

Review

# Annotated Bibliography of the Global Literature on the Secondary Transportation of Raw and Comminuted Forest Products (2000–2015)

Anil Koirala <sup>1,2</sup> , Anil Raj Kizha <sup>1,\*</sup>, Cornelis F. De Hoop <sup>3</sup>, Brian E. Roth <sup>4</sup> , Han-Sup Han <sup>5</sup> , Patrick Hiesl <sup>6</sup> , Dalia Abbas <sup>7</sup> , Shuva Gautam <sup>8</sup> , Srijana Baral <sup>9</sup>, Steve Bick <sup>10</sup> and Kamalakanta Sahoo <sup>11</sup>

<sup>1</sup> School of Forest Resources, University of Maine, Orono, ME 04469, USA; anil.koirala@psu.edu

<sup>2</sup> Department of Agricultural and Biological Engineering, Pennsylvania State University, University Park, PA 16802, USA

<sup>3</sup> Louisiana Forest Products Development Center, Louisiana State University, Baton Rouge, LA 70803, USA; cdehoop@lsu.edu

<sup>4</sup> Cooperative Forestry Research Unit, University of Maine, Orono, ME 04469, USA; brian.roth@maine.edu

<sup>5</sup> Ecological Restoration Institute, Northern Arizona University, Flagstaff, AZ 86011, USA; Han-Sup.Han@nau.edu

<sup>6</sup> Department of Forestry and Environmental Conservation, Clemson University, Clemson, SC 29634, USA; phiesl@clemson.edu

<sup>7</sup> Department of Environmental Science, American University, Washington, DC 20016, USA; saleh@american.edu

<sup>8</sup> College of Natural Resources, University of Wisconsin-Stevens Point, WI 54481, USA; shuva.gautam@uwsp.edu

<sup>9</sup> Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA 30602, USA; Srijana.Baral@uga.edu

<sup>10</sup> Northeast Forest LLC, New York, Thendara, NY 13472, USA; steve@northeastforests.com

<sup>11</sup> Forest Products Laboratory, US Forest Service, Madison, WI 53726, USA; ksahoo@fs.fed.us

\* Correspondence: anil.kizha@maine.edu; Tel.: +1-207-581-2581

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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 and safety, other modes of transportation, and supply chain and 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. 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

## 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 from 2000 to 2015.

## 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 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 literature. 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, 2000–2015.

Journal	Number of Publication
<i>Biomass and Bioenergy</i>	29
<i>Croatian Journal of Forest Engineering</i>	26
<i>International Journal of Forest Engineering (Journal of Forest Engineering before 2001)</i>	25
<i>Renewable and Sustainable Energy Reviews</i>	10
<i>European Journal of Operational Research</i>	3
<i>Forest Policy and Economics</i>	3
<i>Transportation Research: Part A</i>	2

Table 1. Cont.

Journal	Number of Publication
<i>European Journal of Forest Research</i>	2
<i>Canadian Journal of Forest Research</i>	2
<i>Journal of Cleaner Production</i>	2
<i>Western Journal of Applied Forestry</i>	2
<i>European Journal of Forest Engineering</i>	2
Others (Journals with single publication) <sup>1</sup>	23
Total	131

<sup>1</sup> 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 the 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.

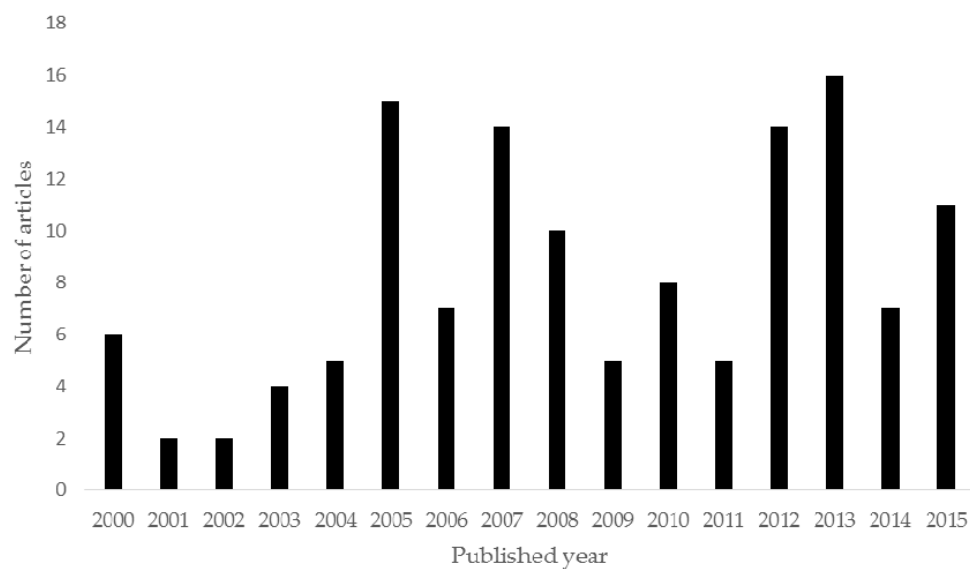
**Table 2.** Distribution of articles related to forest products secondary transportation based on the geographic location of the study.

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

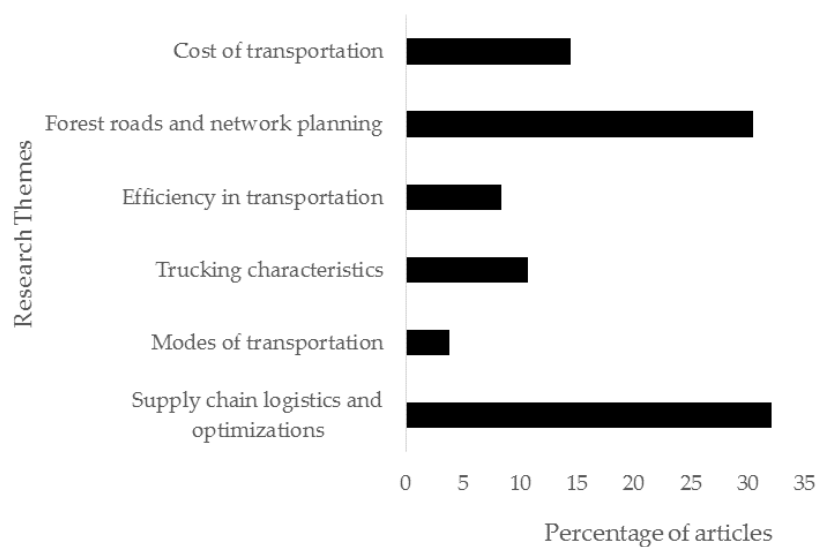
### 3. Results

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 the *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).



**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 18 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 (six articles) were based in the USA, followed by Sweden, Finland, and Austria.

### 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 (Geographic Information Systems/Studies) modeling and linear and 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).

**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. [5]	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. [6]	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. [7]	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. [8]	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. [9]	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.
Jones et al. [10]	USA	4	Analyzed financial effects of changes in diesel and delivered biomass price on transportation.	In case of lowest delivered biomass price (\$32 ODT <sup>-1</sup> ) and diesel price (\$0.05 L <sup>-1</sup> ), the financially viable volume was 28%; while only 6% was available with the highest diesel price (\$1.32 L <sup>-1</sup> ).
Junjinger et al. [11]	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 <sup>-1</sup> had the highest potential supply of woody biomass for the region.
Kurka et al. [12]	UK	3	Allocated biomass feedstock supply to bioenergy plants and estimated transportation costs.	Ten bioenergy plants could potentially produce 49 MW (megawatts) and 129 MW of electrical and thermal energy respectively. Based on this the transportation cost was calculated at ~\$23 million year <sup>-1</sup> .
Möller and Nielsen [13]	Denmark	3	Estimated transportation costs.	Large energy plants with optimal road connections had higher costs of fuel supply.
Paolotti et al. [14]	Italy	6	Compared and evaluated economic feasibility of various transportation modes.	Road and water transport cost ranged between \$19–120 ton <sup>-1</sup> and \$73–88 ton <sup>-1</sup> , respectively.
Ranta and Rinne [15]	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 [16]	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.

Table 3. Cont.

Author(s)	Country	Wood Products *	Research Objective(s)	Major Finding(s) and/or Suggestions
Rauch et al. [17]	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. [18]	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 the cut-to-length (CTL) system. The pulp chips delivered cost from WT was ~\$21 GT <sup>-1</sup> while it was \$27–30 GT <sup>-1</sup> from CTL.
Tahvanainen and Antilla [19]	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 a distance range of 135–165 km, rail transportation provided lower cost.
Yemshanov et al. [20]	Canada	4	Potential amount and financial costs of forest residue biomass supply.	Annual available biomass was about ~19.2–23.3 Tg year <sup>-1</sup> and 16.5–20.0 Tg year <sup>-1</sup> . If residue extraction cost was decreased by 35%, the residues availability would have increased by ~5.5 to 5.7 times at \$45 ODT <sup>-1</sup> supply price and ~1.5 to 1.6 times at the \$60 ODT <sup>-1</sup> supply price.
Yoshioka et al. [21]	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). ODT, oven dry ton; Tg year<sup>-1</sup>, tera-gram per year.

**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. [22]	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 a radius more than 100 m provided fewer maintenance costs.
Akay and Sessions [23]	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 <sup>-1</sup> and \$28 m <sup>-1</sup> , respectively. for two given stations (A and B). Construction cost was the largest component, followed by maintenance and transportation costs.
Akay et al. [24]	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. [25]	USA	Optimized road alignments using the Dijkstra shortest path method and cubic spline function.	The solution with a spline function was inferior compared to the solution without it. Additional investigations using given functions were recommended.
Beck and Sessions [26]	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. [27]	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. [28]	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. [29]	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, the ACO algorithm took less computational time than the latter.
Contreras et al. [30]	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 the case of hilly and rugged terrain.
Demir [31]	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.



Table 4. Cont.

Authors	Countries	Objective(s)	Major Findings and/or Suggestions
Devlin et al. [32]	Ireland	Comparing the existing timber transportation routes from a central depot to other destinations with GIS (Geographic Information System/Studies) generated simulated routes.	The findings showed that the real GPS (Global Positioning System) routes were not as same as the shortest route generated by the Network Analyst Tool (NAT). Nevertheless, after manipulation of NAT the similarity increased to more than 90%.
Ghaffarian and Sobhani [33]	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 <sup>-3</sup> .
Ghajar et al. [34]	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 [35] (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 the 20th century, this theory sustained its development in America. In the last 50 years, there has been swift development in Europe and America, with Asia also offering significant contributions.
Gumus [36]	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, 20% of the roads were in worse condition.
Gumus et al. [37]	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 <sup>-1</sup> .
Hernández-Díaz et al. [38]	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 [39]	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 [40]	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.

Table 4. Cont.

Authors	Countries	Objective(s)	Major Findings and/or Suggestions
Lugo and Gucinski [41]	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 [42]	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 [43]	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. [44]	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. [45]	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 the traffic load examination suggested that the construction of the individual sections of same forest road could be done differently.
Olsson [46]	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 [47]	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 [48]	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. [49]	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. [50]	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%.

Table 4. Cont.

Authors	Countries	Objective(s)	Major Findings and/or Suggestions
Pentek et al. [51]	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 <sup>-1</sup> , respectively.
Péterfalvi et al. [52]	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. [53]	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 the rotation year of selection cutting.
Potočnik et al. [54]	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 [55]	Slovenia	Innovations and trends in forest road construction in Slovenia.	The study showed forest road network in Slovenia was not considered optimal. It was becoming increasingly worn out, and the new transportation technologies demand certain adaptations to be made in the existing technical elements.
Saito et al. [56]	Japan	Examined a model that uses LiDAR data to spontaneously design forest roads on shallow landslides area.	The program that used a LiDAR-based digital terrain model could minimize the earthwork costs while avoiding shallow landslide risk areas.
Sessions and Boston [57]	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. [58]	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 [59]	Australia	Optimized internal forest road location.	A programming procedure integrated with a spatial database and transportation network models were used to assist foresters in determining the optimum location for a forest road.
Trzciński and Kaczmarzyk [60]	Poland	Evaluated the carrying capacity of forest roads with slag and gravel pavements.	The 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 carried out in the USA followed by four in Finland. Apart from trucking features, Theme III also included topics such as GPS tracking systems, options for backhauling empty trucks, and a solution for truck scheduling problems in forest operations.

### 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 one article was published per year (Table 6).

### 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.

### 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. The highest number of studies were carried out in Canada and the US with eight articles each, followed by Sweden (six articles), and Finland and Greece (five articles each).

**Table 5.** Published scientific articles handling various aspects related to forest trucking. The recommendations/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. [61]	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 axle.
Devlin and McDonnell [62]	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 [63]	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. [64]	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 <sup>−1</sup> . The roll-off trucking system was found to be better for short hauling distances because trucking costs significantly increased with small increases in distance.
Laitila and Väättäinen [65]	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. [66]	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. [67]	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 24,000 km of road per year.
Nurnimen and Hainonen [68]	Finland	1	Introduced time-consumption models for general logs transportation in Finland.	The models included explanatory variables like driving distance, number of log decks, log product and load volume. The models showed optimal solution to calculate the cost and profitability of trucking activities.
Palander et al. [69]	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.

Table 5. Cont.

Authors	Countries	Wood Products *	Objectives	Major Finding(s) and/or Suggestions
Picchi and Eliasson [70]	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 <sub>0</sub> 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 [71]	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 [72]	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. [73]	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 [74]	USA	2	Evaluated the transportation of in-wood chipped biomass.	The larger trailers (94 m <sup>3</sup> ) can accommodate 19% more volume than conventional trailers (76 m <sup>3</sup> ). However, it only increased the payload by 10%. If used exclusively, larger trailers can reduce to six loads to transport all chips from the site.

\* Wood products: sawlogs (1); pulpwood (2); wood chips (3); and logging residue (4).

**Table 6.** Published scientific articles handling various aspects related to efficiency in transportation. The recommendations/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. [75]	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. [76]	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. [77]	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. [78]	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 <sup>−1</sup> for residues from the landing and NZ\$29–42 per ODT for those collected from the cutover.
Hedlinger et al. [79]	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. [80]	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 <sup>−3</sup> for average load size of 25 m <sup>3</sup> . The average fuel consumption was 0.77 L km <sup>−1</sup> of diesel.
Jerbi et al. [81]	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. [82]	Czech Republic	Evaluated fuel consumption by timber trucks.	The results showed that the fuel consumption of trucks decreased by 0.5 L m <sup>−3</sup> by the use of new trucks and trailers during study period.
Rackley and Chung [83]	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 [84]	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 (terawatt hour(s)) at a maximum transportation distance of 100 km.
Sikanen et al. [85]	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.

**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 [86]	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 <sup>-3</sup> . This showed the need of maintaining good quality forest roads and eliminating the SIT system.
Asikainen [87]	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 [88]	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. [89]	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. [90]	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).



**Table 8.** Published scientific articles handling various aspects related to forest products supply chains. The recommendations/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. [91]	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 to 50% of the total delivered costs.
Arabatzis et al. [92]	Greece	3, 5	Examined the uncertainty of demand in the biomass supply chain (BSC).	The generated model can be used to minimize the total cost of operation, including fuel wood transportation.
Asikainen [93]	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. [94]	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. [95]	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 [96]	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 [97]	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. [98]	Europe	3	Reviewed the current procurement methods for wood chips.	The main source of wood chips in EU (European Union) 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. [99]	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. [100]	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 [101]	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. [102]	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.

Table 8. Cont.

Authors	Countries	Wood Products *	Objectives	Major Finding(s) and/or Suggestions
Freppaz et al. [103]	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. [104]	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. [105]	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. [106]	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 [107]	Germany	3, 5	Synthesized the information from scientific literatures that covers issues of bioenergy production and BSC.	Most of the articles were from the <i>Biomass and Bioenergy</i> journal, whereas the year with most publications was 2007. The primary focus was on the system design for bioenergy production.
Gronalt and Rauch [108]	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 obtain an optimal supply network, the costs of transporting to terminals and to plants should be considered.
Gunnarsson et al. [109]	Sweden	5	Mathematical model to analyze BSC.	Two modeling approaches were used. The heuristic method was two time faster than “CPLEX 6.5” programming. The presented model could be used for strategic and tactical planning of forest biomass supply chain.
Haartveit and Fjeld [110]	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. [111]	Austria	5	Designed forest energy supply network using multi-objective optimization.	The results showed that to minimize CO <sub>2</sub> emissions, 30% of biomass should be transported in chipped condition from the terminal, 50% in chipped condition directly from the forest, and the remaining should be transported in raw or solid form from forest to plant.
Kühmaier and Stampfer [112]	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. [113]	Canada	3	Reviewed the alternative logistical practices for important ligno-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. [114]	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. [115]	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.

Table 8. Cont.

Authors	Countries	Wood Products *	Objectives	Major Finding(s) and/or Suggestions
Nivala et al. [116]	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 the train-based system.
Rantala et al. [117]	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 from 13% to 37%, depending upon number of nurseries and other factors.
Rauch and Gronalt [118]	Austria	5	Suggested choice of spatial arrangement of terminal facility in the 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%.
Ravula et al. [119]	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. [120]	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. [121]	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. [122]	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 in future studies.
Sharma et al. [123]	USA	3	Reviewed BSC design and modelling.	Approximately 41% of the work related to modelling of BSC was from 2011. Common network design for most of the models had biomass supply sites, collection sites, and processing sites.
Stone et al. [124]	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 the forest products industry.
Troncoso and Garrido [125]	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 [126]	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. [127]	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 problems with 20 worksites took 30 min.
van Belle et al. [128]	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 the least expensive system.
Van Dyken et al. [129]	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.

Table 8. Cont.

Authors	Countries	Wood Products *	Objectives	Major Finding(s) and/or Suggestions
Windisch et al. [130]	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 [131]	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 <sub>2</sub> emissions.
Zhang et al. [132]	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 and timber (1); pulpwood (2); biomass (3); short woods (4); bioenergy and 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 forests 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 [133].

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-value forest products. Much of this is driven by interests in atmospheric carbon issues and in the reduction of hazardous forest fire fuels.

Several governments have supported logistics research on national or regional grounds, substantiating the significance of the topic. For example, the United States has published the Billion-ton Report which focuses on the holistic nature of logistics from a utilization perspective [134]. Even though the results derived from these studies can be helpful in acquiring regional information, they should still be used with caution for local research. The primary constraint in adopting these results lies in the variation of multiple factors, including policies, road conditions, vehicles utilized, biomass yield, transportation distance, and social aspects of the region. To a large extent, on the ground research is also being conducted by the forest products industries; however, this knowledge remains confidential due to the inter-competition within the industry.

An important outcome of analyzing the literature was to assess the possibilities of implementing strategies developed or applied in other regions to any given situation. Such approaches will be crucial to policymakers, natural resource managers, and the forest product industry for the continual improvement of the forest products supply chain. Even though abundant studies have been conducted on the different themes discussed in the article, there was still a dearth of knowledge on the social aspects of logistics [135]. These opinions from the stakeholders, including public, foresters, landowners, loggers, truck drivers, and policymakers, are critical in terms of actual implementation of any research. Another gap in the knowledge base is the lack of connection between the engineering advancements in modern trucks and its application in forestry. There was limited scientific research conducted on the productivity of different trucking systems (based on the products hauled) on distinct road conditions. This aspect is a crucial input for developing accurate logistic models. Moreover, it may not be either practical or cost effective to perform experiments to quantify transport performance. Therefore, discrete-event simulation models for biomass supply logistics can be an inexpensive tool to estimate transport cost and its performance. With the integration of Geographic Information Systems, biomass logistics simulation models can provide more accurate and reliable information regarding transport cost and identify bottlenecks. Other than cost, biomass transportation also affects the environment (i.e., greenhouse gas emissions, forest ecology, wildlife, etc.) and social aspects of society (job creation, fatal accidents, traffic congestion, etc.), which requires further study.

On a regional basis, a 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 the large area of managed timberland, and a developed economy which sustains a high level of research.

The *Biomass and Bioenergy* journal published the 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 was

a significant number of articles in journals like the *Croatian Journal of Forest Engineering* and the *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 directly related to trucking characteristics, however, most of the other articles (dealt with 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 conducted in Finland, there was no research focusing on the overall challenges facing the forest trucking industry as a whole [66]. The cost of transportation is also another major topic that needs to be addressed in the future.

## 5. Conclusions

Regardless of the categorization into different research themes, the main aim of all of 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 with, primary objectives, and key findings related to transportation, were presented in tabular format. This review is expected to help researchers by summarizing prior studies on forest transportation. It will also serve as a repository for the strategies implemented for addressing distinct challenges. This could eventually help in assessing the suitability of these strategies for specific on-the-ground situations. The variabilities and uncertainties for the forest biomass transportation cost were due to the variability of input factors, such as biomass yield, transport distance, road conditions, vehicle utilization, etc. More research is required in the area of the development of integrated logistics models to provide site-specific transportation costs and its performance. The review is also expected to provide insight on the details 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 a critical literature synthesis article.

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## Abbreviations

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	Megapascals

MW	Mega Watts
ODT	Oven Dry Ton
PMH	Productive Machine Hour
Tg year <sup>−1</sup>	Tera-gram per year
TWh	Terawatt Hour(s)
WPS	Wood Procurement System
WT	Whole-tree
US/USA	United States of America

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