Development and implementation of productivity norms for forwarders in Croatia

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Abstract:
In the area of Croatian lowland forests, forwarders aretypically used for extraction of timber assortments. Within the project, "Systematization of norms and standards for the production of the timber assortments", which was financed by the state company "Hrvatske šume" d.o.o., the process of development and implementation of new productivity norms for forwarders was carried out.
Initially, for the execution of the research, it was necessary to gather data about technical characteristics of the most frequently used forwarders in Croatia, but also around the world. The morphological analysis, which was the basis for classification of forwarders into classes, was performed. Three classes of forwarders were obtained after cluster analysis and the most important factor appeared to be load capacity. Study of machine work was carried out on 30 research sites. The classic method of time study (snap-back chronometric technique) was used. During recording process, data of forwarding influential factors (stand and terrain conditions) were collected.
After analysis of collected data, it was determined that forwarding productivity depends on class of the forwarder, average extraction distance, load characteristics, terrain and stand conditions. Regression analysis identified the time consumption of the individual work components, and productivity model for forwarding was developed.
The obtained model was implemented into the application HsPPI. This is a part of information system developed by IT department of the state enterprise "Hrvatske šume" d.o.o. and is used for production planning in timber harvesting. The system is based on dBase IV databases and two main program modules. The main parts of the system are: tree marking plan, assortment structure plan, production plan (felling, processing and extraction) and sales plan. Within a part of the production plan there is a module for calculating productivity norms for timber forwarding.

Keywords: forwarder; productivity norms; planning; lowland forests, Croatia

1 Introduction and problems

Forests in Croatia are diverse due to the terrain, climatic and management conditions, as well as due to the different tree species. Four large relief areas can be identified: lowland, hilly, mountainous and karst area. The total forest and forest land area in Croatia amounts to 2,688,687 ha, which is 47% of the continental area of the state. Out of the total area, 2,106,917 ha are in the state possession, while 581,770 ha are owned by the private forest owners. The largest part of state-owned forests and forest land (2,018,987 ha) is managed by the state trade company "Hrvatske šume" d.o.o. (HŠ, eng. "*Croatian Forests"* LLC).

The lowland area of forests and forest land owned by the state amounts to something more than 322 thousand ha (Pentek et al., 2011). According to some authors, lowland forests form 25% of the total high forests area (Krpan, 1996). The lowland forests are of the particular importance for this research, as forwarders are mainly used in this part of Croatia only. Lowland forests consist of forest stands of the pedunculate oak, narrow-leaved ash, black alder, willow and poplar. Annual removal amounts to more than 1 mill m³ of wood (Anon., 2011). The figures might not be impressive, however, wood from these forests (pedunculate oak) has been achieving high prices on the roundwood market, which is where the importance of the lowland forests can be seen at its best.

Regarding the economic value of wood, high selective and regular forests are the most valuable in the Republic of Croatia. In the case of selection forests, timber is felled and processed by the motor-manual method, by use of power chainsaw for felling and processing, while skidders are used for the primary transport of timber to landings (Sabo and Poršinsky, 2005). Due to the satisfactory primary and secondary forest openness, there is no need for forest skylines. In the case of selective forests, by development of forest stands, the harvesting systems wouldn't be changed.

On the other hand, in the case of growth of the even-aged forests, different harvesting systems are implemented within the management procedures. Felling and processing are regularly done motor-manually with use of power chainsaw. Skidders and forwarders are used for timber extraction, whereas the use of the farm tractors with winch and farm tractors with semitrailer has been reduced (Krpan, 1996). In the lowlands skidders are used for wood extraction after early thinnings, and in the hilly areas after the main fellings. Forwarders are implemented mainly in the lowland forests for the extraction of timber from main fellings and from late thinnings (Poršinsky, 2002).

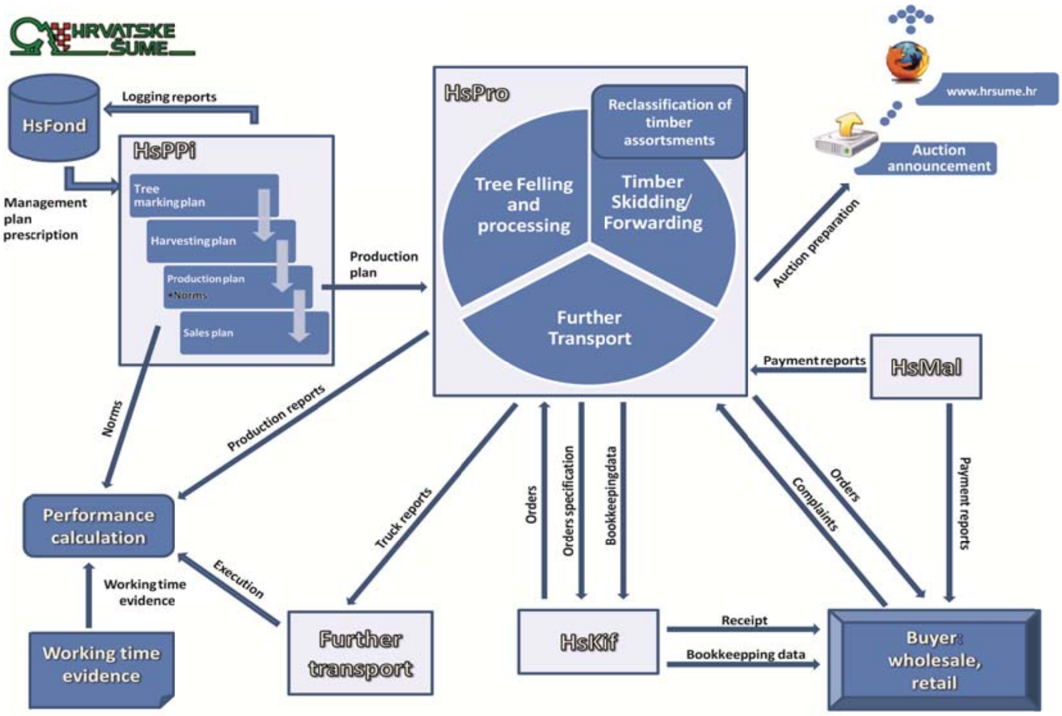

Figure 1: Production information subsystem of the state trade company "Hrvatske šume" d.o.o.

From all that was mentioned can be seen that harvesting operations in Croatian forestry have not been fully mechanized. Tree felling and timber processing are mainly done motor-manually. This has been predetermined by natural factors (natural forests, large tree dimensions, significant share of broadleaved species etc.), but also by traditional harvesting systems (Bojanin and Krpan, 1997). On the other hand, roundwood extraction and further transport has been fully mechanized. The production of timber assortments has been completed by the matching information systems that are used for monitoring and recording of the timber assortments production on the part of the state company HŠ. The information system has been continuously developing for twenty years, since the founding of the company, and it is a work of own development program of the company's IT Department. Since the beginning of the development, the basis of the system form personal computers with programs made in computer language FoxPro 2.6 For DOS (dBase IV as database). Although the computerization of the company has gone a long way from those times on, a part of these programs and FoxPro2.6 as program language are still being used, while new programs are being developed for Windows operating systems in Visual FoxPro 9.0 and on .NET platform with MS SQL database.

A part of the information system of the company Croatian Forests is the production subsystem by which all the timber harvesting processes from production planning to making out of bills to buyers are being monitored. *HsPPI* and *HsPro* are important parts of this subsystem. *HsPPI* refers to the production planning, while *HsPro* refers to the monitoring of timber assortments production.

As shown in Figure 1, the basis of the information flow is in the forest database *HsFond* that basically represents digitalized Management plan prescriptions. One of the factors is the Harvesting plan, which represents the beginning of the production planning. On that basis, the harvesting (sub)compartment is being selected, tree marking plan is prepared, distribution of marked trees is entered, harvest is planned out, cut block is established, the technology of timber processing is chosen along with the production plans where the felling and processing norms, as well as the primary transport, have to be determined.

At the end of the planning process, the sales plan is being developed. All these processes are carried out within the *HsPPI* application that HŠ is using for the production preparation within harvesting.

2 Materials and Methods

2.1 Classification of forwarders

A good knowledge of forwarders as instruments of labor in the forestry production is of a crucial significance. Many research methods are already known, from those that determine borderline usability, to those that study the historical development of its construction. One of the studying methods for the machines used in forestry is the morphological analysis based on the selected geometrical, mass and other factors, on which basis dependencies are calculated and opinion on validity of machine selection is made (Poršinsky, 1997). One of the first morphological analyses of machines was carried out by Bekker in 1956 (Sever, 1980). During time the method was widely accepted and is used even today for evaluation of forestry machines or tools like hydraulic cranes (Šušnjar et al., 2007), power chainsaws (Poršinsky at al., 2008) or farmer winches (Šušnjar and Borić, 2008).

In the Croatian forestry the following forwarders are used most frequently: Timberjack 1210, Timberjack 1410, Timberjack 1710, Valmet 840.2 and Valmet 860. Modeling of productivity for each individually would be cost-ineffective, so it was necessary to group them in classes and analyze them on that basis. Many forwarder classifications are already known, according to which they are classed according to net mass, load capacity or gross mass (vehicle + load, Poršinsky, 1997). In the literature there is the newest forwarder classification by their loading capacity to light (<10 t), medium (10 t – 14 t) and heavy forwarders with capacity over 14 t (Brunberg, 2004). As a basis for grouping vehicles in classes in this case the morphological analysis of forwarder families according to their numerical values (dimensions, mass, load capacity etc.) will be used. The data have partly been taken from obtained and adapted databases, as for the vehicles of new generation (Lugmayr et al., 2009), like for vehicles of older production date (BWF, 2003), and for vehicles from the nineties of the past century from previous publications (Poršinsky, 1997).

2.2 Assortments characteristics

The Croatian lowland forests are characterized by great variety of stand conditions. There is a wide range of tree species, from willows and poplars, over black alder and narrow-leaved ash, to pedunculate oak and common hornbeam. The area is characteristic by the assortment method of processing, with forwarding as a special way of timber extraction. The assortment volume is important for obtaining the correct mean load volume figures that impact the forwarder productivity. The aim was to obtain mean assortment dimension, so it was formed on the basis of trees taken from the marking data, that is by connecting the data from two applications of the information production subsystem *HsPPI* and *HsPro*. Data on marked trees to be felled and data on processed timber assortments in the work yards were collected for those yards where the extraction has been carried out with forwarders over the last couple of years (Figure 2.).

Data on tree species whose share in the lowlands is low (fruit trees, common maple, lowland elm, walnut etc.) were left out from the analysis, as well as cutting blocks with small number of samples. 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. The goal of the analysis is to determine the mean assortment volume, mean diameter and length from the volume of marked tree by the tree species. The stated is necessary to determine the productivity of forwarders in this system of harvesting.

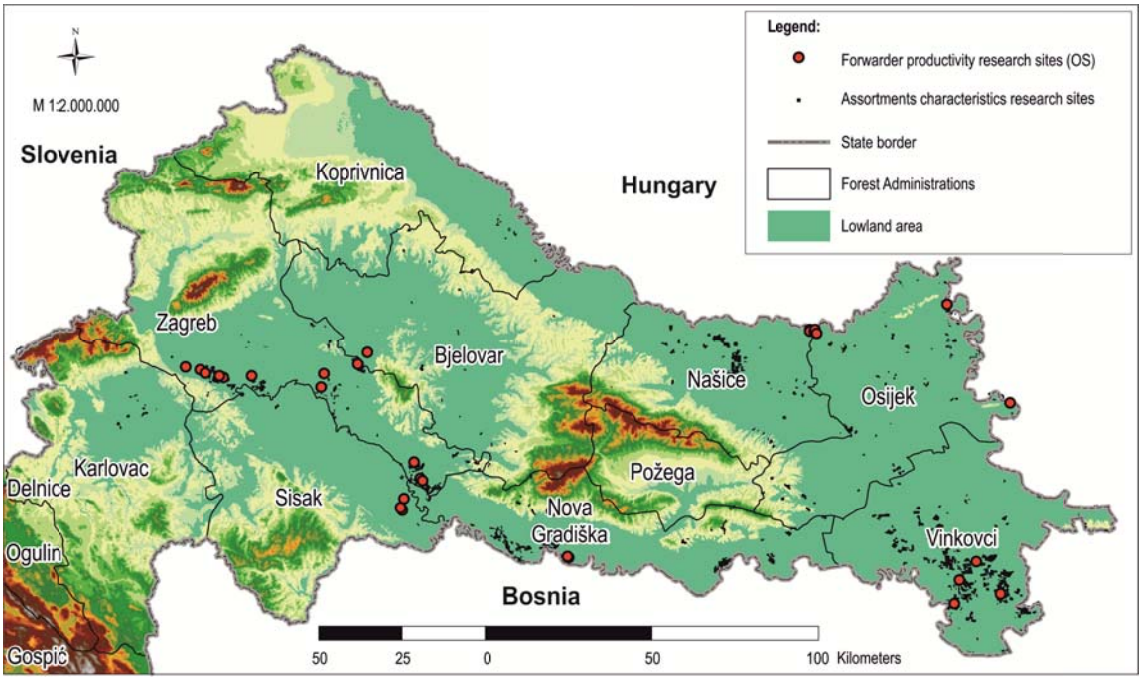

Figure 2 Research sites of forwarder productivity and timber assortments characteristics

2.3 Forwarder productivity

The research of forwarder productivity was carried out in the area of Croatian lowland forests (Figure 2.). In this research, term Object of Study (OS) is used, which refers to individual stand, that is the compartment/sub-compartment where harvesting is carried out. Raw data for productivity analysis were taken from the previous publications of a total of 30 objects; 5 OS (Poršinsky, 2000) + 3 OS (Poršinsky, 2005) + 22 OS (Stankić, 2010).

The research of the machine work is based on the time and work study. The basis is the of work and time study, division of work process or work phase into consisting parts of the shortest possible time duration, that still can be measured precisely enough. Contemporary approach to time study presupposes the implementation of analytical measuring methods, whereby work process is divided under particular schemes into work components with the goal of synthesis during data and results processing.

Extraction of timber by forwarders has the characteristics of the cyclic work. Each cycle (turn) consists of four main cyclic work components (unloaded traveling, timber loading, loaded traveling and unloading of timber), plus work pauses or time consumptions whose character isn't cyclic, but periodic.

Forwarder productivity is modeled by the following module:

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

Study of forwarder work time was carried out by snapback method, using manual digital chronometer. Besides the time study, data on all work process impacting factors were collected. Forwarding distance was measured by hand GPS devices. In order to obtain the forwarder performance, 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, whereby data on tree species, mean diameter and length were entered into a corresponding form. The ground bearing capacity was determined for each individual cycle, by visual estimate of the recorder. Bearing capacity of soil was studied in line with the modified classification of ground bearing capacity that was already used in similar form within research of machine performance in areas of the Croatian lowland forests (Poršinsky, 2000). Under this classification, forest soils were classified into following load-bearing groups, and it was applied in further analyses:

⇒ 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. By single pass of a vehicle, the tracks depth amounts less than 5 cm, and by multiple passes the depth amounts up to 25, maximally 30 cm. When walking on such soil, shoe soles are dry or humid.

⇒ 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. Sinking of vehicles into the ground and slipping of wheels are recorded, speed of vehicles is reduced, and after single pass, the mineral layer of the soil can be exposed. Implementation of semi-tracks on the rear wheels of bogi axle and chains on the front wheels of single axle is recommended to obligatory (in extremely unfavorable conditions).

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.

3 Results of the research

3.1 Forwarder classification

Forwarder analysis was carried out in the program package Statistica 08. In this analysis, the following vehicle morphological values were used: length, width, height to the cab roof, clearance of the vehicle from the ground, mass, payload, reach and lifting moment of the hydraulic crane. For those values whose data weren't existing in the established database, substitution was made with the value of the arithmetic mean of the individual variables. Through a thorough consideration of the disposable data on morphological characteristics of vehicles, the connection of the vehicle mass with the most of other values is evident (Table 1.), which is logical due to the fact that existence of mass determines the occurrence of other features. Vehicle mass is mostly correlated to the power of the engine and to payload and it is the key parameter, which all other forwarder characteristics except the hydraulic crane reach are dependent of. If the mass value increases, all other vehicle characteristics increase, too.

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

Payload (PL, load weight, load capacity) is one of the most important exploitation characteristics of forwarders. By reviewing the vehicles' technical characteristics database it can be determined that mass and load capacity of forwarders are approximately the same. 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 k-mean algorithm was used for grouping of forwarders. This algorithm assigns each item to the group whose centroid is closest to it. Centroid is a point created by calculating the arithmetic mean for each dimension, separately for each items in the group. By implementing the mentioned algorithm, grouping of data into groups based on PL was made. 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.

As it is obvious that increase of PL in the forwarder family results with the increase of other studied dimensions, it can be concluded that there are three forwarder classes – light, medium and heavy forwarders. In line with the performed classification it can be determined that light forwarders are not implemented in the Croatian forestry. Therefore further research will be focused on the medium and heavy forwarders. Timberjack 1210 and Valmet 840 fall into the class of medium forwarders, whereas Timberjack 1410, Timberjack 1710 and Valmet 860 are in the heavy forwarders class.

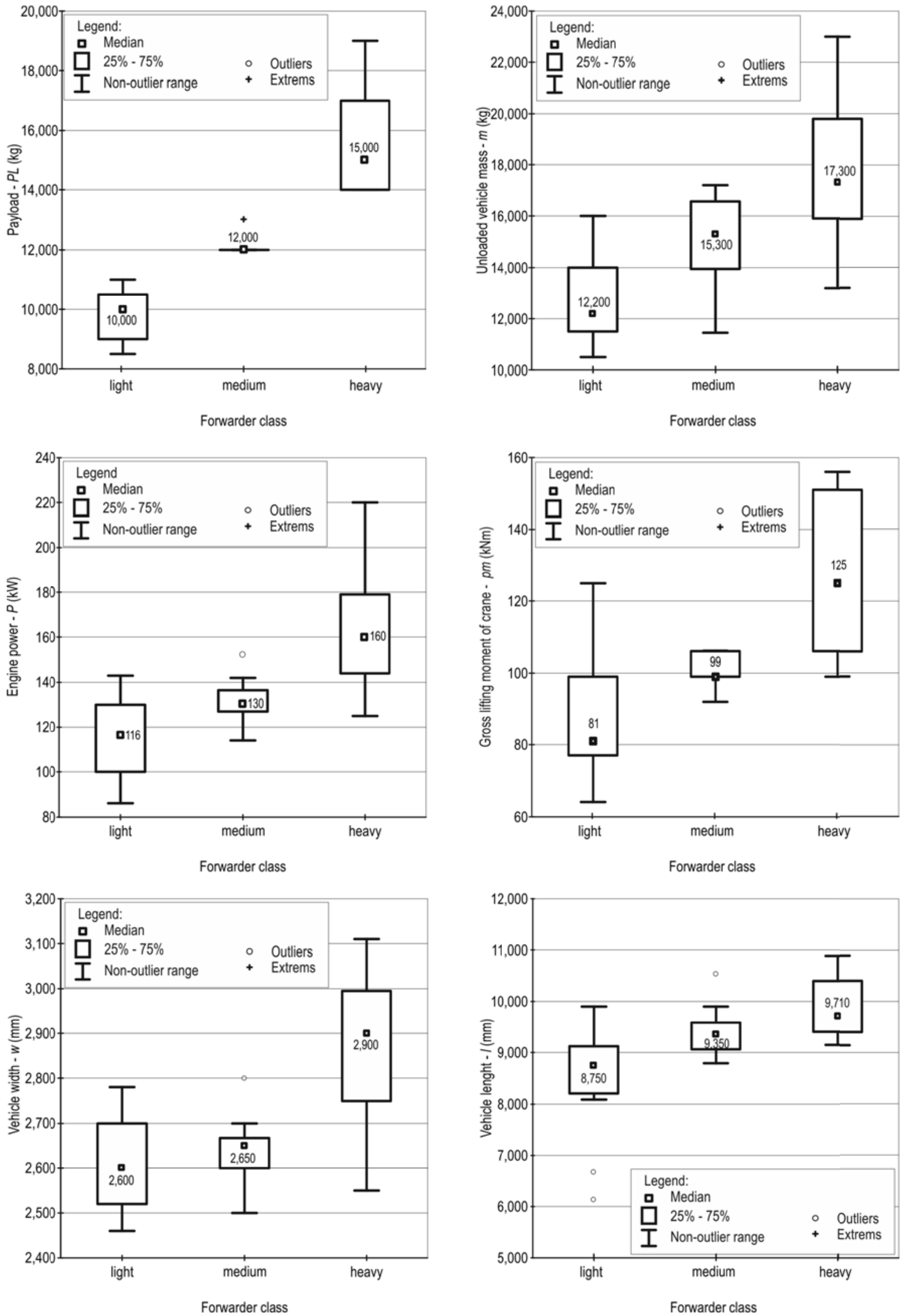

Figure 3: Some of the technical features according to forwarder class

3.2 Characteristics of assortments and vehicle load

In order to gain insight into the load characteristics (mean volume and mean diameter), 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*). Work sites were situated in the area of the Croatian lowland forests, and they are characterized by motor-manually felling and assortment method of timber processing along with the timber extraction by forwarders.

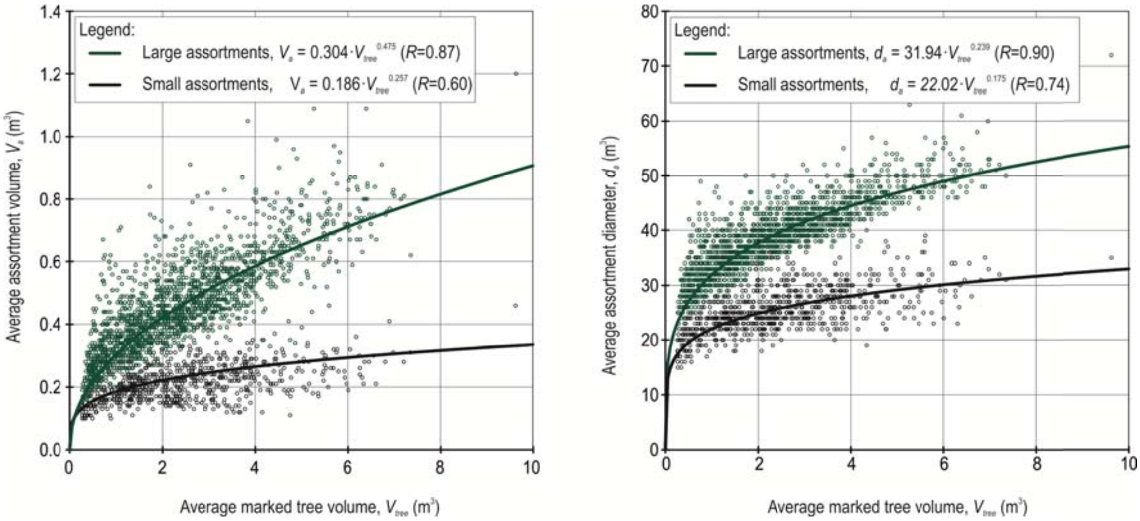

Figure 4: Characteristics of roundwood from lowland forests

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. With both assortment groups a large dissipation of raw data is demonstrated, which is a consequence of buck-to-quality (BTQ) and assortment method of timber processing.

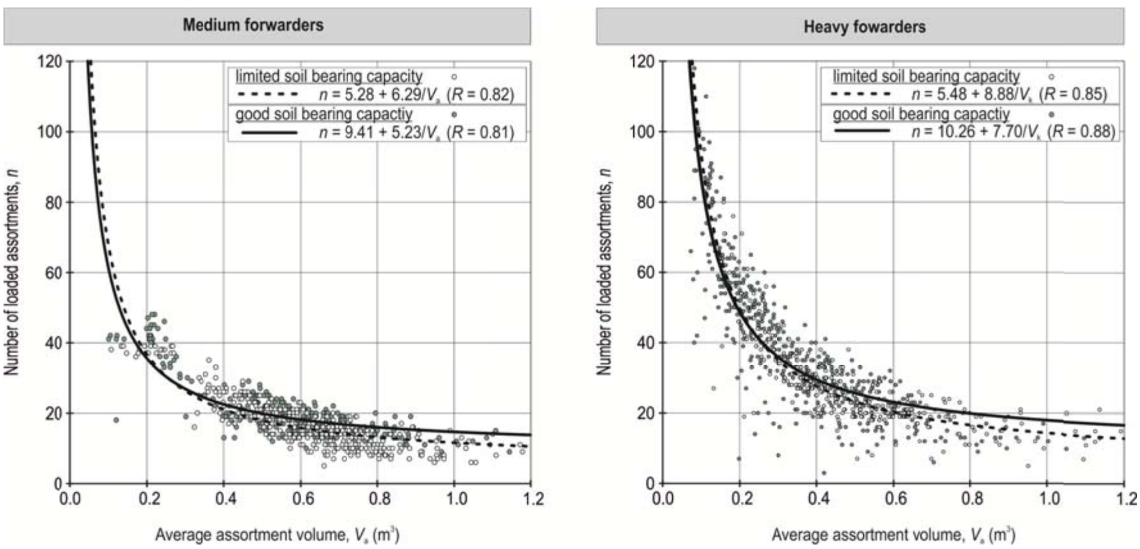

Figure 5: Number of roundwood pieces in the bunk area of forwarder

Dependence of the number of loaded assortments on the decrease of soil bearing capacity has been determined (Figure 5.). By decrease of soil bearing capacity, the number of loaded roundwood assortments is reduced as well. In some cases there was found the overload of forwarder in the conditions of limited soil bearing capacity, with the aim to increase productivity in spite of decrease of vehicle speed. This can be explained by the subjective influence of some forwarder operators and their overloading of the vehicle in the unfavorable conditions, all with the goal of increasing the work efficiency. Reduction of loaded assortments in conditions of reduced soil bearing capacity was more expressed with the large than with the medium size forwarders.

The analysis that was carried out, that is the modeling of the mean assortment volume, is the input indicator by determining the further load characteristics. One of the more important parameters is also the number of loaded assortments (Figure 5). The product of mean assortment volume and number of assortments gives the load volume ($V_T = V_a \cdot n$).

3.3 Modelling of the forwarder productivity

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

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 (Table 2.). Medium size forwarders have a better movability 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.

Table 2: Forwarders' speed

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.

Timber loading time consumption

Timber loading time covers time of forwarder's work in the felling area during loading, and this variable is characteristic for not changing with the change of the forwarding distance. Forwarder's work in the felling area starts with the end of the unloaded vehicle's drive, in other words, on the spot of the first loading. After processed assortments loading within the reach of the hydraulic crane, forwarder moves towards the next loading place, and continues doing so until reaching the optimal load. During timber loading (t_U), two significantly different groups of work components can be detected ($t_U = t_{UD} + t_{UP}$, Figure 6.):

⇒ 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.

Time consumption of timber loading by the hydraulic crane is dependent on the forwarder class and the number of loaded assortments. The recorded data are equalized by a linear model line from the source. 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). Relocation time consumption is higher within the group of heavy than medium forwarders. This is due to the fact that most of the medium forwarders have larger hydraulic crane reach, as they are equipped with the fourth (boom extension) arm.

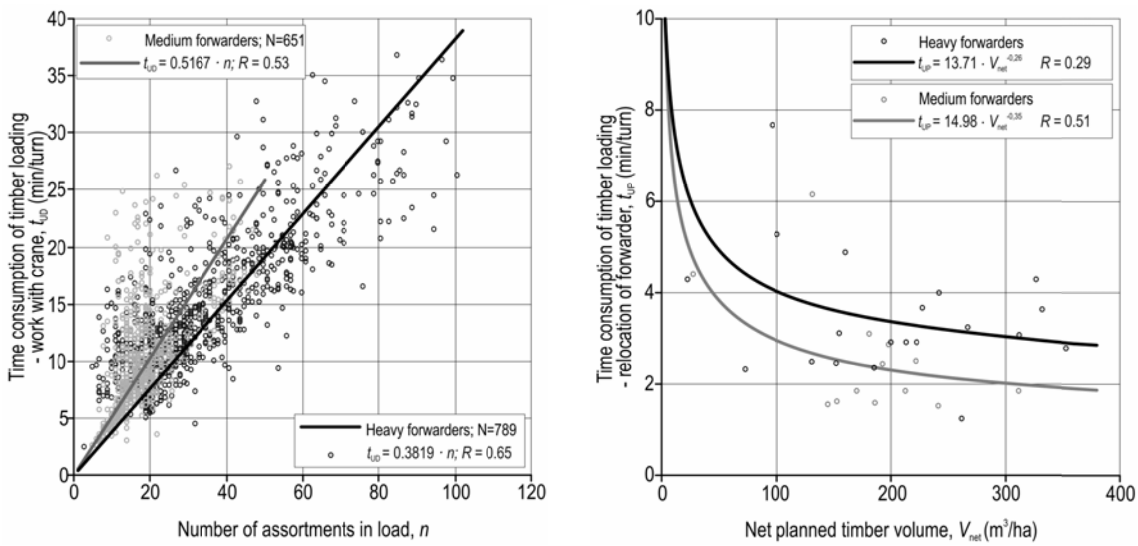

Figure 6: Timber loading time consumption

Timber unloading time consumption

With the end of moving of the loaded forwarder starts its work on the roadside landing with the goal of unloading, stacking and sorting of timber. 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. During unloading, the operators have classified the timber according to tree species and quality classes, piling the unloaded timber onto separate stacks. The regression curve of recorded data are shown in Figure 7. The asymptotic model was used. Noticeable is the increase of time consumption of crane unloading with reference to the increase of number of loaded assortments. It is decreased with the larger number of loaded assortments of smaller mean volume. This is explained by the fact that when unloading, the crane grips two or more pieces of roundwood assortments.

The absence of wood classification and relocation has been noticed on a smaller part of observed research sites. This was conditioned by the stand characteristics (pure stands), silvicultural measures (type of cutting), type of processing firewood, quality and dimensions of assortments and landing space. In the cases when timber was sorted on the roadside landing, higher time consumption of this work component was recorded. Mean time consumption for heavy forwarders was 0.84 min/turn, whereas the medium forwarders it amounted to 0.73 min/turn. This phenomenon is explained with the higher initial acceleration of medium forwarders. The sorting of assortments at the roadside landing has impacted on the decrease of forwarder efficiency in relation to its efficiency when not performing the timber separation when unloading. By the increase of forwarding distance, negative effect of timber separation on forwarding efficiency is diminished, due to the growth of vehicle relocating share in the total cycle time.

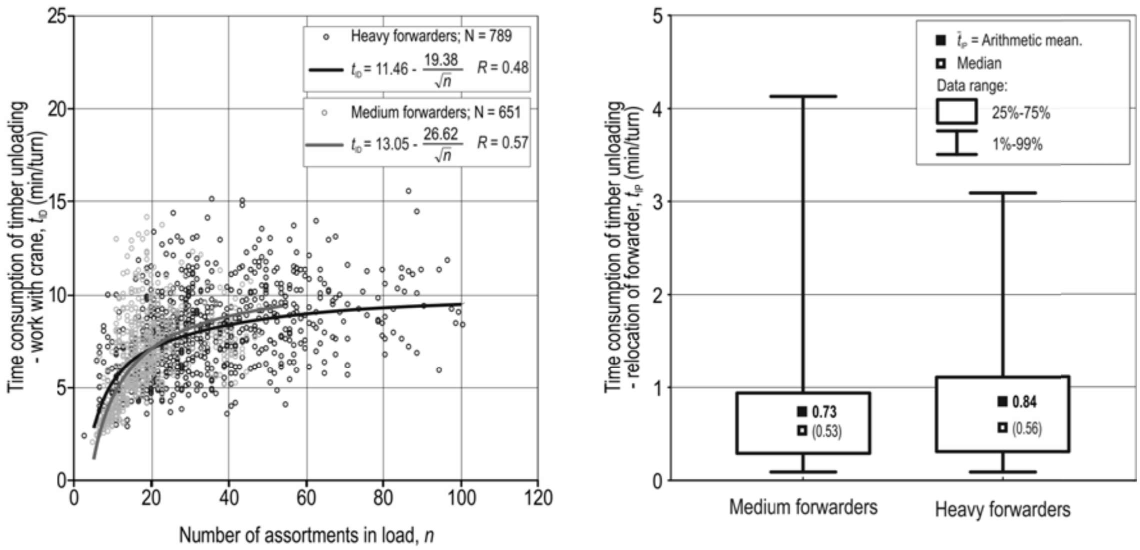

Figure 7: Time consumption of timber unloading

General times (delays, downtime) and additional time factors

Downtime (delays, general time) consist of unavoidable and avoidable of work 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. Vehicle breakdowns that cannot be eliminated without the intervention of a mechanic are also included into the avoidable delays. Avoidable and unavoidable delays were taken into analysis together and shown in Figure 8 (left).

The additional time and the additional time factor are determined through analysis of unavoidable delays only. By the executed study it was determined that the additional time factors vary in a wide range, that they are bigger than in previous studies and that their value decreases in relation to the higher forwarding distance. The additional time was determined for each individual site (Figure 8, right). The mean additional time factor value amounts to 1.33, that is 33% of the effective time. Considering the structure of the additional time, it can be determined that the preparatory time takes up 33%, occasional works 33%, and personal breaks 33% of the total unavoidable delays. The increase of unavoidable delay share within shorter forwarding distances can be explained by the greater fatigue of workers (forwarder operators), as in such cases the timber loading and unloading time share increases in relation to the travelling time.

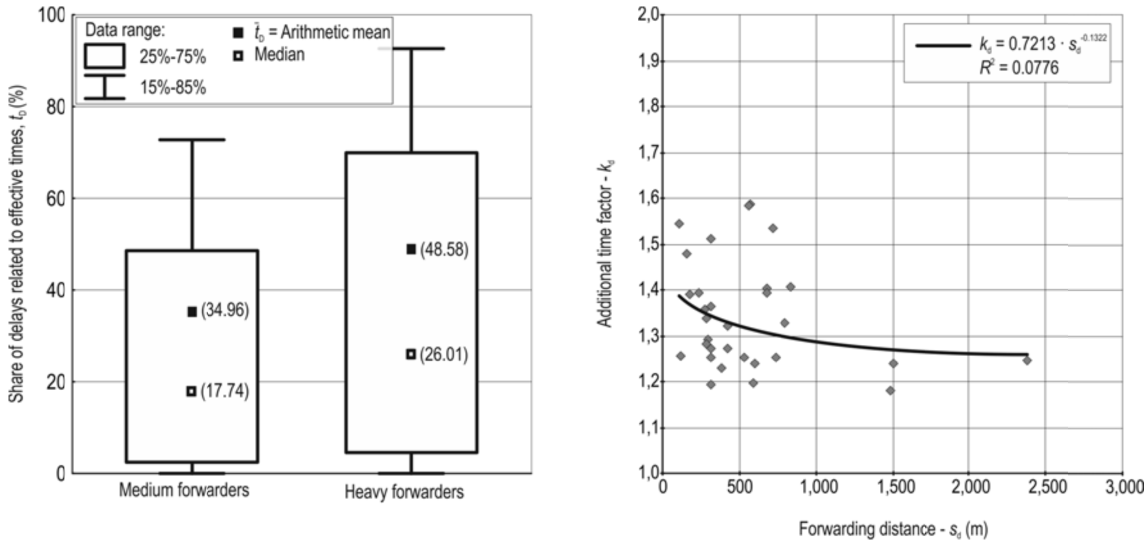

Figure 8: Share of delays in relation to effective time and additional time factor

4 Implementation of the model into the information system

One of the components of production planning process is the determination of norms for felling and processing, as well as for timber extraction. The existing norms (official and still in use) are inherited from times before the company HŠ was founded (before 1990), and there are still a couple of regional systems functioning.

In order to unify the norm system on the level of the company, "new norms" as a result of work of the Forestry Faculty (project bearer) and HŠ (project investor) were created. New norms have been integrated into the *HsPPI* program (Figure 9). Determination of norms starts with the selection of the management unit (*Gospodarska jedinica*) and type of yield (*Vrsta prihoda*), followed with the list of the marked compartments/subcompartments from the Management Plan with all the data needed for norm calculation. Those are: type of yield (*Prihod*), silvicultural form (*Uzgojni oblik*) and total area of the compartment/subcompartment (*Površina*). For each compartment/subcompartment from the list there is norm calculated for individual work phase, and this is made by selecting tabs: "Felling and Processing" (*Sječa i izrada*), "Extraction – Skidders" (*Privlačenje - Traktori*) or "Extraction – Forwarders" (*Izvoženje - Forvarderi*).

The first step in the norm calculation process is the calculation of felling and processing norm, due to the fact that by selecting the work method, the final assortment structure is obtained, for whose extraction the norm is to be developed. From other data necessary for the development of forwarding norms, a part is taken from the Felling Plan (main tree species – *Glavna vrsta*; volume of mean stand tree – *SKS;* net marked wood volume per unit of area – *Neto doznačeno*), while other parameters are entered (Figure 9):

⇒ machine type (*Tip stroja*),

⇒ equipped with semi-tracks (*Upotreba polugusjenica*),

⇒ soil-bearing capacity (*Nosivost tla*),

⇒ forwarding distance off-road (*Srednja udaljenost kretanja vozila po bespuću*)

⇒ forwarding distance on the forest road (*Srednja udaljenost kretanja vozila po pomoćnom stovarištu*).

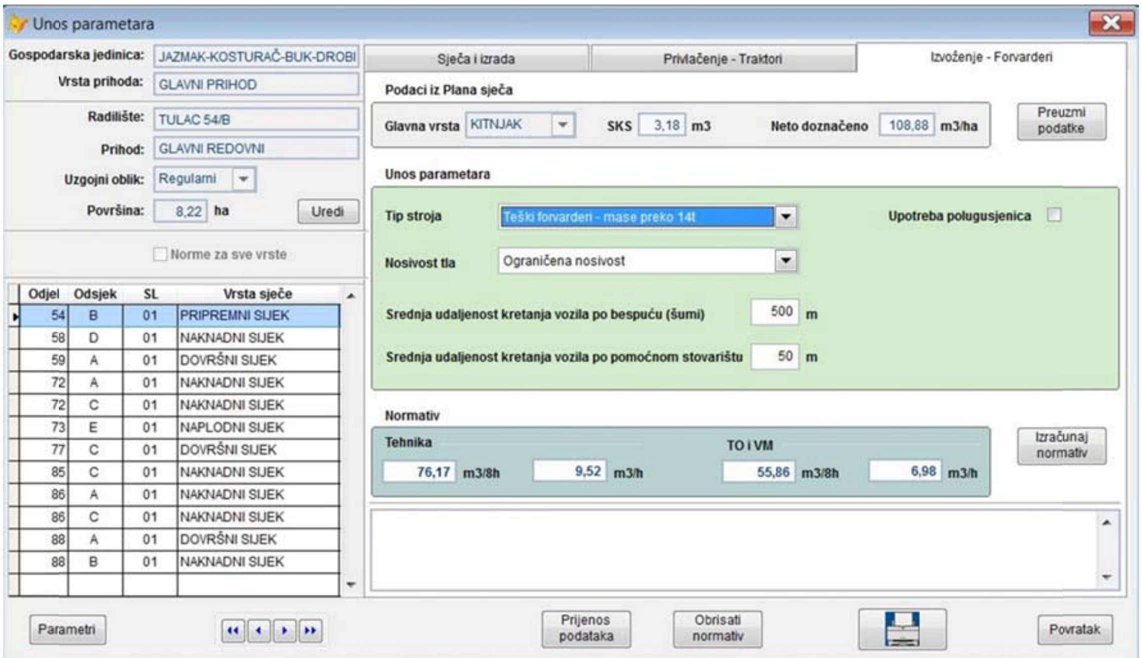

Figure 9: Screenshot of tab for norm calculation for forwarders in *HsPPI*

Output data are norms for large (*Tehnika*) and small assortments (*TO i VM*) per hour and per workday (8 hours) for selected work conditions.

Through a thorough analysis carried out by forestry experts it was established that the productivity model presented in this study plans higher norms and decreased delay times than the existing ones (Tomić, 2007).

5 Conclusions

The research that was carried out covered the analysis of the factors impacting on forwarding, as a special aspect of primary transport of timber in the lowland forests of the Republic of Croatia. Characteristic of the timber harvesting systems in the area is that felling is performed motor-manually and timber is processed by power chainsaw, timber is bucked according to its quality, and extraction of timber to roadside landings is fully mechanized. The method used is not classic cut-to-length (CTL), but buck-to-quality (BTQ) method.

Aiming to develop an operatively implementable system of timber forwarding planning, division 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 for all the species represented in the lowland forests. The data were gathered by joining together two 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).

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, and it does so primarily through its payload, or possible load volume, but also through its speed and time consumption during loading and unloading.

⇒ Diminished levels of timber extraction by forwarders are influenced by conditions of soil-bearing capacities off-roads through increase of time consumption of forwarding, that is by the speed drop and lesser load volume.

⇒ Use of semi-tracks, which insure the movability of forwarders in unfavorable conditions, additionally impact the drop of speed, which increases the time consumption of forwarding.

⇒ Increase of the forwarding distances diminishes forwarder's productivity, as the share of the time spent moving grows within the structure of the total time consumption of the work shift. However, the influence of distance on the forwarding productivity should be viewed 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

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