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Overview of Global Long-Distance Road Transportation of Industrial Roundwood

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Abstract

The aim of the study was to provide a comprehensive overview of global long-distance road transportation of industrial roundwood. The study focused on the maximum gross vehicle weight (GVW) limits allowed with different timber truck configurations, typical payloads in timber trucking, the road transportation share of the total industrial roundwood long-distance transportation volume, and the average long-distance transportation distances and costs of industrial roundwood. The study was carried out as a questionnaire survey. The questionnaire was sent to timber transportation logistics experts and research scientists in the 30 countries with the largest industrial roundwood removals in Europe, as well as selected major forestry countries in the world (Argentina, Australia, Brazil, Canada, Chile, China, Japan, New Zealand, South Africa, Türkiye, the United States of America and Uruguay) in February 2022, and closed in May 2022. A total of 31 countries took part in the survey. The survey illustrated that timber trucking was the main long-distance transportation method of industrial roundwood in almost every country surveyed. Road transportation averaged 89% of the total industrial roundwood long-distance transportation volume. Timber truck configurations of 4 to 9 axles with GVW limits of around 30 tonnes to over 70 tonnes were most commonly used. The results indicated that higher GVW limits allowed significantly higher payloads in timber trucking, with the lowest payloads at less than 25 tonnes, and the highest payloads more than 45 tonnes. The average road transportation distance with industrial roundwood was 128 km, and the average long-distance transportation cost in timber trucking was €11.1 per tonne of timber transported. In the entire survey material, there was a direct relationship between transportation distance and transportation costs and an inverse relationship between maximum GVW limits and transportation costs. Consequently, in order to reduce transportation costs, it is essential to maximise payloads (within legal limits) and minimise haul distances. Several measures to increase cost- and energy-efficiency, and to reduce greenhouse gas emissions in road transportation logistics, are discussed in the paper. On the basis of the survey, it is recommended that up-to-date statistical data and novel research studies on the long-distance transportation of industrial roundwood be conducted in some countries in the future.

Keywords: timber logistics, timber hauling, timber trucking, gross vehicle weight (GVW) limit, payload, transportation distance, transportation cost, cost efficiency

1. Introduction

Globally, timber trucking plays an essential role in the wood supply chain of forest industries (Shaffer and Stuart 2005, Hamsley et al. 2007, Koirala et al. 2018). Most timber is transported by timber trucks directly from harvesting sites to mills, and partly as initial transportation from the roadside landings of harvesting sites to timber terminals, where it awaits secondary transportation by trucks, railways or waterways to mill customers (sawmills, plywood mills, as well as pulp, paper and paperboard mills). There are estimates on the transportation component of the total costs of the wood supply chain. For instance, Sinnet (2016) estimated that timber transportation represents 35–50% of the total raw material costs in Canada, while McConnell (2020) reported that secondary transportation costs average 36% of the total contract rate in Lousiana, USA. For Central Europe, Hirsch (2011) estimated that transportation accounts for around 30% of the total costs of roundwood, while in New Zealand, Murphy (2003) reported that timber transportation accounts for 20–30% of the total supply costs to the gate of the mill. Correspondingly, in Finland, statistics show that the long-distance transportation of industrial roundwood – sawlogs and pulpwood – was, on average, 9–15% and 20–23% of the total wood supply costs, respectively, and Finnish forest industries used a total of €460 million for timber transportation from harvesting sites to their mill sites in 2021 (Natural Resources Institute Finland 2022, Strandström 2022).

According to the statistics of the Food and Agriculture Organization (FAO) (2021), the global annual removal of industrial roundwood in recent years has been around 2 billion solid cubic metres under bark (sub). While the cutting of industrial roundwood globally is comprehensively recorded, global statistics on the long-distance transportation of roundwood have not been produced by the FAO or any other entity. For example, there is no statistical overview of the shares of different long-distance transportation methods (i.e. road, railways and waterways) in various countries. Similarly, there is no summary of the kinds of timber trucking fleets with maximum gross vehicle weight (GVW) limits that are used to transport industrial roundwood by country. Neither is there readily accessible information on the long-distance transportation distances or costs for industrial roundwood in different countries globally.

There are many variables that influence the transportation of forest products, and these variables (e.g. transportation distance, road type, moisture content of wood raw material, GVW) affect the efficiency and cost of long-distance transportation (Holzleitner et al. 2011, Sosa et al. 2015a, Akay and Demir 2022). It is logical that the higher the GVW limits allowed, the greater payloads can be achieved in timber trucking (Hamsley et al. 2007, Šušnjar et al. 2011, 2019, Trzciński et al. 2018, Tymendorf and Trzciński 2020a). Many studies on timber transportation logistics have illustrated that higher GVW limits and greater payloads mean lower trucking costs in long-distance roundwood transportation (Brown 2008, 2021, Trømborg et al. 2009, Lukason et al. 2011, Conrad 2022). Siry et al. (2006) estimated that the higher GVW limits and payloads could lead directly to potential cost savings, most likely at the level of 9% and possibly reaching as high as 18%.

Moreover, it has been revealed that higher GVW limits and high-capacity transport (HCT) vehicles or longer heavier vehicles (LHVs) in timber trucking reduce the total distance travelled and the total number of timber payloads required, as well as fuel consumption and greenhouse gas (GHG) emissions per volume of timber supplied (McKinnon 2005, Woodrooffe 2016, Asmoarp et al. 2018, Liimatainen et al. 2020, Palander et al. 2021, Kärhä et al. 2023). For instance, Woodrooffe (2016) studied the effect of truck size and weight regulation on trucking efficiency and analysed the benefits associated with improvements (i.e. higher GVW limits) in trucking efficiency in the USA. He presented the benefits associated with a 10% reduction in truck travel distance, which in turn provides fuel savings, a reduction in emissions and a reduction in truck crash frequency, and concluded that a 10% reduction in truck distance travelled for a fixed national freight task would generate annual cost savings of approximately $16 billion USD. There are challenging targets related to the transition to more efficient and sustainable transportation systems in Europe and across the globe. For example, the Transport White Paper set a goal to reduce GHG emissions from the European transportation sector by 60% by 2050 compared to 1990, and by around 20% by 2030 compared to emission levels in 2008 (European Commission 2011).

Consequently, the main aim of this study – conducted by the University of Eastern Finland and a total of 34 other universities, research institutes, organisations and companies – was to provide a comprehensive, global overview of the long-distance road transportation of industrial roundwood. The study aimed to investigate:

- ⇒ maximum gross vehicle weight (GVW) limits allowed on the roads in domestic timber trucking logistics in different countries
- ⇒ road transportation share of the total industrial roundwood long-distance transportation volumes

⇒ typical payloads and average transportation distances and costs of industrial roundwood long-distance transportation in timber trucking globally.

2. Materials and Methods

2.1 Data Collecting

The study was carried out as a questionnaire survey. The questionnaire was sent to timber transportation and logistics experts and research scientists in all European countries that had more than one million m^3 sub of industrial roundwood removals in 2019 (Food and Agriculture Organization 2021). Therefore, the questionnaire was sent to a total of 30 countries in Europe. In addition to European countries, the questionnaire was sent out to selected major forestry countries globally (i.e. Argentina, Australia, Brazil, Canada, Chile, China, Japan, New Zealand, South Africa, Türkiye, the United States of America and Uruguay) in February 2022, and closed in May 2022. A total of 31 countries took part in the survey, including all the aforementioned non-European countries. In 2019, the industrial roundwood removals in all countries that participated in the survey totalled 1.43 billion m^3 sub (Table 1).

2.2 Questionnaire

There were six questions in the questionnaire. First, each participant was asked to report the maximum GVW limits by the number of axles in the timber truck configurations used in domestic industrial roundwood long-distance transportation in their country. In the second question, participants were asked if there were plans to increase the GVW limits in industrial roundwood long-distance road transportation in their countries in the coming years. There were two options: Yes, with an extra question of what kind of plans, and No plans. The third question asked for the share of direct road transportation (i.e. from roadside landings of harvesting sites to the timber yards of mills) within the total industrial roundwood long-distance transportation volume in the participant's country. The fourth question requested information regarding typical payloads (tonnes) associated with commonly used truck configurations in the participant's country. The fifth question asked for the average transportation distance (km) of timber trucking (all by road) in industrial roundwood long-distance transportation in the participant's country. The last question of the questionnaire asked for the average transportation cost of timber trucking (all by road) in industrial roundwood long-distance transportation in the participant's country. The participants could select the most suitable currency (e.g. Euro, US Dollar) and unit (e.g. m^3 sub, m^3 solid over bark (sob), tonne) in reporting their average transportation costs of timber trucking.

Except for question 2, participants were asked to provide the data source(s) associated with their responses. There were three options:

⇒ statistics

⇒ studies

⇒ neither statistics nor studies; my own expert estimation.

Table 1 Industrial roundwood removals in surveyed countries in 2019 (Food and Agriculture Organization 2021)

Country	Industrial roundwood removals hm^3 sub
Argentina	13.8
Australia	32.7
Austria	13.3
Bosnia and Herzegovina	2.9
Brazil	143.0
Bulgaria	3.5
Canada	144.0
Chile	47.6
China	180.2
Croatia	3.4
Czech Republic	26.7
Denmark	1.8
Estonia	6.7
Finland	56.0
France	25.7
Germany	53.4
Italy	7.5
Japan	23.4
Latvia	10.7
New Zealand	36.0
Norway	11.0
Poland	38.9
Romania	10.2
Slovenia	3.5
South Africa	16.3
Spain	15.9
Sweden	68.5
Türkiye	22.7
Ukraine	9.3
United States of America	387.7
Uruguay	13.4

Table 2 Allowable gross vehicle weight (GVW) limits for different timber truck configurations* by number of axles and by country

Country	Number of axles										
	2	3	4	5	6	7	8	9	10	11	12
	Gross vehicle weight (GVW), t										
Argentina [1]	–	–	–	42–45	52.5	60	–	75	–	–	–
Australia [2]	–	–	–	–	42.5–45	–	–	62.5	–	79	82.5
Austria [3]	18	26	32	40/44	–	–	–	–	–	–	–
Bosnia and Herzegovina [4]	–	36	36/40	40	–	–	–	–	–	–	–
Brazil [5]	–	–	–	–	48.5–50	57	–	74	–	–	–
Bulgaria [6]	–	–	–	40	40	–	–	–	–	–	–
Canada [7]	–	–	–	–	52.2	61.3	63.5	63.5 (72.5)	63.5	–	–
Chile [8]	–	–	45	45	45	45	–	–	–	–	–
China [9]	18	27	36	43	49	–	–	–	–	–	–
Croatia [10]	–	26	36	40	–	–	–	–	–	–	–
Czech Republic [11]	18	25	32	48	–	–	–	–	–	–	–
Denmark [12]	–	–	–	–	50	56	60	–	–	–	–
Estonia [13]	–	–	–	40	44	52	–	–	–	–	–
Finland [14]	–	–	–	–	–	60	68	76	74	76	–
France [15]	–	–	–	44/48	44/57	–	–	–	–	–	–
Germany [16]	–	–	–	40/46	–	–	–	–	–	–	–
Italy [17]	–	30	40	44	–	–	–	–	–	–	–
Japan [18]	20	20	27/36	27/36	–	–	–	–	–	–	–
Latvia [19]	–	–	36–42	40–44	52	–	–	–	–	–	–
New Zealand [20]	–	–	–	–	–	42–45	46–58.8	44–61.8	–	–	–
Norway [21]	–	–	–	–	50	60	–	–	–	–	–
Poland [22]	–	–	36	40	40	–	–	–	–	–	–
Romania [23]	–	–	–	40	40	–	–	–	–	–	–
Slovenia [24]	18	25	31–36	40	40	–	–	–	–	–	–
South Africa [25]	–	25.5	40	43.5	49.5	56	67.5	73.5–75	–	–	–
Spain [26]	–	–	36–38	40/42–44	–	–	–	–	–	–	–
Sweden [27]	–	–	–	–	–	64	70	74	–	–	–
Türkiye [28]	18	25	32	40	–	–	–	–	–	–	–
Ukraine [29]	18	25/26	36–40	40	40	–	–	–	–	–	–
United States of America [30]	–	–	–	36.3–41.8	40.9–47.2	–	47.9	–	–	74.5	–
Uruguay [31]	–	–	34.5–37.5	42–45	45–48	57	–	74	–	–	–

* Gray color indicates the most frequently used timber truck configurations of industrial roundwood by country

[1] Argentina: Ministerio de Transporte 2018

[2] Australia: Australian National Vehicle 2016. 6 axles (Semitrailer), 9 axles (B-double), 11 axles (Pocket train) and 12 axles (Road train). Figures presented are average GVW limits for all the states in Australia. Some truck configurations cannot operate in some states (e.g. pocket and road trains in Tasmania)

[3] Austria: Austrian Motor Vehicle Law 2022. 44 tonnes are an exception within the Austrian Motor Vehicle Law for direct transportation of timber from forests to mills up to a maximum distance of 100 km. The last axle of the trailer must be equipped with double wheels

[4] Bosnia and Herzegovina: Pravilnik o ukupnoj masi 2007

The reference year of the data was also requested in questions 3, 5 and 6. In cases where the data source was requested, the answer from Finland was provided by way of example to the respondent in each question.

2.3 Analysing Survey Data

In the survey, the currency units used were converted into Euros, if needed, applying the average exchange rates from February 2022 (Bank of Finland 2022). The conversion from under-bark volume to over-bark volume was carried out using a coefficient of 1.14, and these volumes were converted to (metric) tonnes using a green density of 820 kg m^{-3} (cf. Haavikko et al. 2022). Thus, all tonnes presented in this paper are metric tonnes.

When reporting the road transportation share of the total industrial roundwood long-distance transportation volumes, as well as the average transportation distances and costs of industrial roundwood long-distance transportation in timber trucking, values were calculated by weighting them with the industrial roundwood removals of each survey country in 2019 (Table 1). The responses given to the survey were based on the most frequently reported data and estimations for the year 2021.

The survey variables were analysed using descriptive statistics (percentage shares, average, median, mode and standard deviation (*SD*)). The Spearman correlations (r_s) were calculated between the survey variables of maximum GVW limits, road transportation share and average road transportation distances and costs. A significance level of 0.05 was used.

3. Results

3.1 Gross Vehicle Weight Limits on Roads

There was high variation in the maximum GVW limits in timber trucking logistics in the participating countries (Table 2). The maximum GVW limits were strongly correlated with the number of axles used: for 4-axle timber truck configurations, the mode GVW limit was 36 tonnes (Table 2), while for configurations of 5, 6, 7, 8 and 9 axles, the mode GVW limits were 40, 40, 60, 68 and 74 tonnes, respectively. By participating country, the smallest maximum allowable GVW limits were found in Japan, where the largest GVW limits allowed in timber trucking were below 30 tonnes (Table 2). Correspondingly, in many countries, the maximum GVW limits allowed in

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[5] Brazil: Resolution 211 2021. Resolution 12 provides for the classification of road transportation vehicles, Law 9.503 provides the Brazilian Traffic Code (CTB), and Resolution 211 the necessary requirements for the circulation of cargo vehicles configurations. Vehicle configurations over 45 tonnes require a special transit permit (AET) to operate on public highways. AET is provided for in Article 101 of the CTB and is required for vehicles transporting indivisible payloads, with excess weight and/or dimensions and/or for special vehicles, whether these are loaded or empty. 7-axle 57 tonnes and 9-axle 74 tonnes require a special transit permit

[6] Bulgaria: Ordinance 2001

[7] Canada: Task Force on Vehicle Weights 2019. GVW varies by province, truck configuration, season and whether the truck is operated on a public (on-highway) or a private industrial (off-highway) road system. Canadian log hauling trucks typically have 6–8 axles and, in western Canada, over 50% of these trucks are 8-axle B-trains. In eastern Canada, most trucks are 7-axle truck configurations. Maximum GVW for on-highway travel in Canada varies from 45.5–63.5 tonnes, with 9-axle B-trains operating on approved routes in British Columbia and Ontario permitted up to 72.5 tonnes. Winter weight programs allow for increased GVW when roads are frozen. On-highway GVW are up to 88 tonnes for 10-axle B-trains operating in Alberta, while the same trucks operate at 100 tonnes when on off-highway (private) routes. Road weight restrictions (seasonal or permanent) may reduce GVW by 10–50%

[8] Chile: Chilean Law 2015

[9] China: Outer dimensions 2022

[10] Croatia: Pravilnik o tehničkim uvjetima vozila 2016

[11] Czech Republic: Regulation 2018. 32 tonnes: motor vehicle with four or more axles; 48 tonnes: limit for truck sets

[12] Denmark: Kortlægning af kørsel 2020. 60 tonnes on some sections of road network

[13] Estonia: Majandus- ja kommunikatsiooniministri 2011

[14] Finland: Tieliikennelaki 2018. 8-axle, if at least 65% of the weight of trailer is applied to axles equipped with double wheels, 68 tonnes; 9-axle, if at least 65% of the weight of trailer is applied to axles equipped with double wheels, 76 tonnes; 10-axle 74 tonnes; 11-axle 76 tonnes. Truck configurations of more than 76 tonnes require special permits from the authority (Traficom)

[15] France: Ministére de l'Agriculture 2022. Specific French roundwood regulation that concerns specific roads only (road network defined for each French department (i.e. »district«)). Otherwise, it is 44 tonnes whatever the number of axles (5, 6 or 7). More than 44 tonnes (48 & 57) on specific roads only

[16] Germany: Road traffic act 2022. 40 tonnes for vehicle configurations; 44 tonnes for intermodal transport; 46 tonnes with temporary derogation, e.g. salvage loggings caused by windstorms or bark beetles

[17] Italy: Road Code Art. 62 2022. 5-axle or more 44 tonnes

[18] Japan: Japan Road Association 2021. 36 tonnes on the highway only

[19] Latvia: Regulations of Cabinet of Ministers 2015. 52 tonnes with special permit

[20] New Zealand: Waka Kotahi New Zealand 2021. Common timber truck-trailer configurations allowed up to 44 tonnes as of right, before specific dimension, axle configuration, route and permitting requirements are needed for exceeding the default limit

[21] Norway: In western Norway, truck vehicle length is limited to 19.5 m, and GVW to 50 tonnes

[22] Poland: Regulation of the Minister 2002

[23] Romania: PD 003-11 1997

[24] Slovenia: Zakon o motornih vozilih 2017, Regulations on vehicle parts 2022

[25] South Africa: National Road Traffic Act 1996. Maximum under Road Traffic Act is 56 tonnes, but under the Performance Based Standards Approach, GVW is limited to the sum of the axle limits, subject to road and bridge capacities

[26] Spain: Ministry of Transports, Mobility 2022. 4-axle 36 to 38 tonnes; 5-axle or more 40 tonnes; 5-axle or more with a container 42 to 44 tonnes

[27] Sweden: Trafikförordning 1998

[28] Türkiye: Republic of Türkiye General Directorate of Highways 2022

[29] Ukraine: Resolution 105 amended 2022

[30] United States of America: GVW limits vary by state. In Michigan, GVW is limited to 74.5 tonnes with an 11-axle timber truck configuration

[31] Uruguay: Guía Nacional de Conducción 2013. 6-axle 48 tonnes, 7-axle 57 tonnes; 9-axle 74 tonnes only on certain roads

timber trucking were more than 70 tonnes when hauling timber with truck configurations with eight or more axles, including in Argentina, Australia, Brazil, Canada (the provinces of Alberta, British Columbia and Ontario), Finland, South Africa, Sweden, the US state of Michigan and Uruguay.

However, there were frequent exceptions to the reference maximum GVW limits reported above; for example, higher GVW limits were used on some sections of the road network in Canada, Denmark, France, Japan, Norway and Uruguay. Temporary increases in GVW limits were allowed when there was significant damage caused by windstorms and bark beetles in Central Europe (i.e. Austria, Germany). Furthermore, it was acceptable to transport timber with higher GVW limits in wintertime in Canada and the US state of Minnesota. With a special permit from the relevant authorities, it was also possible to exceed the reference GVW limits in Brazil, Finland and Latvia.

Twenty-six percent of participants reported that there were plans to increase GVW limits for timber trucking in their country. In these countries, the intention was typically to increase the GVW limits to the same level as their neighbouring countries in order to simplify industrial roundwood long-distance transportation logistics between countries, states and provinces.

3.2 Payloads in Timber Trucking

Predictably, a higher GVW limit resulted in a greater payload. For 4-axle timber truck configurations, the industrial roundwood payloads were approximately 20–25 tonnes (Table 3). When utilising timber truck configurations of 5, 6, 7, 8 and 9 axles, the roundwood payloads were typically 22–30, 24–35, 29–38, 38–45 and 47–51 tonnes, respectively. As a consequence, industrial roundwood payloads over 45 tonnes could be achieved in Argentina, Australia, Brazil, Canada, Finland, South Africa, Sweden, the United States of America (Michigan) and Uruguay (Table 3).

Table 3 Typical industrial roundwood payloads with different timber truck configurations by number of axles and country

Country	Number of axles										
	2	3	4	5	6	7	8	9	10	11	12
	Payload, t										
Argentina [1]	–	–	–	30	35–37	45	–	60	–	–	–
Australia [2]	–	–	–	–	24	–	–	39.8	–	49.8	63
Austria [3]	–	–	–	22–24	–	–	–	–	–	–	–
Bosnia and Herzegovina [4]	–	–	–	18.5–22.0	–	–	–	–	–	–	–
Brazil [5]	–	–	–	–	33–35	37	–	50	–	–	–
Bulgaria [6]	–	–	–	26	26	–	–	–	–	–	–
Canada [7]	–	–	–	–	30–35	33–42	43–44	42–51	41	–	–
Chile [8]	–	–	29	29	29	29	–	–	–	–	–
China [9]	–	–	18–23	30	35	–	–	–	–	–	–
Croatia [10]	–	–	–	17–22	–	–	–	–	–	–	–
Czech Republic [11]	–	–	–	22–30	–	–	–	–	–	–	–
Denmark [12]	–	–	–	–	24	33	35	–	–	–	–
Estonia [13]	–	–	–	–	24	32	–	–	–	–	–
Finland [14]	–	–	–	–	–	–	43–46	48–51	–	–	–
France [15]	–	–	–	24–27/26–30	24–27/35–39	–	–	–	–	–	–
Germany [16]	–	–	–	17–22	–	–	–	–	–	–	–
Italy [17]	–	–	–	27–30	–	–	–	–	–	–	–
Japan [18]	10	10	20	20	–	–	–	–	–	–	–
Latvia [19]	–	–	–	–	25	–	–	–	–	–	–
New Zealand [20]	–	–	–	–	–	29	32	35	–	–	–

Norway [21]	–	–	–	–	29	38	–	–	–	–	–
Poland [22]	–	–	–	30–31	30–31	–	–	–	–	–	–
Romania [23]	–	–	–	25	25	–	–	–	–	–	–
Slovenia [24]	–	–	25–28	–	–	–	–	–	–	–	–
South Africa [25]	–	16	27	30	32	38	47.5	51	–	–	–
Spain [26]	–	–	20–22	25	–	–		–	–	–	–
Sweden [27]	–	–		–	–	45.3	47.1	47.3	–	–	–
Türkiye [28]	–	16–22	22–26	32	–	–	–	–	–	–	–
Ukraine [29]	–	–	23–25	23–25	23–25	–	–	–	–	–	–
United States of America [30]	–	–	–	24–29	27–32	28–31	31	–	–	49	–
Uruguay [31]	–	–	–	30	33	38	–	53	–	–	–

[1] Argentina: Study (Gómez et al. 2013)
[2] Australia: Studies (Brown 2008, 2021)
[3] Austria: Own expert estimation based on legal limits
[4] Bosnia and Herzegovina: Own expert estimation
[5] Brazil: Historical data
[6] Bulgaria: Own expert estimation
[7] Canada: Own expert estimation
[8] Chile: Own expert estimation
[9] China: Own expert estimation
[10] Croatia: Study (Šušnjar et al. 2019)
[11] Czech Republic: Historical data
[12] Denmark: Own expert estimation
[13] Estonia: Own expert estimation
[14] Finland: Studies (Palander and Kärhä 2017, Palander et al. 2020, Anttila et al. 2022, Kärhä et al. 2023)
[15] France: Own expert estimation
[16] Germany: Study (AGR 2012)
[17] Italy: Own expert estimation
[18] Japan: Own expert estimation
[19] Latvia: Own expert estimation
[20] New Zealand: Own expert estimation from historical experience
[21] Norway: Own expert estimation
[22] Poland: Studies (Trzciński et al. 2018, Tymendorf and Trzciński 2020a)
[23] Romania: Own expert estimation
[24] Slovenia: Study (Janc 2010)
[25] South Africa: Internal data (Road Transport Management System monthly statistics of payloads)
[26] Spain: Own expert estimation
[27] Sweden: Study (Asmoarp and von Hofsten 2019). Note that the comparatively small increase in payload between 70 and 74 tonnes GVW is due to lack of load space volume.
[28] Türkiye: Studies (Öztürk 2005, Akay 2021)
[29] Ukraine: Own expert estimation
[30] United States of America: Study (Mason et al. 2008) and own expert estimation
[31] Uruguay: Own expert estimation

3.3 Road Transportation Share

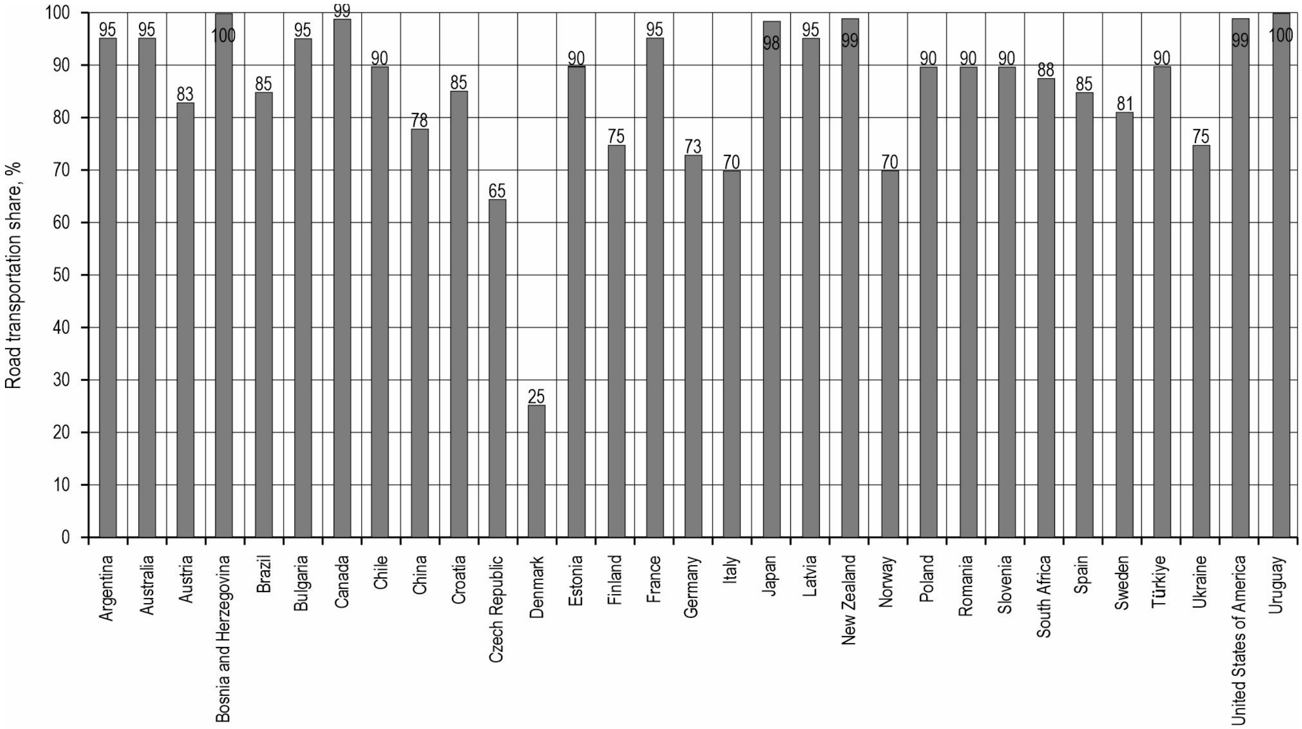
The survey revealed that road transportation was the main long-distance transportation method for industrial roundwood in almost all participating countries (Fig. 1). Only in Denmark was the proportion of road transportation less than 50% of the total volume of industrial roundwood transported over long distances. On the other hand, the road transportation share exceeded 95% in Bosnia and Herzegovina, Canada, Japan, New Zealand, the United States of America and Uruguay (Fig. 1). Overall, road transportation accounted for 89% of the total industrial roundwood moved over long distances (i.e. geometric average, weighted by the industrial roundwood removals of the survey countries in 2019; Table 1). The median road transportation share was 90% and the standard deviation of the proportions reported was 15%.

3.4 Average Transportation Distances and Costs in Timber Trucking

The road transportation geometric average distance for industrial roundwood was 128 km (*SD* = 65 km), and the median road transportation distance was 100 km. In Bulgaria, Poland, Türkiye and Uruguay, the average long-distance transportation distances in timber trucking exceeded 200 km (Fig. 2). In contrast, the shortest average long-distance transportation journeys in the timber trucking of industrial roundwood were in Denmark, Estonia, Japan and Slovenia, where they were less than 60 km long on average (Fig. 2).

The geometric average cost of long-distance industrial roundwood timber trucking was €11.1 per tonne of timber transported (*SD* = €4.6 t^{-1}). The variation range in average costs was €4–24 t^{-1}, depending on the country (Fig. 3). The lowest average road transportation costs were in South America (Argentina and Brazil) and in the Baltic countries (Estonia and Latvia). In contrast, the highest average long-distance transportation costs of industrial roundwood reported in timber trucking were in southern Europe (Bosnia and Herzegovina, Italy, Romania and Spain), eastern Canada and China (Fig. 3).

In the entire survey material, there was a direct relationship between transportation distance and transportation costs, and an inverse relationship between maximum GVW limits and transportation costs. In other words:



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[7] Canada: Own expert estimation
[8] Chile: Own expert estimation
[9] China: Official statistics (Three-Year Action Plan 2020)
[10] Croatia: Study (Šušnjar et al. 2019)
[11] Czech Republic: Study (Maslikiewiczová 2016) and own expert estimation
[12] Denmark: Own expert estimation
[13] Estonia: Own expert estimation
[14] Finland: Official statistics (Strandström 2022)
[15] France: Studies (FCBA study in 2009 and updated in 2015)
[16] Germany: Official statistics (Deutschland, Statistisches Bundesamt 2022) and study (Borcherding 2007)
[17] Italy: Official statistics (Istituto Nazionale di Statistica 2010) and own expert estimation
[18] Japan: Official statistics (Ministry of Agriculture, Forestry and Fisheries 2019)
[19] Latvia: Own expert estimation
[20] New Zealand: Own expert estimation
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[22] Poland: Official statistics (Statistics Poland 2021)
[23] Romania: Own expert estimation
[24] Slovenia: Internal report (Letno poročilo o doseganju 2020) and own expert estimation
[25] South Africa: Own expert estimation
[26] Spain: Own expert estimation
[27] Sweden: Study (Asmoarp et al. 2020)
[28] Türkiye: Own expert estimation
[29] Ukraine: Official statistics (Official website of State Statistics 2022)
[30] United States of America: Own expert estimation
[31] Uruguay: Own expert estimation

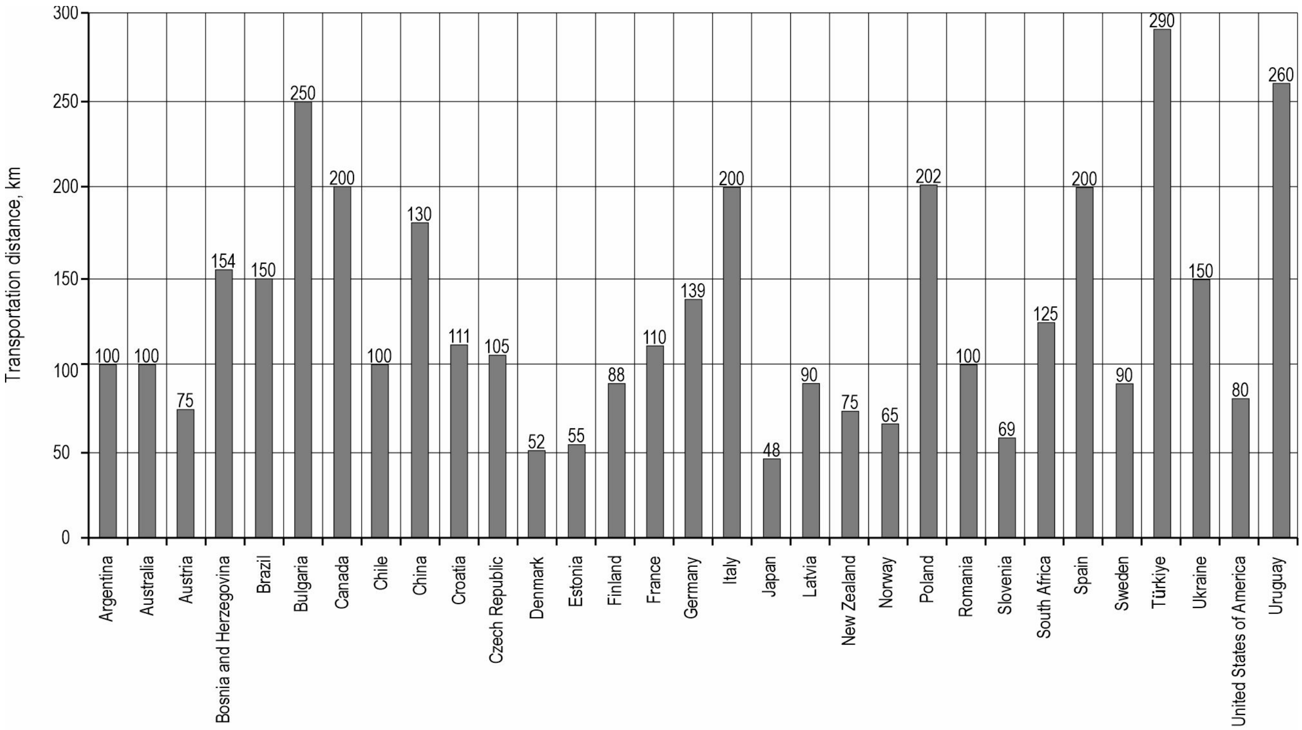
Fig. 1 Road transportation share of the total industrial roundwood long-distance transportation volume by country

- ⇒ there was a significant positive correlation ($r_s = 0.475$; $p < 0.01$) between the average road transportation distance and the transportation cost of industrial roundwood (Figs. 2 and 3)
- ⇒ there was a significant negative correlation ($r_s = –0.473$; $p < 0.01$) between the maximum GVW limits and average road transportation costs (Table 2 and Fig. 3).

4. Discussion

4.1 Survey Data

Extensive study material was collected on the long-distance road transportation of industrial roundwood; a total of 31 countries participated in the survey. In the responding countries, the industrial roundwood removals in 2019 comprised 1.43 billion m^3 sub, which represented around 71% of the total global industrial roundwood removals for 2019 (Food and Agriculture Organization 2021). From the countries with large industrial roundwood removal volumes, only the Russian Federation (203 hm^3 sub in 2019) was excluded from this survey. Among the European countries with annual industrial roundwood removals above 10 million m^3 sub, Belarus (16.0 hm^3 sub) and Portugal (12.7 hm^3 sub) were the only ones that did not take part in the survey. Globally, of the other major forestry countries where industrial roundwood removals were over 10 million m^3 sub in 2019, the survey did not cover Indonesia (83.3 hm^3 sub), India (49.5 hm^3 sub),



[1] Argentina: Own expert estimation
[2] Australia: Own expert estimation
[3] Austria: Studies (Friedl et al. 2004, Kanzian 2004, Kühmaier et al. 2019) and own expert estimation
[4] Bosnia and Herzegovina: Own expert estimation
[5] Brazil: Own expert estimation
[6] Bulgaria: Own expert estimation
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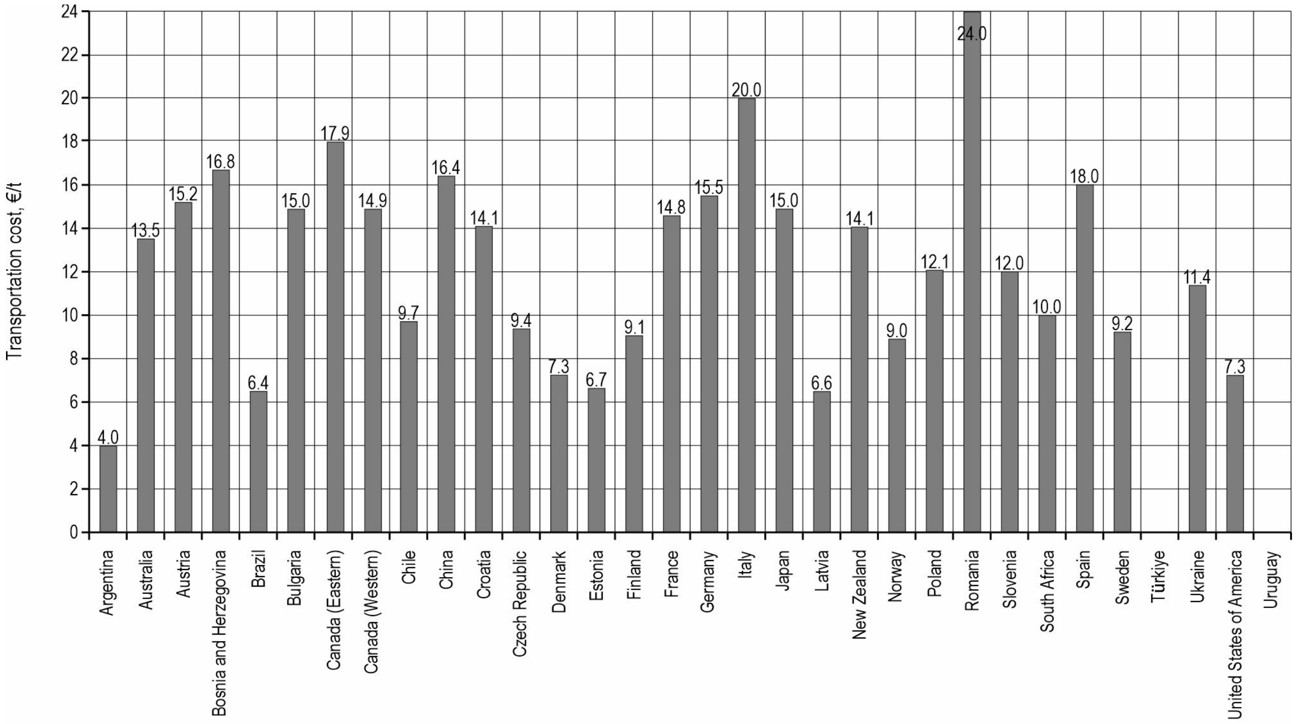
[8] Chile: Own expert estimation
[9] China: Official statistics (China Statistical Yearbook 2019)
[10] Croatia: Study (Šušnjar et al. 2019)
[11] Czech Republic: Historical data
[12] Denmark: Own expert estimation
[13] Estonia: Own expert estimation.
[14] Finland: Official statistics (Strandström 2022)
[15] France: Study (FCBA study in 2015)
[16] Germany: Studies (Wegener et al. 2004, Gößwein et al. 2019)
[17] Italy: Own expert estimation
[18] Japan: Study (Forestry Agency 2019)
[19] Latvia: Own expert estimation
[20] New Zealand: Study (Manley et al. 2015)
[21] Norway: Own expert estimation
[22] Poland: Studies (Sieniawski and Trzciński 2010, Trzciński and Tymendorf 2020, Tymendorf and Trzciński 2020b)
[23] Romania: Own expert estimation
[24] Slovenia: Study (Janc 2010)
[25] South Africa: Internal data
[26] Spain: Own expert estimation
[27] Sweden: Study (Asmoarp et al. 2020)
[28] Türkiye: Study (Akay 2021)
[29] Ukraine: Own expert estimation
[30] United States of America: Studies (Conrad 2021a, TimberMart-South 2022) and own expert estimation
[31] Uruguay: Own expert estimation

Fig. 2 Average road transportation distance in timber trucking by country

Vietnam (37.3 hm^3 sub), Malaysia (14.8 hm^3 sub) and Thailand (14.6 hm^3 sub) within Asia, and Nigeria (10.0 hm^3 sub) within Africa (Food and Agriculture Organization 2021). To summarise, globally, of the countries where the industrial roundwood removals in 2019 were more than 10 hm^3 sub, representatives of 71.9% of them participated in the survey. In addition, several European countries with <10 hm^3 sub industrial roundwood removals (Bosnia and Herzegovina, Bulgaria, Croatia, Denmark, Estonia, Italy, Slovenia and Ukraine; Table 1) brought their valuable contribution to the survey. Hence, the survey material can be regarded as comprehensive and representative, with responses from a diverse collection of countries accounting for the majority of sustainably produced timber.

The survey documented each participating country's maximum GVW limits with commonly used truck configurations in industrial roundwood long-distance transportation, typical payloads, road transportation share of the total industrial roundwood long-distance transportation volume, and average industrial roundwood long-distance transportation distances and costs. Data for these survey questions were produced by top-level long-distance transportation research scientists and operators from each participating country. Thus, the survey can be considered to have covered the most fundamental aspects characterising timber trucking in a global comparison.



[1] Argentina: Own expert estimation
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[3] Austria: Studies (Holzleitner et al. 2011, Santner 2018)
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[5] Brazil: Historical data
[6] Bulgaria: Own expert estimation
[7] Canada: Own expert estimation
[8] Chile: Own expert estimation
[9] China: Own expert estimation
[10] Croatia: Internal data
[11] Czech Republic: Official statistics (Ministry of Agriculture 2021)
[12] Denmark: Own expert estimation
[13] Estonia: Own expert estimation
[14] Finland: Official statistics (Strandström 2022)
[15] France: Own expert estimation
[16] Germany: Study (Becker 2019)
[17] Italy: Own expert estimation
[18] Japan: Study (Forestry Agency 2019)
[19] Latvia: Official statistics (Latvian Official Forest Statistics 2022)
[20] New Zealand: Study (Manley et al. 2015)
[21] Norway: Own expert estimation
[22] Poland: Historical data
[23] Romania: Own expert estimation
[24] Slovenia: Official statistics (Cene gozdarskih storitev 2022) and internal report (Slovenski džavni gozdovi 2021)
[25] South Africa: Historical data and own expert estimation
[26] Spain: Own expert estimation
[27] Sweden: Official statistics (Skogforsk 2021)
[28] Türkiye: No estimation
[29] Ukraine: Internal data and own expert estimation
[30] United States of America: Studies (Conrad 2021a, TimberMart-South 2022) and own expert estimation
[31] Uruguay: No estimation

Fig. 3 Average road transportation cost in timber trucking by country

In most countries, national and state/province road traffic laws, acts and regulations describe and define the maximum GVW limits for domestic road transportation. Hence, for each participant, it was easy to answer the GVW limit question in the survey. As for the other survey questions, the participants had less documented information available. For instance, while there were statistics available on the shares of the different long-distance transportation methods for industrial roundwood in China, Finland, Germany, Italy, Japan, Poland and Ukraine, only China and Finland had official statistics on the industrial roundwood long-distance transportation distances. On the same note, official statistics were available on the road transportation costs of industrial roundwood in the Czech Republic, Finland, Latvia, Slovenia and Sweden. Therefore, many participants of the survey had to look for other information sources for many survey questions, and in some countries, neither statistics, recent studies nor other data were available for the questions. Hence, many participants were only able to answer some survey questions with their own best expert estimation or, in some cases, were unable to answer certain survey questions at all.

The participants reported the average road transportation costs using different currencies and quantities in the survey. All currencies and quantities reported were converted to Euros and tonnes, where necessary. One fresh density coefficient (820 kg m^{-3}) was used in the study. It must be remembered that globally the green densities of different tree species vary considerably. Moreover, it must be acknowledged that, when comparing unit costs based on different currencies, the exchange rates used for the conversion have a substantial effect on the absolute cost levels (cf. Siry et al. 2006). In addition to the exchange rates used, it must be noted that globally all cost components increased very rapidly in 2022, especially in the second half of 2022, i.e. after the data collection period. Consequently, the transportation costs gathered at the beginning of 2022 should be regarded as a snapshot in time. Changes in inflation and the price of oil can lead to rapid changes in these values. However, when costs increased globally during 2022, the relative cost levels between the countries that participated would have remained similar, even if the absolute costs had risen since the data were collected.

4.2 Survey Results

This survey contributed new, previously unavailable data on the long-distance road transportation of industrial roundwood. In particular, it indicated that timber trucking is the most important long-distance transportation method for industrial roundwood volumes in almost every country covered by the study. At a global level, rail and water transportation play a relatively small role in the logistics of industrial roundwood transportation within the country of origin. The survey also showed that the most common timber truck configurations are in the 4- to 9-axle range. In some countries the maximum GVW limits are below 35 tonnes, while in others they are over twice as large. The same was observed for payloads: the smallest payloads were less than 25 tonnes and the heaviest payloads more than 45 tonnes. Hence, the survey confirmed that the GVW limits for timber truck configurations strongly affect the payload that can be legally delivered to mills (Šušnjar et al. 2011, 2019, Owusu-Ababio and Schmitt 2015, Trzciński et al. 2018, Tymendorf and Trzciński 2020a). Therefore, it can be concluded that countries allowing the highest GVW limits create a meaningful competitive advantage for themselves relative to countries with low GVW limits. However, GVW limits can also be related to terrain and road infrastructure in those countries. Hilliness and high curvature of mountainous roads limit truck sizes and subsequently the number of axles, which in turn limits GVWs.

The survey results demonstrated that the lower maximum GVW limits and longer road transportation distances resulted in higher timber transportation costs. These results are consistent with earlier studies (Brown 2008, 2021, Trømborg et al. 2009, Lukason et al. 2011, Conrad 2022). In order to reduce transportation costs, it is necessary to have reasonable GVW limits, maximise legal payload and minimise haul distance. Several measures are presented to develop the cost- and energy-efficiency of road transportation logistics. For example, to improve the cost efficiency of timber trucking businesses, Conrad (2021b) proposed both short-term (e.g. reducing turn-times at harvesting sites and mills, increasing the use of in-woods (platform or truck-based) scales to reduce payload variability) and long-term development measures (e.g. increasing GVWs, investing in new timber truck configurations).

When maximising payloads in timber trucking, it is extremely important that the tare weight is minimised. Brown (2008) pointed out that the only way to legally increase payload is to decrease the tare weight of the vehicle configuration by using the lightest design available. According to Brown (2008), tare weights can be reduced by changing the specifications of the vehicle, i.e. by using lightweight bullbars, completely removing bullbars, or using lightweight material (aluminum or carbon over steel) for trailer construction. Furthermore, increasing log length (≥5 m) would decrease the number of bunks in both the truck and the trailer, thus contributing to tare weight reduction. Besides, Tufts et al. (2005) stated that the tare weight of timber truck configurations should be substantially reduced, for example by replacing steel with aluminum components, while Shaffer and Stuart (2005) emphasised that every kilogram saved in tare weight allows another kilogram of timber to be legally hauled on every payload.

Hamsley et al. (2007) assessed opportunities for improving trucking efficiency by reducing the variability of gross, tare and payload weights. They highlighted that decreased GVW variability was associated with higher payloads, and further suggested that reduced variability across the 221 million tonnes of roundwood annually consumed in the US South could result in cost savings in the range of $100 million. Reduced variablility in log truck axle loading and GVW may also justify higher bridge load ratings for those trucks. In practice, payloads and GVWs in timber truck configurations can be controlled by using onboard weight scales or a crane scale during loading at roadside landings or terminals. Reddish et al. (2011) reported that scaling payload and gross weights would accrue a 4% saving on transportation costs. Moreover, Sosa et al. (2015a), Strandgard et al. (2021) and Acuna et al. (2022) proposed in-forest log drying and calculated that log drying could result in transportation cost savings of more than $2 per tonne of timber transported, CO_2 emission reductions of around 15%, and the number of truck payloads to mills and fleet size of about 20%.

In order to achieve maximum legal and safe payloads, it is essential to apply proper loading techniques (Shaffer and Stuart 2005, Sosa et al. 2015b, Ghaffariyan 2021). Effective loading and unloading techniques also have a meaningful effect on the productivity of timber trucking (Ghaffariyan 2021). Conrad (2021b) stressed that timber transportation logistics and timber receiving operations in mill sites should focus more on reducing turn-times at harvesting sites and mills. Deckard et al. (2003) and Dowling (2010) emphasised that reductions in loading and waiting times can have significant effects on the overall turn-time of timber trucks. Several studies on timber trucking have underlined that the impact of timber truck drivers' driving and work skills and methods are critical to safe and productive timber trucking (Nader 1991, Shaffer and Stuart 2005, Koirala et al. 2017, Smidt et al. 2021). Thus, the additional training and education of timber truck drivers on effective working methods – including loading full and safe payloads – has an important effect on the performance of timber trucking.

A measure to improve the efficiency of road transportation is to put more effort into planning timber trucking logistics. Malladi and Sowlati (2017) highlighted the possibilities of truck routing and scheduling in their review paper. Acuna (2017) reviewed timber transportation optimisation tools and applications in the planning of scheduling and routing timber trucking logistics. Among other things, with better planning, one may achieve shorter average transportation distances and a lower percentage of empty driving. Backhauling should be maximised, especially for longer transportation distances (Murphy 2003, Carlsson and Rönnqvist 2007, Hirsch 2011, Vitale et al. 2021).

Moreover, in many countries the poor condition of the road network makes transportation more difficult and causes additional transportation distances when roads and bridges in poor condition must be bypassed, or payload reduced to levels deemed safe based on the condition of the roads and bridges (Nicholls et al. 2006, Malinen et al. 2014, Visser and Harvey 2021, Kärhä and Rantala 2022). Nicholls et al. (2006) suggested that repairing roads that are in poor condition could result in a significant reduction in total transportation costs.

Finally, increasing GVW limits in timber trucking could reduce timber transportation costs. Conrad (2021b) pointed out that increasing GVW limits is a long-term measure to improve the cost- and energy-efficiency of timber trucking, because it requires legislative changes in the country. In most cases, this calls for additional studies to clarify the effects of higher GVW limits on the road structure, bridges and truck dynamic performance. Some countries (i.e. Canada, the US state of Minnesota) located in cold regions utilise seasonal weight programs to allow substantially higher GVW limits in the wintertime on routes with sufficient bridge capacity. Similarly, some jurisdictions may permit the use of high-efficiency truck configurations (i.e. HCT, LHV) to operate on designated heavy haul corridors. Nonetheless, one fourth of the participants in this survey stated that there are ongoing plans and discussions on increasing the GVW limits in their country.

This study produced a global overview of the long-distance road transportation of industrial roundwood. In the future, it could be interesting to conduct a similar global review on the long-distance transportation of forest energy (i.e. uncomminuted forest biomass and forest chips). It is evident that there have been more studies conducted on the transportation of forest energy during the last ten years than in the case of industrial roundwood road transportation (cf. Koirala et al. 2018, Väätäinen et al. 2021). In addition to road transportation, the global review on industrial roundwood long-distance transportation by railways and waterways could be interesting for the international research community and practitioners in the field of forest industry wood supply logistics.

5. Conclusions

The goal of this study was to compile a global overview of the long-distance road transportation of industrial roundwood. The survey concentrated on the maximum GVW limits for different truck configurations in industrial roundwood long-distance transportation, typical payloads in timber trucking, road transportation share of the total industrial roundwood long-distance transportation volume, as well as the average industrial roundwood long-distance transportation distances and costs. The results of the survey illustrated that relatively low GVW limits with timber truck configurations and long road transportation distances increase transportation costs. Several measures to increase cost- and energy-efficiency and reduce GHG emissions in road transportation logistics were broadly discussed in the paper: maximising payloads in timber trucking; decreasing the tare weight of timber truck configurations; reducing the variability of gross, tare and payload weights; scaling payload and gross weights of timber truck configurations; reducing the overall turn-time of timber truck configurations;

managing log drying; educating timber truck drivers, including in proper loading techniques; intensifying planning of timber truck scheduling and routing; improving poor road infrastructure; and increasing GVW limits.

In the survey, most of the participants complained about the absence of comprehensive official statistics and research studies in their respective countries, and hence some experts could not answer all questions or – alternatively – gave their own best expert estimations as a replacement. On the basis of the survey, it is recommended that up-to-date statistical data and novel research studies on the long-distance transportation of industrial roundwood be conducted in some countries in the future. To summarise, a global-level, standardised data collection method should be established, with a single shared database. This data could be collected, presented and illustrated by the FAO.

Acknowledgments

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