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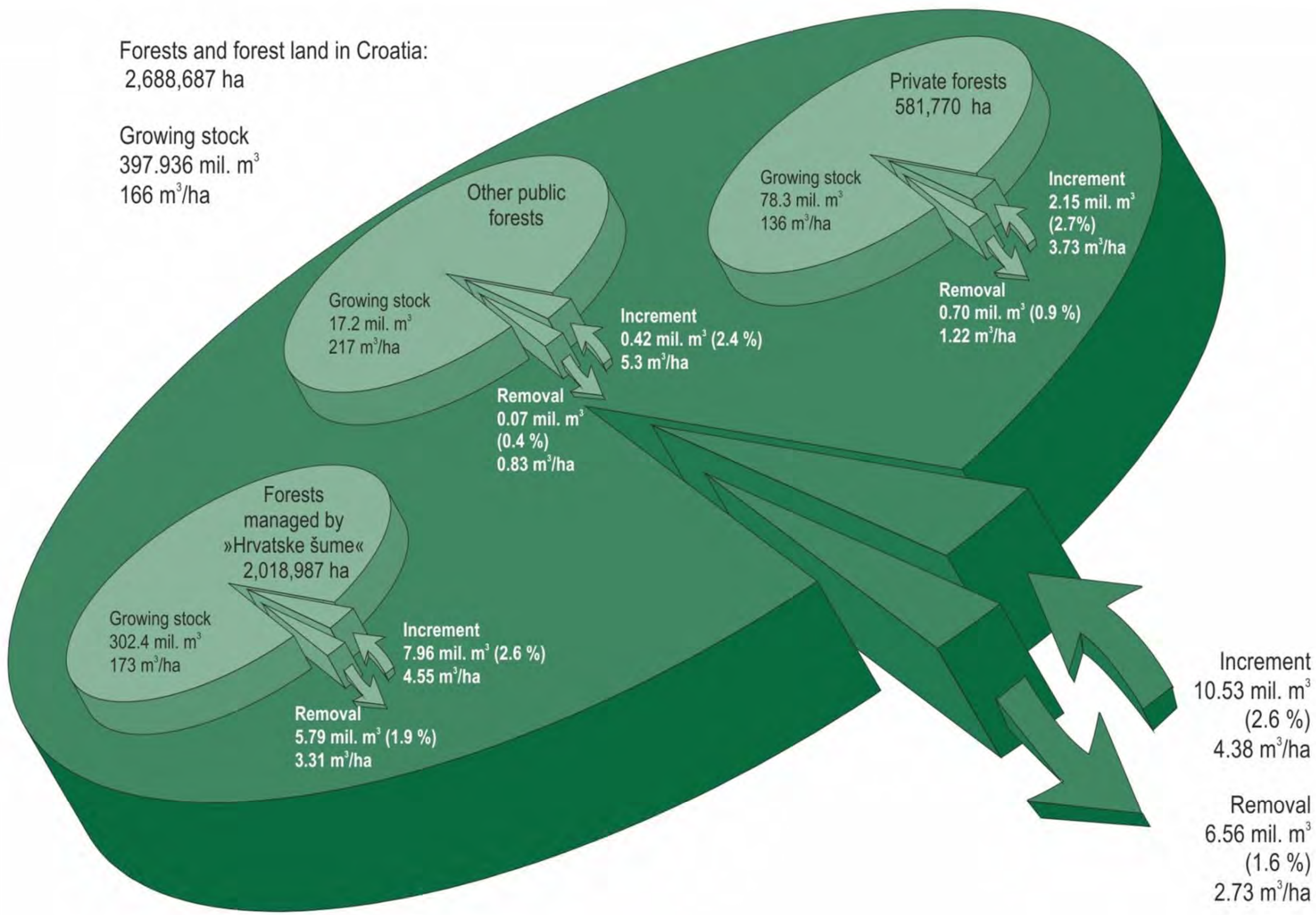
DEVELOPMENT AND IMPLEMENTATION OF PRODUCTIVITY NORMS FOR FORWARDERS IN CROATIA

FORMEC 2011 - Pushing the Boundaries with Research in Forest Engineering
44th International Symposium on Forestry Mechanisation, October 9-13, 2011, Graz, Austria


Forests and forest land in Croatia:
2,688,687 ha
Growing stock
397.936 mil. m³
166 m³/ha
Other public forests
Growing stock
17.2 mil. m³
217 m³/ha
Increment
0.42 mil. m³ (2.4 %)
5.3 m³/ha
Removal
0.07 mil. m³
(0.4 %)
0.83 m³/ha
Private forests
581,770 ha
Growing stock
78.3 mil. m³
136 m³/ha
Increment
2.15 mil. m³
(2.7%)
3.73 m³/ha
Removal
0.70 mil. m³ (0.9 %)
1.22 m³/ha
Forests managed by »Hrvatske šume«
2,018,987 ha
Growing stock
302.4 mil. m³
173 m³/ha
Increment
7.96 mil. m³ (2.6 %)
4.55 m³/ha
Removal
5.79 mil. m³ (1.9 %)
3.31 m³/ha
Increment
10.53 mil. m³
(2.6 %)
4.38 m³/ha
Removal
6.56 mil. m³
(1.6 %)
2.73 m³/ha

1. Forests in Croatia…






2. The lowland forests…

⇒ > 322 thousand ha

⇒ 25% of the total high forests area.

⇒ Even-aged forests

⇒ Species: pedunculate oak, narrow-leaved ash, black alder, willows and poplars

⇒ Annual removal over 1 mill m³ of wood

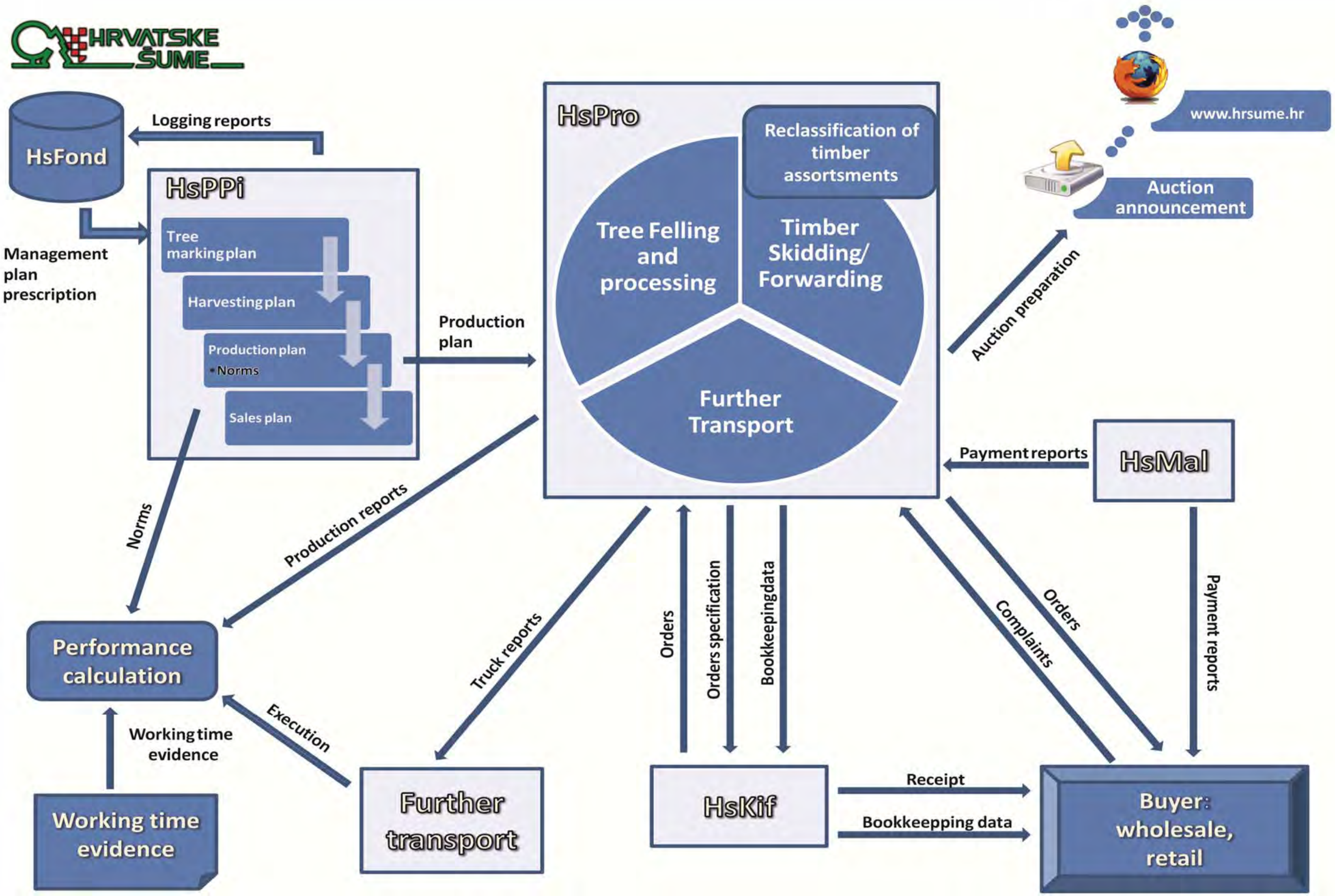
⇒ High prices on the roundwood market (ped. oak)

⇒ Motor-manually tree felling and processing (assortment method, BUCK-TO-QUALITY)

⇒ Timber extraction:
- ⇒ light and medium skidders – after early thinnings
- ⇒ farm tractors with semitrailer
- ⇒ **forwarders – after main fellings**

Timberjack 1210, Timberjack 1410, Timberjack 1710, Valmet 840.2 and Valmet 860

3. Production information subsystem of the state trade company "Hrvatske šume" d.o.o.



4. Materials and Methods

4.1 Classification of forwarders

⇒ A good knowledge of forwarders is of a crucial significance

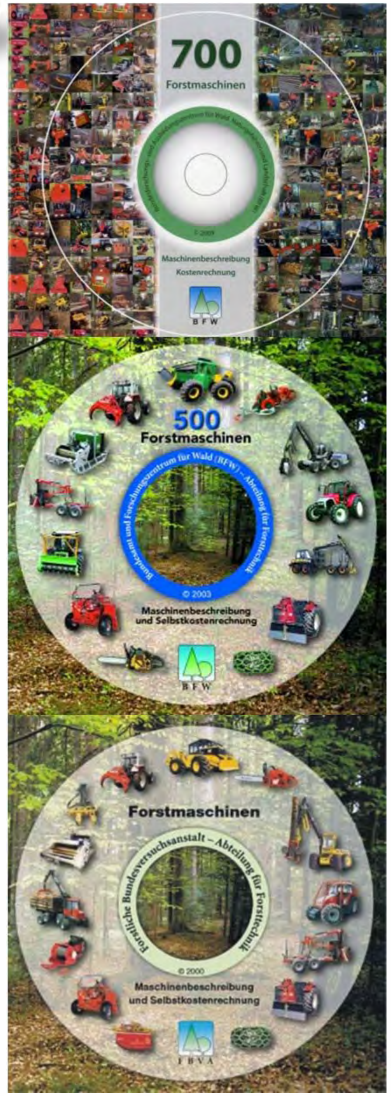
⇒ Many research methods are already known (as determination of usability, development of theirs construction, morphological analysis etc.)

⇒ There are many forwarder classifications which classify them according to net mass, load capacity or gross mass.

⇒Latest classification according to payload:
- ⇒Light (<10t)
- ⇒Medium (10 – 14 t)
- ⇒Heavy (>14 t)

⇒ As a basis for grouping vehicles in classes in this case will be the k-means cluster analysis algorithm (more objective classification and manufacturer independent)

⇒ Forwarder database was created from multiple sources (BWF 2009, BWF 2003, previous publications, promotional flyers)



4. Materials and Methods

4.2. Assortments characteristics

⇒ The assortment volume is important for obtaining the correct mean load volume that impact the forwarder productivity

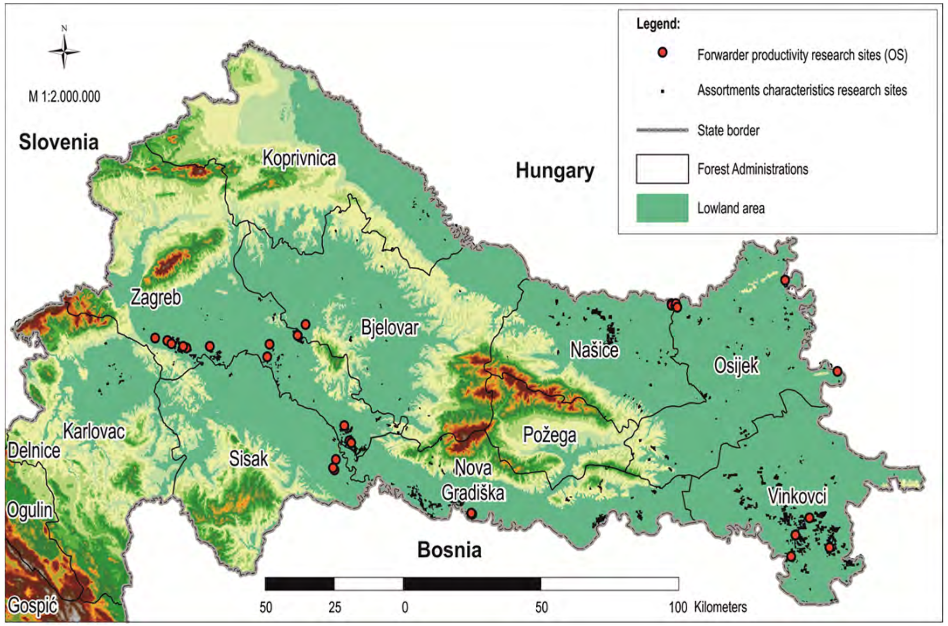
⇒ Connecting the databases of two applications:

HsPPI (marked tree volume)

\+

HsPro (assortments volume)

⇒ Only data for the most important species by share in the prescribed removal of the Croatian lowland forests were taken into analysis: pedunculate oak, common hornbeam, narrow-leaved ash and black alder.



4.3 Forwarder productivity

⇒ Raw data for productivity analysis were taken from the previous publications: 5 OS (Poršinsky, 2000) + 3 OS (Poršinsky, 2005) + 22 OS (this investigation) = Total of 30 OS

⇒The classic method of time study (snap-back chronometric technique) was used.

4.3 Forwarder productivity

⇒Data of forwarding influential factors (stand and terrain conditions) were collected.

⇒Forwarding distance was measured by hand GPS devices

⇒Loaded assortments were counted and the number of the identification plastic tag was recorded in case of large sawtimber and veener assortments. In other cases (with small assortments – pulpwood and long firewood), direct measurement of processed assortments took place

⇒The ground bearing capacity was determined for each individual cycle, by visual estimate of the recorder

⇒ Soil of good load-bearing capacity – firm and moderately firm soil. It includes dry, frozen or occasionally wet soil which doesn't present problems for moving vehicles

⇒ Soil of limited load-bearing capacity – soft and very soft soil. It is a soil that is partly to fully saturated with water. Man's walking on it is hard, tracks of shoes are fully visible.

Total time – t_{UK} [min/turn]

$$t_{UK} = k_D \cdot \left[s_B \cdot \left(\frac{60}{v_{NB}} + \frac{60}{v_{OB}} \right) + s_C \cdot \left(\frac{60}{v_{NC}} + \frac{60}{v_{OC}} \right) + t_U + t_I \right] \left[\frac{min}{tura} \right]$$

Forwarding productivity – V_h [m³/h]

$$V_h = \frac{60 \cdot V_T}{t_{UK}} \left[\frac{m^3}{h} \right]$$

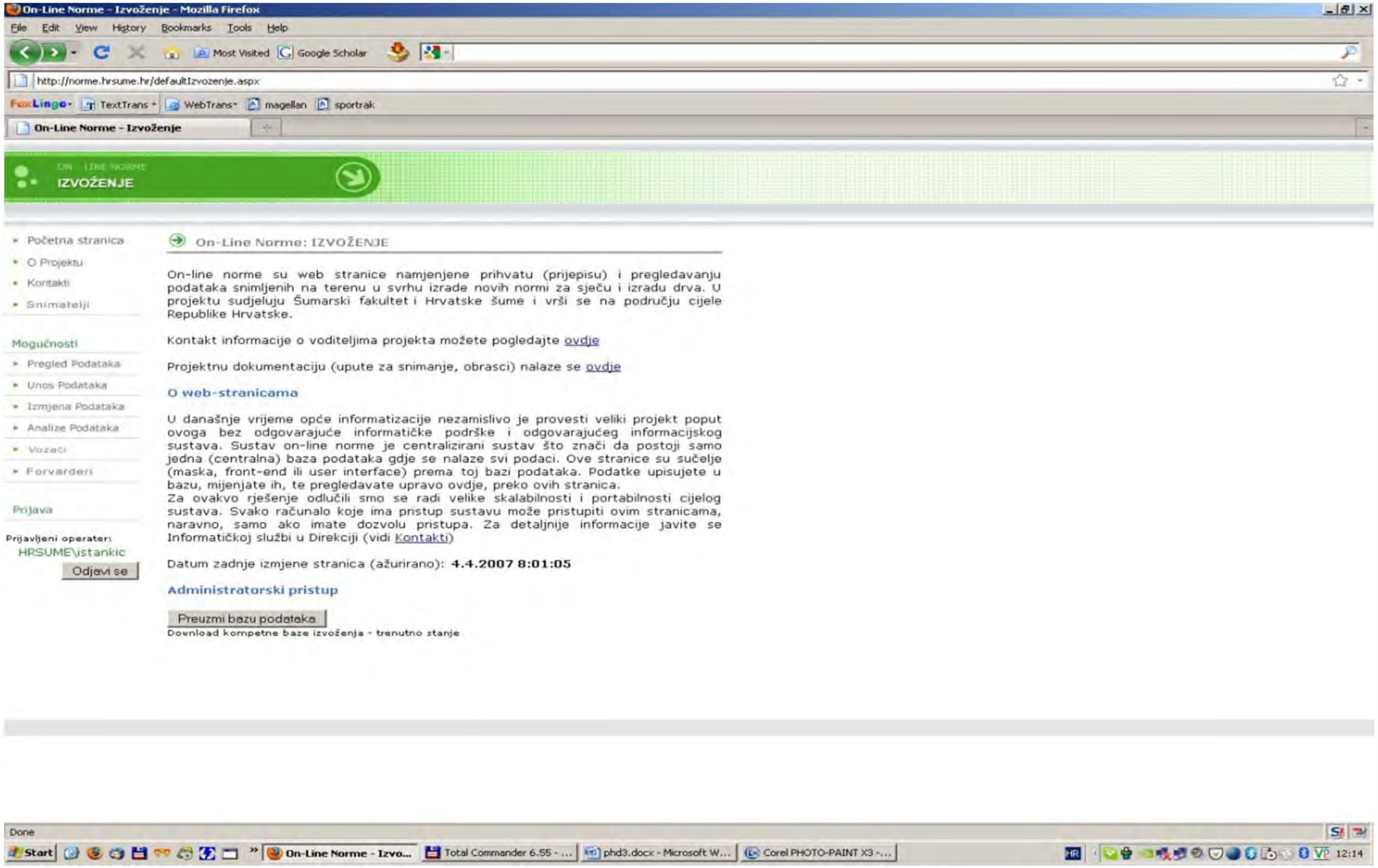
where:

s_B – forwarding distance (offroad), km
v_{NB} – unloaded vehicle speed (offroad), km/h
v_{OB} – loaded vehicle speed (offroad), km/h
s_C – forwarding distance (road), km
v_{NC} – unloaded vehicle speed (road), km/h
v_{OC} – loaded vehicle speed (road), km/h
t_U – loading time, min/turn ($t_U=t_{UD}+t_{UP}$)
t_I – unloading time, min/turn ($t_I=t_{ID}+t_{IP}$)
k_D – additional time factor
V_T – load volume, m³/turn

4.3 Forwarder productivity

⇒Before the start of the recording, an online form for input of recorded data was developed. The form was developed using .NET technology and it could be found at the address http://norme.hrsume.hr.

⇒At the end of the work process recording, each recorder would register to the stated webpage and entered the data into the integral database. MSSQL database was used.



5 Results of the research

5.1 Forwarder classification

Table 1. Correlation table of studied values (marked are significant)

Characteristics	Means	Std. Dev.	Engine power	Lenght	Width	Height	Clearance	Mass	Payload	Crane reach	Lifting moment (gross)
Engine power	138.24	28.51	1.00	0.60	0.72	0.53	0.53	0.82	0.81	0.08	0.79
Lenght	9,314.38	874.15	0.60	1.00	0.63	0.32	0.60	0.66	0.67	-0.02	0.67
Width	2,716.63	170.42	0.72	0.63	1.00	0.59	0.47	0.80	0.84	0.12	0.82
Height	3,710.45	133.33	0.53	0.32	0.59	1.00	0.34	0.64	0.65	0.35	0.70
Clearance	637.36	57.64	0.53	0.60	0.47	0.34	1.00	0.58	0.60	-0.08	0.61
Mass	15,183.75	3,038.63	0.82	0.66	0.80	0.64	0.58	1.00	0.85	0.11	0.84
Payload	12,672.46	2,702.39	0.81	0.67	0.84	0.65	0.60	0.85	1.00	0.12	0.89
Crane reach	8.88	1.21	0.08	-0.02	0.12	0.35	-0.08	0.11	0.12	1.00	0.27
Lifting moment (gross)	107.10	24.42	0.79	0.67	0.82	0.70	0.61	0.84	0.89	0.27	1.00

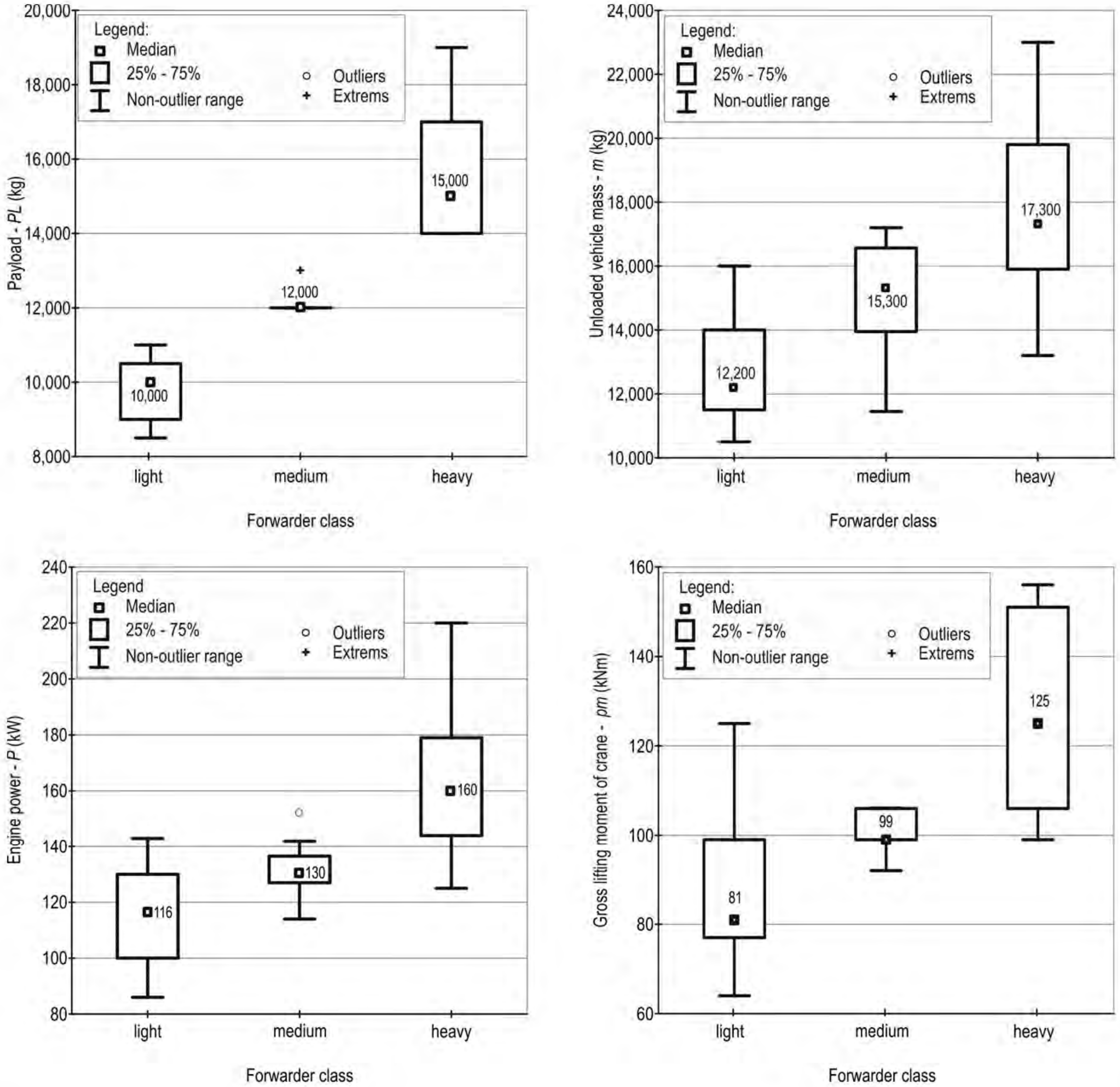
⇒ The highest correlation to other values is indicated precisely by the PL of the vehicle (!). For this reason, PL was used for the classification of forwarders.

⇒ The first group includes forwarders whose PL is closest to the centroid of 9,929.37 kg. The second group includes those whose PL is closest to the centroid value of 12,125.00 kg, while the third group is formed by the forwarders whose PL is closest to the value of 15,571.43 kg.

⇒ Through further analysis for the needs of operative classification of forwarders, rough borderlines can be set among three forwarder classes by their PL, and those are: 11,000 kg and 14,000 kg. The first class consists of vehicles whose PL is less than 11,000 kg, the second of those whose PL amounts from 11,000 to 14,000 kg, while the third class consists of forwarders whose PL is above 14,000 kg.

⇒ Timberjack 1210 and Valmet 840 are into the medium forwarders class, whereas Timberjack 1410, Timberjack 1710 and Valmet 860 are in the heavy forwarders class.

5 Results of the research
5.1 Forwarder classification

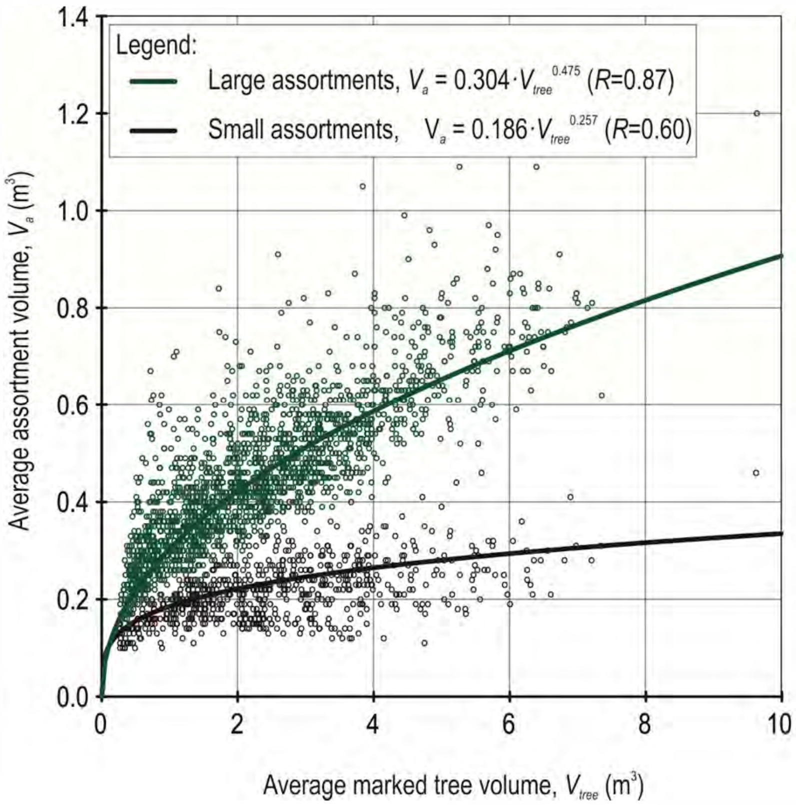


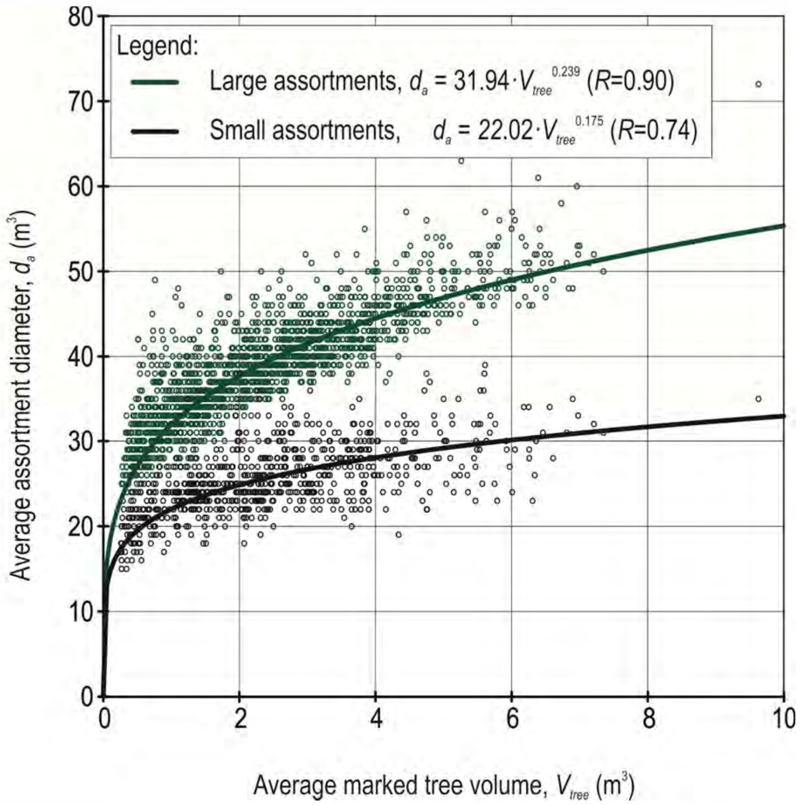
5 Results of the research

5.2 Characteristics of assortments and vehicle load

Data from 1532 working sites were analyzed, where timber extraction was carried out by forwarders over last few years (since the beginning of full implementation of information production subsystem *HsPPI* and *HsPro*).

Two groups of assortment size can be detected. The first group is formed by the classes of large assortments of big dimensions – veneer logs, sawlogs (1st, 2nd and 3rd class) and logs for peeling. The second group includes small assortments, usually of smaller dimensions – long firewood, mining wood and thin industrial roundwood.





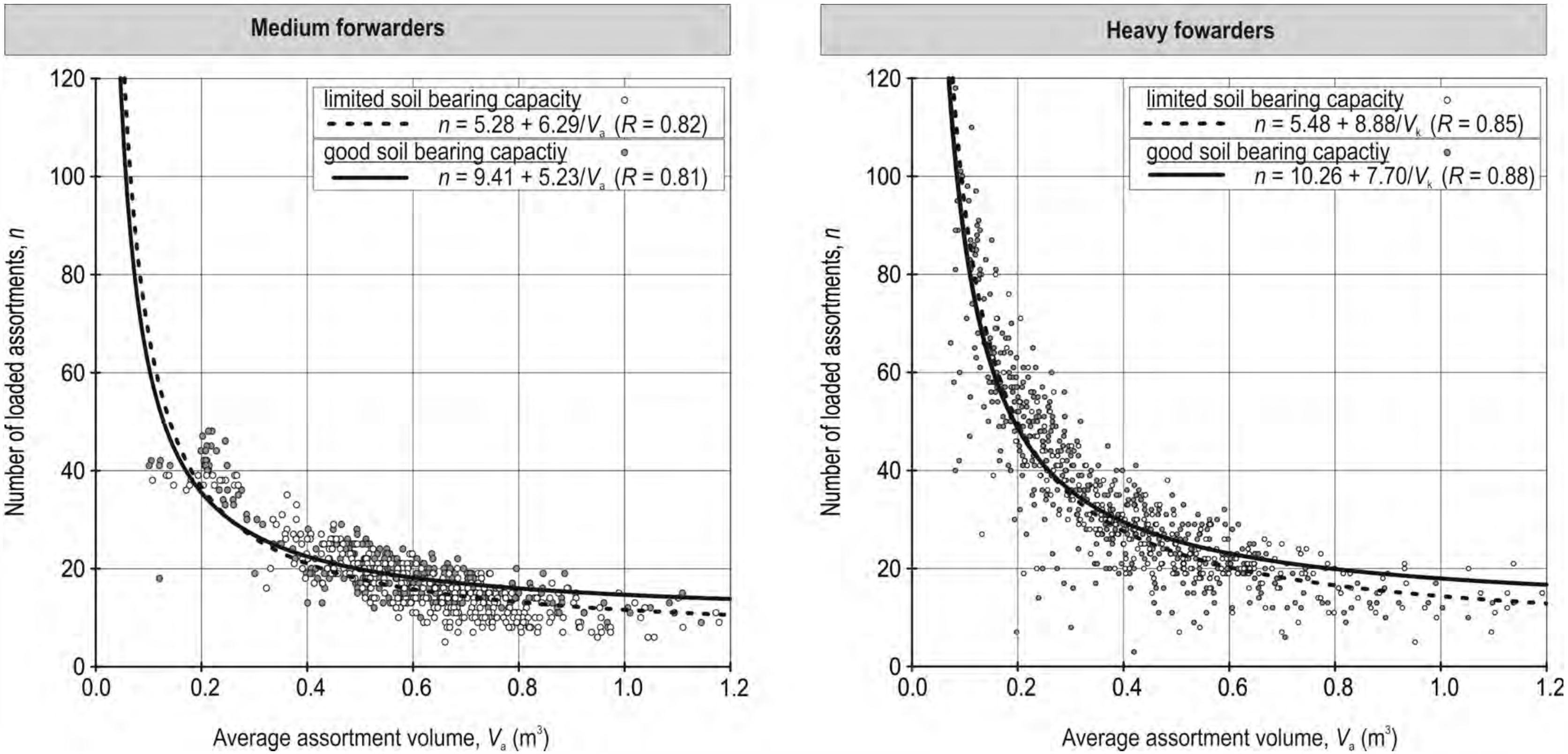
5 Results of the research

5.3 Number of roundwood pieces in the bunk area of forwarder

⇒Dependence of the number of loaded assortments on the decrease of soil bearing capacity has been determined . By decrease of soil bearing capacity, the number of loaded roundwood assortments is reduced as well.

⇒Reduction of loaded assortments in conditions of reduced soil bearing capacity was more expressed with the heavy than with the medium size forwarders.

⇒The product of mean assortment volume and number of assortments gives the load volume ($V_T = V_a \cdot n$).



5 Results of the research
5.4 Modeling of the forwarder productivity

⇒ The forwarding productivity was studied using the time study on totally 1440 recorded work cycles, out of which 651 cycles were performed with medium, and 789 with heavy forwarders.

5.4.1 Time consumption of loaded and unloaded vehicle traveling

⇒Based on the dependence of time on the distance of traveling, the average speed of (un)loaded forwarders on forest road and off-road was calculated. The assumption was that forwarders are moving at uniform speed.

⇒Medium size forwarders are faster in the conditions of limited soil bearing capacity than heavy forwarders. This is not the case in the conditions of good soil bearing capacity where heavy forwarders reach higher speeds. Larger differences in the speeds of vehicles on the forest road between the forwarder classes are caused by bigger variety of conditions on the monitored sites - in the areas of roadside landings.

Forwarder classes	Off-road speed (km/h)								Forest road speed (km/h)			
	Limited soil bearing capacity				Good soil bearing capacity							
	Loaded vehicle		Unloaded vehicle		Loaded vehicle		Unloaded vehicle		Loaded vehicle		Unloaded vehicle	
	No semi-tracks	Semi-tracks	No semi-tracks	Semi-tracks	No semi-tracks	Semi-tracks	No semi-tracks	Semi-tracks	No semi-tracks	Semi-tracks	No semi-tracks	Semi-tracks
	v_{OB}	v_{OB}	v_{NB}	v_{NB}	v_{OB}	v_{OB}	v_{NB}	v_{NB}	v_{OC}	v_{OC}	v_{NC}	v_{NC}
Medium	3.17	2.80	4.25	3.35	3.43	2.90	4.38	3.62	7.98	6.11	12.05	8.16
Heavy	3.02	2.67	4.14	3.26	3.51	2.97	4.45	3.72	4.84	3.71	5.68	3.84

⇒Based on the modeled driving speeds of vehicles and average traveling distances off-road (s_B) and on the forest road (s_C), time consumption of a moving vehicle is obtained.

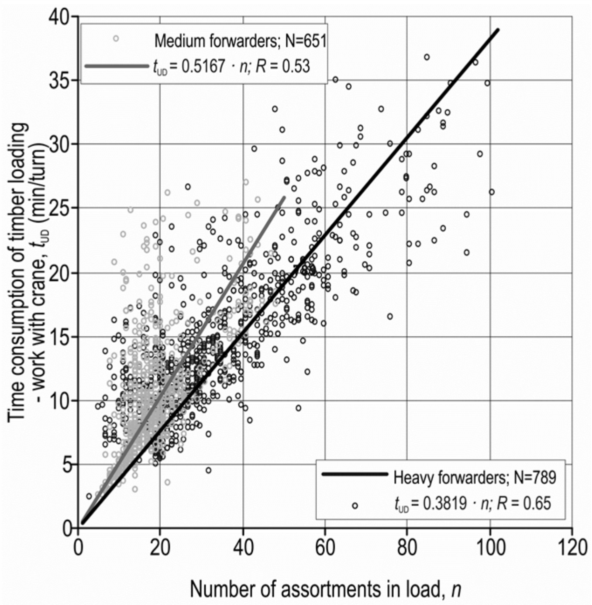
5 Results of the research

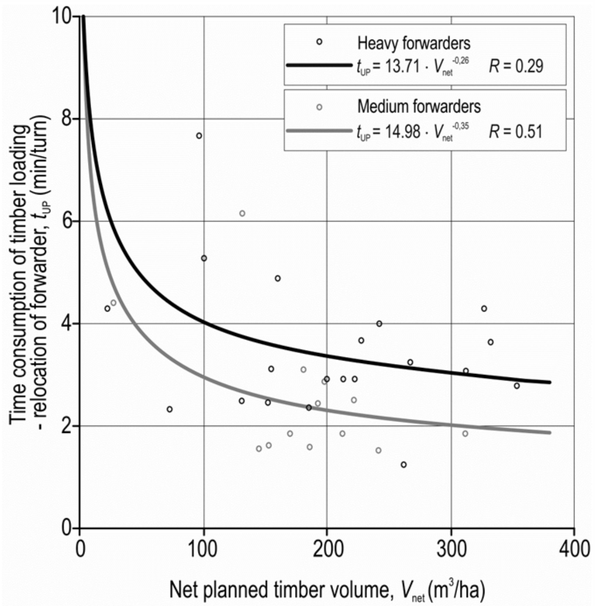
5.4 Modeling of the forwarder productivity

5.4.2 Timber loading time consumption

⇒During timber loading (t_U), two significantly different groups of work components can be detected ($t_U = t_{UD} + t_{UP}$):

- ⇒Timber loading with crane (t_{UD}) – the operator loads the timber into the bunk area using only the hydraulic crane,
- ⇒Relocation of forwarder (t_{UP}) – forwarder moves from one to the next loading area.





⇒Timber loading expressed the influence of the "*Volume-piece law*", as because of the smaller dimensions of the loaded roundwood, the number of loaded pieces and the crane time consumption have increased.

⇒Time consumption of forwarder relocation is strongly impacted by the "*Production law*", that is by the quantity of cut and processed timber per unit of area. It is reflected in the exponential increase of time consumption of forwarder relocation due to diminished felling density (thinning) and vice versa (regeneration and clear cutting).

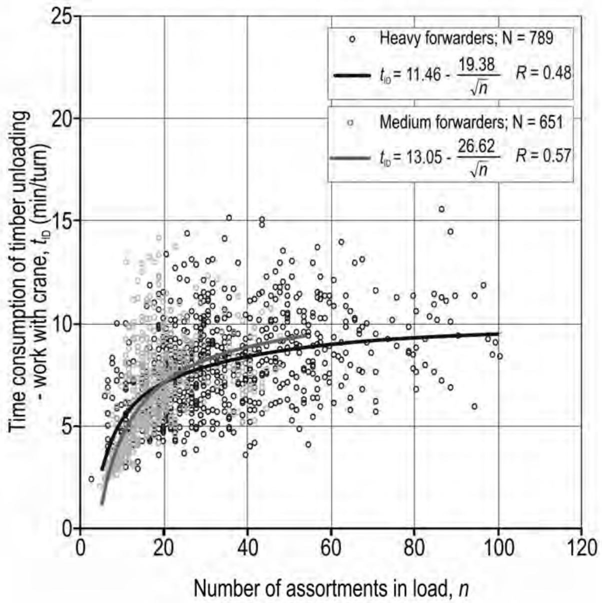
5 Results of the research

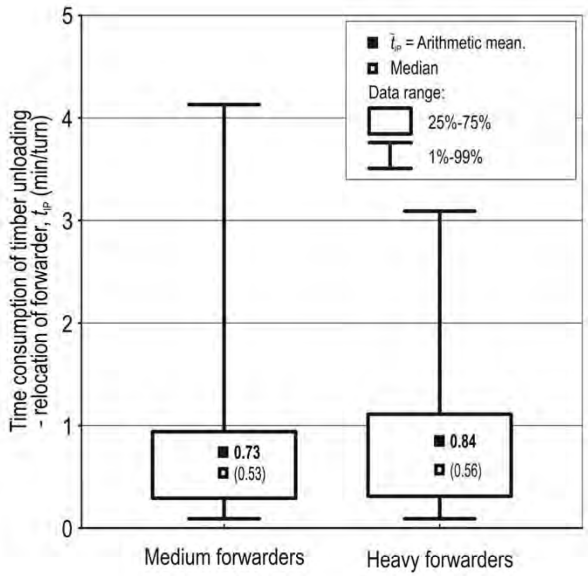
5.4 Modeling of the forwarder productivity

5.4.3 Timber unloading time consumption

⇒ Similar to the loading, the unloading at the roadside landing (t_I) is additionally divided into two groups of work components ($t_I = t_{ID} + t_{IP}$):

- ⇒Crane work time (t_{ID}, where the operator works solely with the hydraulic crane with the goal of unloading the timber), and
- ⇒Relocation time during unloading (t_{IP}, where the forwarder moves from pile to pile with the goal of timber separation according to tree species and quality class).





⇒Time consumption of crane unloading depends on the forwarder class and number of roundwood in the load. The asymptotic model was used.

⇒ Mean time consumption of relocation for heavy forwarders was 0.84 min/turn, whereas the medium forwarders it amounted to 0.73 min/turn.

5 Results of the research

5.4 Modeling of the forwarder productivity

5.4.4 Delays and additional time factors

⇒ Consist of unavoidable and avoidable times.

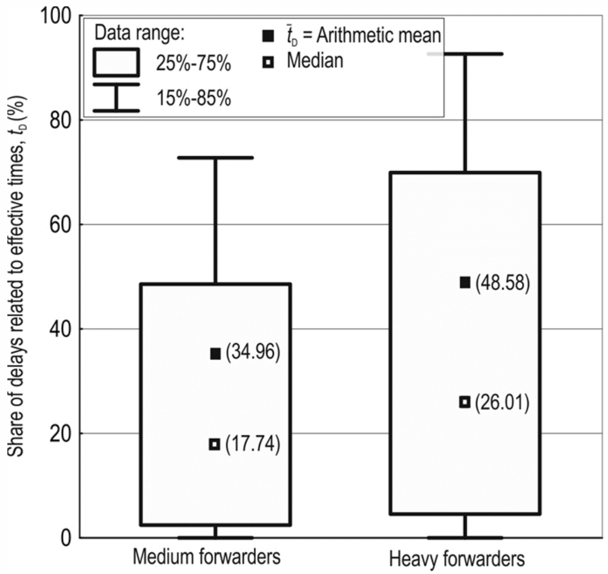
⇒ Various technological and organizational measures are taken to try and reduce it to the necessary level.

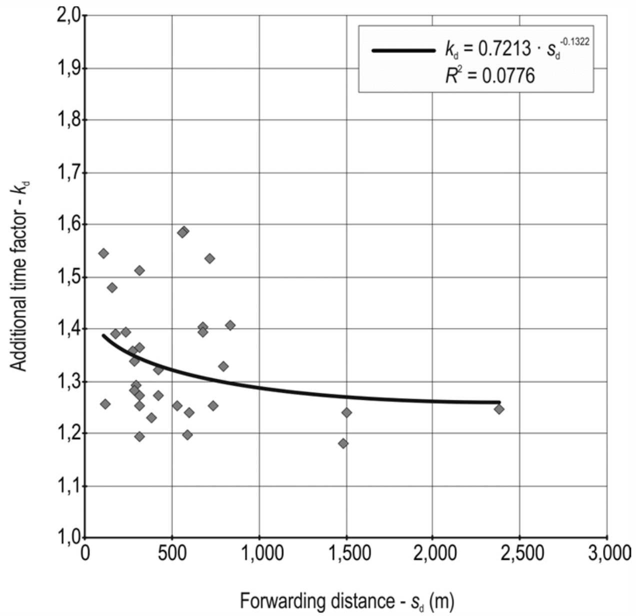
⇒The unavoidable delays are classified as

⇒preparatory time, occasional works and breaks.

⇒The avoidable delays include

⇒unnecessary conversations among workers, conversations between workers and passers-by and recorders, and excessive resting time.

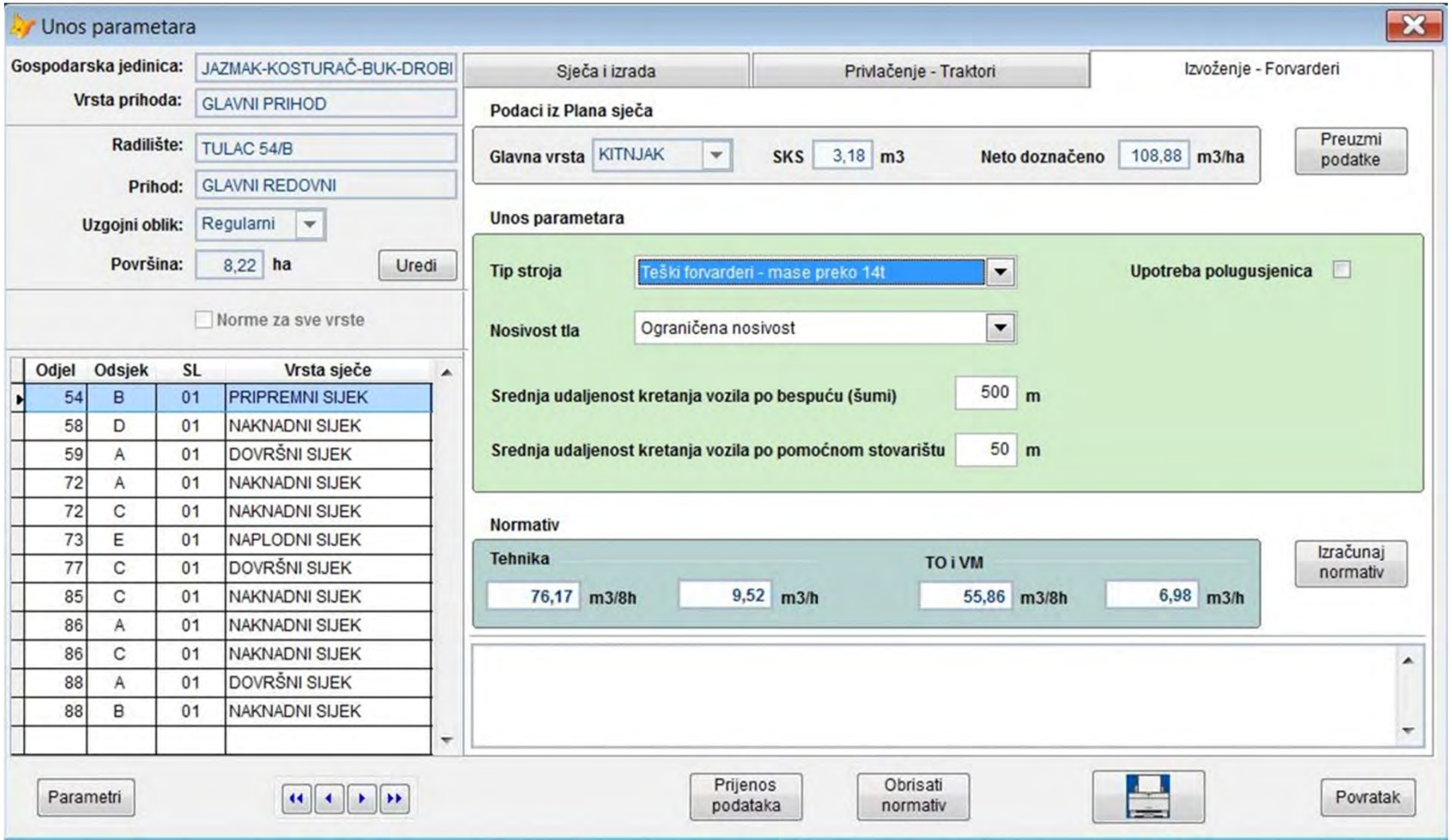




⇒The additional time and the additional time factor are determined through analysis of unavoidable delays only. The additional time was determined for each individual site. The mean additional time factor value amounts to 1.33, that is 33% of the effective time. The increase of unavoidable delay share within shorter forwarding distances can be explained by the greater fatigue of workers.

5 Results of the research
5.5 Implementation of the model into the information system

Screenshot of tab for norm calculation for forwarders in *HsPPI*



5 Conclusions

Aiming to develop an operatively implementable system of timber forwarding planning, classification of forwarders in relation to their technical characteristics was done.

The most important factor appeared to be the payload, so this variable was used for clustering of vehicle types.

Three classes of forwarders were determined: light, medium and heavy forwarders.

- ⇒ Light forwarders have load capacity up to 11,000 kg,
- ⇒ Medium from 11,000 kg to 14,000 kg, and
- ⇒ Heavy forwarders above 14,000 kg.

Light forwarders are not implemented in the Croatian forestry, and their place is taken by farm tractors with semi-trailers.

Determination of loaded roundwood features with the goal of productivity calculation (norm projection) was performed by modeling the volume of large and small assortments from an average marked tree volume. The data were gathered by joining together two parts of information subsystems *HsPro* and *HsPPI*.

By the increase of marked tree volume, the average volume of large assortments grows exponentially, whereas with the small assortments after the initial growth the relations take values closer to the asymptote of the curve (0.34 m^3/pcs).

5 Conclusions

Results of the forwarding productivity study are under a strong influence of the interaction of important factors prevailing in the Croatian lowland forests, and the study came to the following conclusions:

⇒The forwarder class influences the level of forwarder productivity through its payload (possible load volume) but also through its speed and time consumption during loading and unloading.

⇒Timber extraction by forwarders are influenced by conditions of soil-bearing capacities through increase of time consumption of forwarding - by the speed decrease and lesser load volumes.

⇒Usege of semi-tracks increases the time consumption of traveling.

⇒Increase of the forwarding distances decreases forwarder's productivity, as the share of the time spent on traveling grows within the structure of the total time consumption of the work shift. However, the influence of distance on the forwarding productivity should be observed through its interaction with the classes of soil-bearing capacity and classes of forwarders. Likewise, with the increase of forwarding distance grows the significance of the load volume (!).

⇒Stand conditions and forest management guidelines demonstrated the impact on the productivity of timber forwarding through the well known *Laws of mechanizing of forest works*, that is through felling density (*Productivity law*), features and dimensions of processed roundwood (*Volume-piece law* and *Product type law*).

Based on the obtained research results, a model of forwarder productivity was established and finally incorporated into the production information subsystem. Real data from first stage of planning (forest inventory data, tree marking plan, assortment structure plan etc.) and developed forwarder productivity model, together with input work parameters ensures the objectivity of norms used in timber forwarding.

Thank You for your attention!