Modeling of incidental cuttings in tree growth model SIBYLA

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Introduction

Climatic changes are very important aspect with significant influence to forest structure, stability and production. Frequency of natural disasters is systematic increasing in forestry. Not only frequency is increased. Also amount of destroyed wood production is increased at the same time. For instance, in November 2004, huge windstorm has appeared in High Tatras in Slovakia. Windstorm has completely destroyed spruce area with size 2-5 km by 40-50 km. Production loss were 90% of planned annual coniferous cutting in Slovak Republic. Increasing tendency of incidental cuttings is very important reason that models for forest injurious agents become more popular in Slovakia. Second reason for development of the models is new trends in education system. E-learning methods are joined with strategic computer games and simulators. Our intention is to create strategic game for simulation of forest behavior, to place it to WEB, and to make accessible for students and for e-learning process at Technical University of Zvolen. But it is impossible to create "real simulations" of forest behavior without the incidental cutting model. Till now in Slovakia, only a few authors have been involved to estimation and quantification of natural risk in forest ecosystems. Calculation of risk was mainly concentrated to insurance models. One from newest is model of HOLECY (2000) and MIKUSIKOVA (2005), which has been implemented also in Germany (HOLECY and HANEWINKEL 2006). However, this approach is still very rough. For purposes of forest simulators we need more detailed model. We submit new model of incidental cuttings in this paper. The model has been developed for purposes of tree growth simulator SIBYLA (FABRIKA 2005).

Material and methods

We used data from forest inventory databases and management records covered all Slovakian area (Figure 1.). Database is composed from 89707 forest stands. In total 388830 hectares have been investigated. This sample represents approximately 19% of Slovakian forest area. Stands have been selected from all 47 Forest Eco-regions. Minimal number of forest stands selected from one Eco-region is 56 (295 ha), and maximal number is 6687 (21188 ha). Data of forest inventory have been composed from following: Forest Eco-region, stand density, aspect, slope, site category, age, tree species (percentage, mean diameter, mean height, growing stock). Data of management records have been composed from following: tree species, year and amount of incidental cutting, and type of injurious agent. All information is related to stand identifier. Four types of abiotic injurious agents have been observed (wind, snow, icing, drought), three types of biotic agents (bark miner and timber borer, defoliator and other insect, wood-destroying fungus) and three types of human agents (air pollutants, fire, steal). Data comes from 2000-2005, with different period from 1 to 6 years depending to individual stands. We processed totally 26246 damaged stands with wind, 993 with snow, 912 with icing, 3048 with drought, 9803 with stem insect, 504 with crown insect, 2800 with fungi, 3278 with air pollutants, 97 with fire, and 1808 with steals. Data are totally composed from 47437 spruce stands, 5719 fir stands, 8034 pine stands, 20048 beech stands, and 9234 oak stands.

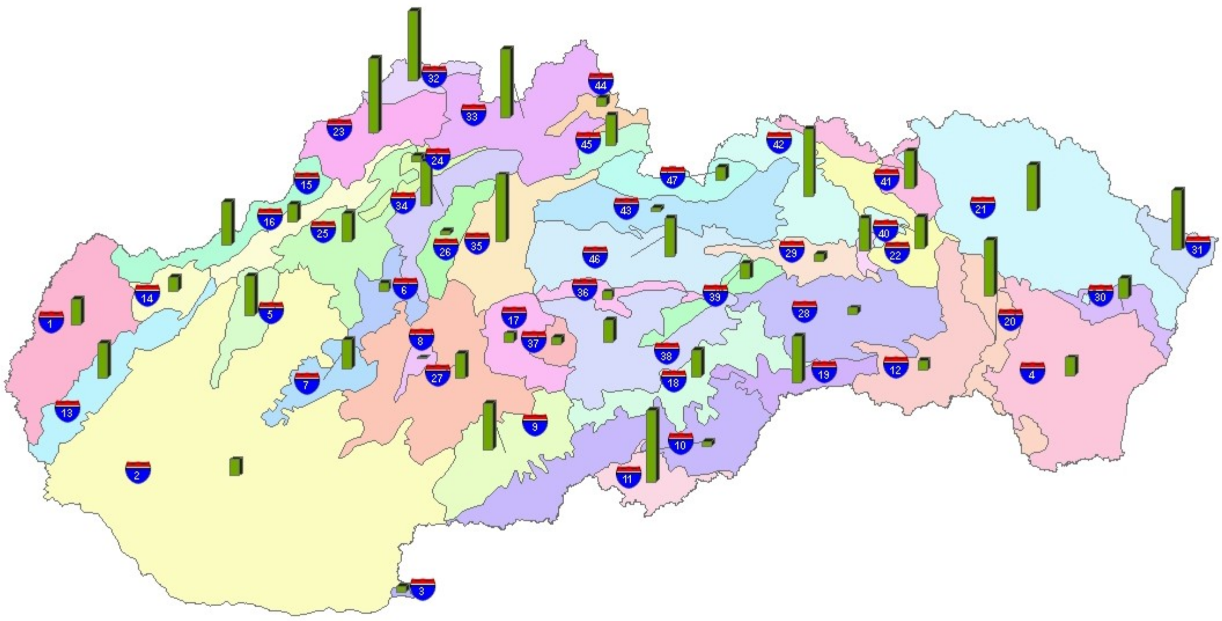


Figure 1: Investigated area of all 47 Forest Eco-regions in Slovakia

Risk for appearance of incidental cuttings have been calculated:

$$risk = \frac{\sum_{i=1}^{m} \sum_{k=1}^{l_i \in [1..6]} 1}{\sum_{j=1}^{n} \sum_{k=1}^{l_j \in [1..6]} 1} .100 \qquad (1)$$

where m is number of stands with existing incidental cutting, n is number of all stands, l_i is number of years with incidental cutting in management records for stand i, l_j is number of maximal possible years in management records for stand j. The risks have been calculated for stands within following cross-classification: Forest Eco-region (FER), tree species (SPECIES), category of site (SITE) and type of injurious agent (AGENT).
Then, relative (5-years) amount of incidental cutting have been calculated for each stand:

$$\%V_i = \min\left\{ \frac{\left(\sum_{k=1}^{l_i \in [1..6]} Vic_{ik} \right) . \frac{5}{l_i}}{Vorig_i} ; 1 \right\} .100 \qquad (2)$$

where Vic_{ik} is amount of incidental cutting of stand i in year k in m^3 and $Vorig_i$ is initial growing stock of stand i in m^3 from forest inventory. Then arithmetic means $AVG(\%V)$ and standard deviations $SD(\%V)$ have been calculated for the same cross-classified categories. Classification table (C-TAB) is result from mentioned calculations. Classification table includes Forest Eco-region, tree species, site category, type of injurious agent and for these cross-classified categories are saved risk of appearance, mean relative amount of incidental cutting and its standard deviation, together with mean stand variables: vegetation zone, aspect, slope, age, stand density, tree species percentage, site index, and relation between mean height and mean diameter. Selection table (S-TAB) has been derived from investigated database, together with C-TAB. Selection table represents frequency (%) of appearance for each type of injurious agent in cross-classified categories: Forest Eco-region and tree species.
Moreover, next modeling approaches have been utilized as instrument of modeling:

- *factor analysis*, because incidental cuttings are activated by many factors (climate, geomorphology, stand stability, maturity, resistance, productivity, and others),
- *regression analysis*, because incidental cuttings are dependent to many variables (altitude, aspect, slope, site, age, stand parameters, and others),
- *Monte Carlo method*, because incidental cuttings appear randomly thanks to unknown and complicated situation,
- *planar geometry*, because some injurious agents are propagated in typical space elements (ellipse, strip, circle, spot-propagation),
- *fuzzy based rules*, because some injurious agents are propagated on basis of uncertain rules.

Model

The model of incidental cuttings is composed from 2 parts. The first part selects incidental cutting on stand level: type of injurious agent, their risk and total amount of cutting. This part is statistically oriented. Factor analysis, regression analysis and Monte Carlo method are utilized. The second part selects incidental cutting on tree level. Fuzzy based rules and planar geometry are utilized. Complete flowchart of the model is presented in Figures 2-4. The procedure is explained in following steps:

1. Frequencies of injurious agent appearance are found from the S-TAB. Frequencies depends to Forest Eco-region and tree species. Example for one Forest Eco-region and spruce is presented in Table 1. Further frequencies are modified (increased) for some injurious agents in case of existing dead trees in last 5-years period in the stand. Modification is applicable for bark miners and timber borers, wood-destroying fungi and fire, because frequencies are higher if stand sanitation is worse. Multipliers increase frequencies. The multipliers are derived from functions (Figure 5) and they depend to percentage of dead trees in last growth period. Then current injurious agent is selected. *Probability proportional to size (PPS)* is applied: cumulative frequencies are calculated, random number between 0 and maximal cumulative frequency is generated and injurious agent with equal or nearest cumulative frequency is selected.

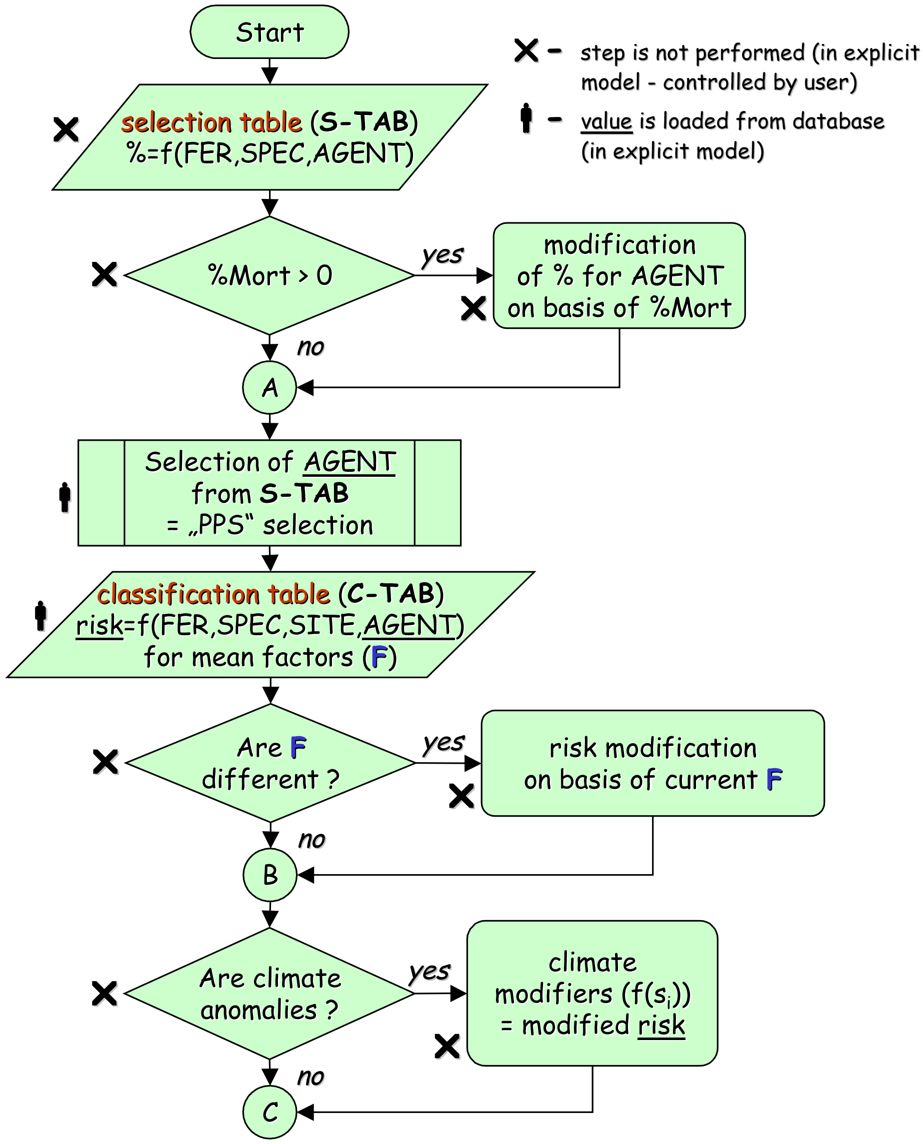


Figure 2: Flowchart of the incidental cutting model (part 1)

Table 1: Example from "Selection table" (S-TAB)

Forest Eco-region		tree species	injurious agent	frequency
23	JAVORNIKY	spruce	windstorm	46,7
23	JAVORNIKY	spruce	bark miners	31,3
23	JAVORNIKY	spruce	other	10,9
23	JAVORNIKY	spruce	snow damage	4,3
23	JAVORNIKY	spruce	steal	3,5
23	JAVORNIKY	spruce	drought	1,4
23	JAVORNIKY	spruce	defoliator	1,2
23	JAVORNIKY	spruce	fire	0,5
23	JAVORNIKY	spruce	air pollutants	0,3

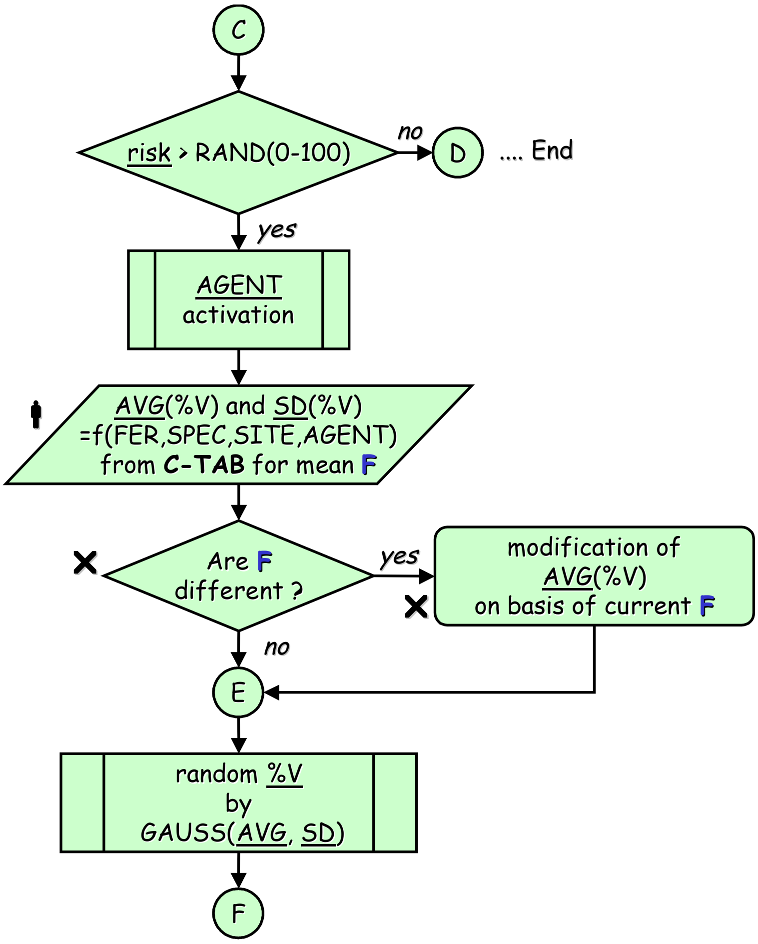


Figure 3: Flowchart of the incidental cutting model (part 2)

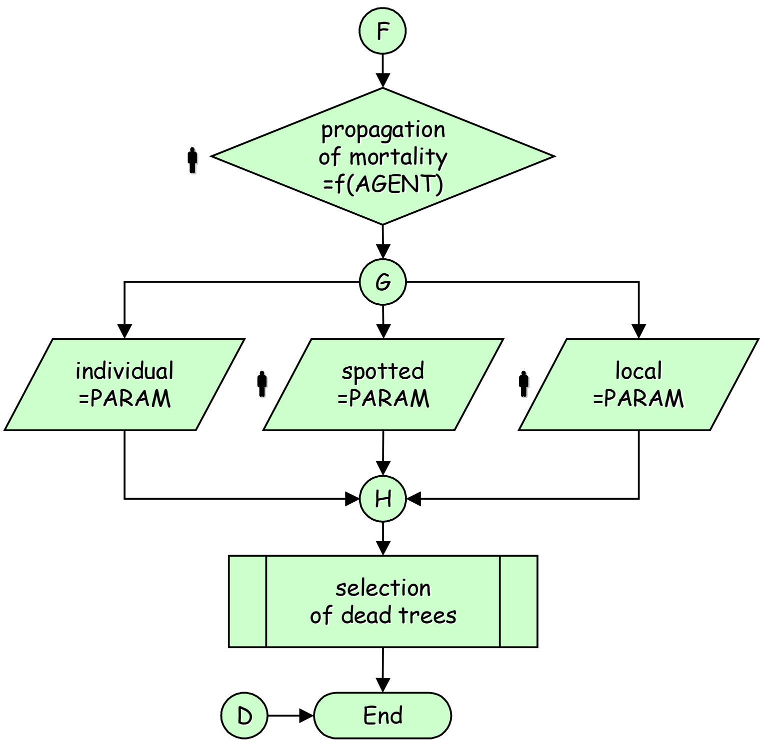


Figure 4: Flowchart of incidental cutting model (part 3)

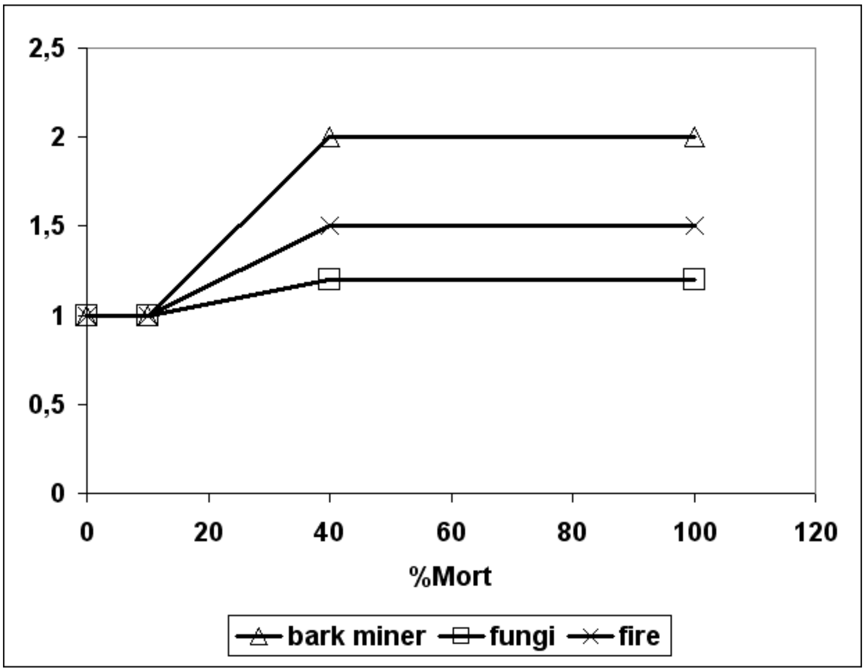


Figure 5: Multipliers for increasing of frequency

Table 2: Example from “Classification table” (C-TAB)

FER	SPEC	SITE	AGENT	RISK	AVG(%V)	SD(%V)	vegzone	aspect	slope	age	sdensity	percentage	siteindex	hd
23	spruce	1	windstorm	13,27	18,39	31,03	4,8	183	29	81	0,80	79	30	0,78
23	spruce	2	windstorm	28,04	15,76	19,64	5,0	164	39	89	0,78	90	31	0,76
23	spruce	3	windstorm	15,28	7,90	11,88	4,1	184	39	83	0,79	80	32	0,81
23	spruce	4	windstorm	18,52	14,28	19,20	4,0	212	44	85	0,78	74	31	0,83

2. Mean risk ($risk^{mean}$) of injurious agent is retrieved from the C-TAB. The risk depends to Forest Eco-region, tree species, site category, and injurious agent. Example for one Forest Eco-region, spruce and windstorm is presented in Table 2. This risk is valid for mean conditions in cross-classified category. Mean conditions are specified by 8 mean variables (x_j): vegetation zone (1), aspect (2), slope (3), age (4), stand density (5), percentage (6), site index (7), and relation between mean height and mean diameter (8). At the same time real conditions of the stand are used. The real conditions are specified by identical variables valid for real situation in the stand. Then risk is modified by model derived from *factor analysis*. Mentioned 8 stand variables are associated in factors. Different number of factors ($k=2..4$) is derived for each tree species and injurious agent (VACULCIAK 2007). The factors F_i are calculated by transformation of stand variables into normal variables and their linear combination on basis of their scores:

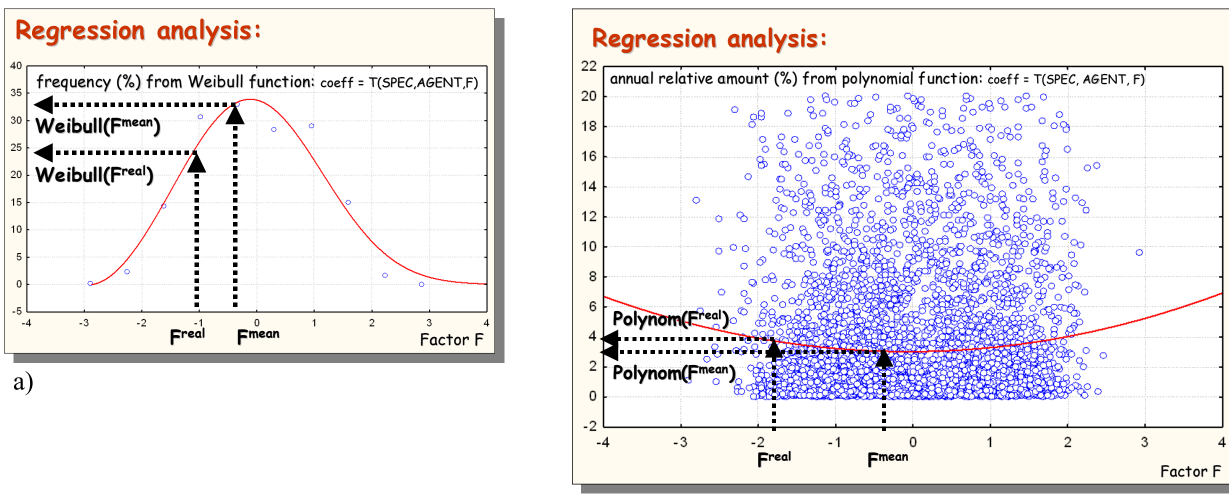
$$F_i = \sum_{j=1}^{8} \left(score_{ij} \cdot \frac{x_j - \bar{x}_j}{s_{x_j}} \right) \quad (3)$$

Example of factors for windstorm and all tree species is presented in the Table 3. Mean factors for mean conditions and real factors for real conditions are calculated. Risk modification is based on multipliers. Multipliers are derived from frequencies of incidental cuttings depending to factor value. Frequencies have been derived by *regression analysis* for all factors. Weibull function has been applied. Frequency for mean factor (F^{mean}) and real factor (F^{real}) are calculated from the regression function (example in Figure 6a). Finally, real risk ($risk^{real}$) is calculated by:

$$risk^{real} = risk^{mean} \cdot \frac{\sum_{i=1}^{k} \frac{Weibull\left(F_i^{real}\right)}{Weibull\left(F_i^{mean}\right)}}{k} \quad (4)$$

Table 3: Example of factors table

SPEC	AGENT	FACTOR	scores of linear combination							
			vegzone	aspect	slope	age	sdensity	percentage	siteindex	hd
spruce	windstorm	stability	-0,123243	0,057766	-0,224123	**-0,738731**	0,207547	0,174868	**0,815942**	**0,793160**
		diversity	**-0,793107**	0,023538	-0,173181	0,070574	0,162982	**-0,799766**	0,035486	-0,004895
		terrain	0,314044	0,006772	**0,706223**	0,081063	**0,638186**	-0,239916	-0,073781	0,088126
		aspect	0,080726	**0,916622**	0,236525	-0,051582	-0,329803	-0,076033	-0,092671	0,044231
fir	windstorm	stability	-0,072138	0,008514	-0,102457	**-0,819394**	0,025576	-0,062213	**0,845124**	**0,724375**
		diversity	0,140796	-0,003404	-0,284255	0,097013	**0,710334**	**-0,804328**	0,035255	0,181635
		terrain	**0,838617**	0,054434	**0,743003**	0,115097	-0,148218	-0,065398	-0,144667	0,042374
		aspect	0,062678	**0,981793**	-0,007793	-0,025703	0,134595	0,145238	0,027565	-0,041866
pine	windstorm	stability	0,002035	-0,077524	-0,014910	**-0,799566**	0,095944	0,042437	**0,696902**	**0,848855**
		terrain	**-0,794081**	-0,436846	**-0,860241**	0,077155	0,039856	0,258176	0,251750	0,021108
		density	-0,018982	0,359042	-0,050020	0,038754	**0,922050**	0,073460	0,145289	0,049189
		diversity	0,178664	0,118310	-0,004555	0,239430	-0,086423	**-0,879039**	0,465678	0,052959
beech	windstorm	stability	0,128001	0,033452	0,086098	**0,803614**	-0,029059	0,012653	**-0,760635**	**-0,884057**
		diversity	-0,529656	-0,087224	0,105628	0,186517	0,145024	**0,907098**	0,309903	0,020474
		density	0,197946	**0,635618**	-0,143354	0,151555	**0,772599**	0,078975	0,049473	0,079477
		terrain	**0,606860**	-0,010171	**0,903248**	0,106998	-0,041415	0,046732	-0,247284	0,067404
oak	windstorm	stability	0,070130	-0,001142	0,004954	**0,814447**	0,012914	0,100096	**-0,644454**	**-0,884375**
		diversity	**0,886811**	0,057240	0,342279	0,132466	0,107642	**-0,810566**	0,283735	0,032391
		density	-0,014329	0,046729	-0,591642	0,217322	**0,798093**	0,051661	0,395113	0,049584
		aspect	0,113164	**0,988673**	0,022911	-0,051688	0,073637	0,037037	-0,106577	0,000466



a) b)

Figure 6: Example of correction for: a) risk of incidental cutting, b) amount of incidental cutting

3. Real risk for real condition is modified by climate anomalies:

$$risk^{modif} = risk^{real}.b.\left(1+\frac{\sum_{i=1}^{8} a_i.\left(\frac{s_i - s_i^{norm}}{0,5.\left(s_i^{max} - s_i^{min}\right)}\right)}{\sum_{i=1}^{8}\left|a_i\right|}\right) \quad (5)$$

where s_i are real site variables and s_i^{norm} are standard site variables from regionalized climate (FABRIKA et al. 2005). Site variables are equal with variables necessary for ecological site classification in model SIBYLA (FABRIKA 2005). They are NO_x in air (1), CO_2 in air (2), nutrient supply in soil (3), vegetation days (4), year temperature amplitude (5), mean temperature in vegetation season (6), soil moisture (7), and precipitation in vegetation season (8). Variable s_i^{min} and s_i^{max} are minimal and maximal site variables for ecological amplitude of current tree species (KAHN 1994). If dummy variable a_i is equal to 0 site difference is without influence, if variable is equal to +1 site difference has positive influence, and if it is equal to -1 site variable has negative influence. Dummy variables are in the Table 4. Coefficient b is multiplier between 0,5 and 1,5 sensitive to tree species. Equation 5 is calculated only in the case if summary of absolute dummy variables in denominator is bigger than 0, otherwise result of equation is 1.

Table 4: Dummy variables for model of climate anomalies

AGENT	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8
windstorm	0	0	0	0	0	0	0	0
snow damage	0	0	0	-1	0	0	0	0
icing damage	0	0	0	-1	0	0	0	0
bark miner	0	0	0	1	0	1	0	0
defoliator	0	0	0	1	0	1	0	0
wood-destroying fungi	0	0	0	1	0	1	0	1
air pollutants	0	0	0	0	0	0	0	0
fire	0	0	0	0	0	1	0	-1
drought	0	0	0	0	0	1	0	-1
steal	0	0	0	0	0	0	0	0
other	0	0	0	0	0	0	0	0

4. Estimated risk is compared with random number within uniform distribution U[0,100). If risk is higher than random variable, then injurious agent is activated in the growth period.
5. Mean relative volume of incidental cutting *AVG(%V)* and standard deviation *SD(%V)* is retrieved from the C-TAB. See example in Table 2. The volume is modified on basis of mean factors and real factor as has been described in Step 2. Polynomial function is used for mentioned purposes (example in Figure 6b). Function has been derived from *regression analysis.* Modification is:

$$AVG(\%V)^{real} = AVG(\%V)^{mean} \cdot \frac{\sum_{i=1}^{k} \frac{Polynom\left(F_i^{real}\right)}{Polynom\left(F_i^{mean}\right)}}{k}$$

Standard deviation is not modified because variance has been homoskedastic, without exchange depending to factor value.

6. Final step of statistical part generates random relative amount of incidental cutting *%V* in the stand. The principle of *Monte Carlo method* is applied. Random number is generate within Normal (Gauss) distribution defined by mean (*AVG(%V)*) and standard deviation (*SD(%V)*). Generation is repeated in each period. For plausible conclusion, we must repeat simulation many times. After high numbers of simulations, mean converges to origin average with origin standard deviation. Therefore single simulation simulate one possible amount of incidental cutting very well.
7. Individual trees are selected for incidental cutting. Selection depends to spatial propagation of mortality in the stand space. Propagation should be individual, spotted or local. In *individual (scattered)* propagation, trees are selected on basis of their individual tree parameters (tree diameter, tree height, coefficient of slightness, crown diameter, crown length, crown shape coefficient, tree vitality, bio-sociological tree status, tree competition pressure, tree quality, and score of existence). Parameters calls selectors and their are selected for each injurious agent. Then selectors are transformed by fuzzy functions and joined by OR/AND operators. Fuzzy functions are sensitive to individual parameters and should be in positive or negative position. Negative position is derived from positive one by NOT operator. Trees with the biggest final values are selected as dead trees for incidental cutting. Number of trees is defined by *%V*. Individual propagation is automatically activated for snow damage, icing damage, drought, wood-destroying fungi, air pollutants, and steal. Default adjustment of the model is in the Table 5. In *spotted* propagation *(expanded from local point)*, trees are selected on basis of generated parameters of spotted elements. Random number of spots is generated from uniform distribution U[1,5). Propagation is defined by length of propagation period (usually 3 years). Size of spotted elements is defined by *%V*. Amount during years is linear expanded. All trees inside of spotted elements are dead and prescribed for incidental cutting. Spotted propagation is automatically activated for bark miners and timber borers. In *local* propagation (*for specified sub-area*), trees are selected on basis of generated parameters of local area. Shape of the area is selected (circle, strip, ellipse). Position of area is generated. Size of local area depends to *%V*. All trees inside of local area are dead and prescribed for incidental cutting. Local propagation is automatically activated for wind damages (in strip), defoliators (in ellipse), and fires (in ellipse).

Table 5: Default adjustment of the model for individual propagation of dead trees
(+ means positive position, - means negative position)

		snow	icing	fungus	air pollutants	drought	steal
selector	tree diameter						
	tree height						
	coeff. of slight.	+					
	crown diameter	+	+				
	crown length		+				
	crown shape coeff.						
	tree vitality			-		-	
	bio-soc. status				-		
	compet. pressure				+	+	
	tree quality			-			
	score of existence						
link		AND	AND	OR	AND	OR	
random		NO	NO	NO	NO	NO	YES

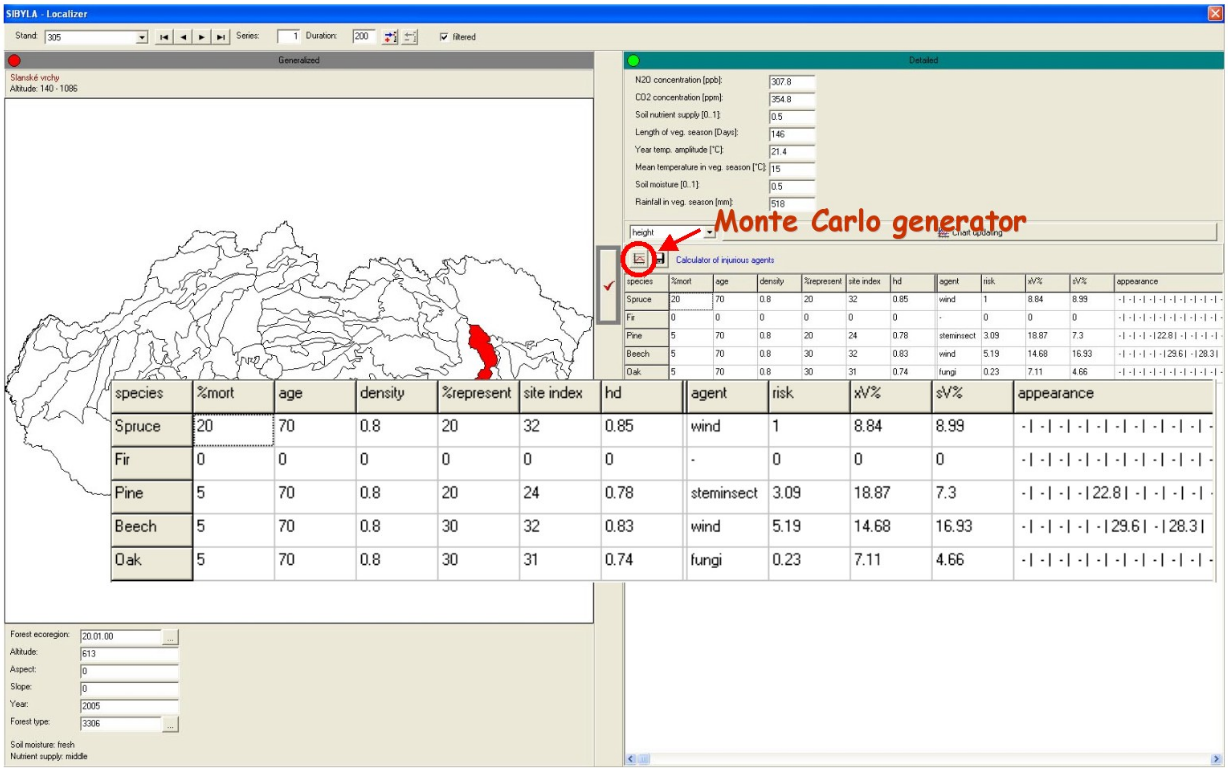


Figure 7: Monte Carlo generator of incidental cuttings in Localizer unit

Software solution

The model has been implemented as software tool. The software is integral component of the SIBYLA growth simulator (FABRIKA 2005). User can specify if he (she) want to use implicit or explicit model for incidental cuttings. *Implicit model* is fully automatic. All necessary input data are retrieved from SIBYLA database. They are data about the site, and about the stand. It is necessary to specify generalized data about site (Forest Eco-region, altitude, aspect, slope, and forest type). At the same time, it is important to select also detailed climate and soil data, if they are known. It is concentration of NO_x and CO_2 in air, soil nutrient supply, number days of vegetation season, year temperature amplitude, mean temperature in vegetation season, soil moisture, and total rainfalls in vegetation season. The software compare standard climate from generalized specification and real climate specified by user. Differences are used for modeling of climate anomalies and their influence to appearance of incidental cuttings. If detailed climate and soil data are not specified, then climate anomalies will be not applied in the model. Except of site data, user must specify also stand data. The data are derived from forest structure, which is generated by structure generator or directly specified by user. This is information about age, stand density, tree species composition, site index, and relation between mean height and mean diameter. Amount of dead trees in recent period is modeled by SIBYLA mortality model. Mortality is necessary for modification of injurious agent frequencies. User can check functionality of Monte Carlo generator for appearance and amount of incidental cuttings in periods of simulation (Figure 7) before prognosis. *Explicit model* is fully controlled by user. User selects which injurious agent should be activated in period of simulation and inserts its risk and amount of incidental cutting (specified by average and standard deviation). At the same time, user must justify propagation of injurious agent on tree level. Options are available from software dialog (example in Figure 8) together with fuzzy functions of individual tree selectors. All options are also saved in table DAMAGE in SIBYLA Microsoft Access Database. Explicit model is simplified and flowchart of the model is reduced. See pictograms in Figures 2-4. Final model has been implemented as integral component of the PROPHESIER Unit and its sub-unit is called AGGRESSOR (Figure 9). Results from the model are dead trees. Reason of mortality is transparent. It is possible to check it in the SIBYLA database after simulation or check it in console of virtual reality (if cursor go over dead tree).

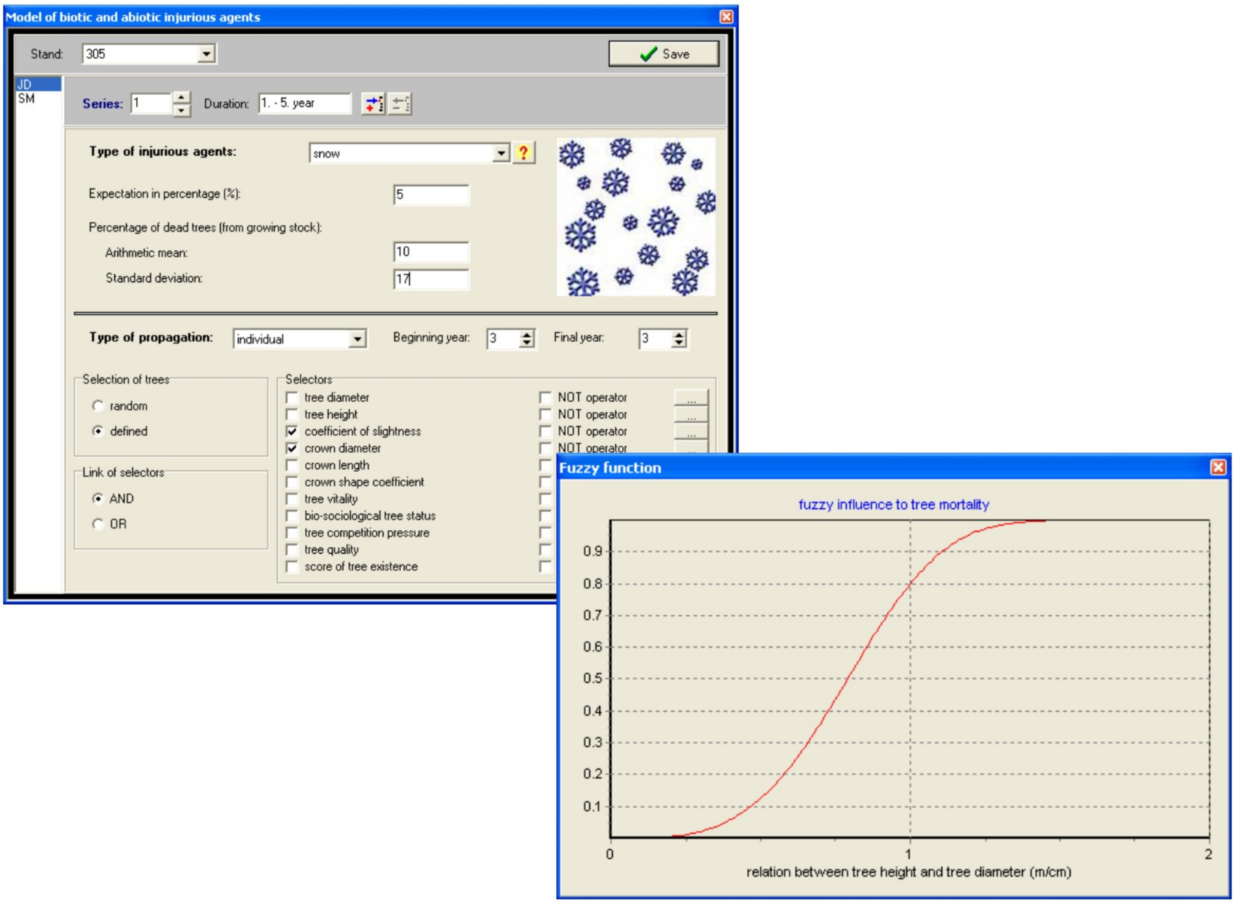


Figure 8: Example of dialog for model fully controlled by user

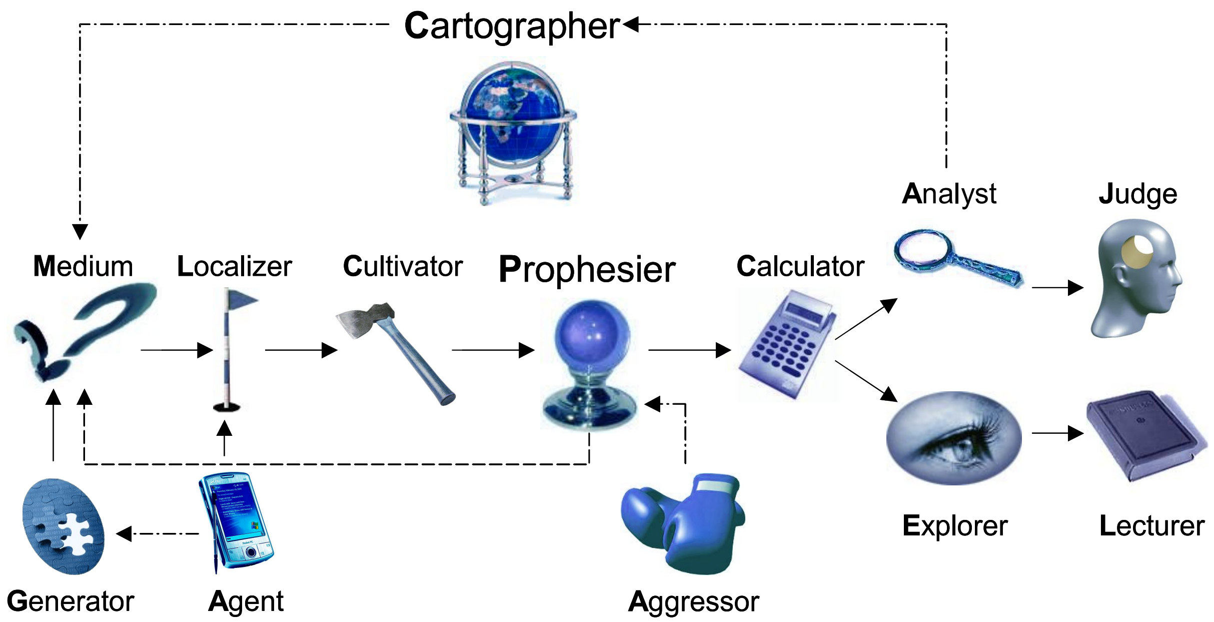


Figure 9: The position of Aggressor unit in SIBYLA software structure

Conclusion

We can not imagine forest development without influence of external factors as lifeless nature, live nature, and human are. They often have non-predictable character. This is reason, why this kind of the factors is not usually regular component of many growth simulators. We tried to implement first version of complex model for incidental cuttings. This model responds to wide range of injurious agents: wind, snow, icing, bark miners, timber borers, defoliators, wood-destroying fungi, air pollutants, drought, fire, and steal. Injurious agents are activated by wide range of external variables: geomorphology parameters (altitude, aspect, slope), climate (temperature, precipitation, vegetation season), sanitation parameters (remain dead trees), site parameters (Forest Eco-region, vegetation zone, site class), and stand parameters (age, stand density, tree species composition, site index, mean height and mean diameter). The model combines different modeling instruments: factor analysis, regression analysis, Monte Carlo method, planar geometry, and fuzzy based rules. Incidental cuttings are simulated hierarchically from stand level (risk and total amount) to tree level (tree selection). The model can help for answering of wide scale of scientific questions, but also is applicable for e-learning process, and decision support in forest management. But first of all, we must evaluate model on scientific level. This is nearest task for next research. Also we must solve additional problems, which are not implemented yet. For example sequential character of some injurious agents, gradations of some injurious agents, and of course problems of tree increment change regarding to damages together with tree quality change.

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References

Fabrika, M.: Simulátor biodynamiky lesa SIBYLA, koncepcia, konštrukcia a programové riešenie (Simulator of forest biodynamics SIBYLA, conception, construction, and software solution), Habilitation work, Technical University of Zvolen, Zvolen, 238S., 2005

Fabrika, M., Dursky, J., Pretzsch, H., Sloboda, B.: Regionalisation of climatic values for ecological site classification using growth simulator SIBYLA with GIS. In: "Remote Sensing and Geographical Information Systems for Environmental Studies, Application in Forestry, Edited by KLEIN, CH., NIESCHULTZE, J. and SLOBODA, B., Band 138, Universität Göttingen, J.D. Sauerländer's Verlag Frankfurt am main: 245-255, 2005

Holecy, J.: Forest fire insurance problem in Slovakia and its solution by methods of elementary statistics. In: Development trends of processes management in wood processing industry and in forestry. Proceedings of the International Association for Technology Management-Wood/Technical University of Zvolen Publishers, Zvolen: 53-60, 2000

HOLECY, J., HANEWINKEL, M.: A forest management risk insurance model and its application to coniferous stands in southwest Germany, Forest Policy and Economics, 8:161-174, 2006

KAHN, M.: Modellierung der Höhenentwicklung ausgewählter Baumarten in Abhängigkeit vom Standort, Forstliche Forschungsber, München, Vol. 141, 221S., 1994

MIKUSIKOVA, B.: Modely poistenia lesného majetku proti riziku výskytu náhodných ťažieb (Forest property insurance models aginst risk of incidental cuttings appearance), Dissertation work, Technical Univerzity of Zvolen, Zvolen, 80S., 2005

VACULCIAK, T.: Kvantifikácia faktorov ovplyvňujúcich vetrové kalamity prostredníctvom faktorovej analýzy (Quantification of factors influenced to wind disasters by factor analysis), Acta Facultatis Forestalis Zvolen Slovakia, XLIX, Technical University of Zvolen, Zvolen: in printing, 2007

Summary

The paper deals with modeling of incidental cuttings as consequence of abiotic and biotic injurious agents (windstorm, snow damages, icing damages, bark miners, timber borers, defoliators, wood-destroying fungus, air pollutants, drought, and fires). The model construction is presented in the first part. Software solution is presented in the second part.

The model is composed from 2 parts. The first part is based on statistical approach. Data covered all Slovak area has been utilized for mentioned purpose. They are data from stand forest inventory and management records. Data are composed from 3 forest districts for all 47 Slovak Forest Eco-regions. Totally 89707 stands with total area 388830 hectares have been processed. It is approximately 19% of Slovak forest area. Data includes all necessary stand and tree species information, together with information about incidental cuttings (year of cutting, type of injurious agent, amount of cutting). We utilized data from period 2000-2005. We applied factor analysis and regression analysis for estimation of probability of incidental cutting and amount of incidental cutting (together with standard deviation). In first step we select type of injurious agent from frequency table for individual forest eco-regions and tree species. Random selection with probability proportional to frequency is applied. Then we estimate mean probability of selected injurious agent, together with amount of incidental cutting and its standard deviation. Values are selected from statistical classification table on basis of Forest Eco-region, category of site and tree species. The values are modified by relative differences between classification factors and real factors. Factors are derived from factor analysis and they are composed from linear combination of following variables: forest vegetation zone, aspect, slope, age, stand density, percentage of tree species, site index, and relation between mean height and mean diameter. Then modified probability of incidental cutting (risk) is compared with random number (within 0-100%). If probability is higher than random number, then incidental cutting is applied in the simulation. Amount of cutting is generated from Gauss distribution defined by mean amount of cutting and its standard deviation.

The second part of the model is based on fuzzy logic rules. The model specifies individual trees for incidental cutting. Three different selection rules are applied: individual (scattered), spotted (expanded from focal point), and local (for specified sub-area). Type of rules depends to type of injurious agent. Individual selection is based on fuzzy functions and their combination (or, and). Fuzzy functions are composed on basis of following tree variables: tree diameter, tree height, coefficient of slightness, crown diameter, crown length, coefficient of crown shape, tree vitality measured by crown surface, bio-sociological tree status, tree competition pressure, and tree quality. Selected trees are defined as trees for incidental cutting.

Key words: forest modeling, injurious agent, tree mortality, factor analysis, Monte Carlo method