAR for forest road extraction	Comparing geometric variables from aerial and terrestrial LiDAR datasets showed that the average difference in road width was 1.1 m while the slope differences of cut/fill was minimum of 4%. In addition, the difference in slope across road was only 2%.
Boston et al. [30]	USA	Discussed the potential economic gain in construction of surface layer of roads by improving subgrade	Results from the study showed that a 34% saving in road aggregates cost was possible with improvement in road subgrades.
Contreras et al. [31]	USA	Compared ant colony optimization (ACO) meta-heuristic and mixed-integer programming (MIP) to solve forest transportation planning problems	The solutions obtained from ACO were equal to or inferior to the MIP solution. However, ACO algorithm took less computational time than latter.
Contreras et al. [32]	USA	Developing a model to enhance earthwork volume estimation for forest roads using digital elevation model with high resolutions.	As the spacing of cross-section increased, the capability of the model to capture differences in terrain decreased. Thus, the correctness of earthwork volume estimation was low. As a result, short cross-section spacing was favorable to improve accuracy in earthwork volume estimation in case of hilly and rugged terrain.

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Demir [33]	Turkey	Analyzed forest road network system	There was a need of ~201,000 km forest roads in Turkey. The anticipated time to complete those planned road networks was about 20 years.
Devlin et al. [34]	Ireland	Comparing the existing timber transportation routes from a central depot to other destinations with GIS generated simulated routes.	The findings showed that the real GPS routes were not as same as shortest route generated by Network Analyst Tool (NAT). Nevertheless, after manipulation of NAT the similarity increased to more than 90%.
Ghaffarian and Sobhani [35]	Iran	Determining the best-fit forest road network that could minimize the total cost of road maintenance.	The data analysis in Network 2000 based on pre-existing forest road network showed that the best solution can be achieved in the cost of 27.19 €/m^3.
Ghajar et al. [36]	Iran	Demonstration of a procedure that incorporated rock proportion for embankment construction in forest roads.	This approach was useful to show the variability of rock proportion and model excavation costs.
Greulich [37] (review paper)	USA	Analyzed the evolution of transportation network in forest harvesting	Theoretical basis for transportation networks in forest harvesting was mainly developed by early European academics. From twentieth century, this theory sustained its development in America. In the last fifty years, there has been swift development in Europe and America, with Asia also putting significant contributions.
Gumus [38]	Turkey	Assessed the future use of forest road networks for sustainable forestry	The findings showed that most of the roads in the study area was in the standard to fulfill sustainable forestry target. However, the 20% of the roads were in worse condition.
Gumus et al. [39]	Turkey	Developing a new road network planning procedure and comparing it to pre-existing networks for environmental impact assessment (EIA)	More than 90% of the planned roads were in minimum negative impact zone while only about 10% of the planned roads were in maximum risk zone. The purposed criteria for future road development was 20 m/ha.
Hernández-Díaz et al. [40]	Mexico	Assessing the impacts of forest roads on soil in a timber harvesting area	The level of ground along the truck ruts was decreased to about 38-58 mm in rainy season by run-off. Removal of some tertiary roads were proposed for road density reduction. The expected soil loss reduction could be 20% with this proposed plan.
Košir and Krč [41]	Slovenia	Presented the existing condition of forest road design and construction in Slovenia and adopt multi-criteria decision model to build new forest roads	Results showed that the terrain was suitable for the planning and execution of forest roads construction. The model proposed could be considered for future forest road construction in Slovenia.
Krč and Beguš [42]	Slovenia	Developed a model that can identify inaccessible forests and helped in future forest roads planning.	There was still 210,385 ha of inaccessible forests. The construction of 758 km of new roads was planned at the national level to access some parts of the inaccessible forests. The researcher believed that the model could be used for different scenarios and for other regions in the world.

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Lugo and Gucinski [43]	USA	Analyzed the function and effects of forest roads on forested rural landscape.	The study suggested that a road ecosystem approach that incorporates environmental gradient analysis should be used for planning and design of forest roads.
Murphy and Stander [44]	USA	Developed a two-stage robust optimization model to deal with the actual transportation problems in forestry.	The results showed that the deterministic solution was unstable and dependent on some degree of uncertainty, that the robust solution was dependent on the variables used.
Najafi and Richards [45]	Iran and Canada	Developed a model using mixed integer programming to design a forest road system including logging roads for trucking and access spurs for skidding.	The model was able to reduce overall costs of road construction and maintenance. High quality solutions were obtained in considerably less time.
Najafi et al. [46]	Iran	Developed a model that can evaluate the efficiency of road network from the viewpoint of cost.	The accepted network model had less environmental impacts, and the costs of road networking were minimized.
Nevečerel et al. [47]	Croatia	Categorized forest roads by calculating the traffic loads and distance with GIS tools	Designation of the forest roads by GPS and snap-back method offered a comparatively efficient technique. The findings from traffic load examination suggested that the construction of the individual sections of same forest road could be done differently.
Olsson [48]	Sweden	Mixed integer model (decision support system) for strategic planning of road investments for large areas focusing solely on gravel road upgrading.	The study concluded that the all forest roads network should be optimized simultaneously. Even if the study area included 440 roads, it was expected that the approach could be useful for getting global optimal solutions.
Olsson [49]	Sweden	Comparison of a solution from two-stage stochastic model (SM) to optimize the upgrading of a forest road network with that of deterministic scenario analysis model (SAM).	The solutions obtained from SM and SAM were different. In fact, the solution from SM model was 2.9% better than that of SAM.
Olsson and Lohmander [50]	Sweden	Optimized round wood transport and road investments on the gravel road	The solutions obtained were near to optimal for investment decisions for gravel roads.
Pellegrini et al. [51]	Italy	Use of decision support system to prioritize the maintenance of forest road network	The findings suggested that the combined use of GIS tools and Analytic Hierarchy Process techniques could give important decision regarding forest road management. The priority ranking was made for road maintenance based on actual conditions.
Pentek et al. [52]	Croatia	Analysis of the quality of existing forest road network using GIS	The analysis helped the forest managers to allocate resources efficiently to specific forest areas. The overall relative openness of the selected forest areas was 81.04%. The road network efficiency coefficient obtained from the analysis was 42.37%.

Pentek et al. [53]	Croatia	Analyzed and discussed the overall status of forest roads in Croatia with focus on planned openness, and average construction and design cost.	An average of 272 and 319 km of lower and upper forest road layers were constructed annually at an average cost of 118,134 and 135,020 Croatian Kuna km^{-1}, respectively.
Pentek et al. [54]	Croatia	Prepared the registry of secondary forest roads traffic.	In order to establish the registry of the secondary forest infrastructure, the snap-back method of surveying proved to be quick and exact.
Péterfalvi et al. [55]	Hungary	Assessed the lime-stabilization effects on the forest road pavement	The bearing capacity of the lime stabilization was 500 MPa. For long term performance, 25–35 cm of lime stabilization under the pavements was considered good.
Potočnik et al. [56]	Japan	Maintenance of forest road network in the natural forest management conditions	The main roads were maintained every year while the management roads every 10 years, coinciding with rotation year of selection cutting.
Potočnik et al. [57]	Slovenia	Analyzed traffic load on forest roads due to forest operations	The cumulative traffic load and hauled forest products quantity were highest at the cross-section of forest roads and public roads while it was lowest at the farthest point from public road.
Robek and Klun [58]	Slovenia	Innovations and trends in forest road construction in Slovenia.	The study showed forest road network in Slovenia was not considered optimal. It was getting increasingly worn out, and the new transportation technologies demand certain adaptations to be made in the existing technical elements.
Saito et al. [59]	Japan	Examined a model that uses LiDAR data to spontaneously design forest roads on shallow landslides area	The program that used LiDAR based Digital Terrain Model could minimize the earthwork costs while avoiding shallow landslide risk areas.
Sessions and Boston [60]	USA	Determined optimal policies for road aggregates management	A mathematical model was suggested to determine optimal policies to manage high quality durable rock aggregates resources
Stückelberger et al. [61]	Switzerland	Estimated the life-cycle costs of forest roads	By using location-specific slope gradients, costs reduced by 17% from that of available practices. Nevertheless, when both slope gradient and geotechnical formations were included, the costs decreased by 20%.
Tan [62]	Australia	Optimized internal forest road location	Programming procedure integrated with spatial database and transportation network models were used to assist foresters in determining the optimum location for a forest road.
Trzciński and Kaczmarzyk [63]	Poland	Evaluated the carrying capacity of forest roads with slag and gravel pavements	Carrying capacity of slag and gravel pavements was insufficient. The largest mean deformation module for gravel pavement was 123 MPa. The two-ply gravel pavements that was 25 cm in thickness was only able to comply with the requirements of low traffic intensity.

3.3. Theme III – Trucking characteristics

This section comprised of 14 articles which was about 11% of the total (Table 5). About 60% of the studies were related to the transportation of sawlogs and pulpwood. A total of five studies were

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carried out in the USA followed by four in Finland. Apart from trucking features, Theme III also included topics such as GPS tracking system, options for backhauling empty trucks, and solution for truck scheduling problems in forest operations.

Table 5. Published scientific articles handling various aspects related to forest trucking. The recommendation/ findings are specific to the research/ region and conditions described in the article.

Authors	Countries	Wood products*	Objectives	Major finding(s) and/or suggestions
Antonaide et al. [64]	Romania	1	Estimate maximum loading heights for vehicles used in timber transportation	The maximum truck load height for average conditions varied the main characteristics of the loading-unloading equipment, as well as the maximum allowable loads per axles.
Devlin and McDonnell [65]	Ireland	1	Evaluated the performance of real-time GPS asset tracking systems for timber hauling trucks	The horizontal root mean square (HRMS) accuracy values were 2.55–2.47 m for public roads, while for forest road the values were 27–41 m.
Han and Murphy [66]	USA	3	Modelled woody biomass truck scheduling problem	An optimization model was developed for transporting four types of woody biomass. The model was significantly improved by using 50-load order size within 18 s. The transportation costs and travel time reduced by 18 and 15%, respectively.
Han et al. [67]	USA	4	Evaluate the economic feasibility of removing hand-piled slash using a roll off trucking system in mountainous terrains	The overall cost to collect and haul hand-piled slash was \$34 ODT^{-1}. Roll-off trucking system was found to be better for short hauling distances because trucking costs significantly increased with small increase in distance.
Laitila and Väätäinen [68]	Finland	2	Evaluated the truck transportation productivity for whole trees and energy woods	Whole-tree harvesting, chipping, and trucking near roadside landing was the most cost-efficient technique. The transportation productivity of energy shortwood was higher than whole-tree.
Malinen et al. [6]	Finland	1,2	Surveyed challenges related to timber trucking in a changing operational environment	Half of respondents thought that the profitability of timber trucking had decreased greatly. Results showed most influential infrastructure factor affecting timber trucking was winter maintenance, including removing snow and ice and anti-slip measures.
McDonald et al. [69]	USA	1,2	Applying optimization techniques to reduce the distance driven by log-truck	The optimized route achieved a loaded-distance driven proportion of 66%, which was significantly higher than the human-assigned routes. This could save the firm up to 24000 km of road per year.
Nurnimen and	Finland	1	Introduced time-consumption models for	The models included explanatory variables like driving distance, number of log decks, log product and load

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Hainonen [70]			general logs transportation in Finland	volume. The models showed optimal solution to calculate the cost and profitability of trucking activities.
Palander et al. [71]	Finland	3	Presented a backhauling model to minimize empty travel phase of trucks while returning	The results proved that the method was able to minimize the travel empty route of log trucking.
Picchi and Eliasson [72]	Sweden	3	Evaluated the use and performance of container handling chipper trucks (CCT)	The average productivity varied between 9.3 and 13.5 ODT PMH_0 based on grapple choice. For CCT, a standard residue grapple proved better. With wise planning and adjusting the number of container trucks used, total waiting expenditures could be minimized.
Roscher et al [73]	Sweden	1,2,3	Examined transport patterns of trucks with (first group) or without the support (second group) using mobile data systems (MDS)	Trucks with MDS attached were able to reach more destinations per day than trucks without.
Shafer and Stuart [74]	USA	1,2,3	Developed a checklist for efficient log trucking	A guideline for efficient timber trucking for the state of Virginia.
Spinelli et al. [75]	Europe	2	Tested a chipper truck performance in different geographic conditions	Productivity was from 13 to 19 tons green chips per hour with delays. Fuel consumption was between 1.8 and 2.8 liter per ton of green chips. Machine utilization was from 68 to 89%.
Thompson et al [76]	USA	2	Evaluated the transportation of in-wood chipped biomass	The larger trailers (123 yd^3) can accommodate 19% more volume than conventional trailers (100 yd^3). However, it olny increased 10% payload. If used exclusively, larger trailers can reduce 6 loads to transport all chips from the site.

* Wood products: Sawlogs (1); Pulpwood (2); Wood chips (3); and Logging residue (4).

3.4. Theme IV – Efficiency and safety

There were 11 articles in this category contributing to 8% of total literature, with an average of less than 1.0 article was published per year (Table 6).

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Table 6. Published scientific articles handling various aspects related to efficiency in transportation. The recommendation/ findings are specific to the research/ region and conditions described in the article.

Authors	Countries	Objectives	Major finding(s) and/or suggestions
Abbas et al. [77]	USA	Surveyed current forest operation capacity and its supply potential for large scale startup industries	The survey had 28% response rate. The study provided the new insight to forest trucking in the region.
Arce et al. [78]	Brazil	Solved forest-level bucking optimization problem by considering transportation costs.	There were two modules in the system: Cutting Pattern Generation (CPG) and the Global Bucking Optimization (GBO). Apart from these the biometrics like tree height, taper and volume were also integrated in the system for optimal solution.
Greene et al. [79]	USA	Analyzed log hauling vehicle accidents in Georgia, USA	Accidents per million tons of wood consumed had increased steadily from 11 in 1991 to 19 in 2003.
Hall et al. [80]	New Zealand	Identified promising delivery systems of logging residues to an energy plant and evaluate the associated costs	The cheapest system identified ranged from NZ$22 - 37 ODT^{-1} for residues from the landing and NZ$29 – 42 per ODT for those collected from the cutover.
Hedlinger et al. [81]	Sweden	Examined the service divergence potential of round wood transport	The results showed that the focus for the wood suppliers and transporters was the mill service. The top ranked service focus was "maintaining suitable stock level", while the second ranked was "delivery precision".
Holzleitner et al. [82]	Austria	Analyzed time and fuel consumption in road transport for round wood	The transport distance from the forest to sawmill averaged 51 km. The average share on forest roads within a route to the sawmill was 14% with an average speed of 14 km per hour. Transport cost was € 11 m^{-3} for average load size of 25 m^{3}. the average fuel consumption was 0.77 L/km of diesel.
Jerbi et al. [83]	Canada	Evaluated supply chain management policies in the forest products industry using simulation based framework	The framework was based on two phases. The tactical phase was supported by software called LogiLab. In the second phase, the user evaluated this policy at the operational/execution level on combination with execution policies, using a discrete events simulation supported by Simio software.
Klvač et al. [84]	Czech Republic	Evaluated fuel consumption by timber trucks	The results showed that the fuel consumption of trucks decreased by 0.5 L m^{-3} by the use of new trucks and trailers during study period.
Rackley and Chung [85]	USA	Analyzed the effects of forest road erosion and incorporated it on transportation planning	The results indicated that by considering different environmental effects in transportation plans, an alternative road networks could be made. This can help reduce the loss of large amount of sediments.
Ranta and Corpinen [86]	Finland	Maximized the forest fuel supply availability to power plants	The total availability of forest fuel to the CHP (combined heat and power) plants was 7 TWh at a maximum transportation distance of 100 km.

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Sikanen et al. [87]	Finland	Investigated an internet-based, general-purpose logistics control system, using mobile terminals in forest fuel chipping and transportation	The management tool, Arbonaut Fleet Manager TM, was tailored for forest fuel supply chain management and trailed for three months. It was found that use of mobile handsets with GPS and map display assisted in finding exact location of in-wood storage piles.

3.5. Theme V – Other modes of transportation

Only five articles comprised this category which was the least of all categories (Table 7). Even though this theme is associated with modes of transportation other than trucking, certain articles involved trucking as internodal or intermediate transportation.

Table 7. Published scientific articles handling various aspects related to other modes of primary transportation. The recommendation/ findings are specific to the research/ region and conditions described in the article.

Authors	Countries	Wood products*	Objectives	Major finding(s) and/or suggestions
Ackerman and Pulkki [88]	South Africa	2	Analyzed economic impact of secondary intermediate transportation (SIT) of pulpwood	The findings showed that the average annual penalty because of maintaining SIT for South African forest industry was SA$4.32 million or US $0.82 m^{-3}. This showed the need of maintaining good quality forest roads and eliminating the SIT system.
Asikainen [89]	Finland	1	Simulated barge transportation of wood from forests to an island	A new push barge system was compared to the available powered barge system for wood transportation. Setting with three barges' together gave the lowest transportation costs when the distance was higher than 100 km. However, for shorter distance, the available system was cheaper.
Flodén and Williamsson [90]	Sweden	3	Evaluated the business models for sustainable biofuel transport using intermodal transport	Some of the key findings that can increase the potential of intermodal transportation were increased cooperation, sharing of transport resources and infrastructure, joint purchases, and others.
Gonzales et al. [91]	USA	3	Evaluate cost and productivity associated with various mode of transportation; rail, road and barge.	Barge transportation was the cheapest option for transporting densified biomass feedstock from mid-west to southeast USA. Unit trains were the cheapest mode for distance over 340 km, from mid-west to the west USA. For shorter distances, trucking was the cheapest option.
Lautala et al. [92]	USA	3	Analyzed the role of railroads in multimodal transportation in Michigan, USA	Challenges associated with rail transportation of forest products were short length of trip; many point of origins with limited shipping volumes; difficulty to reach destination without rail to rail interchanges; and lack of rail access.

*Wood products: Sawlogs (1); Pulpwood (2); Biomass (3).

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3.6. Theme VI – Supply chain and optimization

The supply chain logistics and optimization was the most studied topic related to forest products transportation in the given timeline. There were 42 articles in this category with an average frequency of 2.6 articles per year (Table 8). More than 70% of the studies were based on biomass, energy woods and logging residues. Highest number of studies were carried out in Canada and US with eight articles each, followed by Sweden (6 articles), Finland, and Greece (5 articles each).

Table 8. Published scientific articles handling various aspects related to forest products supply chains. The recommendation/ findings are specific to the research/ region and conditions described in the article.

Authors	Countries	Wood products*	Objectives	Major finding(s) and/or suggestions
Akhtari et al. [93]	Canada	3	Literature review on economic assessment of district energy systems using forest biomass feedstock	Bulk density showed the highest impact for the transportation cost and choice of biomass type. Transportation cost contributed 50% of total delivered costs.
Arabatzis et al. [94]	Greece	3, 5	Examined the uncertainty of demand in Biomass Supply Chain (BSC)	The generated model can be used to minimize total cost of operation including fuel wood transportation.
Asikainen [95]	Finland	1, 2, 3, 5	Analyzed the effects of integration of work tasks and supply chains in wood harvesting	At the operational level, integration enabled in improving cooperation between the sawlog and biomass logging crews and fleet.
Aydinel et al. [96]	Canada	1, 2, 3	Analyzed different options for a wood manufacturing company for transportation of different forest products to different customers	Models were run, and the test results indicated the possibilities of cost savings over the company's current practices. The company further customized the models. The approach resulted in real cost savings for the company.
Beaudoin et al. [97]	Canada	1, 2, 3	Developed a detailed tactical model to support centralized annual planning by an integrated forest company that may own several mills, and allowed for wood exchanges between companies	The results showed that the purposed MIP approach could achieve 9% profit compared to deterministic model that uses average parameter value. The sensitivity analysis showed that the accurate inventory of standing trees and market conditions were the most important variables.
Cambero and Sowlati [98]	Canada	3	Reviewed studies focusing on the economic, social and environmental aspects of forest BSC	Most of the problems studied used mixed integer programming models. The main objectives of the reviewed articles were to minimize biomass supply chain cost and to some extent maximize profit.
Carlsson and Rönnqvist [99]	Sweden	1, 2, 3	Developed a supply chain management model	Five projects to improve supply chain were described. The models provided better decision support. The major benefit included objective based discussions and decision ''over the borders'' between stakeholders.

Díaz-Yáñez et al. [100]	Europe	3	Reviewed the current procurement methods for wood chips	The main source of wood chips in EU was logging residue which in future could be replaced by stumps and round wood. With the development of novel technology, countries could improve the efficiency of the supply.
Dumanli et al. [101]	Turkey	5	Investigated logical aspects of forest BSC	Results showed that Turkey has good rail and road infrastructures to transport and utilize its available biomass resources in coming future.
Eriksson et al [102]	Sweden	3, 5	Evaluated numerous systems for stump wood transport to minimize costs	The results showed high variation in productivity and costs of different systems. The system that utilized the self-loading truck was proved efficient.
Forsberg [103]	Sweden	5	Life cycle methods to analyze bioenergy transport.	The results showed that there was possibilities to transport biomass from Scandinavian countries to Netherland without affecting the environmental benefits from it.
Frayret et al. [104]	Canada	1, 2, 3	Developing a new generic software to test forest products distribution planning and scheduling systems.	The program presented significant improvements in wood supply chain than manual level of planning process.
Freppaz et al. [105]	Italy	3	Assessed the supply of forest biomass for thermal and electric energy production	The biomass resources available in the study area was split into subsections of varying sizes. This system helped in determining and analyzing the cost of harvesting and transporting of forest biomass for energy production.
Frombo et al. [106]	Italy	3	Detail description of strategic planning of woody biomass logistics	The GIS-based Environmental Decision Support System (EDSS) was able to generate an optimal solution in terms harvesting and transportation.
Gautam et al. [107]	Canada	1, 2, 3	Analyzed scientific articles focusing on the improvement of the agility of wood procurement systems (WPS)	The review identified opportunities to improve the agility of WPS. The suggestion from the review was to focus on higher investments in agility section to gain higher profits in wood supply chain.
Gerasimov et al. [108]	Russia	4	Developed a GIS-based system to support planning of shortwood transport in Russia.	The system showed an increase of 40% in the efficiency of shortwood transportation. The system could be used for numerous purposes.
Gold and Seuring [109]	Germany	3, 5	Synthesized the information from scientific literatures that covers issues of bioenergy production and BSC	Most of the articles were from Biomass and Bioenergy journal, whereas the year with most publications was 2007. The primary focus was on system design for bioenergy production.
Gronalt and Rauch [110]	Austria	5	Designed a regional forest fuel supply network in Austria	The overall supply chain cost decreases with reduction in distance. The regional terminals were crucial for cost reduction. In order to get optimal supply network, costs of transporting to terminals and to plants should be considered.

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Gunnarsson et al. [111]	Sweden	5	Mathematical model to analyze BSC	Two modeling approaches were used. The heuristic method was two time faster than CPLEX programming. The presented model could be used for strategic and tactical planning of forest biomass supply chain.
Haartveit and Fjeld [112]	Norway and Sweden	1, 2, 3, 4	Using Wood Games (WG) approach to study the effects of different components of supply chain on its performance	The wood game (WG) approach was useful for finding out the challenges associated with forest products supply chain.
Kanzian et al. [113]	Austria	5	Designed forest energy supply network using multi-objective optimization	The results showed that to minimize CO_2 emissions, 30% of biomass should be transported in chipped condition from the terminal, 50% in chipped condition directly from forest and the remaining should be transported in raw or solid form from forest to plant.
Kühmaier and Stampfer [114]	Austria	5	Developed a decision tool for managing energy wood supply.	The cut-to-length and tree-length methods were more suitable than whole-tree system. The comminution of wood was preferred at terminals or plants rather than on forest roads.
Kurian et al. [115]	Canada	3	Reviewed the alternative logistical practices for important lingo-cellulosic biomass feedstock	Results showed that it was not economical to increase transportation distance of biomass for its value addition. Involvement of locals in biomass collection, and transportation could help to systemize the process.
Lautala et al. [116]	USA	3	Reviewed opportunities and challenges in designing BSC	Important challenges were availability of data; lack of a mutual agenda; and less integrated analysis.
Miao et al. [117]	USA	3	Reviewed equipment configuration, regulations and transportation costs of supplying biomass feedstock for bioenergy	At present, road transportation is the most used system for biomass transport. The findings suggested to consider the use of intermodal system (using more than one system together) in near future.
Nivala et al. [118]	Finland	5	Assessed the hauling of energy woods from forests to power plants for longer distances	Train-based system was cost efficient than traditional trucking system. The total cost of supply chain that used high capacity transport (HCT) vehicles of 68 and 76 tons was lower than train-based system.
Rantala et al. [119]	Finland	6	Analyzed the cost and spatial information for long distance seedling transportation	Cost-effectiveness was improved by centralized transportation strategy than decentralized transportation strategy. The cost saving observed was from13 to 37%, depending upon number of nurseries and other factors.
Rauch and Gronalt [120]	Austria	5	Suggested choice of spatial arrangement of terminal facility in forest fuel supply network	A simulated increase made in the transportation cost of forest fuel depicted that the presented model was stable for such increase up to 20 – 50%.

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Ravula et al. [121]	USA	3	Simulated cotton logistics as a model for a forest biomass transportation system	The utilization factor of the transportation system improved to 99% by implementing the new strategy.
Rentizelas et al. [122]	Greece	3	Compared three biomass storage techniques, in terms of total supply chain cost	The lowest cost storage system was the most efficient solution. However, it showed some health and safety risks.
Selkimäki et al. [123]	Finland and Sweden	3	Analyzed the trends in wood pellets supply chain logistics	The transportation cost was lower because of the vicinity of wood pellet plants to the source. Trucks were the primary means of transportation.
Shabani et al. [124]	Canada	3	Reviewed scientific research on deterministic and stochastic mathematical models in BSC	The focus of those studies was on the economic aspects of BSC. Topics like environmental and social aspects should be considered for the future studies.
Sharma et al. [125]	USA	3	Reviewed BSC design and modelling	Approximately 41% of the work related to modelling of BSC was from year 2011. Common network design for most of the models had biomass supply site, collection sites and processing sites.
Stone et al. [126]	USA	3	Evaluated BSC and harvesting innovation activities among logging contractors	Extraordinary collaboration among the key players of BSC (landowners, logging contractors, and biomass consuming facilities) was regarded essential for innovations to enter in forest products industry.
Troncoso and Garrido [127]	Chile	1,2,3	Presented a mathematical model to solve problems related to forestry logistics	The validation process showed that the model was applicable to the real world problems. The model was expected to enhance the capabilities of forest companies.
Uusitalo [128]	Finland	1	Developed an outline for CTL (cut-to-length) based wood products logistics	The future studies should focus more on improving harvesting type classification and available transportation systems.
Valenzuela et al. [129]	USA	1,2,3	Proposed a computer meta-heuristic model for scheduling several silvicultural projects simultaneously.	A small size problem with five worksites, solutions could be obtained in less than four minutes using the model. Larger problem with twenty worksites took 30 minutes.
van Belle et al. [130]	Belgium	5	Presented a technique to create a wood-based supply chain for power plants by taking into account of different economic, financial and resources constraints	The total available wood resources in the study area was 400,000 dry tons per year. The capital cost for equipment ranged from 45,860 to 545,366 Euros. The productivity of high cost system was 105 Euro per dry ton while it was only 31 Euro for least expensive system.
Van Dyken et al. [131]	Norway	3	Developed a linear mixed-integer models for biomass supply chains	A linear model for biomass supply chain was developed and tested for case study. The model presented in the study was regarded as a baseline model by researchers for future studies and development.

Windisch et al. [132]	Germany	1, 5	Integrated business process modeling and engineering approaches to an integrated forest products and biomass supply chain in Germany.	This new approach of redesigning the available business process had potential of saving 20-39% of total costs. The study proved that a very simple business approach could achieve substantial savings.
Wolfsmayr and Rauch [133]	Austria	5	Investigated the key issues on the transportation of primary forest fuel to heat and/or power plants	Key challenges were: transportation modes, terminal types, and BSC management. The rail system and water transportation were recommended for longer distances because of low cost and low CO_2 emissions.
Zhang et al. [134]	USA	3	Developed simulation model for biomass supply chain	The model proved to be important for BSC management including transportation logistics and other factors.

* Wood products: Sawlogs & timber (1); Pulpwood (2); Biomass (3); Short woods (4); Bioenergy & forest fuels (5); Seedlings (6).

4. Discussion

The collection and classification of scientific literature on secondary forest products transportation found that more than half of the studies addressed the transportation of woody biomass from forest, and industrial residues for bioenergy generation. Generally, woody biomass generated from forest operations and forest products industries are regarded as low value products compared to the primary forest products such as sawlogs and pulpwood. This raises a question as to why the frequency of the scientific studies was higher for transportation of low-value biomass. Woody biomass constitutes forest residues with low bulk density that are not economically feasible to transport in the raw form. In regions without a demand for biomass, forest residues are generally left at the harvesting site [5].

Much of the reasoning for this comes from the funding sources for research. Empirical evidence tells us that most research funding comes from government agencies, as opposed to direct industry input, and government policies lately have been focused more upon biomass than high values forest products. Much of this is driven by interests in atmospheric carbon issues and in reduction of hazardous forest fire fuels

On a regional basis, higher number of studies were published from Europe followed by North America and Asia. This high number of articles from Europe can be attributed to the policies favoring biomass utilization. While transportation cost is considered to be one of the major limiting factors for biomass utilization, the feasibility also depends heavily on favorable policies. Country wise, USA had the highest number of publications which could be due to large area of managed timberland, and a developed economy which sustains on high level of research.

Biomass and Bioenergy journal published highest number of articles on the subject. This is related to the higher number of studies focusing on the transportation of forest residues. Forest products transportation is an important component of forest engineering, thus there were significant number of articles in journals like Croatian Journal of Forest Engineering and International Journal of Forest Engineering.

Two of the most studied research topics on forest products transportation were supply chain models and forest roads. Many site and region-specific optimization and supply chain models have been tested and presented, which increased the number of publications. Similarly, forest roads are crucial for hauling wood materials from harvesting sites to the markets. Construction and maintenance of roads requires huge amount of investment. In this study, there were only 14 articles

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directly related to trucking characteristics, however, most of the other articles (dealt in the study) also discussed trucking in many different ways.

Overall, the results indicated a need for more research on increasing the efficiency of transportation systems, specifically trucking. Except for one study done in Finland, there was no research focusing on the overall challenges facing the forest trucking industry as a whole [6]. The cost of transportation is also another major topic that needs to be addressed in the future.

5. Conclusions

Regardless of categorization into different research themes, the main aim of all the collected articles in this study was to address the challenges faced by the secondary transportation of forest products. Major details on each article including research location, forest products dealt, primary objectives and key findings related to transportation were presented in tabular format. This review is expected to help researchers' for summarizing prior studies on forest transportation. It will also provide insight on the specifics that are lacking in this sector and show the way ahead for future research and innovation. This article is based on literature collection and assortment and thus should not be regarded as critical literature synthesis article.

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References

1. Pentek, T.; Poršinsky, T. Forest transportation systems as a key factor in quality management of forest ecosystems. For. Ecosyst. than Just Trees (ed JA Blanco, YH Lo), Tech 2012, 433–464.
2. El Hachemi, N.; Gendreau, M.; Rousseau, L.-M. A heuristic to solve the synchronized log-truck scheduling problem. Comput. Oper. Res. 2013, 40, 666–673, doi:10.1016/j.cor.2011.02.002.
3. Kizha., A. R.; Han, H.-S.; Montgomery, T.; Hohl, A. Biomass power plant feedstock procurement: Modeling transportation cost zones and the potential for competition. Calif. Agric. 2015, 69, 184–190, doi:10.3733/ca.v069n03p184.
4. Koirala, A.; Kizha, A. R.; Roth, B. Forest trucking industry in Maine: A review on challenges and resolutions. In Proceeding of 39th Annual Meeting of the Council on Forest Engineering; Vancouver, Canada, 2016.
5. Kizha, A. R.; Han, H.-S. Processing and sorting forest residues: Cost, productivity and managerial impacts. Biomass and Bioenergy 2016, 93, 97–106, doi:10.1016/j.biombioe.2016.06.021.
6. Malinen, J.; Nousiainen, V.; Palojarvi, K.; Palander, T. Prospects and challenges of timber trucking in a changing operational environment in Finland. Croat. J. For. Eng. 2014, 35, 91–100.
7. Acuna, M.; Mirowski, L.; Ghaffariyan, M. R.; Brown, M. Optimising transport efficiency and costs in Australian wood chipping operations. Biomass and Bioenergy 2012, 46, 291–300, doi:10.1016/j.biombioe.2012.08.014.
8. Aksoy, B.; Cullinan, H.; Webster, D.; Gue, K.; Sukumaran, S.; Eden, M.; Sammons, N. Woody biomass and mill waste utilization opportunities in Alabama: Transportation cost minimization, optimum facility location, economic feasibility, and impact. Environ. Prog. Sustain. Energy 2011, 30, 720–732, doi:10.1002/ep.10501.
9. Frisk, M.; Göthe-Lundgren, M.; Jörnsten, K.; Rönnqvist, M. Cost allocation in collaborative forest transportation. Eur. J. Oper. Res. 2010, 205, 448–458, doi:10.1016/j.ejor.2010.01.015.
10. Graham, R. L.; English, B. C.; Noon, C. E. A geographic information system-based modeling system for evaluating the cost of delivered energy crop feedstock. Biomass and bioenergy 2000, 18, 309–329.

11. Grebner, D. L.; Grace, L. A.; Stuart, W.; Gilliland, D. P. A practical framework for evaluating hauling costs. Int. J. For. Eng. 2005, 16, 115–128.
12. Jones, G.; Loeffler, D.; Butler, E.; Hummel, S.; Chung, W. The financial feasibility of delivering forest treatment residues to bioenergy facilities over a range of diesel fuel and delivered biomass prices. Biomass and Bioenergy 2013, 48, 171–180, doi:10.1016/j.biombioe.2012.11.023.
13. Junginger, M.; Faaij, A.; Björheden, R.; Turkenburg, W. C. Technological learning and cost reductions in wood fuel supply chains in Sweden. Biomass and Bioenergy 2005, 29, 399–418, doi:10.1016/j.biombioe.2005.06.006.
14. Kurka, T.; Jefferies, C.; Blackwood, D. GIS-based location suitability of decentralized, medium scale bioenergy developments to estimate transport CO2 emissions and costs. Biomass and Bioenergy 2012, 46, 366–379, doi:10.1016/j.biombioe.2012.08.004.
15. Möller, B.; Nielsen, P. S. Analysing transport costs of Danish forest wood chip resources by means of continuous cost surfaces. Biomass and Bioenergy 2007, 31, 291–298, doi:10.1016/j.biombioe.2007.01.018.
16. Paolotti, L.; Martino, G.; Marchini, A.; Pascolini, R.; Boggia, A. Economic and environmental evaluation of transporting imported pellet: A case study. Biomass and Bioenergy 2015, 83, 340–353, doi:10.1016/j.biombioe.2015.09.011.
17. Ranta, T.; Rinne, S. The profitability of transporting uncomminuted raw materials in Finland. Biomass and Bioenergy 2006, 30, 231–237, doi:10.1016/j.biombioe.2005.11.012.
18. Rauch, P.; Gronalt, M. The effects of rising energy costs and transportation mode mix on forest fuel procurement costs. Biomass and Bioenergy 2011, 35, 690–699, doi:10.1016/j.biombioe.2010.10.015.
19. Rauch, P.; Gronalt, M.; Hirsch, P. Co-operative forest fuel procurement strategy and its saving effects on overall transportation costs. Scand. J. For. Res. 2010, 25, 251–261, doi:10.1080/02827581003766967.
20. Spinelli, R.; Ward, S. M.; Owende, P. M. A harvest and transport cost model for Eucalyptus spp. fast-growing short rotation plantations. Biomass and Bioenergy 2009, 33, 1265–1270, doi:10.1016/j.biombioe.2009.05.010.
21. Tahvanainen, T.; Anttila, P. Supply chain cost analysis of long-distance transportation of energy wood in Finland. Biomass and Bioenergy 2011, 35, 3360–3375, doi:10.1016/j.biombioe.2010.11.014.
22. Yemshanov, D.; McKenney, D. W.; Fraleigh, S.; McConkey, B.; Huffman, T.; Smith, S. Cost estimates of post harvest forest biomass supply for Canada. Biomass and Bioenergy 2014, 69, 80–94, doi:10.1016/j.biombioe.2014.07.002.
23. Yoshioka, T.; Aruga, K.; Nitami, T.; Sakai, H.; Kobayashi, H. A case study on the costs and the fuel consumption of harvesting, transporting, and chipping chains for logging residues in Japan. Biomass and Bioenergy 2006, 30, 342–348, doi:10.1016/j.biombioe.2005.07.013.
24. Abeli, W. S.; Shemwetta, D. T.; Meiludie, R. O.; Kachwele, M. Road alignment and gradient issues in the maintenance of logging roads in Tanzania. J. For. Eng. 2000, 11, 15–21.
25. Akay, A. E.; Sessions, J. Applying the decision support system, TRACER, to forest road design. West. J. Appl. For. 2005, 20, 184–191.
26. Akay, A. E.; Boston, K.; Sessions, J. The evolution of computer-aided road design systems. Int. J. For. Eng. 2005, 16, 73–79.
27. Aruga, K.; Tasaka, T.; Sessions, J.; Miyata, E. S. Tabu search optimization of forest road alignments combined with shortest paths and cubic splines. Croat. J. For. Eng. 2006, 27, 37–47.
28. Beck, S.; Sessions, J. Forest road access decisions for woods chip trailers using Ant Colony Optimization and breakeven analysis. Croat. J. For. Eng. 2013, 34, 201–215.
29. Beck, S. J.; Olsen, M. J.; Sessions, J.; Wing, M. G. Automated Extraction of Forest Road Network Geometry from Aerial LiDAR. Eur. J. For. Eng. 2015, 1, 21–33.
30. Boston, K.; Pyles, M.; Bord, A. Compaction of forest roads in Northwestern Oregon–room for improvement. Int. J. For. Eng. 2008, 19, 24–28.
31. Contreras, M. A.; Chung, W.; Jones, G. Applying ant colony optimization metaheuristic to solve forest transportation planning problems with side constraints. Can. J. For. Res. 2008, 38, 2896–2910, doi:10.1139/X08-126.
32. Contreras, M. A.; Aracena, P.; Chung, W. Improving accuracy in earthwork volume estimation for proposed forest roads using a high-resolution digital elevation model. Croat. J. For. Eng. 2012, 33, 125–142.
33. Demir, M. Impacts, management and functional planning criterion of forest road network system in Turkey. Transp. Res. Part A Policy Pract. 2007, 41, 56–68, doi:10.1016/j.tra.2006.05.006.

Peer-reviewed version available at Forests 2018, 9, 415; doi:10.3390/f9070415

34. Devlin, G. J.; McDonnell, K.; Ward, S. Timber haulage routing in Ireland: an analysis using GIS and GPS. J. Transp. Geogr. 2008, 16, 63–72, doi:10.1016/j.jtrangeo.2007.01.008.
35. Ghaffarian, M. R.; Sobhani, H. Optimization of an existing forest road network using Network 2000. Croat. J. For. Eng. 2007, 28, 185–193.
36. Ghajar, I.; Najafi, A.; Torabi, S. A.; Khamehchiyan, M.; Boston, K. An adaptive network-based fuzzy inference system for rock share estimation in forest road construction. Croat. J. For. Eng. 2012, 33, 313–328.
37. Greulich, F. Transportation networks in forest harvesting: early development of the theory. Proc. S 2003, 3, 57–65.
38. Gumus, S. Evaluation of forest road networks located in Karadeniz Technical University Research and Practice Forest. Eur. J. For. Eng. 2015, 1, 15–20.
39. Gumus, S.; Acar, H. H.; Toksoy, D. Functional forest road network planning by consideration of environmental impact assessment for wood harvesting. Environ. Monit. Assess. 2008, 142, 109–116, doi:10.1007/s10661-007-9912-y.
40. Hernández-Díaz, C.; Soto-Cervantes, J.; Corral-Rivas, J.; Montiel-Antuna, E.; Alvarado, R.; Goche-Télles, R. Impacts of Forest Roads on Soil in a Timber Harvesting Area in Northwestern Mexico (a Case Study). Croat. J. For. Eng. 2015, 36, 259–267.
41. Košir, B.; Krč, J. Where to Place and Build Forest Roads–Experience From the Model. J. For. Eng. 2000, 11, 7–19.
42. Krč, J.; Beguš, J. Planning Forest Opening with Forest Roads. Croat. J. For. Eng. 2013, 34, 217–228.
43. Lugo, A. E.; Gucinski, H. Function, effects, and management of forest roads. For. Ecol. Manage. 2000, 133, 249–262.
44. Murphy, G.; Stander, H. Robust optimisation of forest transportation networks: a case study. South. Hemisph. For. J. 2007, 69, 117–123, doi:10.2989/SHFJ.2007.69.2.7.293.
45. Najafi, A.; Richards, E. W. Designing a forest road network using mixed integer programming. Croat. J. For. Eng. 2013, 34, 17–30.
46. Najafi, A.; Sobhani, H.; Saeed, A.; Makhdom, M.; Mohajer, M. M. Planning and assessment of alternative forest road and skidding networks. Croat. J. For. Eng. 2008, 29, 63–73.
47. Nevečerel, H.; Pentek, T.; Pičman, D.; Stankic, I. Traffic load of forest roads as a criterion for their categorization – GIS analysis. Croat. J. For. Eng. 2007, 28, 27–38.
48. Olsson, L. Road investment scenarios in Northern Sweden. For. Policy Econ. 2005, 7, 615–623, doi:10.1016/j.forpol.2003.11.002.
49. Olsson, L. Optimal upgrading of forest road networks: Scenario analysis vs. stochastic modelling. For. Policy Econ. 2007, 9, 1071–1078, doi:10.1016/j.forpol.2006.10.005.
50. Olsson, L.; Lohmander, P. Optimal forest transportation with respect to road investments. For. Policy Econ. 2005, 7, 369–379, doi:10.1016/j.forpol.2003.07.004.
51. Pellegrini, M.; Grigolato, S.; Cavalli, R. Spatial multi-criteria decision process to define maintenance priorities of forest road network: an application in the Italian alpine region. Croat. J. For. Eng. 2013, 34, 31–42.
52. Pentek, T.; Pičman, D.; Potočnik, I.; Dvorsčak, P.; Nevečerel, H. Analysis of an existing forest road network. Croat. J. For. Eng. 2005, 26, 39–50.
53. Pentek, T.; Nevečerel, H.; Pičman, D.; Poršinsky, T. Forest road network in the Republic of Croatia – Status and perspectives. Croat. J. For. Eng. 2007, 28, 93–106.
54. Pentek, T.; Nevečerel, H.; Poršinsky, T.; Pičman, D.; Lepoglavec, K.; Potočnik, I. Methodology for development of secondary forest traffic infrastructure cadastre. Croat. J. For. Eng. 2008, 29, 75–83.
55. Péterfalvi, J.; Primusz, P.; Markó, G.; Kisfaludi, B.; Kosztka, M. Evaluation of the Effect of Lime-Stabilized Subgrade on the Performance of an Experimental Road Pavement. Croat. J. For. Eng. 2015, 36, 269–282.
56. Potočnik, I.; Yoshioka, T.; Miyamoto, Y.; Igarashi, H.; Sakai, H. Maintenance of forest road network by natural forest management in Tokyo University Forest in Hokkaido. Croat. J. For. Eng. 2005, 26, 71–78.
57. Potočnik, I.; Pentek, T.; Pičman, D. Impact of traffic characteristics on forest roads due to forest management. Croat. J. For. Eng. 2005, 26, 51–57.
58. Robek, R.; Klun, J. Recent developments in forest traffic way construction in Slovenia. Croat. J. For. Eng. 2007, 28, 83–91.

59. Saito, M.; Goshima, M.; Aruga, K.; Matsue, K.; Shuin, Y.; Tasaka, T. Study of Automatic Forest Road Design Model Considering Shallow Landslides with LiDAR Data of Funyu Experimental Forest. Croat. J. For. Eng. 2013, 34, 1–15.
60. Sessions, J.; Boston, K.; Thoreson, R.; Mills, K. Optimal policies for managing aggregate resources on temporary forest roads. West. J. Appl. For. 2006, 21, 207–216.
61. Stückelberger, J. A.; Heinimann, H. R.; Burlet, E. C. Modeling spatial variability in the life-cycle costs of low-volume forest roads. Eur. J. For. Res. 2006, 125, 377–390, doi:10.1007/s10342-006-0123-9.
62. Tan, J. Application of dynamic programming to optimum location of a forest road. J. For. Eng. 2000, 11, 33–42.
63. Trzcinski, G.; Kaczmarzyk, S. Estimation of carrying capacity of slag and gravel forest road pavements. Croat. J. For. Eng. 2006, 27, 27–36.
64. Antoniade, C.; Şlincu, C.; Stan, C.; Ciobanu, V.; Ştefan, V. Maximum loading heights for heavy vehicles used in timber transportation. În Bull. Transilv. Univ. Braşov, Ser. II–Forestry. Wood Ind. Agric. Food Eng. 2012, 5, 7–12.
65. Devlin, G. J.; McDonnell, K. Performance accuracy of real-time GPS asset tracking systems for timber haulage trucks travelling on both internal forest road and public road networks. Int. J. For. Eng. 2009, 20, 45–49.
66. Han, S.-K.; Murphy, G. E. Solving a woody biomass truck scheduling problem for a transport company in Western Oregon, USA. Biomass and Bioenergy 2012, 44, 47–55, doi:10.1016/j.biombioe.2012.04.015.
67. Han, H.-S.; Halbrook, J.; Pan, F.; Salazar, L. Economic evaluation of a roll-off trucking system removing forest biomass resulting from shaded fuelbreak treatments. Biomass and Bioenergy 2010, 34, 1006–1016, doi:10.1016/j.biombioe.2010.02.009.
68. Laitila, J.; Väätäinen, K. Truck transportation and chipping productivity of whole trees and delimbed energy wood in Finland. Croat. J. For. Eng. 2012, 33, 199–210.
69. McDonald, T. P.; Haridass, K.; Valenzuela, J.; Gallagher, T. V.; Smidt, M. F. Savings in distance driven from optimization of coordinated trucking. Int. J. For. Eng. 2013, 24, 31–41, doi:10.1080/14942119.2013.798133.
70. Nurminen, T.; Heinonen, J. Characteristics and time consumption of timber trucking in Finland. Silva Fenn. 2007, 41, 471.
71. Palander, T.; Väätäinen, J.; Laukkanen, S.; Malinen, J. Modeling backhauling on Finnish energy-wood network using minimizing of empty routes. Int. J. For. Eng. 2004, 15, 79–84.
72. Picchi, G.; Eliasson, L. Chip truck utilization for a container handling chipper truck when chipping logging residues and the effect of two grapple types on chipping efficiency. Int. J. For. Eng. 2015, 26, 203–211, doi:http://dx.doi.org/10.1080/14942119.2015.1099804.
73. Roscher, M.; Fjeld, D.; Parklund, T. Spatial patterns of round wood transport associated with mobile data systems in Sweden. Int. J. For. Eng. 2004, 15, 53–59.
74. Shaffer, R. M.; Stuart, W. B. A checklist for efficient log trucking. Virginia Coop. Ext. 2005, 420–94.
75. Spinelli, R.; De Francesco, F.; Eliasson, L.; Jessup, E.; Magagnotti, N. An agile chipper truck for space-constrained operations. Biomass and Bioenergy 2015, 81, 137–143, doi:10.1016/j.biombioe.2015.06.017.
76. Thompson, J. D.; Klepac, J. Trucking characteristics for an in-woods biomass chipping operation. 2012.
77. Abbas, D.; Handler, R.; Hartsough, B.; Dykstra, D.; Lautala, P.; Hembroff, L. A survey analysis of forest harvesting and transportation operations in Michigan. Croat. J. For. Eng. 2014, 35, 179–192.
78. Arce, J. E.; Carnieri, C.; Sanquetta, C. R. A forest-level bucking optimization system that considers customer's demand and transportation costs. For. Sci. 2002, 48, 492–503.
79. Greene, W. D.; Baker, S. A.; Lowrimore, T. Analysis of Log Hauling Vehicle Accidents in the State of Georgia, USA, 1988–2004. Int. J. For. Eng. 2007, 18, 52–57.
80. Hall, P.; Gigler, J. K.; Sims, R. E. H. Delivery systems of forest arisings for energy production in New Zealand. Biomass and Bioenergy 2001, 21, 391–399.
81. Hedlinger, C.; Nilsson, B.; Fjeld, D. Service divergence in swedish round wood transport. Int. J. For. Eng. 2005, 16, 153–166.
82. Holzleitner, F.; Kanzian, C.; Stampfer, K. Analyzing time and fuel consumption in road transport of round wood with an onboard fleet manager. Eur. J. For. Res. 2011, 130, 293–301, doi:10.1007/s10342-010-0431-y.
83. Jerbi, W.; Gaudreault, J.; D'Amours, S.; Nourelfath, M.; Lemieux, S.; Marier, P.; Bouchard, M. Optimization/simulation-based framework for the evaluation of supply chain management policies in the

forest product industry. In Systems, Man, and Cybernetics (SMC), 2012 IEEE International Conference on; IEEE, 2012; pp. 1742–1748.

84. Klvač, R.; Kolařík, J.; Volná, M.; Drápela, K. Fuel consumption in timber haulage. Croat. J. For. Eng. 2013, 34, 229–240.
85. Rackley, J.; Chung, W. Incorporating forest road erosion into forest resource transportation planning: a case study in the Mica Creek Watershed in northern Idaho. Trans. ASAE (American Soc. Agric. Eng. 2008, 51, 115.
86. Ranta, T.; Korpinen, O.-J. How to analyse and maximise the forest fuel supply availability to power plants in Eastern Finland. Biomass and Bioenergy 2011, 35, 1841–1850, doi:10.1016/j.biombioe.2011.01.029.
87. Sikanen, L.; Asikainen, A.; Lehikoinen, M. Transport control of forest fuels by fleet manager, mobile terminals and GPS. Biomass and Bioenergy 2005, 28, 183–191, doi:10.1016/j.biombioe.2004.08.011.
88. Ackerman, P. A.; Pulkki, R. E. Economic impact of secondary intermediate transport of pulpwood to truck transport depots in South Africa: three case studies. Int. J. For. Eng. 2003, 14, 53–63.
89. Asikainen, A. Simulation of logging and barge transport of wood from forests on islands. Int. J. For. Eng. 2001, 12, 43–50.
90. Flodén, J.; Williamsson, J. Business models for sustainable biofuel transport: the potential for intermodal transport. J. Clean. Prod. 2016, 113, 426–437, doi:10.1016/j.jclepro.2015.11.076.
91. Gonzales, D.; Searcy, E. M.; Ekşioğlu, S. D. Cost analysis for high-volume and long-haul transportation of densified biomass feedstock. Transp. Res. Part A Policy Pract. 2013, 49, 48–61, doi:10.1016/j.tra.2013.01.005.
92. Lautala, P.; Pouryousef, H.; Handler, R.; Chartier, S. The Role of Railroads in Multimodal Woody Biomass Transportation in Michigan. In 2012 Joint Rail Conference; American Society of Mechanical Engineers, 2012; pp. 465–473.
93. Akhtari, S.; Sowlati, T.; Day, K. Economic feasibility of utilizing forest biomass in district energy systems – A review. Renew. Sustain. Energy Rev. 2014, 33, 117–127, doi:10.1016/j.rser.2014.01.058.
94. Arabatzis, G.; Petridis, K.; Galatsidas, S.; Ioannou, K. A demand scenario based fuelwood supply chain: A conceptual model. Renew. Sustain. Energy Rev. 2013, 25, 687–697, doi:10.1016/j.rser.2013.05.030.
95. Asikainen, A. Integration of work tasks and supply chains in wood harvesting-cost savings or complex solutions? Int. J. For. Eng. 2004, 15, 11–17.
96. Aydinel, M.; Sowlati, T.; Cerda, X.; Cope, E.; Gerschman, M. Optimization of production allocation and transportation of customer orders for a leading forest products company. Math. Comput. Model. 2008, 48, 1158–1169, doi:10.1016/j.mcm.2007.12.025.
97. Beaudoin, D.; LeBel, L.; Frayret, J.-F. Tactical supply chain planning in the forest products industry through optimization and scenario-based analysis. Can. J. For. Res. 2007, 37, 128–140, doi:doi:10.1139/X06-223.
98. Cambero, C.; Sowlati, T. Assessment and optimization of forest biomass supply chains from economic, social and environmental perspectives – A review of literature. Renew. Sustain. Energy Rev. 2014, 36, 62–73, doi:10.1016/j.rser.2014.04.041.
99. Carlsson, D.; Rönnqvist, M. Supply chain management in forestry—case studies at Södra Cell AB. Eur. J. Oper. Res. 2005, 163, 589–616, doi:10.1016/j.ejor.2004.02.001.
100. Díaz-Yáñez, O.; Mola-Yudego, B.; Anttila, P.; Röser, D.; Asikainen, A. Forest chips for energy in Europe: Current procurement methods and potentials. Renew. Sustain. Energy Rev. 2013, 21, 562–571, doi:10.1016/j.rser.2012.12.016.
101. Dumanli, A.; Gulyurtlu, I.; Yurum, Y. Fuel supply chain analysis of Turkey. Renew. Sustain. Energy Rev. 2007, 11, 2058–2082, doi:10.1016/j.rser.2006.03.011.
102. Eriksson, A.; Eliasson, L.; Jirjis, R. Simulation-based evaluation of supply chains for stump fuel. Int. J. For. Eng. 2014, 25, 23–36, doi:10.1080/14942119.2014.892293.
103. Forsberg, G. Biomass energy transport: analysis of bioenergy transport chains using life cycle inventory method. Biomass and Bioenergy 2000, 19, 17–30.
104. Frayret, J.-M.; D'Amours, S.; Rousseau, A.; Harvey, S.; Gaudreault, J. Agent-based supply-chain planning in the forest products industry. Int. J. Flex. Manuf. Syst. 2007, 19, 358–391, doi:10.1007/s10696-008-9034-z.
105. Freppaz, D.; Minciardi, R.; Robba, M.; Rovatti, M.; Sacile, R.; Taramasso, A. Optimizing forest biomass exploitation for energy supply at a regional level. Biomass and Bioenergy 2004, 26, 15–25, doi:10.1016/S0961-9534(03)00079-5.

106. Frombo, F.; Minciardi, R.; Robba, M.; Rosso, F.; Sacile, R. Planning woody biomass logistics for energy production: A strategic decision model. Biomass and Bioenergy 2009, 33, 372–383, doi:10.1016/j.biombioe.2008.09.008.
107. Gautam, S.; LeBel, L.; Beaudoin, D. Agility capabilities in wood procurement systems: a literature synthesis. Int. J. For. Eng. 2013, 24, 216–232, doi:10.1080/14942119.2013.851367.
108. Gerasimov, Y.; Sokolov, A.; Karjalainen, T. GIS-based decision-support srogram for planning and analyzing short-wood transport in Russia. Croat. J. For. Eng. 2008, 29, 163–175.
109. Gold, S.; Seuring, S. Supply chain and logistics issues of bio-energy production. J. Clean. Prod. 2011, 19, 32–42, doi:10.1016/j.jclepro.2010.08.009.
110. Gronalt, M.; Rauch, P. Designing a regional forest fuel supply network. Biomass and Bioenergy 2007, 31, 393–402, doi:10.1016/j.biombioe.2007.01.007.
111. Gunnarsson, H.; Rönnqvist, M.; Lundgren, J. T. Supply chain modelling of forest fuel. Eur. J. Oper. Res. 2004, 158, 103–123, doi:10.1016/S0377-2217(03)00354-0.
112. Haartveit, E. Y.; Fjeld, D. E. Simulating effects of supply chain configuration on industrial dynamics in the forest sector. Int. J. For. Eng. 2003, 14, 21–30.
113. Kanzian, C.; Kühmaier, M.; Zazgornik, J.; Stampfer, K. Design of forest energy supply networks using multi-objective optimization. Biomass and Bioenergy 2013, 58, 294–302, doi:10.1016/j.biombioe.2013.10.009.
114. Kühmaier, M.; Stampfer, K. Development of a multi-criteria decision support tool for energy wood supply management. Croat. J. For. Eng. 2012, 33, 181–198.
115. Kudakasseril Kurian, J.; Raveendran Nair, G.; Hussain, A.; Vijaya Raghavan, G. S. Feedstocks, logistics and pre-treatment processes for sustainable lignocellulosic biorefineries: A comprehensive review. Renew. Sustain. Energy Rev. 2013, 25, 205–219, doi:10.1016/j.rser.2013.04.019.
116. Lautala, P. T.; Hilliard, M. R.; Webb, E.; Busch, I.; Richard Hess, J.; Roni, M. S.; Hilbert, J.; Handler, R. M.; Bittencourt, R.; Valente, A.; Laitinen, T. Opportunities and Challenges in the Design and Analysis of Biomass Supply Chains. Environ. Manage. 2015, 56, 1397–1415, doi:10.1007/s00267-015-0565-2.
117. Miao, Z.; Shastri, Y.; Grift, T. E.; Hansen, A. C.; Ting, K. C. Lignocellulosic biomass feedstock transportation alternatives, logistics, equipment configurations, and modeling. Biofuels, Bioprod. Biorefining 2012, 6, 351–362.
118. Nivala, M.; Anttila, P.; Laitila, J. A GIS-based comparison of long-distance supply of energy wood for future needs from young forests to the coast of Finland. Int. J. For. Eng. 2015, 26, 185–202.
119. Rantala, J.; Kiljunen, N.; Harstela, P. Effect of Seedling Production and Long-Distance Transportation Planning Strategies on Transportation Costs of a Nursery Company. Int. J. For. Eng. 2003, 14, 65–73.
120. Rauch, P.; Gronalt, M. The terminal location problem in the forest fuels supply network. Int. J. For. Eng. 2010, 21, 32–40.
121. Ravula, P.; Grisso, R.; Cundiff, J. Cotton logistics as a model for a biomass transportation system. Biomass and Bioenergy 2008, 32, 314–325, doi:10.1016/j.biombioe.2007.10.016.
122. Rentizelas, A. A.; Tolis, A. J.; Tatsiopoulos, I. P. Logistics issues of biomass: The storage problem and the multi-biomass supply chain. Renew. Sustain. Energy Rev. 2009, 13, 887–894, doi:10.1016/j.rser.2008.01.003.
123. Selkimäki, M.; Mola-Yudego, B.; Röser, D.; Prinz, R.; Sikanen, L. Present and future trends in pellet markets, raw materials, and supply logistics in Sweden and Finland. Renew. Sustain. Energy Rev. 2010, 14, 3068–3075, doi:10.1016/j.rser.2010.06.009.
124. Shabani, N.; Akhtari, S.; Sowlati, T. Value chain optimization of forest biomass for bioenergy production: A review. Renew. Sustain. Energy Rev. 2013, 23, 299–311, doi:10.1016/j.rser.2013.03.005.
125. Sharma, B.; Ingalls, R. G.; Jones, C. L.; Khanchi, A. Biomass supply chain design and analysis: Basis, overview, modeling, challenges, and future. Renew. Sustain. Energy Rev. 2013.
126. Stone, I. J.; Benjamin, J. G.; Leahy, J. E. Innovation impacts on biomass supply in Maine's logging industry. For. Prod. J. 2011, 61, 579–585.
127. Troncoso, J. J.; Garrido, R. A. Forestry production and logistics planning: an analysis using mixed-integer programming. For. Policy Econ. 2005, 7, 625–633, doi:10.1016/j.forpol.2003.12.002.
128. Uusitalo, J. A framework for CTL method-based wood procurement logistics. Int. J. For. Eng. 2005, 16, 37–46.
129. Valenzuela, J. F.; Balci, H. H.; McDonald, T. A Transportation-scheduling system for managing silvicultural projects. Int. J. For. Eng. 2005, 16, 65–75.

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Peer-reviewed version available at *Forests* **2018**, *9*, 415; doi:10.3390/f9070415

130. Van Belle, J.-F.; Temmerman, M.; Schenkel, Y. Three level procurement of forest residues for power plant. Biomass and Bioenergy 2003, 24, 401–409.
131. van Dyken, S.; Bakken, B. H.; Skjelbred, H. I. Linear mixed-integer models for biomass supply chains with transport, storage and processing. Energy 2010, 35, 1338–1350, doi:10.1016/j.energy.2009.11.017.
132. Windisch, J.; Röser, D.; Sikanen, L.; Routa, J. Reengineering business processes to improve an integrated industrial roundwood and energywood procurement chain. Int. J. For. Eng. 2013, 24, 233–248, doi:10.1080/14942119.2013.857833.
133. Wolfsmayr, U. J.; Rauch, P. The primary forest fuel supply chain: A literature review. Biomass and Bioenergy 2014, 60, 203–221, doi:10.1016/j.biombioe.2013.10.025.
134. Zhang, F.; Johnson, D. M.; Johnson, M. A. Development of a simulation model of biomass supply chain for biofuel production. Renew. Energy 2012, 44, 380–391, doi:10.1016/j.renene.2012.02.006.