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Loading Round Wood in Forestry Trucks and Forestry Platforms: A Case Study for Romania

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Abstract: Wood, as the main product of the forest, must be brought from the forest to various beneficiaries by various vehicles. The choice of a particular type of vehicle should consider the characteristics of the area from which the wood is loaded, the wood-storage yard, and the availability of a certain model. Besides this, the assortments and quantities of wood to be transported influence, to a large extent, the type of vehicle, which has consequences for transport efficiency and productivity. The aim of the paper was to evaluate the wood-loading process in various types of transport vehicles in terms of time consumption for each working phase and the factors that can affect productivity. The research was carried out in four counties of Romania and addressed the loading of wood in different forestry trucks and platforms, with or without trailers. Transport distances were documented in Brasov County based on 200 transport documents. To evaluate the transport distances in the case of wood intended for contractors, field measurements were carried out in three different are as managed by the private Lignum Forest District (Bacău County). The study of the loading process and productivity estimation at loading was carried out in three locations, namely Bacău County, Sibiu County, and Caraș-Sever in County. To observe whether there are differences in the loading of tree lengths from the harvesting area in various types of vehicles (forestry trucks—ATF—and forestry platforms—APF), research was carried out in Caraș-Sever in County. After processing the data, it was found that in the forests managed by the state and in the forests owned by the local public administrations, the fuelwood reaches mainly locals, and the working wood reaches some wood processing companies. For forestry trucks (ATFs), the loading time was somewhat constant, while for forestry platforms (APF), it varied, with differences observed from the first to the last loading. Following the evaluation of the work-element phases specific to the operation of loading round wood into vehicles, it was found that, sometimes, significant importance is given to the working elements as phases of preparation of the wooden material that can be carried out before the loading process, in order to load it. To eliminate delays in the loading process, it is recommended that logs are prepared before loading, which will increase productivity and it will decrease the risk of accidents for workers who perform these tasks during the loading process.

Keywords: wood transport; round wood; forestry trucks; forest; accessibility; Romania

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1. Introduction

Forests represent a public asset, with multiple benefits for society in their economic, ecological, or even social features [1,2]. In Romania, forests occupy an area of approximately 6.9 million hectares [3], mostly in the mountain regions [4]. The large geomorphologic and climatic diversity of the country's territories leads to a wide variety of composition in terms of tree species from forests. All of these involve different management regimes that are best suited to the various types of forests that, in Romania, have either protection or production functions [3,5].

Since the sustainable utilization of all forest products [6,7] constitutes 4% of Romania's GDP (gross domestic product) [3], the design and construction of forest roads is imperative [4,5], especially since the long-term storage of wood in improper conditions leads to its downgrading and quality reduction [8–11], with financial losses. Unfortunately, the accessibility of the national forest area is below the optimal level [3,4,12,13], so only 65% of Romanian forests are accessible for a hauling distance of 2 km [4,5], which leads to a density index far below the levels of other countries with similar terrain [5] in terms of large distances to logging [4],which has repercussions on the final cost of the wood [6,13–15].

Even though, over time, the means of transport have varied [16,17], currently, wood is transported almost entirely on forest roads (over 90% [5,12,18]). A similar situation is encountered in Finland [9,19,20]. The use of forest roads as the main transport routes is due to several factors [12,21–23]. Forest roads penetrate deeper into the forest [24], which leads to a more uniform opening of the forest [5,10]. In addition, forest roads can accommodate a wide range of transport vehicles safely and at steeper gradients than railways [24,25]. Furthermore, the forest road network ensures access to the forest both for those involved in forest management [5,16,26] and for those who need to reach some isolated areas because they live there [27], work there, or just want to escape from the daily tumult [1]. Forest roads can also provide transportation for other sectors of the economy [1,16].

To fulfill all these functions, forest roads must be designed and built to withstand the traffic of various means of transport [4] in safe and comfortable conditions [1,10,13,16], especially since the length and distribution of the transport network, its structure, and condition can directly influence the activity of forest transport, especially the transport of wood [28,29], especially as the biggest impact on wood costs is its transport [10,11,14,15,22,30].

Wood, as the main product of the forest [22], must be brought from the forest to various beneficiaries [1,3,14,26] with the help of different vehicles [10,24,31,32], which differ a lot, with different brands and models on the market [12,14,22,25]. The choice of a certain type of vehicle depends on several factors related to the nature of the work performed in the forest [18,30], the type of wood that has to be transported [6,10–12,18],the category of the road used, the transport distances from the forest to the beneficiaries [9,22,29],the constructive characteristics of vehicles and their loading capacity [10,18,20,24], and the distribution of loading on axles [12,15,28,31].

Thus, when transporting wood, one can use trucks, with or without a trailer, forestry platforms, with or without a semi-trailer, and container trucks, which are all used for transporting wood over long distances [1,6,9,15,18,24,30,32,33], but also tractors with trailers or even animal-drawn vehicles in the case of short transport distances [1,24]. Transport vehicles intended for round wood are usually equipped with their own loading systems [14,25,32], usually either hydraulic cranes or cable-loading systems [16,18,22,24]. However, some vehicles do not have these features. The choice of a particular type takes into account the characteristics of the area from which the wood is loaded [10], the wood storage where the wood reaches [10,18], and the availability of a certain model [10,30].

For the efficiency of transport, it must be noted that the organization of transport activities, as well as the scheduling of the vehicle fleet, are of particular importance [6,15,17,30,34]. These aspects take into account, above all, the quantities and types of wood to be transported, but also the main characteristics of forest road transport, which take into account the fact that transport activities have a periodic character [13,35] depending on the type of cuts and the restrictions related to the harvesting areas [18]. These differentiate an "empty transport"—to the forest—from a "full transport"—to the beneficiary [6,21,23], but also acknowledge that the harvested wood is temporarily stored in a harvesting area located, in most cases, on a forest road [1,10,18].

The assortments and quantities of wood to be transported influence the choice of the type of transport vehicle to a large extent [6,10,18,33], with consequences on the efficiency and productivity of work [19,30]. Currently, the constructive characteristics of vehicles have been greatly improved and adapted to ensure economical transport [13,14,29]. The availability of vehicles with 2 to 6 axles [22] or even 9 axles [15] ensures a better distribution of the loading on the wheel–road contact surface [12,20,21,31] as well as high loading capacities [26,30,33].

However, the use of transport vehicles at maximum capacity is not always possible due to the regulations regarding circulation on forest roads and public roads related to the allowable gross vehicle weight [9,10,15,19,21,22,24,28]. Thus, in Romania, vehicles transporting wood must be at most2.5 m wide, 4.0 m high, and 18 m long [24,28]. The allowable gross vehicle weight is 38 t [21,29], but several remarks must be made regarding the distribution of the loading on the axles [21,22,28]. The only method for efficient wood transport consists of evaluating all the work elements corresponding to this process [10,14,19]. In this sense, time studies can be used, which, despite the large consumption of time for their application [10,14], can highlight the aspects that can be improved so as to reach better productivity of the transport activity [17],and to reduce interruptions or delays due to cofactors [6,10,14].

The aim of this paper is to evaluate the wood-loading process in various types of transport vehicles in terms of the time consumption for each working element and the factors that can affect productivity. Thus, the following objectives were set:

- To evaluate transport distances when the wood must be transported to locals or different contractors;
- To evaluate the productivity when loading round wood in forestry trucks (ATF) and forestry platforms (APF) either in the harvesting area or from wood storage;
- To analyze the working time and the working elements of wood loading in forestry trucks;
- To highlight the factors that can influence the productivity of wood loading in different vehicles.

2. Materials and Methods

2.1. Study Area

The study area (Figure 1) and the methodology are presented in accordance with the objectives set to achieve the proposed goal. The research to evaluate the transport distances in the case of wood transported to locals was carried out in Brasov County, within the management unit II Codlea, in the forests managed by the Codrii Cetăților Forest District. The specific natural environment of management unit II Codlea is characterized by altitudes between 500 and 1287 m. The terrain has an undulating configuration dominated by moderate, steep, and very steep slopes. From a climatic point of view, the studied region presents a moderate–continental climate, corresponding to the hills, which offers optimal conditions for the development of the beech trees. Field investigations took into account five areas, which differ in terms of the treatment applied, the harvesting volume, and the distance between the harvesting area and the municipality of Codlea because there are locals who need firewood. Thus, in an area, a group shelter system was applied, obtaining logs with a volume of 424 m^3. In the other two areas, salvage cuts were applied, and 51 m^3 beech and 249 m^3 beech and spruce were harvested. In the other two areas, thinning cuts were made, from where volumes of 16 m^3 were harvested for hornbeam and beech and 169 m^3 for hornbeam, sessile oak, and beech. In all cases, the wood harvested and prepared for transport was found in the form of short and long logs.

To evaluate the transport distances of wood intended for contractors, field measurements were carried out in three different are as managed by the private Lignum Forest District (Bacău county) but also in wood storage managed by the same forest district. In two of the three management units, namely Coasta Uzu and Băzăuța, salvage cuts were applied, and in the third one(PlopuLapoș), conservation cuts were applied. In the end, trees of the following species were harvested: fir, spruce, beech, Scots pine, and mountain maple.

The study of the loading process and determinations regarding the productivity of loading were carried out in three locations in the country, namely Bacău County, Sibiu County, and Caraș-Severin County. In Sibiu County, some of the research was carried out in area 13A, in the management unit I Miercurea Sibiului, under the administration of the

Miercurea Sibiului Forest District. Progressive cuts were applied, and a volume of 254.48 m^3 of sessile oak logs was obtained. In Caraș-Severin County, field investigations were carried out in different are as managed by the Bocșa Montană Forest District (management unit IV Smidă) and the Bocșa Română Forest District (management unit IX Dagnecea). The treatments applied in these areas were progressive cuts, and the resulting wood was in the form of short and long logs from various deciduous species.

Figure 1. The study areas.

2.2. Methodology

The determinations regarding the transport distances carried out in Brasov County (Brasov, Romania) involved the study of 200 transport documents specific to each transport because in Romania, all vehicles that transport wood, regardless of assortment and quantity, must be accompanied by such documents, which attest to the provenance and the traceability of the wood. Data were extracted from the transport documents about the transported assortments, the quantity and dimensions of the logs (by species), the type of vehicle, and the loading and unloading points. A Garmin Montana 680 GPS (Garmin Ltd., Lenexa, KS, USA) was utilized to obtain the coordinates for each harvesting area and is used in the next phase for calculating the distances between the loading and unloading points. Based on these, the distances from the harvesting area (loading points) to the various beneficiaries (unloading points) were determined with the help of Google Maps Pro.

Within the Lignum Forest District (Bacău County, Romania), the fieldwork involved the evaluation of transport distances and the evaluation of the loading time when two types of vehicles were used for wood transport—a Mercedes Benz Arctros 3348 (Figure 2a) and a MAN TGS 33.480 (Figure 2b,c), equipped with a hydraulic crane for loading. To estimate the distance, the previously described methodology was applied. To evaluate the timber-loading operation, the entire operation was timed, from the moment the operators mounted the hydraulic crane until they alighted at the end of the process after placing the grapple in the position of transport and cargo entrance. Using a forest caliper and a tape measure, the dimensions (diameter and length)of each log were measured.

It should also be noted that the wood-loading process was studied both when the wood was loaded from the harvesting area (seven transports) (Figure 3) as well as when the wood was loaded from a wood-storage area in the same forest district (three transports) (Figure 4), because the entire amount of harvested wood from the forests managed by the Lignum Forest District (Bacău County, Romania), regardless of the assortment (working wood or firewood), is initially transported to their wood storage, where it is sorted and utilized differently according to market requirements.

Figure 2. Vehicles used for wood transport in Lignum Forest District: (**a**) Mercedes Actros 3348; (**b**) MAN TGS 33.480 with tipper (**c**) MAN TGS 33.480 with semi-trailer for logs.

Figure 3. Loading wood from the harvesting area (Lignum Forest District).

Figure 4. Loading wood from the wood-storage area (Lignum Forest District).

To observe whether there are differences in the loading of long logs from the harvesting area in various types of vehicles, research was carried out in Caraș-Severin County (Romania). They imposed the same working principle applied to the Lignum Forest District, but additional determinations were made regarding the loading times of each load because forestry trucks (ATF) were used, which were equipped with hydraulic cranes (Figure 5), and forestry platforms, (APF) ROMAN, were equipped with a TA-2 a.m. winch (Figure 6). Seven loading processes were analyzed for each type of transport vehicle (forestry trucks —ATF—and forestry platforms—APF).

Figure 5. Forestry truck (ATF) equipped with a hydraulic crane.

Figure 6. Forestry platform (APF) equipped with a TA-2 a.m. winch.

In Sibiu County, field investigations were carried out to evaluate the staggering of work elements when the wood is loaded in forestry trucks. The entire loading operation was filmed, considering the preparation of the transport vehicle as the starting point and the completion of the transport documents as the endpoint. Investigations were made for 11 different forestry trucks, but in one of them—the Man TGS 33.510 (with 6 × 6 traction), equipped with a trailer—the working process was divided into productive time and non-productive time, in agreement with the working elements. The operation of loading logs in forestry trucks equipped with a hydraulic crane and a trailer took into account the following working elements, which were codified to facilitate the centralization and interpretation of data (Figures 7 and 8): (a) vehicle preparation (PA); (b) actuation of the levers that activate the hydraulic arm and the grapple (IPZ);(c) log measurement (CL); (d) transfer of the log to the truck/trailer (TBC); (e) placement/arrangement of log in truck/trailer (AABC); (f) returning the hydraulic arm and grapple from the truck/trailer to the log (RB); (g) other activities (AA); (h) crosscut technical break (PTS); (i)cancelation of loading by placing the hydraulic arm in the transport position (II); (j)alighting from the crane (CM).

Figure 7. Vehicle preparation (PA).

Figure 8. Getting off the crane (CM) after loading.

All the data from the field or the transport documents were centralized and graphically and statistically analyzed using Microsoft Excel (version 2007 Professional). For transport distances, the dimensions of logs, and the duration of each loading, descriptive statistical analyses were used.

3. Results

3.1. Evaluation of Wood Transport Distances in the Case of Locals and Different Contractors

To evaluate the wood transport distances to various beneficiaries, information was taken from 200 transport documents emitted for the wood harvested from the forests managed by the Codrii Cetăților Forest District. The 200 transport documents correspond to five areas, from where 64, 13, 2, 70, and 51 transport documents were issued. The harvested volumes differ in relation to the applied cuts in each area. It should be mentioned that in most cases, the wood transport from the harvesting areas was carried out with low-capacity vehicles, such as vans and tractors with trailers, because the wood was for locals.

From the analysis of the graphs shown in Figure 9 corresponding to the areas with a large number of transport documents, the predominance of deciduous species can be easily observed, especially beech, followed by oak species. However, coniferous species also appear in a much-reduced quantity. Related to the transported volumes, it should also be noted that these were reduced, most of the time being less than 5 m^3 (Figure 9). However, there were some situations in which the transported volumes were between 15 and 25 m^3. A closer look at Figure 9 shows that when larger volumes were transported, they were made up of a single species or a group of species. For example, from one area—covered with group shelter systems—turns of only beech wood were performed, while in another one—covered with salvage cuts—turns of only coniferous wood were performed.

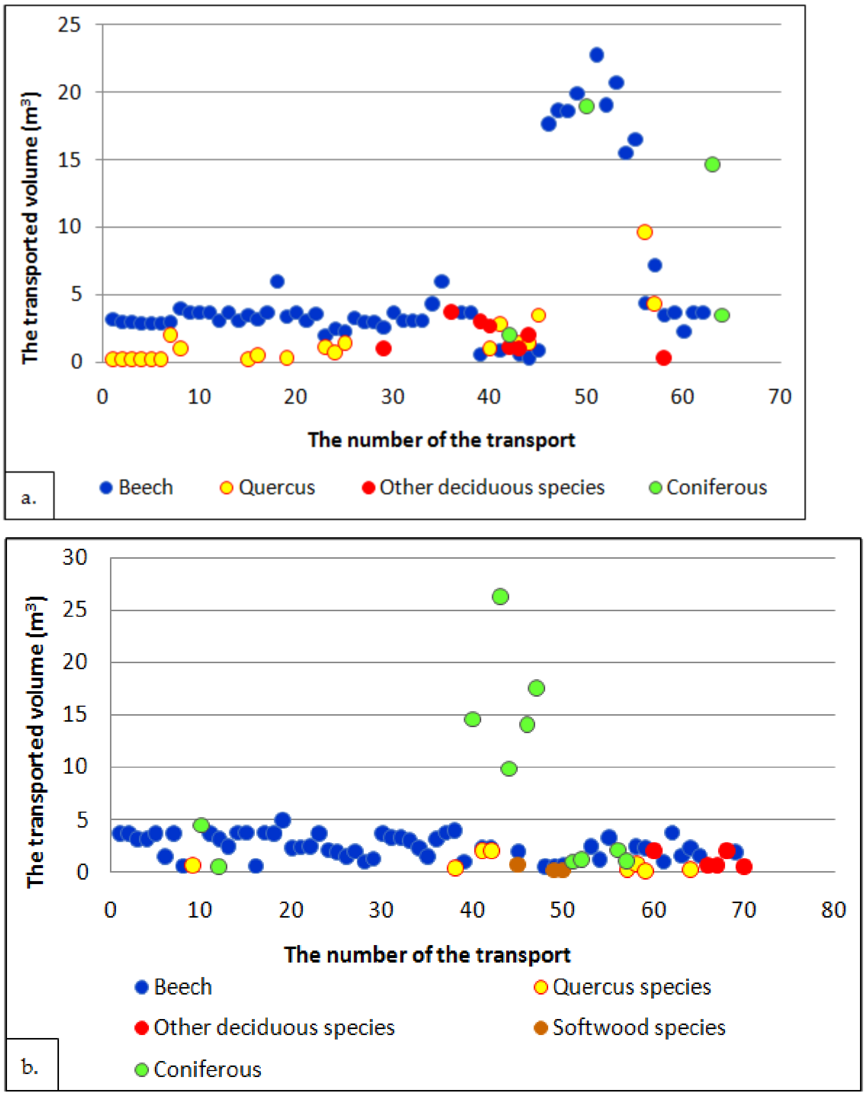

Figure 9. *Cont.*

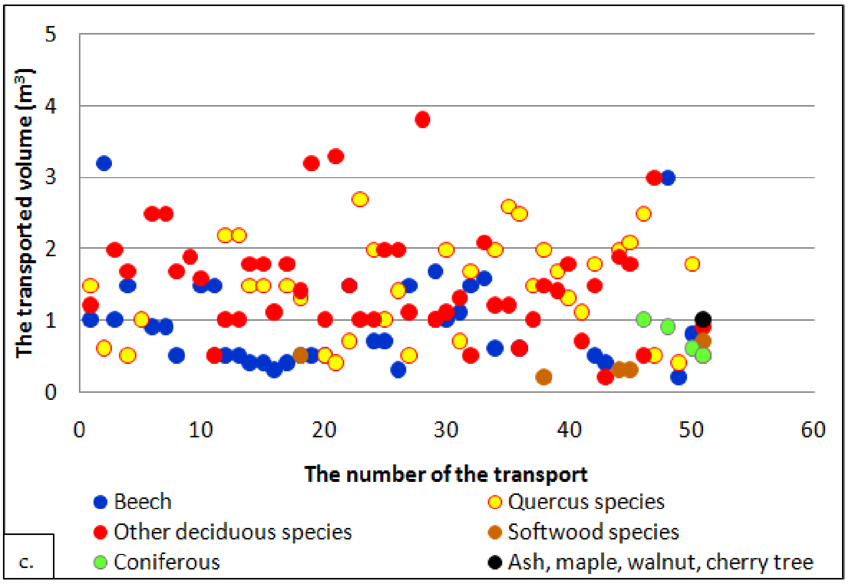

Figure 9. The volumes from each transport carried out in the Codrii Cetăților Forest District: (**a**) compartment 18B; (**b**) compartments 86B, 87, and 88; (**c**) compartment 22A.

When analyzing the volumes transported within the Lignum Forest District from the harvesting area in the wood storage, it can be seen that most of them were smaller than 15 m^3, and they were predominantly pine and beech species (Figure 10). On the other hand, when analyzing the transport documents issued from the wood storage to various beneficiaries, it can be seen that the volumes increased considerably and consisted almost entirely of fir (Figure 10a) from the cellulose round-wood assortment, which was transported to Rădăuți (Suceava County, Romania). Another forest truck, loaded with coniferous (fir and spruce) species, transported wood from the storage area to a processing company located 63 km away(Figure 10b).

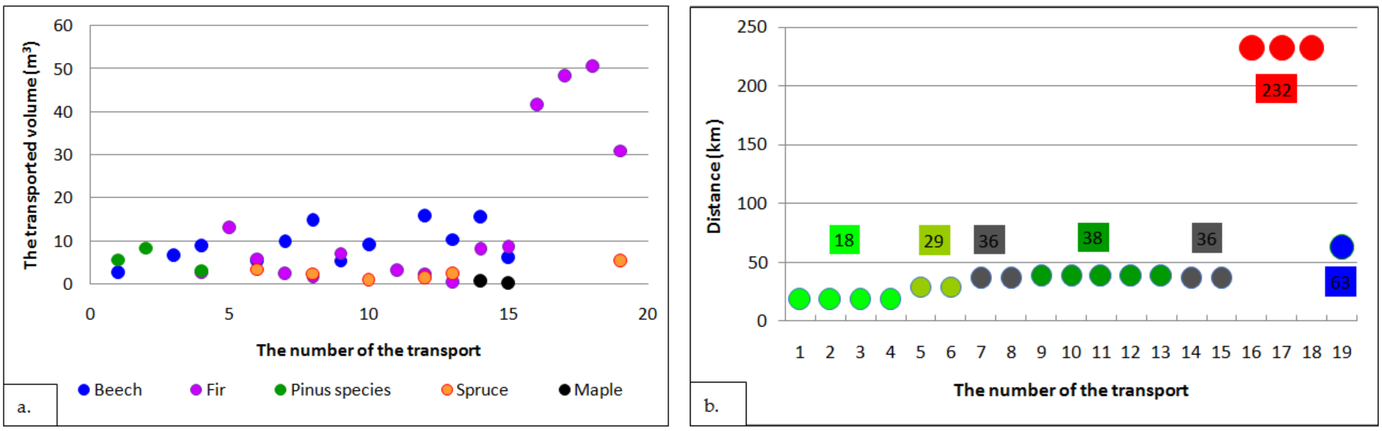

Figure 10. The volumes from each turn carried out inthe Lignum Forest District (**a**) and the transport distances (**b**).

In the Codrii Cetăților Forest District, the situation is completely different (Figure 11), in the sense that the wood was transported over short distances, of 3–16 km, as it is intended to heat the houses of locals.

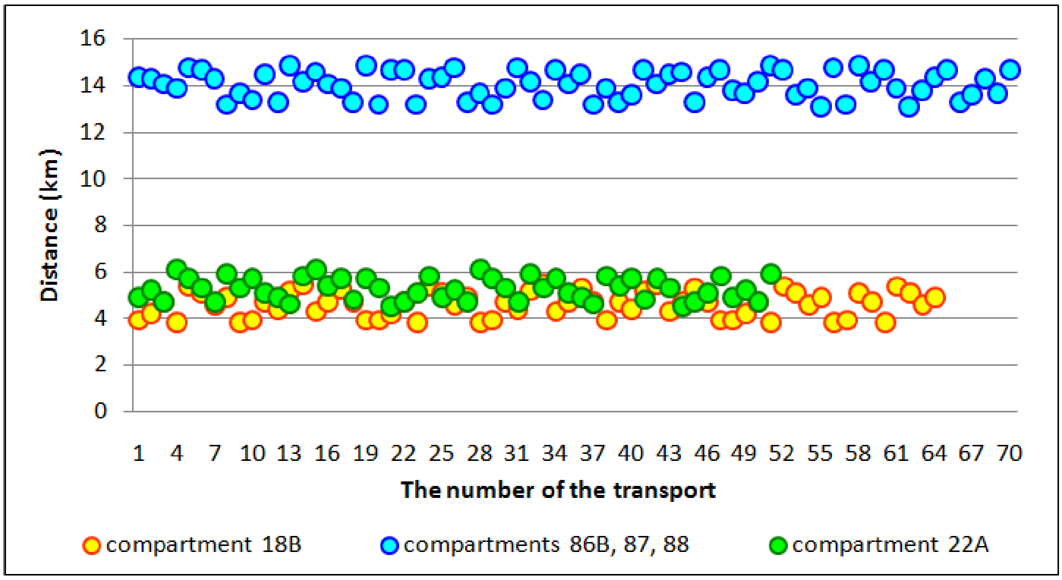

Figure 11. Transport distances specific to the Codrii Cetăților Forestry District.

3.2. Comparisons between the Loaded Volumes and the Loading Times of Wood for Forestry Trucks (ATF) and Forestry Platforms (APF)

The research concerning the comparison of the two most common vehicles for wood transport in Romania, forestry trucks (ATF) and forestry platforms (APF), was carried out in two forest districts in Caraș-Severin County, Romania. In the studied areas, group shelter system cuts were applied, and the harvested wood was in the form of short and long logs. In the forestry trucks (ATF),logs were loaded with diameters between 10 and 44 cm and with lengths varying between 3and7 m, while most of the logs were5 m long. In the forestry platforms (APF), the logs were much longer, 6 to 8 m, with most of them being 7 and 7.5 m long, while the diameters were the same, varying between 10 and 44 cm. These characteristics of logs influenced in a considerable way the productivity and the loading times in the sense that when many logs with small diameters were loaded, the loading operation for forestry trucks was some what more difficult and imposed more time because the operator had to arrange them for optimum loading and to minimize the risk of accidents. The diameters of the logs did not influence the loading operation on forestry platforms because many logs were loaded once. The main factors affecting the productivity in loading wood in the forestry platforms were the diameter and the length of the logs, and in the studied cases the logs had quite big lengths, which positively influenced the loading process.

From the analysis of the graph shown in Figure 12, it can be seen that forestry trucks can carry larger volumes of wood. The volume transported varied between 10 and 30 m^3 in forestry trucks, while for forestry platforms, the volumes varied from 10 to 14 m^3.

Regarding the loading times of each type of vehicle (Figure 13), a very large variation could be found, from 25 to 75 min for forestry trucks (ATF)and from 35 to 50 min for forestry platforms (APF). This very large variation in the case of forestry platforms may be because the loads involve several logs being loaded at the same time with the help of cables, and when forestry platforms are used, additional maneuvers for each individual loading are required.

The analysis of loading times of each loading in forestry trucks (ATF—Figure 14) and forestry platforms (APF—Figure 15) shows clear differences between the two types of vehicles. With forestry trucks (ATF), the time for a single payload was, on average, one minute (Figure 14), while on forestry platforms (APF), the average duration varied between 9 and 12 min (Figure 15). In addition, it was found that the maximum loading time for a single payload was close to 2 min for forestry trucks (ATF—Figure 14), while for forestry platforms (APF), the maximum loading time varied widely, from 11 to 17 min (Figure 15).

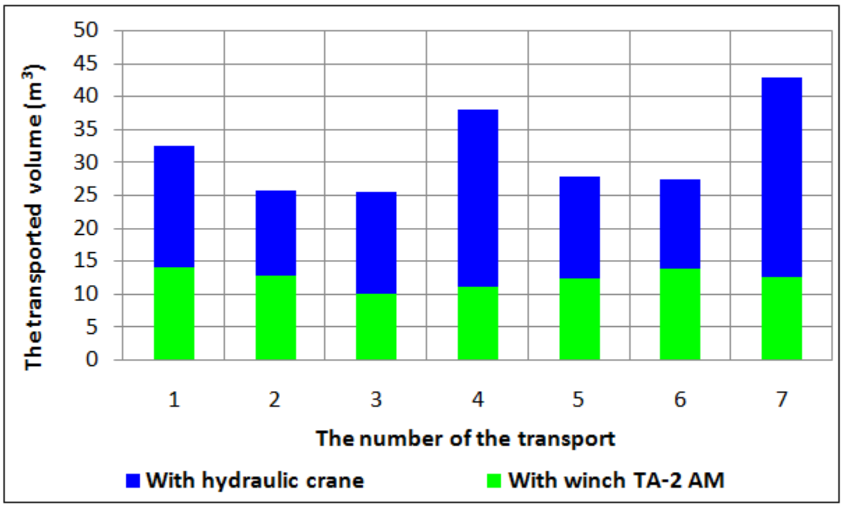

Figure 12. The volumes transported by forestry trucks (ATF) and forestry platforms (ATF) in the Boșca Montană and Bocșa Română forest districts.

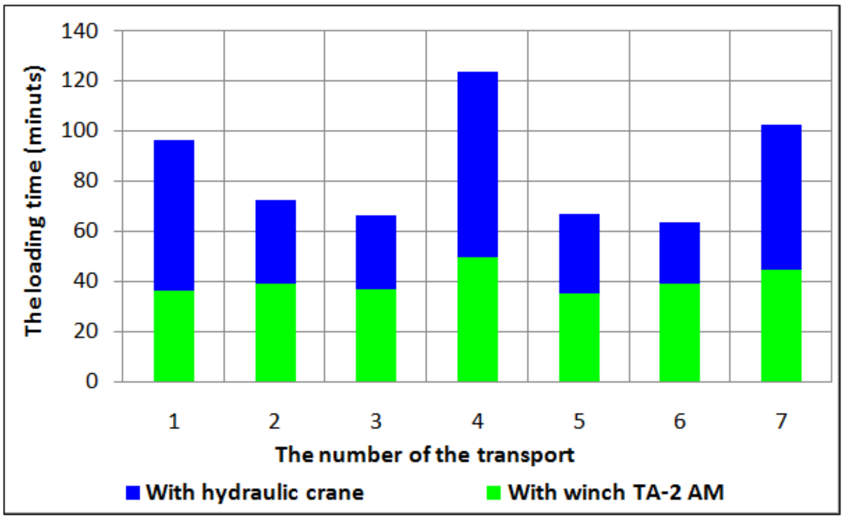

Figure 13. The overall time of loading wood in forestry trucks (ATF) and forestry platforms (APF) in Boșca Montană and Boșca Română forestry districts.

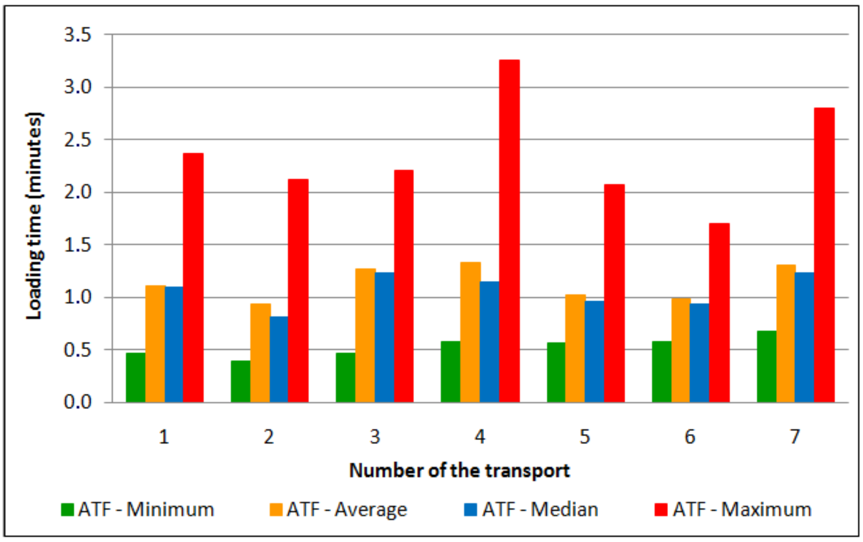

Figure 14. Descriptive statistical indicators for loading times of each payload in forestry trucks (ATF).

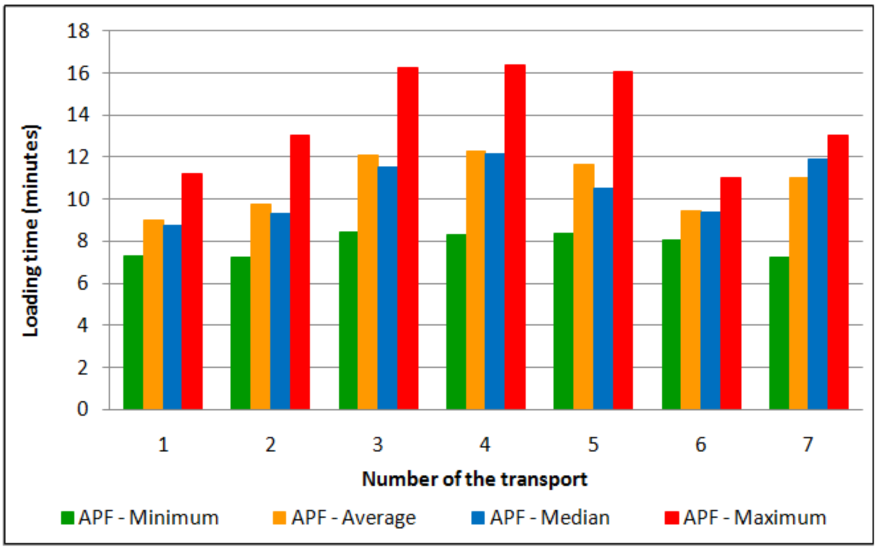

Figure 15. Descriptive statistical indicators for loading times of each payload in forestry platforms (APF).

All these aspects were correlated with the volumes of a payload. Forestry truck(ATF) loading involves fewer logs included in a payload if they have large volumes or more logs if they have reduced volumes. In the present case, the payloads consisted of 1 to 6 logs. Thus, payloads of 0.04–0.47 m^3(minimum) to 0.83–1.16 m^3(maximum) were loaded at the same time, with an average of between 0.33 and 0.67 m^3 (Figure 16).

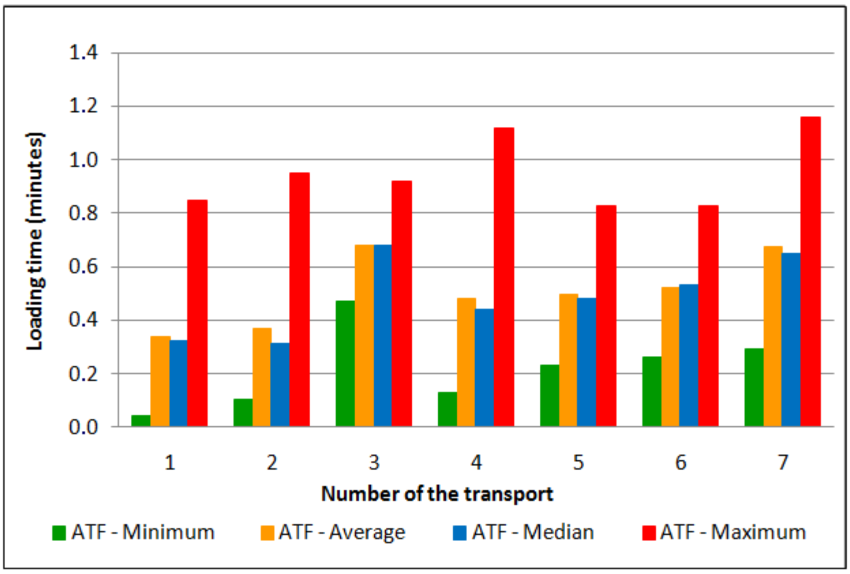

Figure 16. Descriptive statistical indicators regarding the volumes for each payload in the case of forestry trucks (ATF).

By comparison, on forestry platforms (APF), the payloads were made up of 4–10 logs and 8–15 logs, respectively. The large number of logs indicates, to some extent, the volume corresponding to a payload. In this sense, from the analysis of Figure 17, it could be seen that the minimum volumes per payload varied between 1.90 and 2.98 m^3, while the maximum values varied between 3.67 and 5.93 m^3, with an average of 2.73–4.07 m^3.

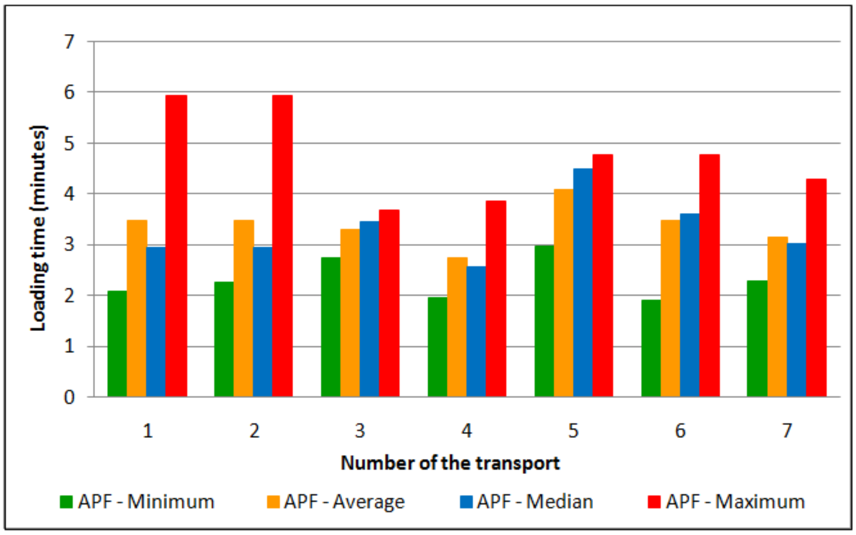

Figure 17. Descriptive statistical indicators regarding the volumes for each pay load in the case of forestry platforms (APF).

3.3. Evaluation of the Loading Operation of Wood in Forestry Trucks

A MAN TGS 33.510 forestry truck (ATF—with 6 × 6 traction) was chosen for the evaluation of the wood-loading operation. The driver had 16 years of experience and had only worked in this field. After measuring the wood, it could be observed that the loaded logs were 5.5–13 m long, with diameters between 20 and 40 cm.

The Figure 18 shows the sequence of working elements specific to the loading of wood into forestry trucks. From the figure the cyclic nature of the operation can be seen, where the following working elements are repeated: actuation of the levers that activate the hydraulic arm and the grapple (IPZ—Figure 19a, encoded with 2); log measurement (CL—Figure 19b, encoded with 3); transfer of the log to the truck/trailer (TBC—Figure 19c, encoded with 4); placement/arrangement of log in truck/trailer (AABC—Figure 19d, encoded with 5); returning the hydraulic arm and grapple from the truck/trailer to the log (RB—Figure 19e, encoded with 6).

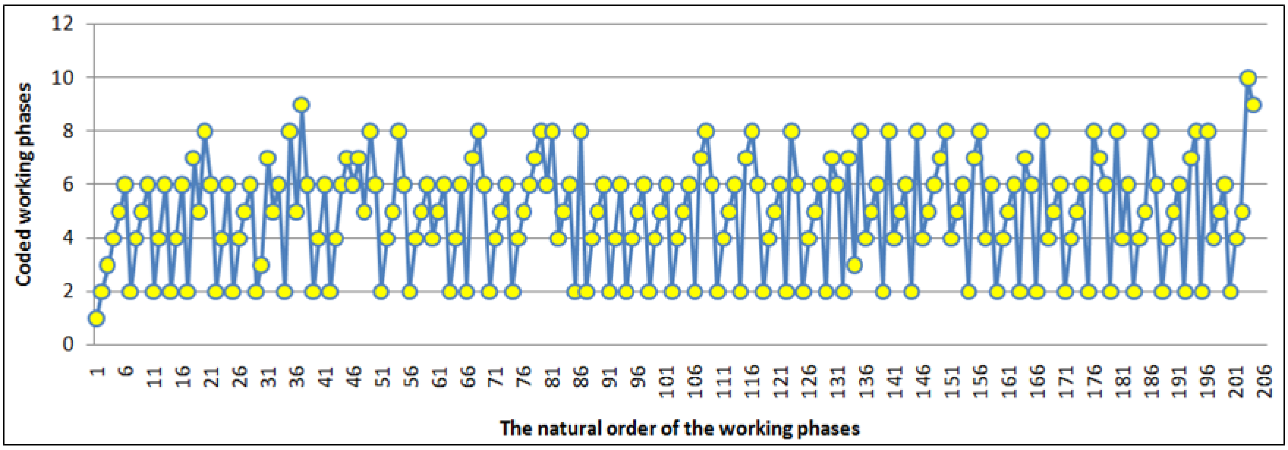

Figure 18. The sequence of working elements from loading wood into a forestry truck: 1—vehicle preparation (PA); 2—actuation of the levers that activate the hydraulic arm and the grapple (IPZ); 3—log measurement (CL); 4—transfer of the log to the truck/trailer (TBC); 5—placement/arrangement of log in truck/trailer (AABC); 6—returning the hydraulic arm and grapple from the truck/trailer to the log (RB); 7—other activities (AA); 8—crosscut technical break (PTS); 9—getting off the crane after loading (CM); 10—cancel the loading by placing the hydraulic arm in the transport position (II).

(**a**) (**b**)

(**c**) (**d**)

(**e**)

Figure 19. The working elements of the loading operation: (**a**) actuation of the levers that activate the hydraulic arm and the grapple (IPZ); (**b**) log measurement (CL); (**c**) transfer of the log to the truck/trailer (TBC); (**d**) placement/arrangement of log in truck/trailer (AABC); (**e**) returning the hydraulic arm and grapple from the truck/trailer to the log (RB).

From Figure 20, it can be seen that the largest share belongs to the technical break imposed by the working method (crosscut technical break PTS—23%), followed by the transfer of the log from the stack to the truck/trailer (TBC—22%) and placing/arranging logs in the truck/trailer (AABC). From the perspective of classifying working elements into productive and non-productive categories of time, it is observed that 64% of the time, productive activities are carried out, while non-productive phases take 36% of the time. From the illustration of the productive activities (Figure 21), the predominance of the working elements that involve the transfer of the logs from the stack to the truck/trailer (TBC)can be seen, followed by the placement/arrangement of the logs in the truck/trailer

(AABC). From the category of non-productive times, the technical break imposed by the need to crosscut the wood hasthe largest share (64%).

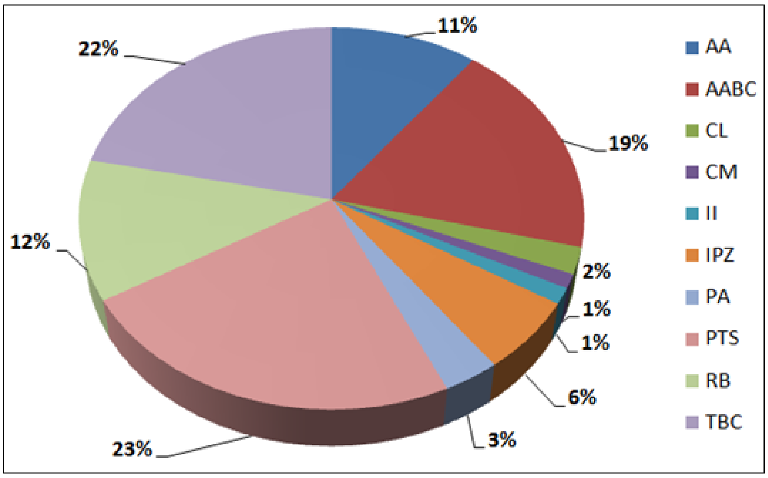

Figure 20. The weight of working elements from the wood loading in the TG 33.510 forestry truck: PA—vehicle preparation; UM—climbing the crane; IPZ—actuation of the levers that activate the hydraulic arm and the grapple; TBC—transfer of the log to the truck/trailer; AABC—placement/arrangement of log in truck/trailer; RB—returning the hydraulic arm and grapple from the truck/trailer to the log; II—cancel the loading by placing the hydraulic arm in the transport position; CM—getting off the crane after loading; CL—log measurement; PTS—crosscut technical break; AA—other activities.

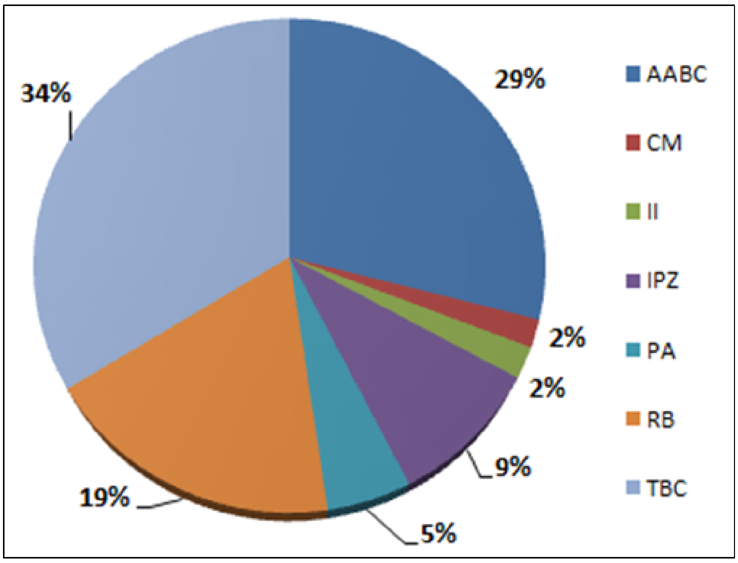

Figure 21. The weight of working elements from the wood loading in the TG 33.510 forestry truck, as productive times: AABC—placement/arrangement of log in truck/trailer; CM—getting off the crane after loading; II—cancel the loading by placing the hydraulic arm in the transport position; IPZ—actuation of the levers that activate the hydraulic arm and the grapple; PA—vehicle preparation; RB—returning the hydraulic arm and grapple from the truck/trailer to the log; TBC—transfer of the log to the truck/trailer.

3.4. The Loading Productivity When Forestry Trucks (ATF) and Forestry Platforms (APF) Are Used

Knowing both the volumes loaded and the corresponding durations for each payload, a series of calculations were made regarding productivity. From the analysis of the two types of vehicles (Figures 22 and 23), it was very easy to see the multitude of tasks corresponding to the loading operation in the forestry trucks (ATF) compared to those specific to the forestry platforms (APF). In addition, it can be found that the productivity when loading wood in forestry trucks (ATF) was predominantly around 0.5 m^3/minute (Figure 22), while in forestry platforms (APF), it varied between 0.2 and 0.6 m^3/minute, approximately (Figure 23). This variation could be due to the specificity of the loading operation for each type of vehicle. The impact of the wood assortments cannot be very large since group shelter system cuts were applied in both forests, resulting in large-sized wood material.

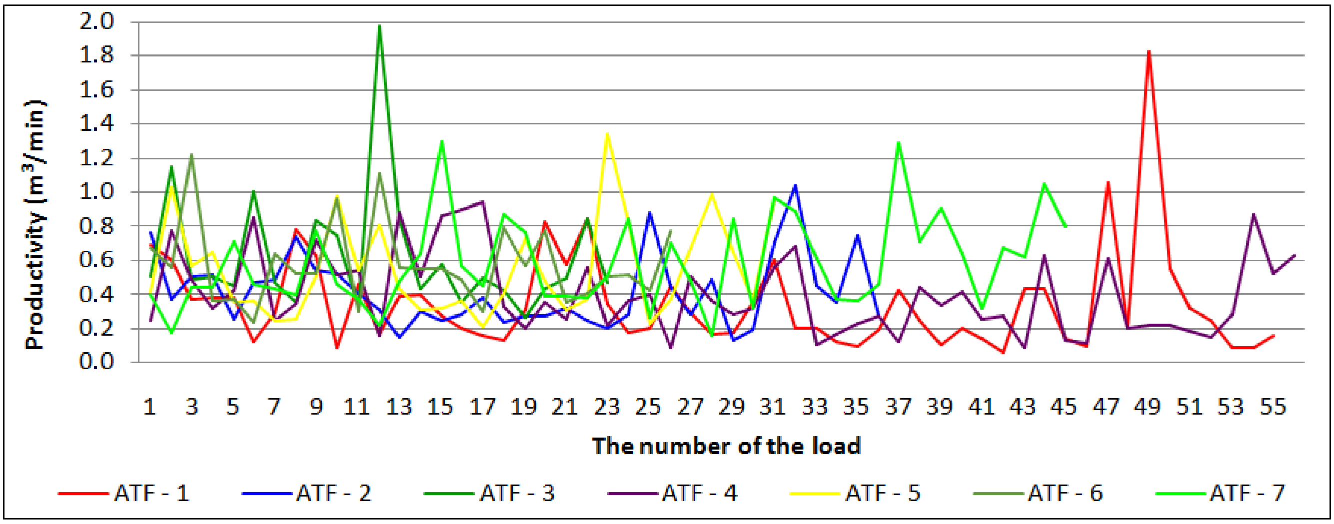

Figure 22. Productivity of wood loading in forestry trucks (ATF).

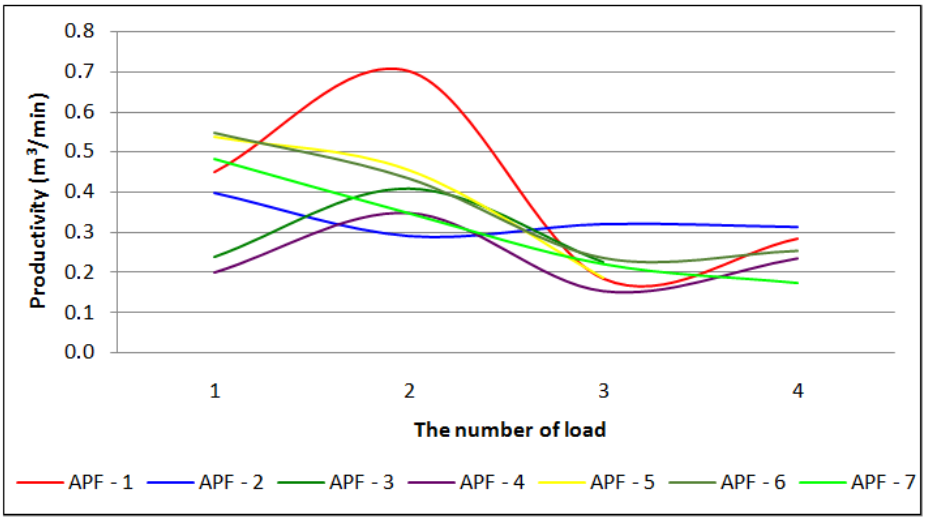

Figure 23. Productivity of wood loading in forestry platforms (APF).

It should also be mentioned that productivity in the case of forestry platforms (APF) decreases more after the first payload, while in the case of forestry trucks (ATF), there are variations in productivity, regardless of the number of payloads.

4. Discussion

Society's need for wood is constantly increasing, which requires efficiency of the transport process [6,9,15,22]. Mainly, the transport of wood from the forest to various beneficiaries is carried out with vehicles of different capacities and types [9,15,22,24,25,33,36], which allow different payloads on the vehicle and different demands on the transport routes [1,31,37]. Thus, roads can determine the use of heavy vehicles through their construction characteristics, the area in which they are built, and also their condition [10,14,15,38]. On the other hand, transport distances and the types of transported wood are directly influenced by the type of cutting, the type of stand, and the way the forest administrator has chosen to sell the wood [1,3,10].

In Romania, in some are as managed by the state through the National Forest Administration [29,39] or forest districts that manage the forests of the local public authorities (UATs), part of the harvested wood is sold to locals near the forested areas [29]. This means that the timber is sold directly from the harvesting area, and buyers must provide their own transport [24]. Because the wood is sold to locals, the volumes are reduced in accordance with the needs of each family and its means of transport [1,29,33]. Thus, when analyzing the volumes of wood transported between the years 2014 and 2019 on a forest road in Romania located near a town, Bitir et al. [39] mention that small-capacity means of transport were used, with loadings of up to 5 m^3, including animal traction. Even if these kinds of transport were numerous, they represented only 2% of the total volume transported during the analyzed period, and it was 90% firewood. In another study by Potocnik and his collaborators [1], which assessed the impact of traffic characteristics on forest roads in Slovenia, it was mentioned that 15% of the wood was transported by tractors with trailers and was intended for domestic needs. A similar situation also appears in the present research, when transport distances vary between 3 and 16 km for wood sold to locals near the Codrii Cetăților Forest District. Conversely, it has been found that when working wood of one or related species was transported, the distances increased, sometimes considerably, which means that the wood was sold to contractors. These situations appeared when the wood was transported to a local contractor 63 km away and when pulpwood was transported 232 km away. In a study by Mușat et al. [36], which analyzed the transport distances of a factory that purchased wood to produce oriented stand boards (OSB), it was mentioned that transport was made with high-capacity vehicles that traveled between 50 and 370 km from the place of loading to the destination. Also related to transport distances, Kärhä and his collaborators [15] mentioned that in some countries such as Bulgaria, Poland, Turkey, and Uruguay transport distances exceeding 200 km, and in others, they are at most 60 km (Denmark, Estonia, Japan, and Slovenia).

In contrast, in the case of private forest districts, as was the case of the Lignum Forest District, the wood was no longer delivered from the harvesting area but from its own wood-storage area. For this reason, when transporting wood from the harvesting area to the storage area, different types of high-capacity transport vehicles were used, some of which were held by the forest district, an aspect also mentioned by Acuna [6], who stated that the wood was transported mainly by trucks either own by the company or rented. In this regard, Mousavi and Naghdi [10] mention that wood from the harvesting area must be transported to a storage area at the right time because otherwise, its quality is reduced due to attacks by insects and fungi [32]. In the storage area, the wood is sorted and delivered to various beneficiaries or to processing companies, which requires large distances and specialized vehicles for transport [10,20,36], such as forestry trucks with or without trailers.

In Romania, although the vehicles used to transport wood are varied, forestry trucks (ATF) and forestry platforms (APF) predominate [18,24,39]. The type of vehicle used to transport wood can greatly influence the loaded volume [15,33]. Thus, the field investigations carried out in the forests managed by the Caraș-Severin Forest District indicated that smaller wood volumes were loaded onto forestry platforms (APF) compared to forestry trucks (ATF).

Due to the loading method, in the two case studies, both the loaded volumes and the loading times varied. For the forestry platforms (APF), the number of logs loaded at the same time influenced the loading time, which was bigger than for forestry trucks (ATF), but the same happened with the volumes of each payload (they were bigger for forestry platforms). According to Kärhä et al. [15], the higher the gross vehicle weight and the loaded volume for transport, the lower the long-distance transport costs for round wood. However, trucks with or without their own loading systems are the main transport vehicle for wood from the forest to beneficiaries in other countries, such as Slovenia [1], Austria [14], Iran [10], Ireland [22], and Australia [30].

The loading method can also influence the volume loaded at the same time. Thus, in the case of forestry platforms (APF), loading involved a variable number of logs that were loaded at the same time by cables [18,24]. In the case of forestry trucks (ATF), the loading was carried out with the help of a hydraulic crane (arm and grapple) mounted on the truck [18,24]. This allows loads to be made of one or more logs (6 in the present case), depending on their diameter and length. In this regard, thick logs are loaded successively, and more thin logs can be loaded at the same time, depending on the aperture of the hydraulic crane. All these aspects also influence the time of loading, which means that in the present situation, the durations were minimal for forestry trucks (ATF) and longer for forestry platforms (APF).

Forestry trucks (ATF),by their loading method, allow an optimal arrangement of the logs in the truck or in the trailer, which reaches the maximum loading capacity of the vehicle [18,24,32]. In addition, with the grapple arm and the hydraulic crane, the logs can be better handled to be placed in the truck/trailer, which leads to the stabilization of the load during transport [24]. On the other hand, with forestry platforms (ATF), the logs must be arranged by workers before the cables are applied [24], which means more time consumption, increased risk of injury [40], and greater physical effort on the part of workers.

Sometimes, loading vehicles without their own loading systems requires another means of loading, such as a front loader or other tractors equipped with loading equipment [10,24]. All these aspects influence the productivity of wood transport by trucks, especially working elements that involve loading and unloading the wood [15]. In addition, vehicle configuration can have a major impact on loading potential through vehicle design and the equipment on it [14,28,30]. In this regard, Sosa and his collaborators [22] mentioned that there is an inverse relationship between the variability of the gross vehicle mass and the average net load, which means that the less the gross weight varies, the higher the net load.

Within the studied working processes, it was found that the productivity when loading wood in forestry trucks (ATF) was somewhat uniform, with 0.5 m^3/loading, while for forestry platforms (APF), it varied a lot, according to the number of loaded payloads (0.2–0.6 m^3/loading). Thus, the volume simultaneously loaded decreased from the first to the last payload, with the first being the most voluminous and made in the shortest time [18,24]. In other words, the equipment of the vehicle played a particularly important role in increasing productivity, along with the type of loaded wood and the experience of the driver [15,41,42].

In addition to the type of vehicle used for transport, the assortment of loaded wood and the place where the loading is carried out can have a special importance on productivity [15]. If the loading was carried out in the harvesting area, the working process was more difficult because, most of the time, the wood was not initially cut to length and measured, which imposed a series of breaks in the working process. When the loading was carried out in wood-storage areas, productivity was higher because the logs were already cut to the dimensions desired by the beneficiary and were placed in stacks. These details ensured that the loading operation was not delayed, thus ensuring greater efficiency.

On the other hand, forestry platforms (APF) required more maneuvering space for loading wood compared to forestry trucks (ATF) [18,24], predominantly for the application of cables and manually arranging logs for loading, which required an important amount of physical effort [40]. A recommendation in this regard is made by Mousavi and Naghdi [10],who recommend that harvesting areas be placed on both sides of the road so that the wood loading is easier and possible from both sides of the truck. In addition, productivity at loading wood onto forestry platforms (APF) could also be improved by placing the logs directly on the ground and not on some crossbars, which could help during the application of cables [18,24]. Thus, with the logs placed directly on the ground, additional activities were required to allow the loading cables to be inserted under the pieces of wood to be loaded, including the manual rolling of the logs, which places a high physical demand on the workers.

From another perspective, productivity in wood transport is also conditioned by delays [6,14] due to factors related to the organization of transport and the reception of wood at the factories [15,43]. Reducing loading and waiting times can have important effects on the duration of a complete transport [44]. In Romania, the average duration of transport is 3.5–4 h [23], which means that it is possible to make two transports per day. This duration includes rest times for drivers, loading and unloading times, and effective moving. Thus, the loading time of a high-capacity vehicle is, on average, one hour per transport, and the unloading time is 0.5 h [23]. In the analyzed vehicles, the loading times varied greatly, mainly in relation to the assortment of loaded wood: between 25 and 75 min for the forestry trucks (ATF) and between 35 and 50 min for the forestry platforms (APF).

As for loaded volumes, they varied in the given situations between 10 and 30 m^3 for forestry trucks (ATF) and between 10 and 14 m^3 for the forestry platforms (APF), with the regulations regarding the allowed payload of 38 tons being respected [21]. This limit varies from country to country [9,10,22,31], depending on the road category, so that in some countries, the allowable gross vehicle weight is less than 35 tons, and in others, it reaches double that value [15].

The analysis of the case study carried out for the MAN TGS 33.510 forestry truck with the aim of highlighting the working elements specific to wood loading indicated the predominance of productive activities, of which the most common involved the effective loading of logs. This can be attributed to the fact that the number of loaded logs was large, and the loading of the vehicle involved repetitive activities through which the logs were brought into the truck/trailer and the hydraulic arm was brought back from the truck/trailer to the logs that must be loaded. On the other hand, non-productive times are greatly influenced by the working elements during which the logs were cut to lengths imposed by the vehicle and/or by the beneficiary. In addition, each transport must be accompanied by a series of transport documents certifying both the origin of the material, the species, and the type of material, in the qualitative sense (round wood, working wood, or firewood) and quantitative (dimensions and volume). For the drawing up of the transport documents, which accompany the transport from the place of loading to the place of unloading, the dimensions of the logs are needed. As they are not prepared prior to the transport and are cut to length just before being loaded, each log is measured, and the data are entered into a specific program. All these working elements, considered unproductive for loading, imposed delays in the working process. In addition, carrying out these activities at the time of loading involves a very high degree of risk for the workers [40], as they move among the logs and close to the vehicle when loading the wood.

5. Conclusions

From forests managed by the state and from forests owned by the local public administrations, firewood goes mainly to locals, and working wood goes to some wood processing companies.

Transport with low volumes of wood from several species involves short distances from the loading point (harvesting areas or wood-storage areas)to the first or the only unloading point.

The type of vehicle used to transport wood can greatly influence the volume of loaded wood.

For forestry platforms (APF), the loading operation is made with cables, which allows the loading of several pieces at the same time, but this leads to longer durations related to each payload and to a lower volume loaded in the vehicle.

For forestry trucks (ATF), the loading capacity can be achieved relatively easily by loading logs one by one, and they can be properly placed to ensure stability and efficiency during transport.

For forestry trucks (ATF), the loading time of a single payload is somewhat constant, while for forestry platforms (APF), it varies a lot, with differences observed from the first to the last payload.

Forestry platforms (APF) require more available space for loading wood compared to forestry trucks (ATF).

The working process of loading forestry platforms is more laborious and requires more physical labor and a larger number of workers compared to forestry trucks, where loading is made only by the operator of the vehicle by carrying out a procedure that involves attention and concentration but not physical effort.

Loading wood from storage areas is more efficient than loading wood from harvesting areas, where the logs must be measured and sometimes cut to length.

Based on the obtained results, the use of forestry trucks is recommended when the wood must be transported overlong distances because the loaded volume is greater than in the cases of forestry platforms. To eliminate delays in the loading operation, it is recommended that the logs are prepared before loading (crosscuts and measuring the logs), which will increase productivity and it will decrease the risk of accidents for workers who perform these tasks during the loading process.

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