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GENERALIZED STEM PROFILE MODEL BASED ON NEURAL NETWORKS

Pero Radonja[1]

Abstract: Generalized stem profile model is used in forest inventory and serves for the more accurate determination of volume and assortment structure of standing trees and whole stands in some region. It is suggested in this paper that the generalized model should be obtained as the mean value of the normalized, individual, separate profile function models. The individual models are obtained by the use of neural network, NN, for which the programs from the program package MATLAB were used. The volumes based on the generalized model obtained in this way were also calculated, and then the referent volumes were calculated in a separate way. The referent volumes were calculated by the use of profile functions obtained by the application of modified Brink's function, MBF. The values of the volumes obtained in these two different way, were compared by regression method, for all the trees in the observed region.

Key words: generalized stem profile function, neural networks, standard modelling error

GENERALIZOVAN MODEL PROFILNE FUNKCIJE DEBLA BAZIRAN NA NEURONSKIM MREŽAMA

Izvod: Generalizovan model profilne funkcije debla nalazi primenu kod inventure šuma i služi da se što tačnije odredi zapremina i sortimentna struktura dubećih stabala i celih sastojina u nekom regionu. U ovom radu predloženo je da se generalizovan model dobije kao srednja vrednost normalizovanih individualnih, pojedinačnih modela profilne funkcije. Individualni modeli su dobijeni koristeći neuronske mreže, NM, pri čemu su korišćeni programi koji se nalaze u programskom paketu MATLAB. Izračunate su zapremine na bazi ovako dobijenog generalizovanog modela a zatim posebno i referentne zapremine. Referntne zapremine su izračunate koristeći profilne funkcije koje su do-

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Translation: Marija Stojanović

bijene na bazi modifikovane Brinkove funkcije, MBF. Regresionim postupkom izvršeno je za posmatrani region, poređenje veličina svih ovako dobijenih zapremina.

Ključne reči: generalizovana profilna funkcija debla, neuronske mreže, standardna greška modeliranja.

1 INTRODUCTION

Generalized stem profile model, GSPM, is usually calculated for some region, because of which it is often called regional stem profile model. This method implies that the generalized model is obtained as the mean value of all the normalized individual, separate, profile function models. The individual models are obtained by the use of neural network, NN, for which the programs from the program package MATLAB, (Beale, 1993) were used. It should be mentioned that there are increasingly number of papers in which NN are used for the modelling of the different biological processes (Zhang et al., 2000; Radonja et al., 2003; Radonja et al., 2004; Hanewinkel, 2005; Radonja et al., 2005b, etc.).

GSPM is used for forest inventory and serves for the more accurate determination of volume and assortment structure of the standing trees and whole stands. The most popular papers which deals with this topic are (Hui and Gadow, 1997) and (Korol and Gadow, 2003). The generalized models are also elaborated in other papers (Radonja et al., 2006a; Radonja et al., 2006b; Matovic et al., 2007). The object is to find GSPM for the observed region which enables the calculation of the approximate values of the individual profile functions.

It is clear that the individual profile functions, obtained only by using GSPM and basic measured stem values, *diameter at breast height,* ***d,*** and *total height,* ***H,*** deviate from the original individual profile function obtained by the detailed measurement of stem. The approximate values of these functions enable the calculation of the approximate values of the individual volumes as well as the volumes of the whole stands. The satisfactory accuracy of the calculated volume enables the successful forest inventory and optimal usage of the forest resources.

Individual volumes deviate from the real volumes. Nevertheless, as it will be presented, these deviations are of the different directions, so the partial cancellation of the introduced (induced) errors occur. The stand volume calculated on the base of the generalized model was considerably more accurate than the one calculated by the use of some other methods, which are also based on only known, measured, basic stem values, i.e. tree stem.

2 MATERIAL AND METHOD

2.1 Data

The observed set of data is made of the data collected from 31 even-aged spruce stands (*Picea abies* L. Karst.) from the region of Bosnia (Maunaga, 1995). The observed stands are situated at the altitude of 550-1,350 meters, and the age of the tree ranges from 12 to 130 years. The measurements were made on one or two trees of each stand. Since 13 pairs of data were measured on each tree and the total number of trees is 42, there are

546 pairs of data (diameter-height). Site quality ranges between I and V, and the sizes of the sample plots depend on the number of trees and range between 0.05 and 0.5 ha.

In Figs. 1 and 2 the values of the total height of trees and radius at breast heights as a function of age are presented.

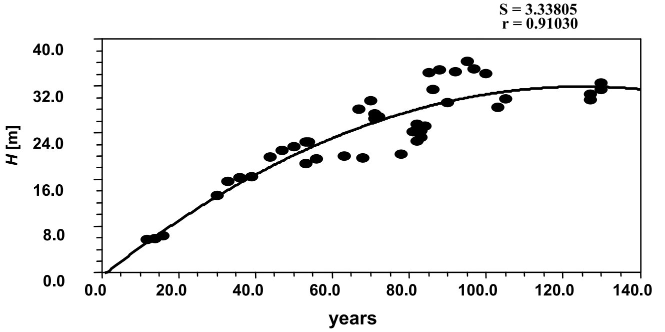

Fig. 1- Tree heights as a function of age

The graphical review of the profile function actually refers to the dependence of radius on the tree height. It should be remarked that there is no function of the dependence of diameter at breast height on the height, stem length. Because of it, the radii calculated according to the measured, readily available diameters at breast height are presented in Fig. 2.

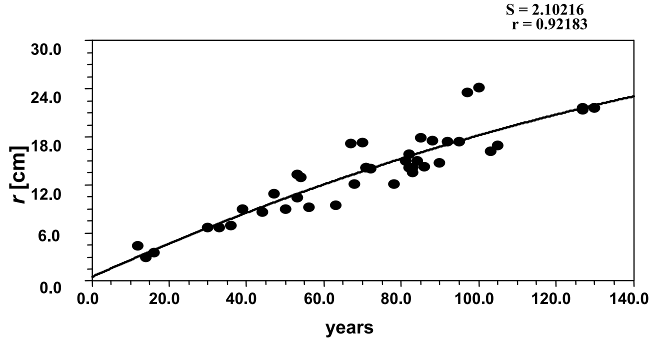

Fig. 2- Radii at breast height as a function of age

In the following Table (Table 1) the basic statistical values of the total height ***H*** and diameter at breast height, ***d*,** of the observed data set are presented.

*Table 1- The basic statistical values of the total height, **H** and diameter at breast height, **d**, of the observed data set.*

	H [m]	***d*** [cm]
Minimum	**5.65**	**6.0**
Maximum	**36.15**	**48.4**
Average	**24.28**	**27.57**
Standard deviation	7.86	10.58

The survey of the altitudes at which the measured trees are situated is presented in Fig. 3. It can be seen that the oldest trees are most usually situated at the highest altitudes, whereas the younger trees are usually situated at lower altitudes.

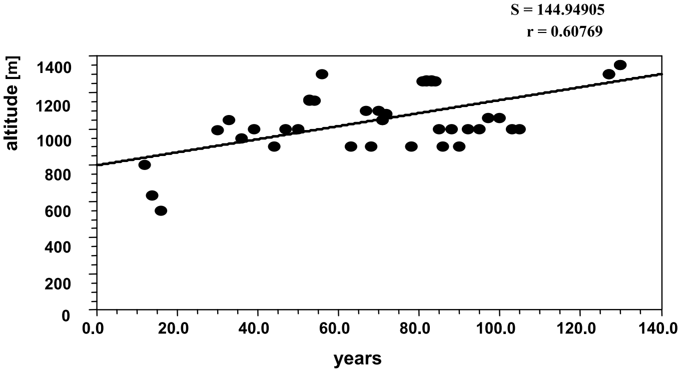

Fig. 3- *The survey of the altitudes at which the measured trees are situated*

2.2 Method

At the first step the individual profile functions, i.e. *individual models of stem profile,* IMSP, by the use of NN, i.e. programs *newff*, *train* and *sim*, from the program package MATLAB (Beale, 1993), are defined. Two-layer NN with two *tansig* neurons in the hidden layer and one neuron with the linear transfer function are used. *Tansig* neuron has hyperbolic tangent sigmoid transfer function (Haykin, 1994). In addition, the stem profile functions based on the use of modified Brink's function, MBF, are calculated. These functions are obtained by fitting the measured pairs of data for each tree by using MBF (Riemer et al.,1995) and (Radonja et al., 2005a).

It is suggested in this paper that the generalized method should be obtained as the mean value of the all normalized individual stem profile models which are obtained by using NN. The individual models are normalized at the second step by ***H*** and the greatest radius value, obtained by measurement of the diameter of the observed tree on the very surface.

3 CALCULATION OF THE INDIVIDUAL PROFILE MODELS

We will illustrate the calculation of the individual profile models with two tree, the first one, 72-year-old trees (***H***=26.8m and ***d***=28cm) and the second, 130-year-old trees (***H***=32.6m and ***d***=43.2cm). In the first case the training method NN is presented in Fig. 4 and it is seen that it practically finishes after 10 steps, when the training error reaches $2.5 \cdot 10^{-4}$. The obtained profile function is presented in Fig. 5. Modelling error is presented in Fig. 6 and it can be seen that it ranges between -0.15 and +0.15. Standard modelling error, $\boldsymbol{S_{em}}$, is 0.0787, whereas in the case when MBF is used it is more than double, i.e. 0.1881. The normalized profile function for normalized ***x*** coordinate, 0.2 has the normalized ***y*** coordinate, 0.65, Fig. 7.

In the second case the training process, Fig. 8, is practically performed in 80 steps when the training error reaches the value $4.5 \cdot 10^{-3}$. In Fig. 9 the obtained profile function is presented, and in Fig. 10 modelling error which ranges between -0.5 and +0.5. It is seen that we obtained greater modelling error for the higher training error. Standard modelling error, S_{em}, is now 0.3348. When MBF is applied, standard modelling error is higher, i.e. 0.3876. In Fig. 11 the normalized profile function is presented. For the normalized $\boldsymbol{x}$ coordinate equals 0.2, the value of the normalized $\boldsymbol{y}$ coordinate is 0.5,

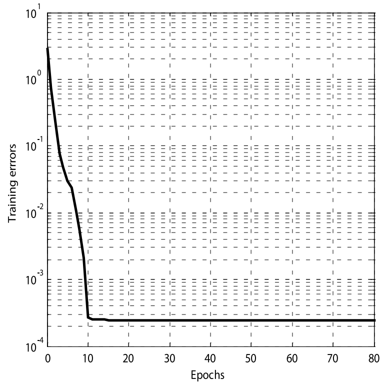

Fig. 4- Training method

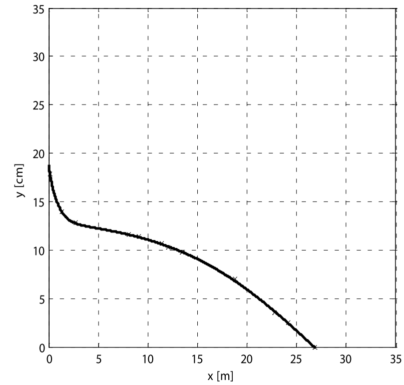

Fig. 5- Profile function o 72-year-old trees

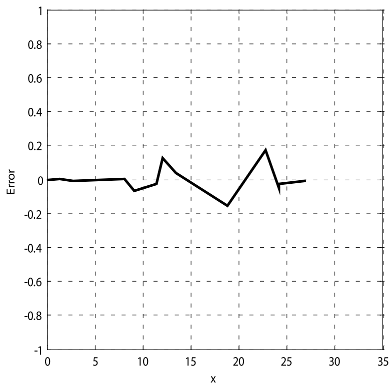

Fig. 6- Modelling errors (72-year-old trees)

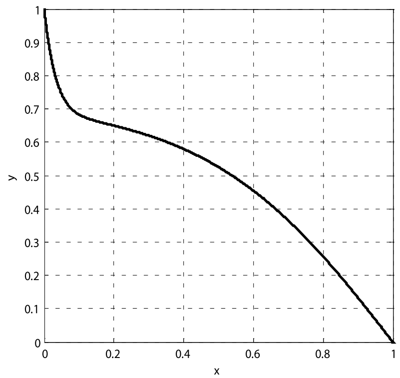

Fig. 7- Normalized profile function (72-year-old trees)

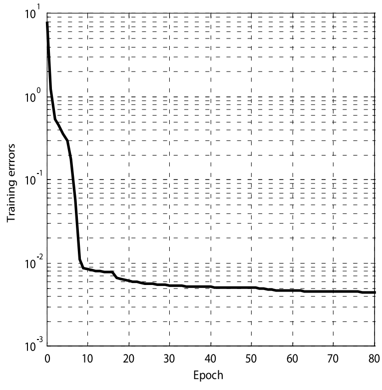

Fig. 8- Training method (130-year-old trees)

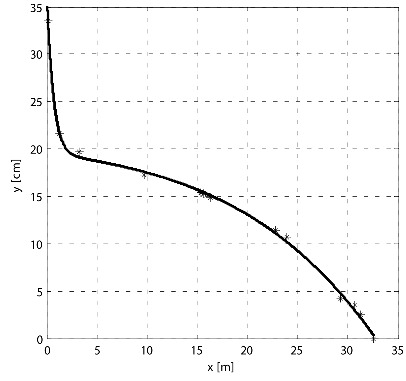

Fig. 9- Profile function of 130-year-old trees

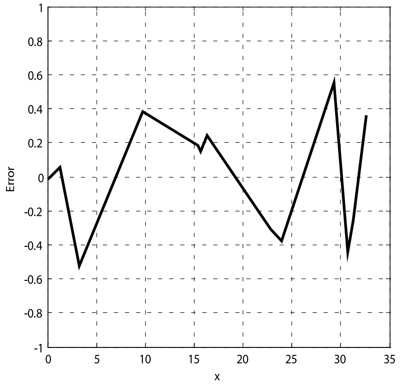

Fig. 10- Modelling errors (130-year-old trees)

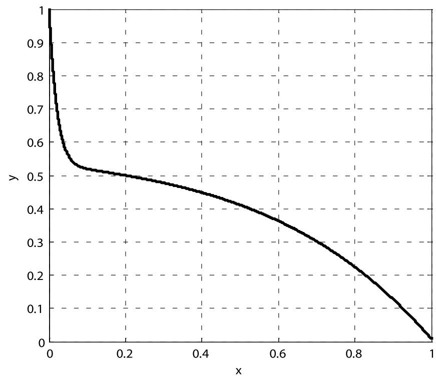

Fig. 11- Normalized profile function (130-year-old trees)

4 GENERALIZED STEM PROFILE MODEL

In the same way as it was done for 72-year-old and 130-year-old trees, the normalized profile functions were determined for the all other trees from the observed sample. The mean value of first 21 normalized profile models is presented in Fig. 12 by the dashed line.

The mean value of the remaining 21 normalized profile models is presented in Fig.12 by the dotted line. It can be seen that another mean value practically represents the verification of the first mean value since the very similar results are obtained in the both cases. The mean value of the all individual normalized profile models from the observed sample, i.e. GSPM, is presented by the whole unbroken line.

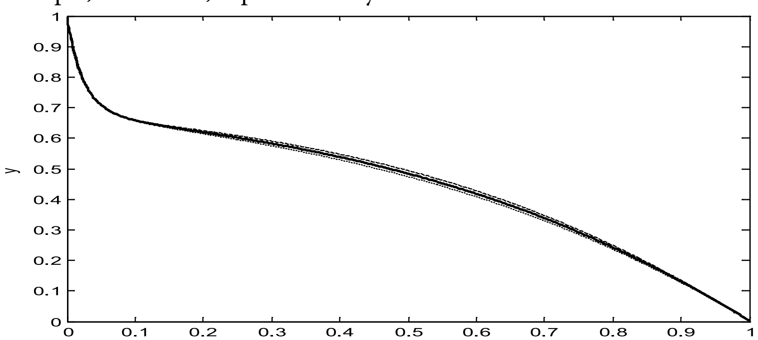

Fig. 12- Generalized stem profile model, GSPM

5 GENERATION OF THE INDIVIDUAL MODELS BY GSPM

The profile functions presented in Figs. 5 and 9 represent the *original individual stem profile models,* OISPM. By denormalization based on GSPM, total height ***H*** and diameter at breast height ***d*****,** the *generated individual stem profile model,* GISPM, is obtained. Since the denormalization GSPM is performed only by two original dimensions, ***H*** and ***d***, it is clear that GISPM can be equal to OISPM at only two points. Denormalization method is performed so that GISPM transverses characteristically points OISPM, radius at breast height (1.3; ***d/2***) and final point (***H;0***). It is clear that denormalization along ***x***-axis is performed by ***H***. In addition, the relative breast height, 1.3/***H***, is calculated for the observed tree, and from Fig. 12 the value of the normalized ***y*** coordinate, y_{norm}, is read. Value ***y(0)*** by which the denormalization is performed along ***y***-axis is calculated by the relation:

$$y(0)=(d/2) / [y_{norm}(1.3/H)] \qquad (1)$$

We should note that ***y(0)*** obtained in this way most usually is not equal to the radius value which was originally measured at the very ground of the observed stem.

6 CALCULATION AND ESTIMATION OF VOLUME

The volumes of the individual trees will be calculated on the assumption that we deal with the symmetric geometric figures which are formed by the rotation of the profile function around the ***x*** axis. Volume is obviously the value of the definite integral in which sub integral function is the square of the profile function, (Riemer et al.,1995), by relation (2).

$$V(x) = \pi \int_0^x y^2(x)dx \qquad (2)$$

The volumes obtained by the application of profile functions which are determined by the use of MBF, ***V(MBF)***, will be regarded as the referent volumes.

When MBF is used sub integral function is integrable function, so it is possible to obtain analytical expression for calculation of volumes (Riemer et al.,1995) and (Radonja et al., 2005a).

When NN is used for the definition of profile function, since the sub integral function is not integrable function in this case, volumes, ***V(NN)***, are in principle calculated by numerical integration. However, in the observed case it is possible to use *inner vector product* instead of numerical integration.

We will estimate individual volumes by the use of generated individual stem profile model, GISPM. The estimated volumes obtained in this way, ***V(GSPM)***, will be compared with the calculated volumes, ***V(MBF)*** and ***V(NN),*** by regressive method.

We will first compare the volumes which are calculated when the profile functions are obtained by NN, ***V(NN)***, with the referent volumes, ***V(MBF),*** Fig. 13.

It is seen that the results of the both methods are practically the same. The standard error of estimate S_{VE} is very low (0.00651), and correlation coefficient, r_{VE}, is very high (0.99997). Coefficients of the regression line, ***a*** and ***b***, are 0.00320 and 0.99758. We see that translation along ***y*** axis is very low and the tangent of angle is close to one. However, since the modelling errors are lower, 0.0787 and 0.3348, when NN is applied, than the modelling errors 0.1881 and 0.3876, obtained when MBF was applied, it can be said that NN enables the obtaining of volumes which are closer to the real values.

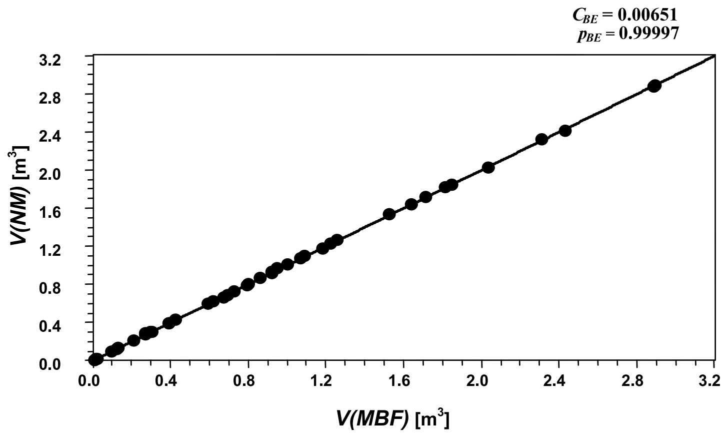

Fig.13- Volumes based on the use of NN and classic MBF procedure
a=0.00320   b=0.99758

Fig. 14 is obtained by the comparison of the estimated volumes based on GSPM with referent volumes.

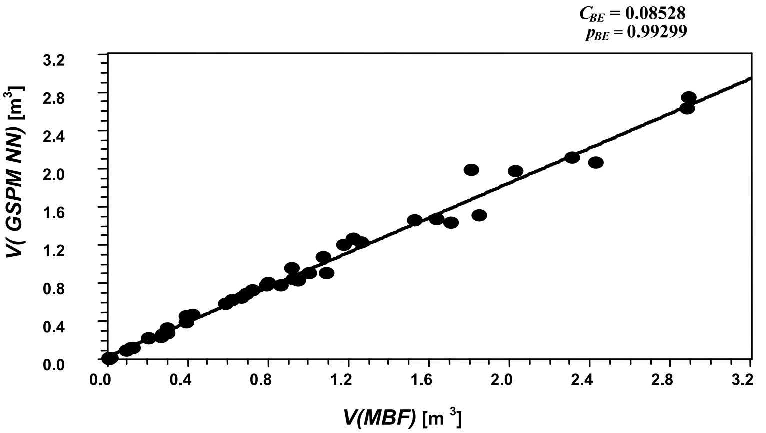

Fig. 14- Volumes based on GSPM and classic MBF procedure
a=0.03257   b=0.90998

The standard error of estimate is 0.08528, and correlation coefficient is 0.99299. The translation along ***y*** axis is 0.03257, and tangent of the angle penetrated by the regression line is 0.90998.

When GSPM is generated by the method suggested by Korol and Gadow (Korol and Gadow, 2003), the very similar result would be obtained. S_{VE}=0.08795 and r_{VE}=0.99371, whereas the values of the coefficients of the regression line are: ***a***=0.03792 ***b***=0.99047. It is seen that both S_{VE} and r_{VE} of the GSPM generated by NN are somewhat lower. In addition, the coefficient **a** is also lower, which is good. However, unfortunately, the coefficient **b** deviates more from the unit, than in the case when Korol-Godow method is used.

In the following Fig. 15 the comparison of the volumes estimated by using GSPM with the volumes obtained when NM is used for profile function modelling is presented.

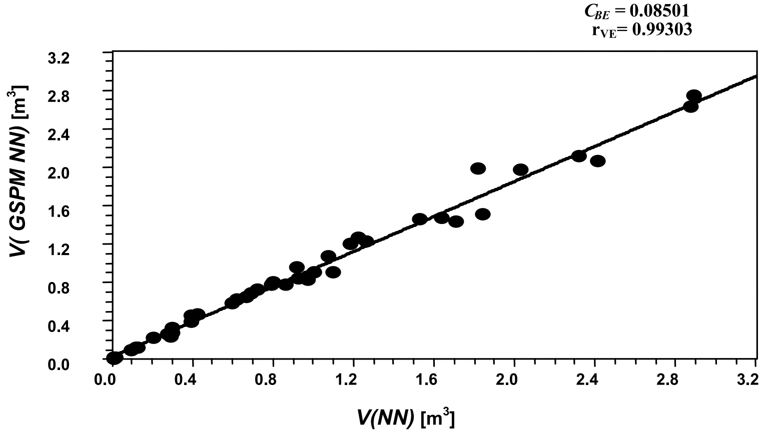

Fig. 15- Volumes based on GSPM and NN,
***a**=0.02965 **b**=0.91220*

The standard error of estimate is now 0.08501, and correlation coefficient is 0.99303. The translation along ***y*** axis is 0.02965, and tangent of the angle penetrated by regression line is 0.91220. It can be said that by the comparison of the estimated volumes, *V(GSPM)*, with the referent, *V(MBF),* or with *V(NN),* practically the same results are obtained. The standard error of estimate is somewhat lower 0.08501 to 0.08528, but the correlation is somewhat higher, 0.99303 to 0.99299. The translation along ***y*** axis is somewhat lower, 0.02965 to 0.03257, and at the same time the coefficient of the direction is closer to one, 0.91220 to 0.090998.

7 CONCLUSION

The results presented in Fig. 14, in regard with the value S_{VE} (0.08528) and value of the slope of the regression line, ***b***=tng***α***=0.90998 (***α*** is very similar to 45^0 angle), show that the real volumes *V(MBF)* can be approximated to the volumes estimated by using GSPM, *V(GSPM)*. In other words, the volumes estimated by using GSPM can be sometimes used for forest inventory.

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Pero Radonja

Rezime

Generalizovan model profilne funkcije debla, GMPFD, obično se računa za neki region i zato se često zove i regionalan model profilne funkcije. Generalizovan model profilne funkcije debla nalazi primenu kod inventure šuma i služi da se što tačnije odredi zapremina i sortimentna struktura dubećih stabala i celih sastojina u nekom regionu. U ovom radu predloženo je da se generalizovan model dobije kao srednja vrednost normalizovanih individualnih, pojedinačnih modela profilne funkcije. Individualni modeli su dobijeni koristeći neuronske mreže, pri čemu su korišćeni programi koji se nalaze u programskom paketu MATLAB. Posmatrani skup podataka čine podaci sakupljeni iz 31 jednodobne sastojine smrče (*Picea abies* L. Karst.) iz regiona Bosne (M a u n a g a, 1995). Merenja su obavljena na jednom ili na dva stabla svake sastojine. Posmatrane sastojine nalaze se na nadmorskim visinama od 550-1350 metara, starost stabala je od 12 do 130 godina, a na svakom stablu izmereno je 13 parova podataka (prečnik-visina). Izračunate su zapremine na bazi ovako dobijenog generalizovanog modela a zatim posebno i referentne zapremine. Referntne, realne, zapremine su izračunate koristeći profilne funkcije koje su dobijene na bazi modifikovane Brinkove funkcije. Regresionim postupkom izvršeno je za posmatrani region, poređenje veličina svih ovako dobijenih zapremina. Dobijeni rezultati pokazuju da je realne zapremine moguće aproksimirati sa zapreminama izračunatim na bazi generalizovanog modela profilne funkcije debla. Drugim rečima dobijene zapremine moguće je uspešno koristiti kod inventure šuma.

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