Skidding Machines Allocation (SMA) Using Fuzzy Set Theory

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Abstract – Nacrtak

Efficient allocation of resources is an essential principle in forest management. An important case in resource allocation is when the available resources are not sufficient to service all requests. One of the key elements in forest management is to minimize the total costs of the unallocated requests. With respect to high capital cost of forest operation machinery, it is necessary to reduce expenses of one cubic meter of wood extraction by appropriate Skidding Machines Allocation (SMA). Fuzzy set theory as a soft methodology and practical decision support system was used to handle uncertain variables and vague range of logs volume and physiographic conditions to develop models.

The aim of this research is to present a decision support method to determine the economical activity zone of forest operation machines so that this allocation would result in the highest net profit for forest managers. To achieve this goal, all skid routes in the study area were divided into work units with 75 m width and 200 m length whereupon 379 units were formed collectively. Within each unit, the related mathematical productivity models were applied to estimate one cycle time and cost of machines. The effective factors of these models included Skidding Distance (SD), Volume of Logs per Cycle (VLC), and Number of Logs per Cycle (NLC). Three separate fuzzy inference models were developed to predict the skidding cost of each machine in the units, and then proper machines were allocated. 70% of data was used as training and the rest was feed to the models for validation and test process through the generation of fuzzy models. Membership functions and fuzzy rule bases were created with the help of scientific knowledge, experts' viewpoints and existing machine productivity models. The results showed that the application of the presented approach helps forest managers to recognize the desirable conditions for skidding machines to reduce the total costs of skidding. In addition, SMA fuzzy rule-based models reflect how to integrate expert knowledge with engineering system design. To present an illustrative example, the models were applied to allocate three commonly used Skidders, i.e. Timberjack 450c, HSM 904, and Zetor, in a mountainous forest, whose inventory data were known and harvesting was planned for the next period. The results showed that the Zetor was the most economical option in »Very short« and »Short« (< 300 m) distances at all levels of NLC and VLC, while HSM 904 was the most cost effective machine at »Medium«, »Long« and »Very long« distances (300 m to 900 m) at all levels of NLC and VLC with the exception of »Long« distance units (around 700 m), with »Low« NLC (2 pieces) and »Low« VLC (around 4 m^3), as well as the units with »Very long« distance and »Low« and »Medium« volume (less than 5.5 m^3), where Timberjack 450C was the most adequate machine from the economic point of view. The result of this application also showed a spatial variability in skidding costs by different machines based on skid route conditions. The implemented method can be very helpful in where and how to use skidders to gain maximum profit from forest operations.

Keywords: Log extraction, Time study, Resource allocation, Fuzzy rule-based modeling, Skidding cost, Forest harvesting

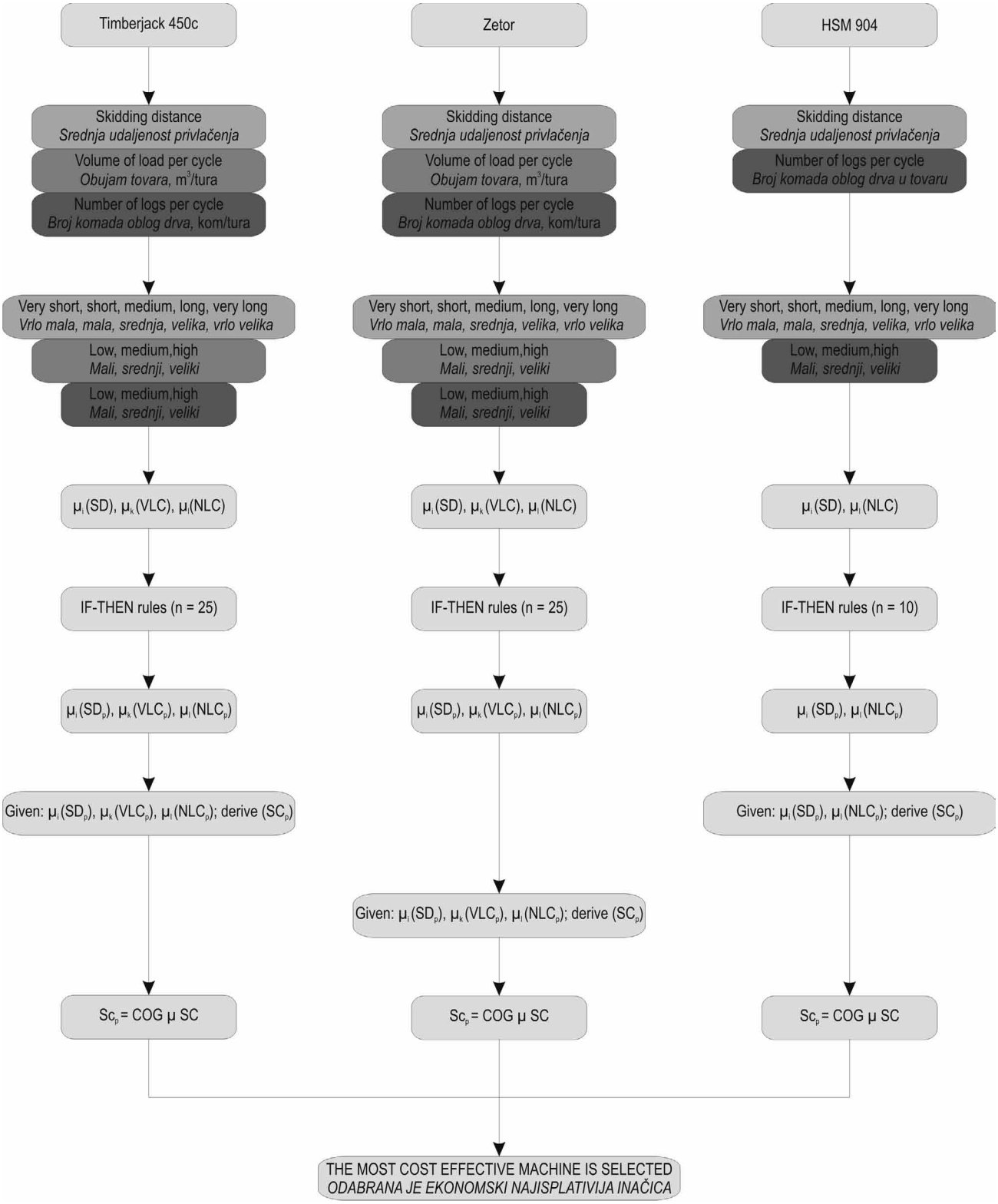

Fig. 1 Diagram of steps of the SMA models including approximate reasoning to assess machines location suitability based on input variables (SD: Skidding distance, VLC: Volume of load per cycle, and NLC: Number of logs per cycle).

Slika 1. *Planiranje rada skidera pomoću neizrazite teorije (ulazni podaci: srednja udaljenost privlačenja, obujam tovara/tura, broj komada obloga drva u tovaru)*

1. Introduction – *Uvod*

Forest planning and management are a complicated proposition in many mountainous regions where there are varieties of physiographic factors. A basic requisite for effective management of felling site in a wooded area is the knowledge of the suitability of the machine to be used in various operations. (Curro and Verani 1990). Machine assignment is an important task during the tactical phase of forest management planning, in which managers can accommodate field activities to obtain maximum efficiency. They have to know where and which skidders must be applied to remove logs from stump to road with the lowest cost. To achieve this aim, initially, forest managers have to know machine productivity model and cost to identify economic zones of each machine. Machinery allocation could be done based on these information and company limitations.

In real world, skidder allocation is usually done based on experiences and budget, while the main aim of this approach is log extraction in a given time, however there is no guarantee for the lowest skidding cost. In traditional logic, inputs are assumed to be unambiguously defined attributes and all inferences are based on clear threshold of class inputs, while most concepts in forest operations cannot be defined precisely or have clearly characterized boundaries in space and time. The analyses of such data entail a technology that applies both intuition (expert knowledge) and engineering heuristic to enhance model-based system designs. To combine knowledge, techniques and methodologies from various sources, an intelligent system that could consider the vague data for inference is needed. In fuzzy logic proposed by Zadeh (1965) by using the elements of everyday language for representing the desired system behavior, the need for rigorous mathematical modeling is circumvented. In fact the theory of fuzzy sets provides a more realistic mathematical representation of the perception of truth than traditional, two-valued logic and Boolean algebra (Hasan et al. 2008). Most former studies were focused on assessment of cost, production and environmental effects of machinery (Adebayo et al. 2000, Ledoux and Huyler 2001) while skidding machine allocation had received scant attention from researchers.

The main objective of this paper was to design three fuzzy models to estimate economical activity zone of three types of commonly used skidders. These models could serve as decision support systems during the tactical planning phase of forest management planning. To provide an example of model output an analysis was conducted on approximately 7323 ha of mountainous forest of northern Iran. The final result of these models is demonstrated as a map in which economical zones of each skidder are shown in detail.

2. Methods –*Metode*

The following steps were made to build the Skidding Machine Allocation (SMA) models:

- ⇒ Identifying work units and determining cost effective input variables,
- ⇒ Planning a fuzzy system including linguistic values, membership functions, fuzzy rule bases and method of defuzzification for each machine,
- ⇒ Evaluating models performance by Neuro-Fuzzy training and validating,
- ⇒ Computing crisp output skidding cost (SC) for each of the three machines in each unit.

2.1 Identifying work units – *Utvrđivanje radnih jedinica*

To determine work units assigned to a machine, a buffer zone of 75 m width and 200 m length was delineated on both sides of skid routes. These buffer zones were assumed as work units of skidders (Fig. 2). The work units map was created using ArcGIS ver. 9.3.

2.2 Cost effective input factors – *Čimbenici koji utječu na trošak strojnoga rada*

The factors affecting positively skidding costs were calculated or estimated in each unit. To establish factors that affect time and consequently the cost of wood skidding from each unit to the landing (road), mathematical models of machine productiv-

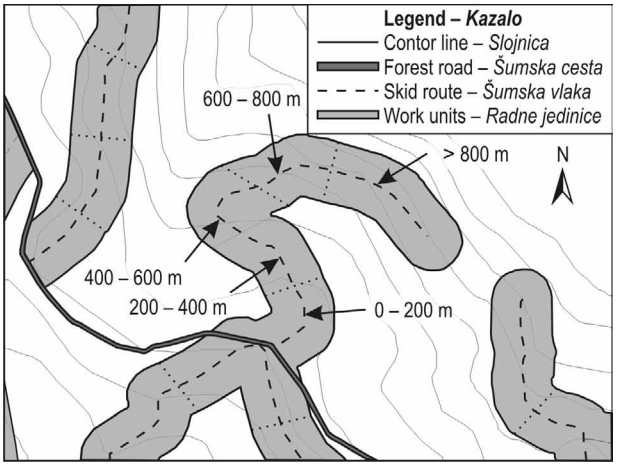

Fig. 2 Forming work units
Slika 2. *Radne jedinice*

Table 1 Linguistic values used in the SMA models

Tablica 1. *Pretvorba vrijednosti u jezične varijable neizrazitoga modela za planiranje rada skidera*

Variables – *Varijable*	Linguistic values – *Jezične varijable*				
Skidding distance, m *Srednja udaljenost privlačenja,* m	Very short *Vrlo mala*	Short *Mala*	Medium *Srednja*	Long *Velika*	Very long *Vrlo velika*
	0 – 200	200 – 400	400 – 600	600 – 800	>800
Number of logs per cycle *Broj komada obloga drva u tovaru,* kom.	Low – *Mali*		Medium – *Srednji*		High – *Veliki*
	2		2.5		3
Volume of load per cycle, m^3 *Obujam tovara,* m^3	Low – *Mali*		Medium – *Srednji*		High – *Veliki*
	3.8		5.8		6.9

ity were used. These models were developed based on time study technique, and then the effective factors in productivity of machinery were identified accordingly. Multiple linear regression models were used to predict skidding cycle times. The number of logs per cycle and volume of load in each unit were estimated using inventory data.

The following mathematical models of productivity were calculated in previous time studies carried out in mountainous forests.

$$F_{(t)} = 4.142 + 1.988N + 0.01769D + 1.093V \quad (1)$$

Timberjack 450c (Jourgholami 2008)

$$F_{(t)} = 1.3789 + 0.0537D + 0.039N + 0.032L + 0.39V \quad (2)$$

Zetor (Najafi 2005)

$$F_{(t)} = 1.873 + 0.02494D + 2.499N \quad (3)$$

HSM 904 (Najafi 2005)

Where:

$F(t)$ time of one cycle hauling, min
D distance of loading, m
N number of logs per cycle
V volume of load, m^3
L winching length, m (25 m)

Skidding distance, number of logs per cycle and volume of load had a significant influence on the time of wood extraction with all machines. The reality fuzzy inference model was based on these effective factors.

2.3 Defining linguistic variables and values – *Utvrđivanje jezičnih varijabli i vrijednosti*

In fuzzy logic, prototypical linguistic rules of a fuzzy model are formulated by use of linguistic variables instead of quantitative variables. For instance if the »skidding distance« (SD) is a linguistic variable, its corresponding term set would be T (SD) =

Table 2 Part of rule bases applied for building the overall models of Timberjack 450C & Zetor

Tablica 2. *Dio modela neizrazitoga skupa za skidere tipa Timberjack 450C i Zetor*

	IF – *Ako*			THEN – *Tada*		
	Distance *Srednja udaljenost privlačenja*	Number *Broj komada obloga drva u tovaru*	Volume *Obujam tovara*	DoS Stupanj podrške pravila	Skidding Cost of Zetor *Trošak strojnoga rada za skider Zetor*	Skidding Cost of Timberjack *Trošak strojnoga rada za skider Timberjack 450C*
1	Very low *Vrlo mala*	Low *Mali*	Low *Mali*	1.00	Very low – *Vrlo nizak*	Low – *Nizak*
2	Very low *Vrlo mala*	Low *Mali*	Medium *Srednji*	1.00	Very low – *Vrlo nizak*	Low – *Nizak*
3	Very low *Vrlo mala*	Low *Mali*	High *Veliki*	1.00	Very low – *Vrlo nizak*	Low – *Nizak*
24	Long *Velika*	High *Veliki*	High *Veliki*	1.00	High *Visok*	High *Visok*
25	Very long *Vrlo velika*	High *Veliki*	High *Veliki*	1.00	High *Visok*	High *Visok*

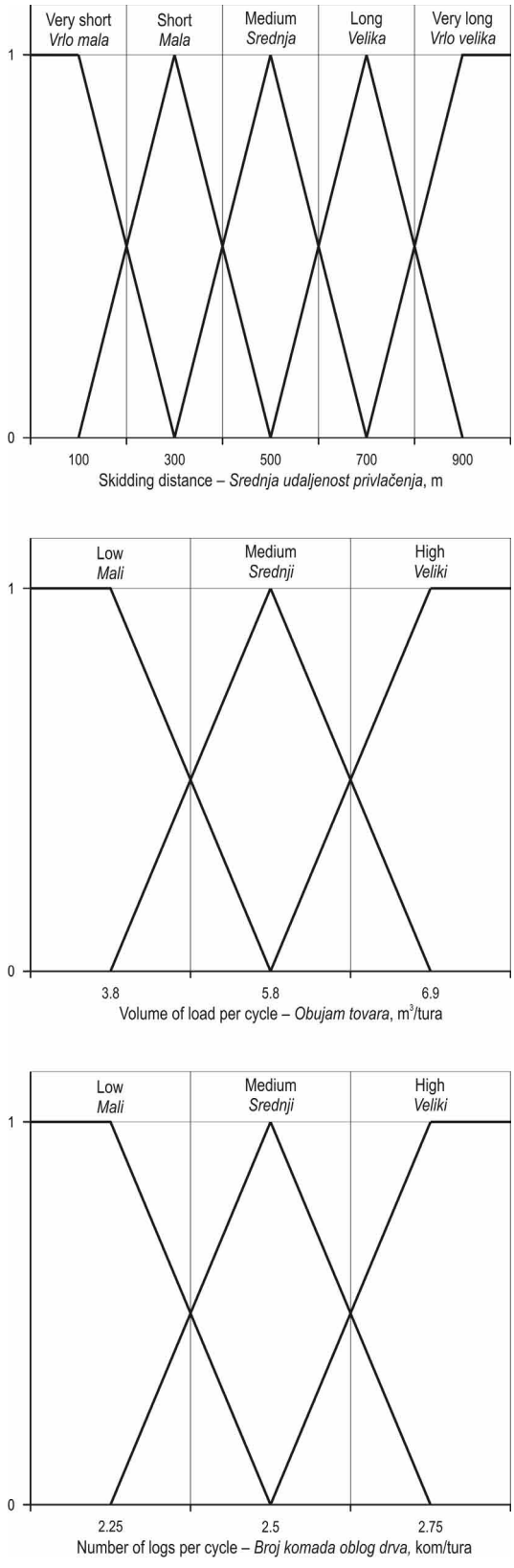

Fig. 3 Membership functions of input linguistic variables
Slika 3. *Stupanj pripadnosti jezičnih varijabli za srednju udaljenost privlačenja drva, obujam tovara i broj komada obloga drva u tovaru*

{very short, short, medium, long, very long}. Each term in T (SD) is delineated by a fuzzy set in the universe of discourse, here, e.g. U = [0. 1950]. We considered »very low« fuzzy set as the skidding distance less than 200 m, »low« as the skidding distance between 200 to 400 m, »medium« as the skidding distance between 400 to 600, »long« as the skidding distance between 600 to 800 and »very long«, the last set, as the skidding distance longer than 800 m. The linguistic values of other variables specified by the fuzzy sets are shown in Table 1.

2.4 Description of membership functions – *Stupnjevi pripadnosti*

Each linguistic value is described by a membership function (Fig. 3). The triangularly shaped membership function was adapted for the models. The class boundaries were fuzzy and determined based on the maximum and minimum value of each variable, scientific knowledge and technical experts' views and experiences. Defining membership functions caused soft thresholds of variable classes compatible with most concepts in forest management, in contrast to classical mathematical models which define hard thresholds. The combination of membership functions used to generate the rule bases in each model.

2.5 Determining the fuzzy rules – *Utvrđivanje pravila neizrazite teorije*

Fuzzy IF-THEN linguistic rules which reflect the knowledge of experts and the previous research results have the general form:

$$\lfloor \text{IF } x_1 \text{ is } A_1 \text{ and } x_2 \text{ is } A_2 \text{ and } x_m \text{ is } A_m \text{ then y is B} \rfloor$$

Where:

$x_1,\ldots,x_m$ are linguistic input variables with linguistic values $A_1,\ldots,A_m$, and linguistic output variables with linguistic value B, respectively.

The production rules included all combinations of input variables as antecedent part and skidding cost as consequent part that represented different degree of suitability of each machine. With Timberjack 450C and Zetor models, there were three linguistic variables e.g. skidding distance, number of logs and volume of load per cycle that had 5, 3 and 3 linguistic values (Equation 1 and 2), respectively. Fuzzy rules included the combination of linguistic values of skidding distance, number of logs and volume of load per cycle. Then, 45 rules were produced, and 15 rules were automatically omitted because there were no »2.5 logs« per cycles. The linguistic value »Medium« of the variable »Number of logs per cycle«

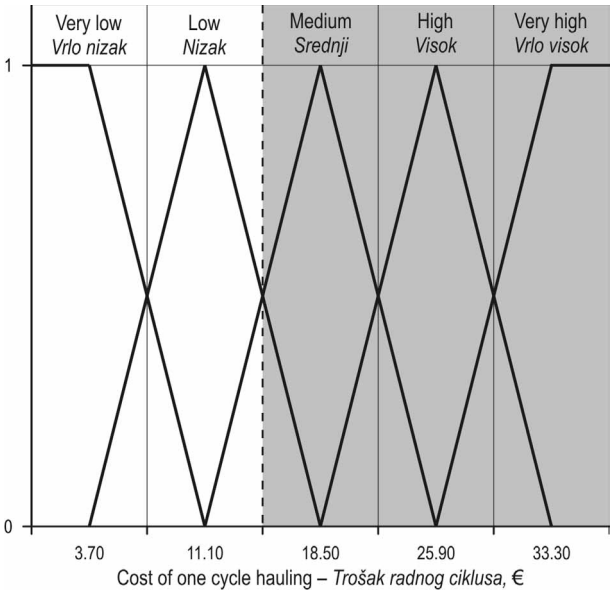

Fig. 4 Membership functions of output skidding cost and methodology of converting crisp values to fuzzy values

Slika 4. *Pretvorba »čvrstih« vrijednosti troška strojnoga rada u neizrazite vrijednosti*

was omitted and all of its combinations were omitted accordingly. Also there was no unit with »High« number of logs per cycle and low volume, so 5 rules were omitted. Consequently, the rule base of Timberjack 450c and Zetor models included 25 rules. In HSM 904 model according to its time prediction model (Equation 3), two factors out of three factors (e.g. Skidding distance and Number of logs per cycle) were identified as the effective factors, so its rule base included 10 rules.

Fuzzy rules could be derived from both experts reasoning and linguistic expressions and from the relationships between the system variables (Borri et al. 1998). In this study fuzzy rule bases in the models were generated using time study and hourly productivity cost of skidding machines. The time of one cycle hauling and consequently the skidding cost of each skidder for all selected work units were calculated. As a result we had three skidding costs (SC) against three machines per unit. As a detailed example of an IF – THEN rule, the skidding time and cost of one cycle by Timberjack 450C from a unit with skidding distance of 700 m (long), the number of logs 3 (high) and volume of load 7.63 (high) were calculated as 30.83 minutes and € 24.78 (based on prices in 2009). These calculations were based on the center of fuzzy sets.

According to the defined output membership functions and considering their threshold values (Fig. 4), this calculated value corresponded to a »High« skidding cost. Assuming that the threshold value is the turning point when hardening the rule, we choose the membership functions so that they take a value of 0.5 at the threshold used by the corresponding crisp rule (Muthu et al. 2008). So fuzzification of any production rule yields a membership function in output variable. In this case we had »High, High, and High« for antecedent part and »High« for inference part of this rule (Table 2). Such calculation was conducted for all rules of each of the three models.

2.6 Defuzzification – *Pretvaranje neizrazitoga konačnoga zaključka*

After generating complete sets of rules for each model, fuzzy variables were combined with respect to their respective membership functions to provide an estimate of the cost of one cycle hauling from a unit on skid routes to the landing. In fact the combination of fuzzy variables presents how their membership functions should be aggregated. Two subjects are usually discussed in aggregation of fuzzy variables. The first is relative importance of fuzzy variables. All criteria and indicators must be assigned with their corresponding weights to reflect their significance (Mendoza and Prabhu 2000), and since we used a mathematical productivity model of machines, in these models relative weights of variables were assigned. The second is the way of combining membership functions.

Two common combination procedures of fuzzy sets, named the »minimum« and the »maximum« operators were first suggested by Zadeh (1965) used to aggregate fuzzy variables.

The minimum operator corresponds to the intersection of fuzzy sets and the maximum operator represents the union of these sets. If the fuzzy sets A and B in universe U are as the following ordered pairs:

$$A = \{\mu_A(x), x\}, \forall_x \in U \quad (4)$$

$$B = \{\mu_B(x), x\}, \forall_x \in U \quad (5)$$

Then the membership function $\mu_C(x)$, as the intersection $C = A \cap B$ defined by:

$$\mu_C(x) = \forall x : \mu_{A \cap B} = \min\{\mu_A(x), \mu_B(x)\} \quad (6)$$

And the membership function $\mu_D(x)$, as the union $D = A \cup B$ defined by:

$$\mu_D(x) = \forall x : \mu_{A \cup B} = \max\{\mu_A(x), \mu_B(x)\} \quad (7)$$

The developed set of rules should be combined with these conjunction operators. Standard max. (union) »or« and min. (intersection) »and« operators are preferred (Babuska 1998). So to determine ap-

Table 3 Part of sample data used in neurofuzzy training
Tablica 3. *Dio uzorka podataka u teoriji neizrazitoga skupa*

Unit number *Broj radne jedinice*	SD, m *Srednja udaljenost privlačenja,* m	NLC *Broj komada obloga drva u tovaru,* kom.	VLC, m^3 *Obujam tovara,* m^3	SC of Timberjack 450C, $ *Trošak strojnoga rada za skider Timberjack 450C*	SC of HSM 904, $ *Trošak strojnoga rada za skider HSM*	SC of Zetor, $ *Trošak strojnoga rada za skider Zetor*
1	100	2	5.59	16	11.73	8.53
2	100	3	7.63	20.21	15.41	8.9
3	300	2	4.88	18.76	16.71	19.15
4	500	2	5.44	22.91	21.7	29.99
5	500	3	7.53	27.18	25.38	30.36
6	700	2	5.44	26.45	26.69	40.73
7	900	3	5.97	32.55	35.36	51.59

proximate reasoning, the standard min/max operators were used. Finally to compute crisp output of the skidding cost (SC) (defuzzification) fuzzy – Mamdani reasoning (Mamdani 1981) and »Center Of Gravity« (COG) method were used.

2.7 Evaluating the model performance – *Procjena modela*

The system performance could be evaluated using a large set of input–output data, and parameters

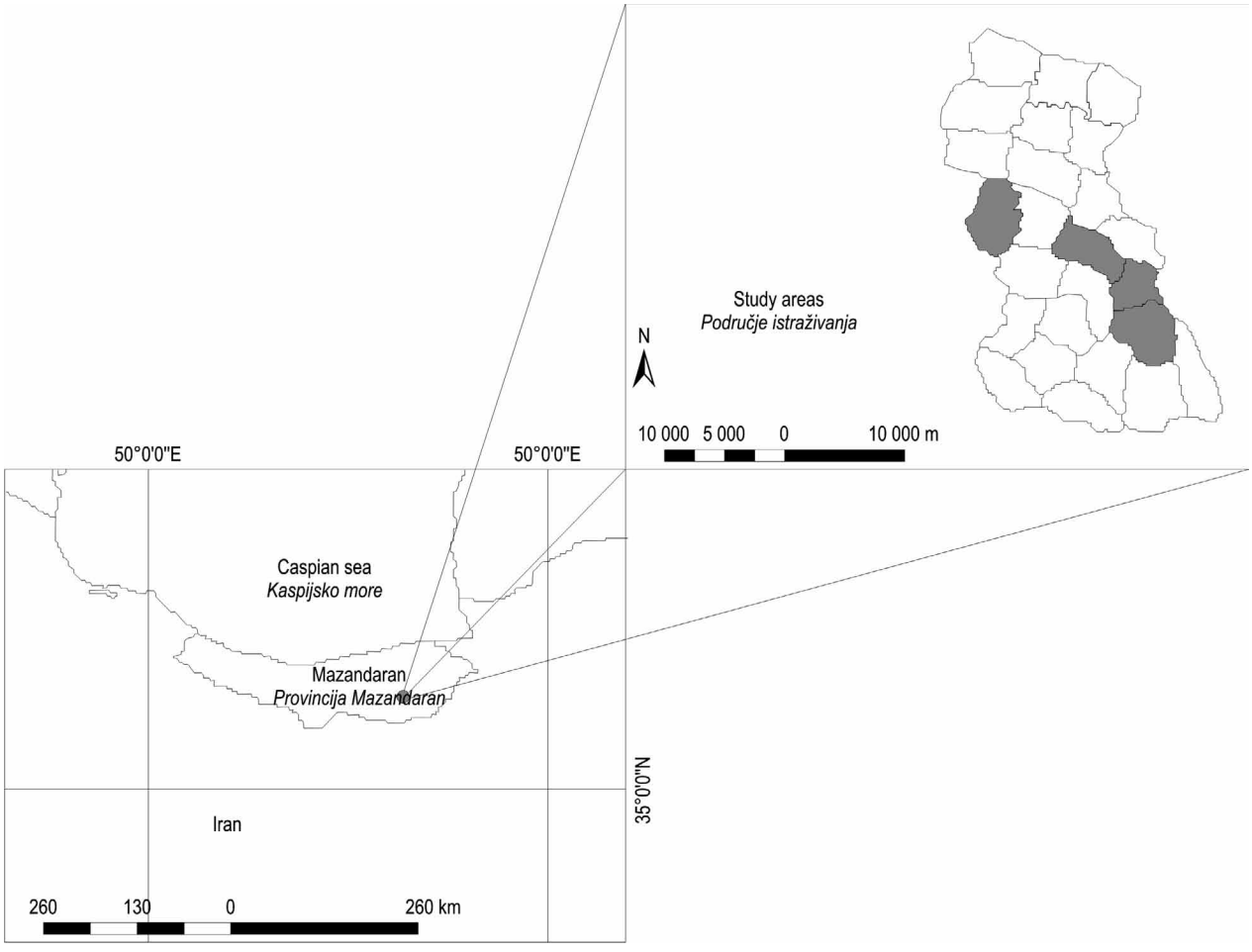

Fig. 5 Location map of study area
Slika 5. *Područje istraživanja*

of the system could be fine tuned in order to achieve a low »generalization error« (Azadi et al. 2009). In our case, 379 work units were indentified, and then units data were collected to enter the models as crisp inputs. In such a data–rich situation, 70% of data was used as training data to fit the models, and then 15% of data was assigned as validation data to estimate the prediction error for model selection. Finally 15% of data was applied to assess the generalization error of the final model chosen. Training data, chosen among all designed units, included all combinations of input variables in the study area. It was used in neurofuzzy training of machine fuzzy models so that input data included collected variables estimated in the units and related cost assigned as output variables in the training stage (Table 3).

3. Application – *Primjena*

The intrinsic motivation toward the problem studied in this research was to find the economical location of skidders in the existing skid routes, to decrease harvesting costs and increase the machine performance in the forest of Mazandaran Wood & Paper Industries (MWPI).

MWPI is the largest wood and paper company in Iran which manages about 180,000 ha of hyrcanian commercial forests in the north of Iran.

In order to conduct this research, four districts (7323 ha) under MWPI management forest were selected (Fig 5).

4. Results and discussion (output of models) – *Rezultati i rasprava*

After assessment of model performance using training data, each of the three models was applied for all 379 work units in the study area. The output variable of skidding cost (SC) resulted from the combination of the fuzzy values of input factors (SD, VLC, and NLC) according to the If–Then rules. The results were obtained as defuzzified discreet values.

Three crisp cost values of one cycle hauling against three skidders were obtained in each work unit when fuzzy model of skidding cost was applied

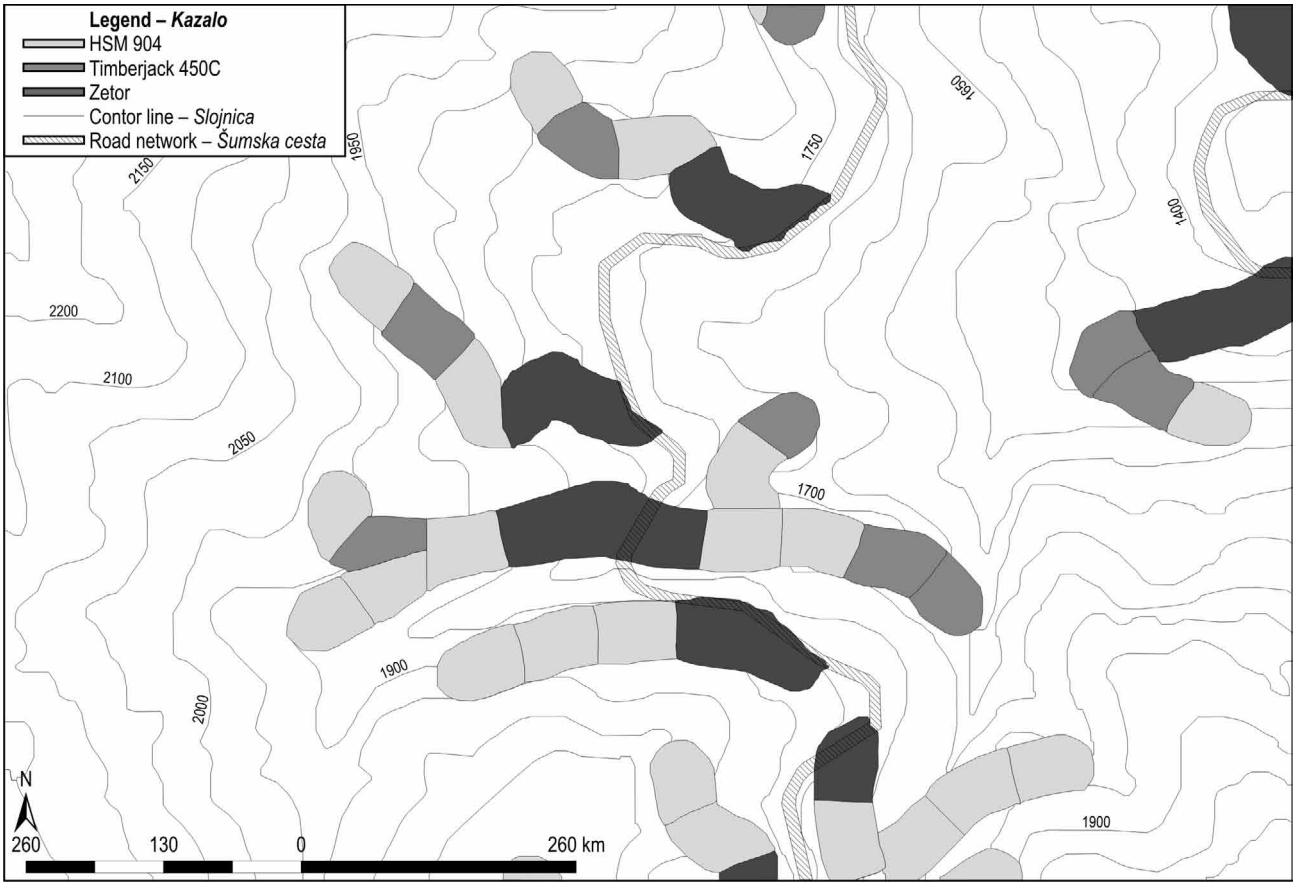

Fig. 6 Allocation map of extraction machines in study area
Slika 6. *Razmještanje vozila na istraživanom području prema neizrazitoj teoriji*

Table 4 Results in some units after running the models for whole data

Tablica 4. *Rezultati u nekim radnim jedinicama nakon provođenja teorije neizrazitoga skupa*

Unit number *Broj radne jedinice*	SD, m *Srednja udaljenost privlačenja,* m	NLC *Broj komada obloga drva u tovaru,* kom.	VLC, m^3 *Obujam tovara,* m^3	SC of Timberjack 450C, $ *Trošak strojnoga rada za skider Timberjack 450C*	SC of HSM 904, $ *Trošak strojnoga rada za skider HSM*	SC of Zetor, $ *Trošak strojnoga rada za skider Zetor*	Selected machine *Odabrano vozilo*
165	700	3	7.84	32.404	32.17	40.58	HSM 904
189	100	3	7.74	24.431	14	8.55	Zetor
227	700	2	8	30.627	25.99	39.91	HSM 904
256	900	2	4.48	29.544	32.17	45	Timberjack 450c
270	300	3	5.79	22.467	21.36	17.63	Zetor
330	500	3	7.32	27.129	25.74	28.9	HSM 904
379	900	2	5.44	30.14	32.17	45	Timberjack 450c

* All values are in USD, adjusted to price level for Year 2009.

for each machine (Table 4). As a result the skidder corresponding to the lowest skidding cost was allocated to each unit.

To create a visual result of extraction machines allocation model, mapping process of defuzzified crisp outputs was conducted using ArcGIS ver. 9.3. Then the final skidding machines allocation map was produced (Fig. 6).

A general comparison of total skidding cost for different allocation strategies was shown in Figure 7. The results showed that the application of a proper combination of machines based on skidding route properties resulted in lower total skidding costs than when using just one machine for the entire project area. SMA model application decreased the total skidding costs by about 8% compared to the case when only Zetor was used for wood extraction. This improvement was 13% and 22%, respectively, for Timberjack and HSM 904. So, it could be proposed to forest managers to apply machines in their respective economic zones through skidding routes if several skidding machines are available.

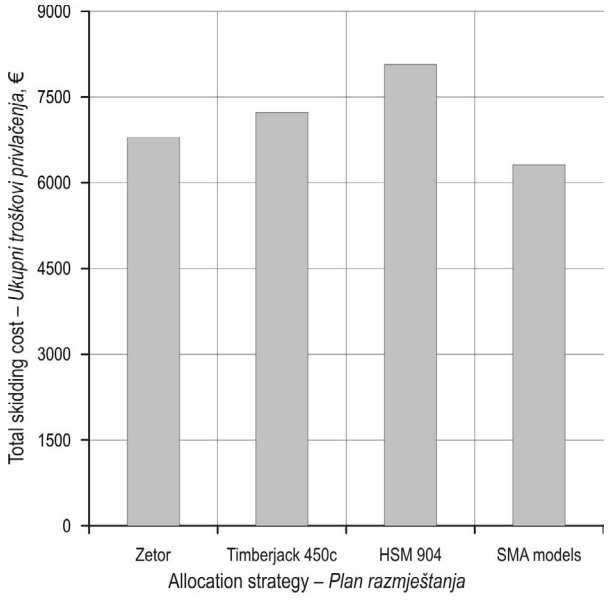

Fig. 7 A general comparison of Total cost of skidding between SMA model and investigated machines in the study area

Slika 7. *Usporedba ukupnih troškova strojnoga rada prema vrsti skidera pomoću neizrazite teorije*

Frequency distribution of extraction machines depending on the skid route distance in the study area was illustrated in Figure 8. The HSM 904 was the most economical machine in 44.19% of work area, while Timberjack 450C and Zetor were allocated in 33.67% and 22.13% of work area, respectively.

The models showed that in all units located at »Very short« distance, the lowest skidding costs were observed by Zetor. This fact could be explained by the fact that Zetor was a steel tracked skidder with wide arch. Expanded wide arch allows the Zetor to increase skidding performance maneuver to set chokers and winching elements of skidding cycle. So this machine is the first priority of managers at all »Very short« distance skid route units to meet minimum costs during skidding activities.

The differences in frequent distribution among the three machines were tested at different levels of skid route distance (Table 5).

The results showed that Zetor was still the most economical at »Short« skidding distances (down to 300 m) too, its costs were lower than others in 71% of units located in short distance skid route. Timberjack 450C was allocated to the units with the VLC fewer than 5 m^3 in this distance class owing to high coefficient of VLC in the productivity model (Equation 1). As a result Timberjack 450C is an appropriate machine for thinning or lightening operations in which young stands are harvested. Equation 3 showed that performance of HSM 904 was not dependant on the

Table 5 Comparisons of machines in skidding distance classes
Tablica 5. *Usporedba statističkih parametara ovisno o udaljenosti privlačenja*

SD – *Sred. udalj. priv.* / Parameters – *Statistički parametri*	Short – *Mala*	Medium – *Srednja*	Long – *Velika*	Very Long – *Vrlo velika*
Chi-Square – *Hi kvadrat*	53.846	64.800	1.756	2.380
Df – *Stupanj slobode*	2	1	1	1
p-Value – *p vrijednost*	0.000	0.000	0.185	0.123

VLC. In contrast, high coefficient of NLC represents a high sensitivity to the number of pieces per cycle. For this reason the cost of HSM 904 was the least when the NLC was 2 and VLC was more than 5 m^3. It could be advised to apply this skidder in mature stands with »Low« NLC and »Medium« or »High« VLC. The results emphasized that despite the fact that Zetor was a steel tracked skidder and could not move fast, it still was the first selection at »Short« distance because of its ability to set chokers and winching elements of skidding cycle and lower hourly production cost. Preference of »Zetor« in »Short« and »Very short« distances was expected because of its low speed and low hourly production cost in comparison with two other machines.

The HSM 904 became the economical machine in the »Medium« distance (average distance of 500 m) and it was used significantly more frequently than Zetor and Timberjack 450C. Timberjack 450C was less costly than HSM 904 in the »Medium« distance only when VLC was less than 6 m^3 and NLC was 3. In the units with long distance (around 700 m), Timberjack 450C and HSM 904 were assigned to 57 % and 43 % of units, respectively. Regarding final results of 379 units, it was observed that HSM 904 was the most cost effective machine in the »Long« distance when NLC was 2 and VLC was more than 5.5 m^3, as well as when NLC was 3 and VLC was more than 7 m^3. Under other conditions of this distance Timberjack 450c was the most cost effective and consequently it was the selected machine.

HSM 904 was used more frequently than Timberjack 450C at the »Very long« distance (around 900 m). It was assigned to 59% of units while Timberjack 450C was allocated in 41% of units where their VLC was less than 5.5 m^3.

The differences between machines in frequency at »Long« and »Very long« distances were not significant based on chi-squared test shown in Table 5.

As a general result for three recent classes of distance, HSM 904 was the economical machine at »Medium«, »Long« and »Very Long« distances in skid routes with the exception of »Long« distance units

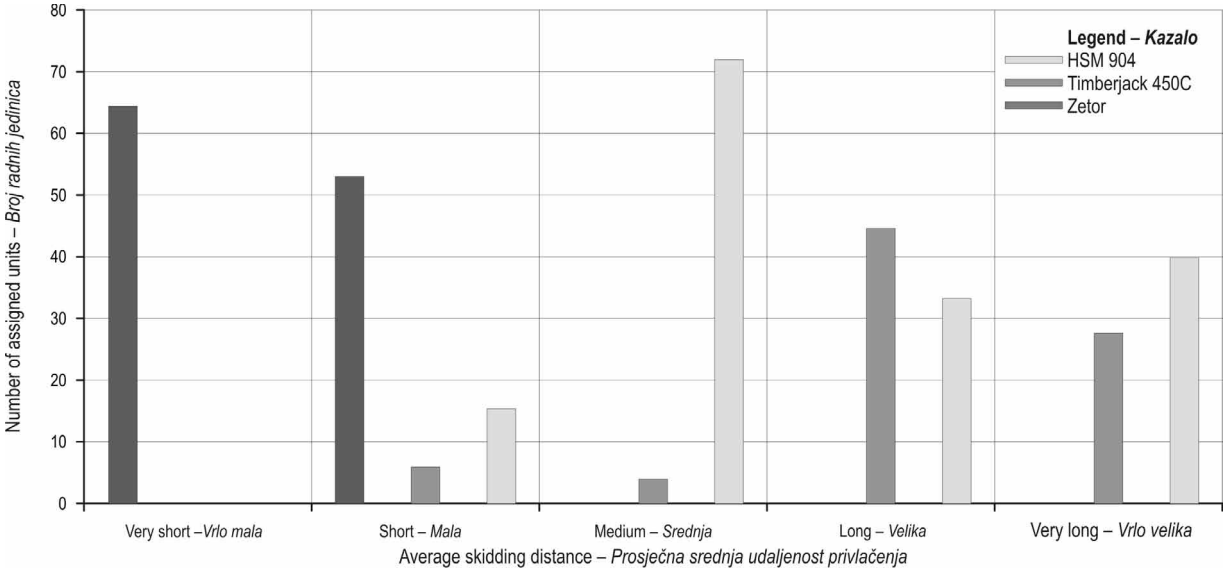

Fig. 8 Frequency distribution of extraction machines in the study area
Slika 8. *Udio rada pojedinoga vozila u radnim jedinicama prema srednjoj udaljenosti privlačenja drva*

with »Low« NLC and »Low« and »Medium« VLC, and also »Very long« distance units with VLC less than »Medium« where Timberjack 450C was less costly than HSM 904 and consequently it was the selected machine.

5. Conclusions – *Zaključci*

The implementation of fuzzy logic seems to be very promising in domains such as forest engineering, environmental modeling and predictive models where imprecise data are dealt with. This paper presents a modeling approach to allocate extraction machines for forest operations through a fuzzy technique using multiple linear regression models of productivity.

The advantages of the SMA models are:

⇒ The models present a linguistic description of each factor and its corresponding values instead of precise quantitative criteria. This kind of variables description is favored by policy makers of forest management.

⇒ Application of fuzzy Mamdani–based models to allocate resources makes the result of research consistent and easy to be understood by managers.

⇒ Flexibility of presented models permits any reform, should the number of variables or their membership functions be changed as a consequence of new scientific researches.

In the current research the input variables were chosen based on mathematical productivity models of skidding machines. In case of a large number of input variables, optimization of fuzzy rule bases using artificial intelligence could help to overcome problems of input variable selection and obtain reliable results. Our results were obtained under conditions including no constraints in skidder allocation models. Linear programming techniques can be used as exact modeling methods to obtain more accurate and realistic results when there are some cost or time constraints in using machinery. More applied research is required in the future to persuade forest managers to apply fuzzy models in practice.

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Sažetak

Planiranje rada skidera (SMA) pomoću neizrazite teorije

Učinkovito planiranje rada jedno je od glavnih zadataka u gospodarenju šumama, posebice kada postojeća sredstva za rad nisu jednako dostupna u svim radnim jedinicama. Smanjenje ukupnih troškova rada svakako je bitna sastavnica gospodarenja šumama posebice u radno nedostupnim ili teže dostupnim područjima. S obzirom na visoke troškove rada specijaliziranih šumskih vozila, u ovom slučaju skidera, potrebno je smanjiti jedinične troškove pridobivanja drva odgovarajućim planiranjem rada skidera te njihovim smještanjem u prostoru (Skidding Machines Allocation – SMA). Neizrazita teorija (fuzzy set theory) i sustav za potporu odlučivanja primijenjeni su za obradu nestalnih varijabli te raspona podataka kao što su obujam obloga drva i terenski uvjeti radilišta, tj. udaljenost privlačenja drva. Svrha je ovoga istraživanja prikazati sustav za potporu pri odlučivanju kojim bi se utvrdilo ekonomski najisplativije područje rada pojedinih vrsta skidera, što će u konačnici smanjiti ukupne troškove te povećati dobit u pridobivanju drva. Da bi se postigao taj cilj, istraživano je područje podijeljeno u radne jedinice od 75 m širine i duljine od 200 m do 900 m. Unutar svake radne jedinice matematički su izračunati modeli proizvodnosti te je procijenjeno vrijeme radnoga ciklusa i trošak strojnoga rada vozila koji su zajedno sa srednjom udaljenosti privlačenja drva (SD), obujmom tovara (VLC) te brojem komada obloga drva u tovaru (NLC) smatrani kao ulazne varijable modela SMA. Razvijena su tri odvojena neizrazita sustava za predviđanje jediničnih troškova privlačenja drva po radnim jedinicama koji su omogućili ekonomski najisplativije smještanje vozila u prostoru. U neizrazitom sustavu ulazni su podaci pretvoreni u jezične varijable i tada se određuje stupanj pripadnosti varijable prema postavljenim pravilima. Primijenjena je Madamijeva metoda najmanjih i najvećih vrijednosti koja za svako pravilo određuje stupanj pripadnosti varijable pojedinomu zaključku, što u konačnici dovodi do stvaranja neizrazitoga skupa podataka određenoga stupnjem pripadnosti pojedine varijable. Modeli su primijenjeni na tri najčešće korištena skidera u iranskom šumarstvu: Timberjack 450C, HSM 904 i Zetor, u planinskim šumama provincije Mazandaran.

Istraživanja su pokazala da je skider proizvođača Zetor najisplativija inačica na vrlo maloj i maloj srednjoj udaljenosti privlačenja (< 300 m) neovisno o vrijednostima obujma tovara i broju komada obloga drva u tovaru, dok je skider HSM 904 najmanje troškove rada postigao na srednjoj, velikoj i vrlo velikoj srednjoj udaljenosti privlačenja (od 300 m do 900 m), neovisno o vrijednostima obujma tovara i broja komada obloga drva u tovaru uz iznimku pri velikoj srednjoj udaljenost privlačenja (oko 700 m), s malim brojem komada obloga drva u tovaru (2 komada) i malim obujmom tovara (oko 4 m^3). Timberjack 450C je najisplativije vozilo na vrlo velikoj srednjoj udaljenosti privlačenja (oko 900 m) pri malom i srednjem obujmu tovara (manje od 5,5 m^3). Istraživanje je pokazalo da se korištenjem modela neizrazitih skupova pri planiranju rada skidera mogu smanjiti troškovi rada vozila, a time i jedinični troškovi pridobivanja drva. Primjenom modela smanjuju se troškovi rada za 8 % u odnosu na slučaj da se na istraživanom području koristi samo vozilo proizvođača Zetor.

Ključne riječi: privlačenje drva, planiranje rada, metoda neizrazitih skupova, troškovi privlačenja drva, sječa drva

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