Influence of Prescribed Method of Roundwood Scaling on Forwarder Efficiency

Andreja Đuka, Tomislav Poršinsky, Tibor Pentek, Mario Šporčić
Department of Forest Engineering, Forestry Faculty of Zagreb University
aduka@sumfak.hr, porsinsky@sumfak.hr, pentek@sumfak.hr, sporcic@sumfak.hr

Abstract: In timber trade in Croatian forestry, roundwood is usually dispatched by volume in accordance with the standard (EN 1309-2:2006) and there is a loss of volume due to the prescribed ways of measurement: 1) length, 2) mean diameter, 3) deduction of double bark thickness and 4) the expression for estimating the volume of roundwood. Impact analysis of transported load (actual timber volume, timber mass, declared – reduced volume due to the prescribed measuring) on Valmet 840.2 forwarder productivity in relation to the transportation distance was determined using a multi-criteria productivity forwarder model (Stankić et al. 2012).

The study was based on five different loads of oak (*Quercus robur* L.) in a forwarder, which differed with respect to: 1) the type of loaded assortments (logs, firewood, mixed load), 2) amount of loaded timber (full height of loading area, <2/3 height of loading area, <1/3 height of loading area of the vehicle). In addition to weighing aimed at determining the load mass, measurement of timber in the load was also performed including as follows: 1) measurement of length to the nearest centimeter, and 2) measurement of diameters on the thicker and thinner end and in the middle of the roundwood. The actual (gross) volume of each log was calculated using Reicke-Newton's formula, and the net volume of timber was calculated in accordance with the standard (EN 1309-2:2006) using Huber's formula.

Differences in forwarder productivity, expressed in terms of timber gross volume and load mass, are negligible (<1%) due to the effects of wood density 995.8 ± 2.5 kg/m^3.

Forwarder productivity, expressed in terms of timber net volume, is lower in the range from 3.5% to 24.3% when compared to the actual timber volume. The obtained results depend on the type and size of loaded assortments and quantity of loaded timber.

Obviously, the transport of timber and trade of timber are two different concepts from the standpoint of timber volume or load volume, with a different impact on the participants in the timber supply chain.

Keywords: prescribed measurement of roundwood, mass, volume, forwarder

1. Introduction

The task of timber transport is to move trees or tree parts from one place to another, and it involves all kinds of timber removal from the forest (stump) to the end user. The basic factors of timber transport are the load (timber) – means of transport (usually vehicles) – transport infrastructure network, all of them significantly interconnected. After tree felling (and) processing, timber (or wood assortments – depending on the processing method) is scattered on a large area, so first it has to be bunched and extracted off road to the roadside landing, and then transported to the primary processing plant. Analyzing timber transport through history, Greulich (2002) concludes that, regardless of the authors, all theories of timber transport are based on two interdependent subphases (Fig. 1):

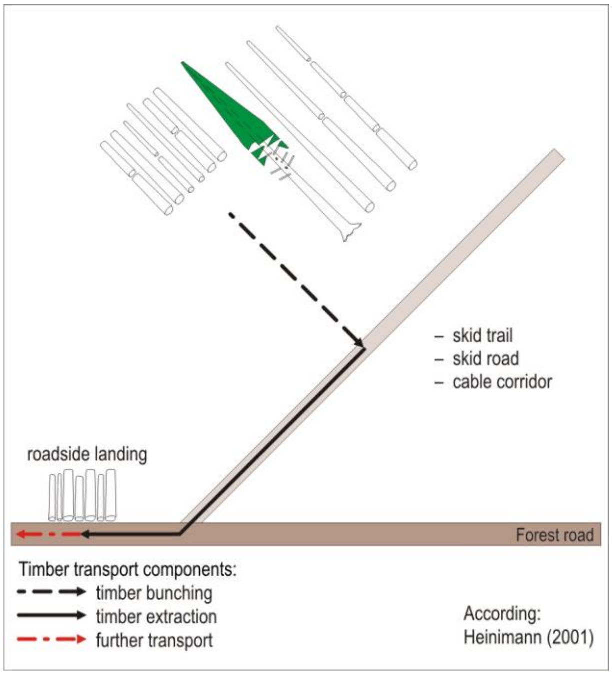

Fig. 1 Timber transport

- ⇒ primary timber transport – timber extraction, off road and on secondary (skid roads and skid trails, cable corridors) forest communications
- ⇒ secondary timber transport – long-distance timber transport by built transport systems (timber transport on public and forest roads or railways), or waterways.

Considering the fact that timber transport is of cyclic nature, the basic factors affecting its efficiency are the distance and timber volume transported in a cycle (Conway 1976, MacDonald 1999, Silversides and Sundberg 1989, Staff and Wiksten 1984).

When transporting roundwood, timber can be measured by volume and mass, respectively. Measurement of timber by mass is affected by the current wood moisture, and it is usually used in dispatching firewood.

Determination of the quantity of roundwood by volume (EN 1309-2:2006) is based on the measurement of dimensions (diameter and length) of individual pieces (m^3), i.e. on the measurement of dimensions (length, height and width) of wood stack. The volume of roundwood that corresponds to the volume of the stack (loose m^3) can be obtained by the application of the appropriate conversion factor. Conversion is not reliable due to differences in the stack type, position of logs in the stack, share of the first logs, mean diameters, sweep and thickening, bark and wood species (Fonseca 2005).

In Croatian forestry, the prescribed method of measuring individual pieces of roundwood (EN 1309-2:2006) is based on the measurement of:

- ⇒ the shortest length defined as the distance between two parallel areas at the end of roundwood perpendicular to longitudinal axis, expressed in meters and rounded to the nearest decimeter (lower);
- ⇒ two mutually perpendicular diameters with bark in the center of the length of the processed roundwood rounded to the nearest centimeter (lower); their arithmetic mean is also rounded to the nearest centimeter (lower);
- ⇒ with roundwood, where the diameter without bark is relevant for determining the dimensions and quality classes (logs), double bark thickness must be deducted from the measured diameter;
- ⇒ For the calculation of volume Huber's formula is used, where Ludolf's number (π) is rounded to 4 decimals (3.1416), and the result is expressed in cubic meters with three decimals.

The paradox occurs when the productivity and costs of transported timber are expressed according to the prescribed way of measuring roundwood by volume due to the loss caused by: 1) measurement of length, 2) measurement of mean diameter, 3) deduction of bark and 4) application of the expression for estimating the volume of roundwood.

The aim of this paper is to compare the efficiency of forwarders with respect to the way of expressing the load: 1) the actual (gross) volume, 2) declared (net) volume, 3) load mass.

2. Material and Methods

Impact analysis of three ways of expressing the transported load (mass, actual volume, declared volume) on the efficiency (productivity and unit cost) of forwarding was carried out on the example of a medium-weight six-wheel Valmet 840.2 forwarder, of the payload of 12 t, which dimensions and load distribution of the unloaded vehicle are shown in Fig. 2. The area of the bunk cross section is 4.1 m^2, and the length 4 m. The vehicle is powered by a six-cylinder diesel engine with turbocharger, of the nominal power of 125 kW at 2200 min^{-1} and the highest torque of 670 Nm at 1400 min^{-1}. The forwarder is equipped with the hydraulic loader Cranab CFR7C, with the lifting force of 7.1 kN at the maximum reach of 9.1 m. The vehicle is equipped with tires: 600/65-34 (front) and 600/55-26.5 (rear).

Data on five different loads (Pedunculate oak) of a forwarder were taken from a previous research (Bosner et al. 2008), which was carried out with the aim of developing and calibrating a portable system for measuring axle loads of a vehicle. For each load, axle loads of a six-wheel Valmet 840.2 forwarder were measured with the use of the portable scale system WLS 101/R2K (BARK System-und Wiegetechnik GmbH & CO.KG). These scales operate on an electro-mechanical principle, they can stand the load of 10 t per scale (20 t in total), and their breaking strength is 150% of the maximum load.

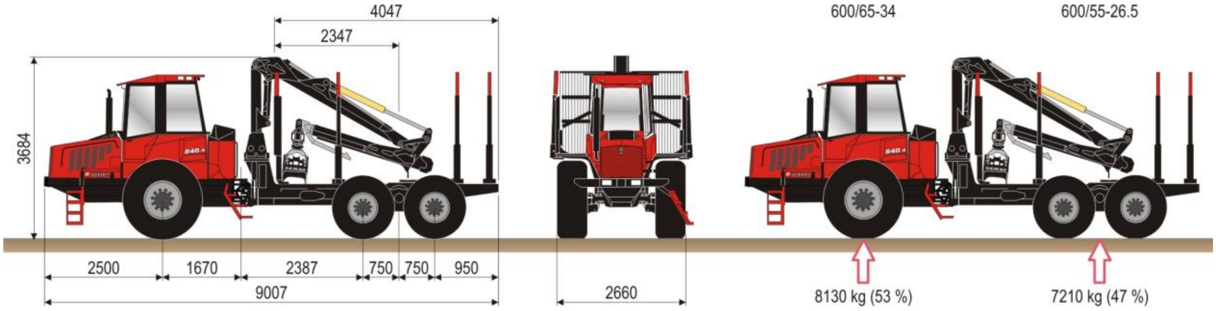

Fig. 2 Valmet 840.2 Forwarder

Apart from scaling aimed at determining the vehicle mass and the mass of each individual load, roundwood in the load was also measured, which included: 1) measurement of length to the nearest centimeter, 2) measurement of diameters on the thicker and thinner end and in the middle of the logs.

The actual (gross) load volume was calculated based on timber length measured to the nearest centimeter and diameters on the thicker and thinner end and in the middle of the logs without deducting double bark thickness, whereby the volume was calculated by Riecke–Newton's formula, for which Sertić (2012) claims to be the most accurate with respect to timber volume determined by sectioning method.

	Load 1 Full height of loading area – logs and long fuelwood –	Load 2 Full height of loading area – long fuelwood –	Load 3 Full height of loading area – logs –	Load 4 Up to 2/3 height of loading area – logs –	Load 5 Up to 1/3 height of loading area – logs –
					
Load mass, kg	12,580	11,295	12,160	8,130	4,310
Actual (gross) volume, m^3	12.651	11.316	12.211	8.193	4.318
Declared (net) volume, m^3	10.658	10.925	9.836	6.388	3.267
No. of roundwood in the load, psc.	21	40	17	11	5
Timber density, kg/m^3	994.4	998.1	995.8	992.4	998.1
Average roundwood volume, m^3/pcs.	0.602	0.283	0.718	0.745	0.864
Average roundwood sweep, cm/m	0.8 ± 0.9	1.8 ± 2.3	0.4 ± 0.7	0.6 ± 0.8	0.7 ± 1.0

Fig. 3 Data of measuring different forwarder loads

Declared (net) roundwood volume (load), for the purpose of timber trading, was measured in compliance with the prescribed way of measurement and expression of roundwood volume in Croatian forestry in accordance with the standard EN 1309-2:2006. This involved the calculation of roundwood volume on the basis of Huber's formula, based on the measurement of the shortest length of roundwood rounded to the nearest decimeter (lower) and two cross diameters in the mid-length rounded to the nearest centimeter (lower). For the logs, for which the diameter without bark is relevant for determining the dimensions and quality classes, double thickness bark is deducted from the rounded mean diameters for pedunculate oak: 2 cm for log diameter ranging from 12 cm to 30 cm, 3 cm for log diameter ranging from 31 cm do 39 cm, 4 cm for log diameter >40 cm with bark.

The impact of the three ways of expressing the transported load (mass, actual volume, declared volume) on forwarder efficiency with respect to the forwarding distance is expressed in accordance with the multicriteria model for the calculation of productivity of these vehicles (Stankić 2010, Stankić et al. 2012), which takes into consideration: 1) forwarder class, 2) soil strength, 3) forwarder equipment with tracks, 4) felling density, 5) volume of the mean felling tree and 6) forwarding distance. Unit cost of forwarding is calculated according to machine rate made by the company »Hrvatske šume« d.o.o Zagreb for Valmet 840.2 forwarder that amount to 452.13 HRK/h.

3. Results

The simulation of different situations that can occur during forwarding is made of five analyzed loads (Fig. 3). Load 1, load 2 and load 3 are a combination of nominally loaded forwarder (load mass <12 t), and load 4 and 5 are the simulation of reduced load due to the limited soil bearing capacity which is usual in Croatian lowland forests during main felling (Horvat et al. 2004, Poršinsky et al. 2012). Each individual load consisted of a different number of roundwood pieces with respect to:

⇒ the type and dimensions of assortments (logs, long firewood, mixed load)

⇒ volume of loaded timber (full height of loading area, <2/3 height of loading area, <1/3 height of loading area of the vehicle).

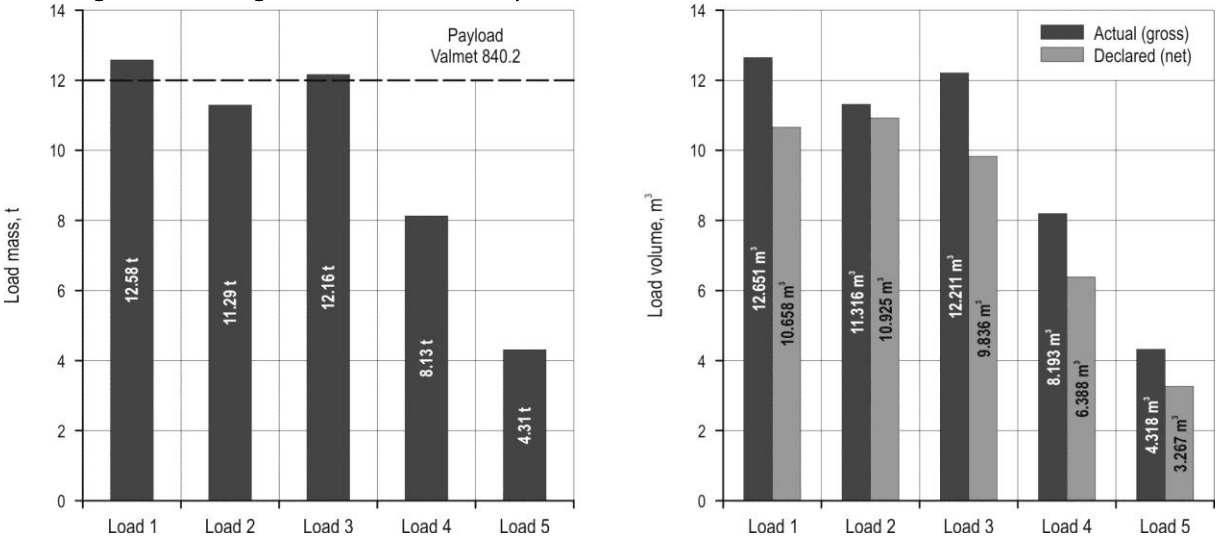

Fig. 4 Comparison of forwarder load mass and volume

Fig. 4 shows the comparison of mass and volume of the researched loads. Mass values of the analyzed forwarder loads are <1 % with respect to the values of the actual load volumes, which is the effect of strong correlation of these two parameters, as physical values, due to constant wood density, which ranged from 992.4 kg/m^3 to only 998.1 kg/m^3, or on average 995.8 ± 2.5 kg/m^3.

Due to the prescribed way of measurement of individual pieces of roundwood, the declared (net) load volume is lower than the actual (gross) volume by 15.75% (load 1), 3.46% (load 2), 19.45% (load 3), 22.03% (load 4) and 24.36% (load 5). The expressed values of the volume reduction of declared loads is significantly affected by:

⇒ type of assortment, especially emphasized in load 2, which consisted entirely of long firewood, and in load 1, where 18% of the actual volume was made of firewood;

⇒ law of piece-volume, which represents the interaction of dimensions of processed roundwood in the forwarder bunk space, with the expressed impact (>0.7 m^3/piece) in load 3, 4 and 5, completely made of logs

⇒ share of first logs processed from the trunk, where due to their irregularity of the shape, significant difference appears when calculating the volume by Huber and Reicke-Newton's formula, respectively (Sertić 2012).

On the basis of data of load measurement, or dimensions of loaded roundwood, analysis of utilization of forwarder bunk space was carried out with respect to: 1) load mass, 2) bunk space volume, 3) bunk cross section area, and 4) bunk space length (Fig. 5).

Utilization of bunk space should be considered based on the volume and also dimensions of the loaded roundwood, taking into account the law of piece-volume (diameter and length of loaded roundwood), as well as the irregularities (curvatures) of roundwood, which is particularly well visible in load 3, exclusively made of long firewood.

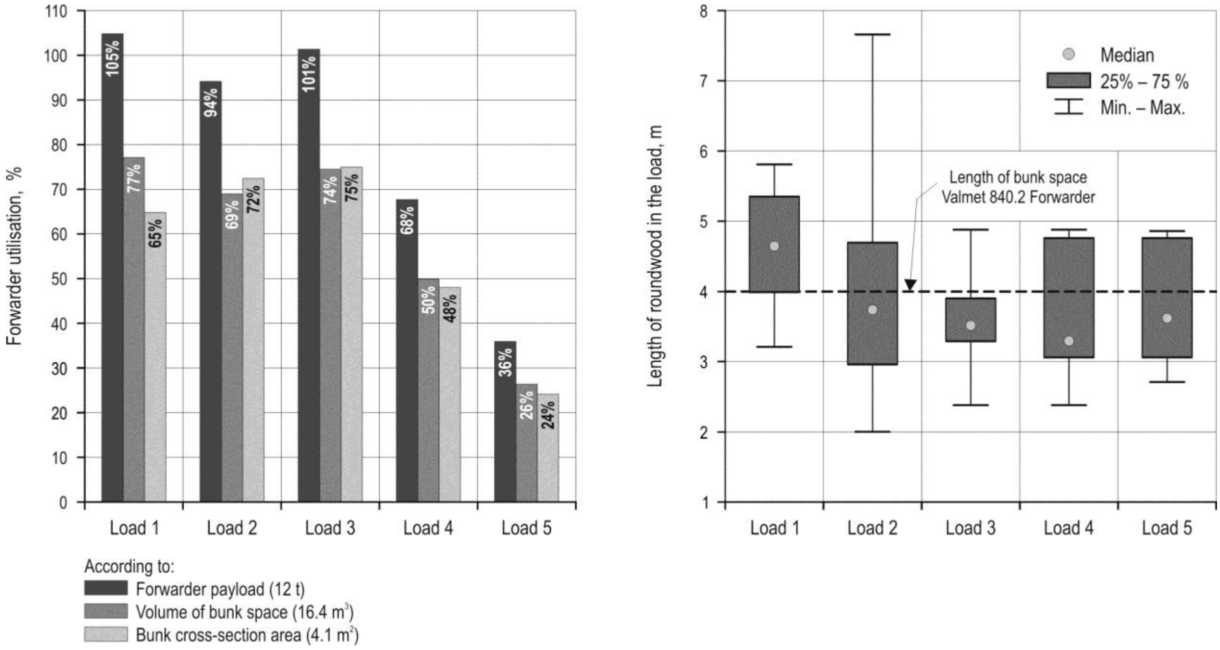

Fig. 5 Comparison of utilization of forwarder bunk space

In calculating forwarder productivity, the following assumptions were made, as required by the multicriteria model for calculating productivity of these vehicles (Stankić 2010, Stankić et al. 2012):

⇒ medium forwarders without semi-tracks;
⇒ for the first three loads, values were used of the average travel speed of unloaded and loaded vehicle on the soil of good bearing capacity (3.71 km/h)
⇒ for loads 4 and 5, values were used of the average travel speed of unloaded and loaded vehicle on the soil of limited bearing capacity (3.01 km/h)
⇒ productivity and unit cost for each load are shown depending on off road forwarding distance (ranging from 100 to 800 m)
⇒ for all loads, the same forwarding distance on the roadside landing was used (50 m) with the same average travel speed of unloaded and loaded vehicle (4.35 km/h)
⇒ for all loads, the same felling density was used (150 m^3/ha)
⇒ for the calculation of time consumption for timber loading and unloading, instead of original algorithm dependence, the number of timber pieces in the load was used (Fig. 3).

The significance of the way of expressing the load (actual volume, declared volume and load mass) on the efficiency of forwarder performance (productivity and unit cost of forwarding) is shown comparatively in Fig. 6.

The density of pedunculate oak roundwood (995.8 ± 2.5 kg/m^3) resulted in negligible differences in the expression of productivity and unit cost with respect as to whether the loads were expressed according to mass (Fig. 6A) or actual volume (Fig. 6B).

The prescribed way of measurement of individual pieces of roundwood affected the forwarder productivity, which can be seen considering the declared (net) load volume (Fig. 6C) compared to forwarder productivity expressed by the actual (gross) volume of the load (Fig. 6B), in the same way as the reduction of the value of the declared load volume, which is lower than the actual volume by 15.75% (load 1), 3.46% (load 2), 19.45% (load 3), 22.03 % (load 4), and 24.36 % (load 5).

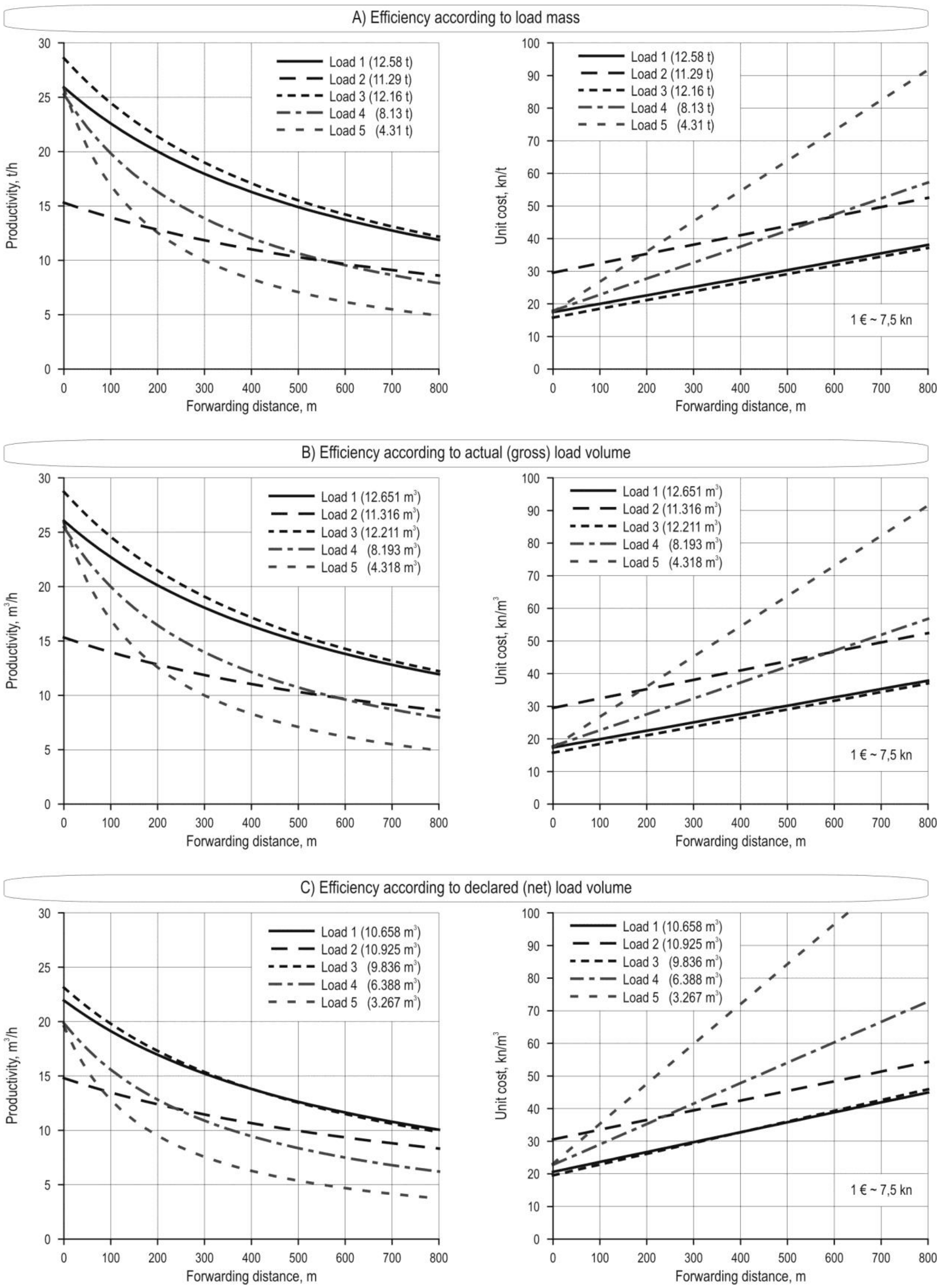

Fig. 6 Comparison of forwarder efficiency according to different load measurements

Also, the prescribed measurements of individual pieces of roundwood affected the growth of unit costs of forwarding, which is expressed with respect to the declared (net) load volume (Fig. 6C). These costs are higher than unit costs of forwarding expressed by the actual (gross) load volume (Fig. 6B) by 18.70% (load 1), 3.58% (load 2), 24.15% (load 3), 28.26% (load 4) and 32.17% (load 5).

Regardless of the way of expressing the load (Fig. 6), wide ranges of productivity and units costs determined depending on forwarding distance, are the effect of interaction between time consumption of (un)loaded travel of the vehicle and loading/unloading of timber and load size, respectively (Poršinsky 2002, Poršinsky 2005, Poršinsky and Stankić 2006). Obviously the decrease of the loaded timber volume strongly affects the forwarder efficiency (especially by the increase of forwarding distance), and hence, from the economic point of view, the method of providing forwarder mobility in conditions of limited soil strength of the Croatian lowland forests is absolutely unacceptable (Poršinsky et al. 2011).

4. Instead of conclusions

Obviously, the transport of timber and trade of timber are two different concepts from the standpoint of timber volume or load volume, with a different impact on the participants in the timber supply chain. The results of this research open a series of questions to which there are no easy answers:

⇒ Are the forests such a rich resource to allow putting the load volume in the context of timber transport and trade under a common denominator?

⇒ Are there any obstacles to change the common denominator (which and who)?

⇒ What does it mean to increase timber transport costs against the actual and declared load volume (of roundwood) from the standpoint of participants in the timber supply chain (forest owners, forestry contractors, timber buyers, and also in the context of compensation fee for the use of forest roads to their owners)?

5. References

Bosner, A., Nikolić, S., Pandur, Z., Benić, D., 2008: Development and Calibration of Mobile Measuring System of Vehicle Axle Load – Measurements on Forwarder. Nova meh. šumar. 29: 1–15.

Conway, S., 1976: Logging practices. Principles of Timber Harvesting Systems. Miller Freeman Publications, 1–432.

Fonseca, M.A., 2005: The Measurement of Roundwood: Methodologies and Conversion Ratios. CABI Publishing, 1–267.

Greulich, F., 2002: Transportation Networks in Forest Harvesting: Early Development of the Theory. Proceedings of the International Seminar on New Roles of Plantation Forestry Requiring Appropriate Tending and Harvesting Opreations, September 29 – October 5, 2002, The Japan Forest Engineering Society & IUFRO 3.04/3.06/3.07, Tokyo, Japan, 1–9.

Heinimann, H. R., 2001: Verfahrenstechnik III – Analyse, Gestaltung und Steuerung technisher Produktionssysteme. D-FOWI, Forstliches Ingenieurwesen, 1–25. (http://www.fowi.ethz.ch/piw/teach/)

Horvat D., Poršinsky T., Krpan A., Pentek T., Šušnjar M., 2004: Suitability Evaluation of Forwarders Based on Morphological Analysis. Strojarstvo 46(4–6): 149–160.

HRN EN 1309–2:2010: Round and sawn timber – Method of measurement of dimensions – Part 2: Round timber – Requirements for measurement and volume calculation rules (EN 1309-2:2006)), 1–20.

MacDonald, A. J., 1999: Harvesting Systems and Equipment in British Columbia. FERIC, Handbook No. HB-12, 1–197.

Poršinsky, T., 2002: Productivity Factors of Timberjack 1210 at Forwarding the Main Felling Roundwood in Croatian Lowland Forests. Glasnik za šumske pokuse 38: 103–132.

Poršinsky, T., 2005: Efficiency and Environmental evaluation of Timberjack 1710B Forwarder on Roundwood Extraction from Croatian Lowland Forests. PhD Thesis, Forestry Faculty of Zagreb University, 1–170.

Poršinsky, T., Stankić, I., 2006: Efficiency of Timberjack 1710B Forwarder on Roundwood Extraction from Croatian Lowland Forests. Glasnik za šumske pokuse, Special Issue 5: 573–587.

Poršinsky, T., Stankić, I., Bosner, A., 2011: Ecoefficient Timber Forwarding Based on Nominal Ground Pressure Analysis. Croat. j. for. eng. 31(1): 345–356.

Poršinsky, T., Pentek, T., Bosner, A., Stankić, I., 2012: Ecoefficient Timber Forwarding on Lowland Soft Soils. In: Global Perspectives on Sustainable Forest Management (ed.: C. A. Okia), In Tech, 275–288.

Silversides, C.R., Sundberg, U., 1989: Operational Efficiency in Forestry – Volume 2: Practice. Kluwer Academic Publishers – Forest Sciences, Dodrechts/Boston/Lancaster, 1–169.

Sertić, M., 2012: Volume Losses of Processed Sessile Oak But-logs due to Prescribed Method of Scaling. Master Thesis, Forestry Faculty of Zagreb University, 1–99.

Staff, K.A.G., Wiksten, N.A., 1984: Tree harvesting Techniques. Martinus Nijhoff/DR W. Junk Publishers, Dodrechts/Boston/Lancaster, 1–371.

Stankić, I., 2010: Multicriterial planning of timber forwarding in Croatian lowland forests. PhD Thesis, Forestry Faculty of Zagreb University, 1–123.

Stankić, I., Poršinsky, T., Tomašić, Ž., Tonković, I., Frntić, M., 2012: Productivity Models for Operational Planning of Timber Forwarding in Croatia. Croat. j. for. eng. 33(1): 61–78.