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Landscaping State Modeling in a Small Town

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Abstract: The article describes a model and forecasting algorithm of landscaping state in a small town for a specified period of time. The model describes the stages of tree growth milestones from planting of saplings to plant loss. The theory of probabilistic finite-state automatons is used to form the model. Expert evaluations serve as the initial conditions of survival probability and tree loss for various technologies of plant care and different natural factors. The data of the environmental passport of the town of Kamyshin in the Volgograd Region are also the initial data. We have provided the results of computational experiments allowing comparing the effectiveness of various landscaping technologies as well as evaluating the impact of external factors on the state of a park of tree species in the distant future. The criterion of greenery planting quality is the age composition of trees and the number of them. The algorithm of forecasting of the state of landscaping imitates frost cracks for different technologies. The area of model application is the future planning of work on landscaping in the town.

Key words: Forecasting model · Town landscaping · A park of tree plantations · Probabilistic finite-state automaton

INTRODUCTION

The issues of preserving and improving the state of urban environment in small towns currently have to be considered as secondary compared with social issues and the issues of preserving the industrial potential. The analysis of approaches to future arrangement planning to upgrade the landscape and the implementation of ideas on town landscaping with expense minimization as the only criterion shows that unsatisfactory technologies that are often used now due to limited resources can lead to complete degradation of vegetation in a city over 20-30 years.

The target of this work is in evaluating the state of the town vegetation in the distant future based on the simulation of the landscaping state dynamics.

The Method of Building a Formalized Model Description of the Landscaping Quality Dynamics: In order to solve the assigned task, the authors suggest a model of the vegetation state simulation based on the theory of probabilistic finite-state automata [1-4]. The main ideas and assumptions taken into account at the model development are briefly described in [5]. The object of simulation is tree plantation; bushes and other plants are neglected in the model.

At first, it is necessary to describe the cycle of calculations based on the model. The calculations include the following: $M[t]$ – a set of point indexes on the map of the considered area (the point can be available or taken by a viable tree), where plants may be located in year t (there are T years in total); M_{grow} ($\tau_f[t]$) and M_{begin} ($\tau_b[t]$) are sub-sets of the indexes of the set $M[t]$, interpreted as sets of point indexes on the map of the studied area where there are plants that survived by the end (M_{grow}) and the beginning (M_{begin}) of year t (at the moments of $\tau_f[t]$ and $\tau_b[t]$ correspondingly). At the moment $\tau_f[t]$ (at the end of the year) there is an inventory count of the tree composition in the group and at the moment $\tau_b[t]$ the campaign of planting seedlings starts.

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The condition of switching from the end of (t – 1) year to the beginning of t year is set as $M_{begin}(\tau_b[t]) = M_{grow}(\tau_f[t-1])$, $M_{grow}(\tau_f[t])$.

$M_{free}(\tau_b[t])$ is a subset of indexes of $M[t]$ set that is interpreted as a set of points on the area under consideration that are not covered by trees (the seedlings can be located at these points). $M_{free}(\tau_b[t])$ satisfies the following relations:

$$M_{free}(\tau_b[t]) = M[t] \setminus M_{grow}(\tau_f[t-1]) \text{ or } M_{free}(\tau_b[t]) = M[t] \setminus M_{free}(\tau_b[t]) \cup M_{begin}(\tau_b[t]) = M[t],\ M_{free}(\tau_b[t]) \cap M_{begin}(\tau_b[t]) = \varnothing.$$

$M_{new}(\tau_n[t])$ is the subset of indexes $M_{free}(\tau_b[t])$ which is interpreted as a set of points of the considered area where in t year a planting of seedlings is planned ($\tau_n[t]$ is the moment when the campaign of seedling planting is finished). These points are either determined according to the plan of vegetation (for example, for the streets), or randomly (for example, for parks and mini-parks). In the latter case, some weight is given to the elements of $M_{free}(\tau_b[t])$ set, which is formed by a procedure selecting non repeating random numbers, uniformly spread on the interval of [0; 1] in the array. Following this, a sorting is done for the set elements with the weight value (for example, in an ascending order). The set $M_{new}(\tau_n[t])$ will include selected values of $|M_{new}(\tau_n[t])|$ elements from the sorted set $M_{free}(\tau_b[t])$ (here $|M_{new}(\tau_n[t])|$ is the number of elements (order) of the set $M_{new}(\tau_n[t])$). As a result, random planting of seedlings in the coordinates of free from planting area is simulated.

$M_{live}(\tau_n[t])$ is a sub-set of $M[t]$ indexes that is interpreted as a set of points of the studied area covered with viable plants after finishing the campaign of planting seedlings:

$$M_{live}(\tau_n[t]) = M_{beging}(\tau_b[t]) \cup M_{new}(\tau_n[t]),\ M_{begin}(\tau_b[t]) \cap M_{new}(\tau_n[t]) = \varnothing.$$

For each element of $M_{live}(\tau_n[t])$ set the weight $V_i[t]$ is used that is interpreted as the age of a tree located at the point with the index $i \in M_{live}(\tau_n[t])$. The value of the weight value for all elements of $M_{new}(\tau_n[t])$ set is the same (it is interpreted as the seedlings' age); the values of weights for the elements in the set $i \in M_{begin}(\tau_b[t])$ are recalculated when switching from the ending of year (t – 1) to the beginning of year t (imitating the change of the tree age):

$$V_i[t] = V_i[t-1] + 1\ \forall_I \in M_{begin}(\tau_b[t]);\ V_i[0] \text{ задано } \forall_I \in M_{grow}(\tau_f[t])$$

$M_{live}(\tau_n[t])$ set elements are broken into G non-overlapping subsets $M_{live}^{(g)}(\tau_n[t])$ according to the initial data on probabilities $P_g[t]$ of plant survival for g-age group during year τ, $g = 1, \ldots, G$. Breaking trees into age groups is performed in order to decrease the size of the task without violating the accuracy of the forecast of vegetation state in general: the probability of the survival of the tree group aggregated by age is consistent with the data on the probability of each tree survival and can be considered the same for all of the trees of the corresponding age group. This assumption agrees with the well-known postulates about the non-linear dependency of the probability of tree survival from its age: there are both long periods of time when the probability of survival doesn't depend that much on the age, as well as short-term transitional periods when the probability of survival abruptly changes [6, 7].

The indexes from set $M_{live}(\tau_n[t])$. with the weights within $\left[\underline{V}_g; \overline{V}_g\right); \underline{V}_g < \overline{V}_g$ ($\underline{V}_g$ – group lower age limit, $\overline{V}_g$ – group upper age limit) group in each sub-set. The index groups are interpreted as plants belonging to g age group, which is considered to have the same probability of survival during year t. The conditions of breaking $M_{live}(\tau_n[t])$ down into sub-sets of $M_{live}^{(g)}(\tau_n[t])$, $g = 1, \ldots, G$ are the following:

$$M_{live}^{(g)}(\tau_n[t]) = \left\{ i : \forall i \in M_{live}^{(g)}(\tau_n[t])\ \underline{V}_g \le V_i < \overline{V}_g \right\},\ g = 1, \ldots, G.$$

$$\bigcup_{g=1}^{G} M_{live}^{(g)}(\tau_n[t]) = M_{live}(\tau_n[t]),\ M_{live}^{(k)}(\tau_n[t]) \cap M_{live}^{(l)}(\tau_n[t]) = \varnothing,\ \forall k, l = 1, \ldots, G;\ k \ne l.$$

For each element $i \in M_{live}^{(g)}(\tau_n[t]),\ g=1,\ \ldots,\ G$, a survival condition for *t*-year is imitated. For that purpose, each element is provided with the weight $w_i^{(g)}[t]$ – a random Boolean value generated according to the Bernoulli's distribution law, which parameter is equal to the probability $P_g[t]$ of plant survival in *g*-age group that is viable at $\tau_n[t]$ moment during *t* year (at the moment of $\tau_f[t]$). The value $w_i^{(g)}[t]=1$ ($w_i^{(g)}[t]=0$) imitates the survival (loss) of the plant condition by the end of *t*-year.

According to the value of the weight $w_i^{(g)}[t]=1$ sets of point $M_{final}^{(g)}(\tau_f[t]),\ g=1,\ \ldots,\ G$ indexes are formed imitating the set of points where all the trees that have survived are located at:

$$M_{final}^{(g)}\left(\tau_f[t]\right)\subset M_{live}^{(g)}\left(\tau_n[t]\right),\ g=1,\ \ldots,\ G,$$
$$M_{final}^{(g)}\left(\tau_f[t]\right)=\left\{i:\ \forall i\in M_{final}^{(g)}\left(\tau_f[t]\right)\ \ w_i^{(g)}=1\right\}.$$

The set M_{final} ($\tau_f[t]$) is formed as a group of sets $M_{final}^{(g)}(\tau_f[t]),\ g=1,\ \ldots,\ G$: $M_{final}\left(\tau_f[t]\right)=\bigcup_{g=1}^{G} M_{final}^{(g)}\left(\tau_f[t]\right).$

Set M_{final} ($\tau_f[t]$) excludes the sub-set of points M_{old} ($\tau_f[t]$) with the plants whose age in (t + 1) year will be higher than $V_{\max}$:

$$M_{old}\left(\tau_f[t]\right)=\left\{i:\ \forall i\in M_{old}\left(\mathrm{t}_f[t]\right)\ \ V_i\geq V_{\max}-1\right\}.$$

Then set M_{grow} ($\tau_f[t]$) is formed:

$$M_{grow}\left(\tau_f[t]\right)=M_{final}\left(\tau_f[t]\right)\setminus M_{old}\left(\tau_f[t]\right).$$

In order to calculate the number M_{trees} ($\tau_f[t]$) of "effective" trees used as a generalized criteria of the vegetation state in *t*-year, it is necessary to form a set of M_{young} ($\tau_f[t]$) $\subset$ M_{grow} ($\tau_f[t]$) point indexes where there are trees with the age that is lower than the extreme $V_{\min}$ (the plants whose age is lower than $V_{\min}$ are considered "ineffective"):

$$M_{young}\left(\tau_f[t]\right)=\left\{i:\ \forall i\in M_{young}\left(\tau_f[t]\right)\ \ V_i<V_{\min}\right\}.$$

A tree is called "effective" when it positively impacts the landscaping look of the city and the atmospheric environmental state (reduces the amount of CO_2, lead, dust and other contaminating substances to the values that are lower than the given values) [8-11].

The number M_{trees} ($\tau_f[t]$) is calculated as the difference between the orders of sets M_{grow} ($\tau_f[t]$) and M_{young} ($\tau_f[t]$):

$$N_{trees}\left(\tau_f[t]\right)=\left|M_{grow}\left(\tau_f[t]\right)\right|-\left|M_{young}\left(\tau_f[t]\right)\right|,\ \text{where}\ N_{trees}\left(\tau_f[0]\right)\ \text{is set.}$$

This operation concludes the cycle of calculations that are made for *t*-year. The calculations for year (t + 1) are done using the same formulas exchanging the index t for (t + 1).

If the probability of *g*-age group survival $P_g[t]$ does not depend on the time (i.e., if $\forall g=1,\ \ldots,\ G,\ P_g[t]=P_g=const$) and whether the intensity of seedling planting is constant (that is, if $N_{new}[t]=N_{new}=const$), then the values M_{trees} ($\tau_f[t]$) come together to the time-invariant value of $N_{trees\_st}=\lim_{t\to\infty} N_{trees}\left(\tau_f[t]\right)$, imitating the evaluation of distant consequences of the impact of the accepted technology on its quality [12].

Examples of Results of Computational Experiments Using the Model of Long-Term Forecasting for Landscaping State the Settings of Some Computational Experiments Are Given Below: Studying the impact of the switch to the new technology of planting and caring for plants. For that reason, we are evaluating the vegetation state dynamics of the existing technology in order to find its characteristics (particularly, the period and level of achieving the lowest as well as the quasi-stationary value of the number of "effective" trees). And then, starting from the given year of the forecasting period, we imitate the implementation of a more effective technology by exchanging the probabilities of tree survival for each age group. It is possible to determine the following values during the experiment: the latest possible deadline of switching for a more effective technology, the rate of achieving the required level of landscaping, the economic expense, the effect of implementing the new technology not on the whole territory, but only on a part of it.

Selecting the composition (the number and types of trees) taking into account the usefulness of tree types for this climate zone and city conditions. Studying the impact of tree type changes (for example, for the trees with shorter life span, but achieving the "effective" age in a shorter time period) on the overall state of the vegetation park.

The analysis of dynamics of the landscaping state at abrupt climate changes (depending on the frequency of frost cracks and drought periods) or extreme environmental impact (fires, loss of plants from pests, loss during area build-up [9, 13]). This type of analysis can answer a question about the landscaping restoration time.

The Results of Some Experiments Are Given below: For small town conditions when the town is located in a sparsely wooded steppe zone we have forecasted the dynamics of changes in the state of the forest park landscaping (the wood species is a poplar). The goal of forecasting is the comparison of two approaches to planting and care for plants hereinafter called "the common-used technology" and "the progressive technology". The first approach aggregates such factors as planting into unprepared land, untimely care, planting the types of plants that are not well adapted for the soil group, etc, i.e. when the planting plan is fulfilled without attracting experts and with the dominating criteria of savings as much funds as possible. The second approach («the progressive technology») excludes the listed factors and means correspondence of the processes of planting and care to the type of plants that would provide the maximum probability of plant viability [6]. The initial data are following:

- Owing to an expert's assistance, we have determined 11 tree age groups. Also, based on the expert data and nature studies [6], the relative probabilities of each tree age group were determined. They did not change during the whole study. The number of trees in each age group for the beginning of the forecasting period and the probabilities of survival for two technologies are given in Table 1.
- Since there are no inventory data available for each tree, the tree age inside the group was imitated by a random whole number equally distributed on the intervals determined by the limits of age groups.
- The planting intensiveness (the number $N_{new}[t]$ of seedlings (order of the set $M_{new}[t]$), planted yearly in the open ground) was taken at the constant level of 1200 trees per year.
- The age limits of a tree «effectiveness»: V_{min} = 10, V_{max} = 50 (years).

As it can be seen from the initial data, each tree for the beginning of the forecasting period has the age close to the extreme. This emphasizes the situation that many small towns are facing when, due to insufficient funding, city landscaping for the latest 20 years was done insufficiently or not at a high quality level. At the same

Table 1: The initial data of the experiment; the total number of trees is 10320 units.

Group number	1	2	3	4	5	6
The age range, years	3	4	5	6 - 10	11 - 20	21 - 30
The number of trees, units	300	220	210	200	180	170
Pg[t], the commonly-used technology	0.3	0.4	0.6	0.8	0.9	0.95
Pg[t], the progressive technology	0.7	0.8	0.85	0.9	0.92	0.95

Table 1: Continuation.

Group number	7	8	9	10	11
The age range, years	31 - 40	41 - 50	51 - 60	61 - 70	71 - 80
The number of trees, units	1380	2970	2490	2000	200
Pg[t], the commonly-used technology	0.9	0.9	0.7	0.2	0.1
Pg[t], the progressive technology	0.92	0.92	0.8	0.5	0.2

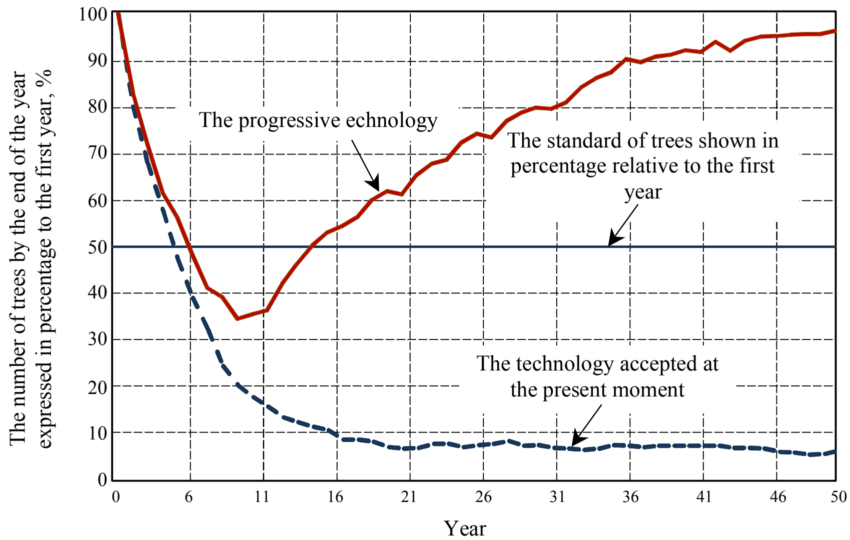

Fig. 1: The dynamics of the tree park when using various technologies

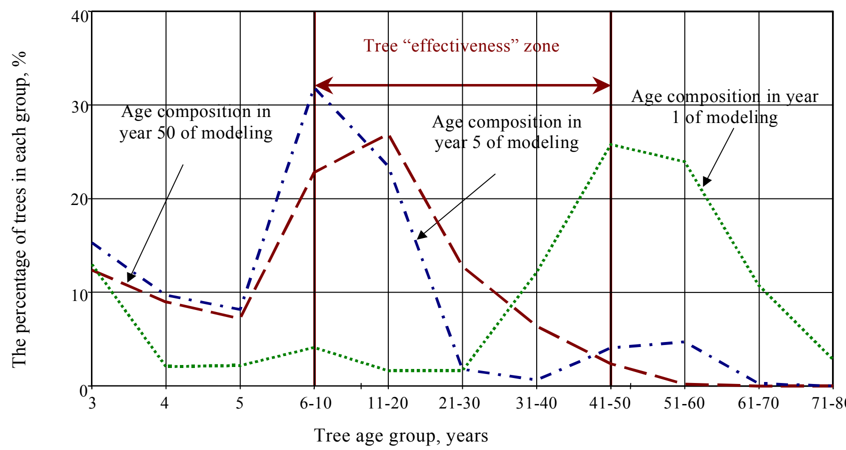

Fig. 2: Change in the number and age composition of trees in different modeling years for the progressive technology

time, the exchange of the dead trees for new plantations cannot happen immediately because the state of the landscaping is evaluated by the number of plants whose age is not less than V_{min}. The determination of the duration and depth of the regressive process (deterioration of landscaping) for different technologies of planting and care for trees is an interesting study point.

The simulation period duration is chosen based on getting the evaluation of the stationary landscaping state. To check that the stationary state has been reached and to evaluate the statistical characteristics of the landscaping state numerous calculations have been done and then the results were averaged out. Figure 1 illustrates that in 5-6 years the number of trees will be lower than the standard level (set for the zone under consideration) regardless of the technology used. However, for the progressive technology, the depth of the regression will reach the level of only 35% from the initial number of trees; in 15 years after that the number of trees will again be above the standard level and by 50 years it will almost achieve the initial value. At the same time, for the commonly-used technology, the level will continue to decrease down to the value of less than 10% from the initial one and will arrive to the stationary value approximately in 25 years.

Figure 2 illustrates the improvement of the age composition of trees by the end of the forecasting period for the progressive technology: the distribution of the number of "effective" trees by age is becoming satisfactory (approximately 50% of "effective" trees from the total number).

Figure 3 shows the result of an experiment determining the impact of frost cracks that happens once in 20 years starting from the 3rd year of modeling (frost cracks' parameters: loss of 80% of young trees under 10 years old and 10% of trees over 10 years old). It is

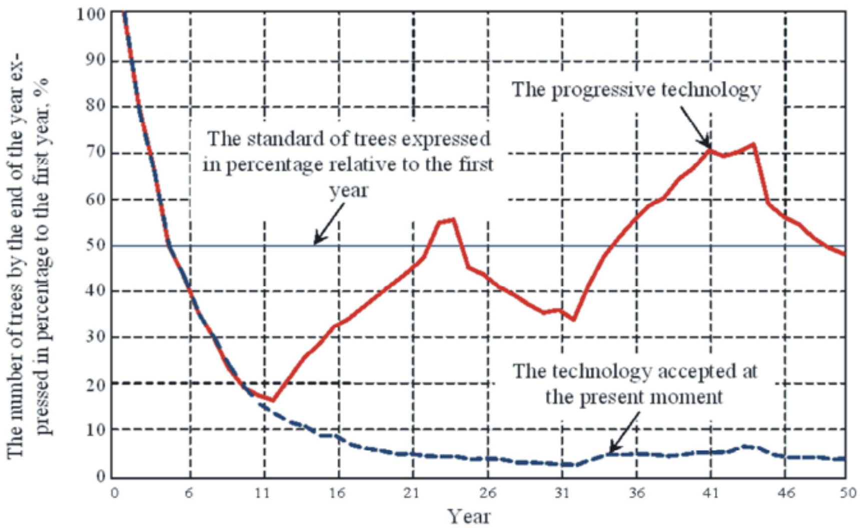

Fig. 3: The dynamics of the tree park using various technologies and frost cracks in 3, 23, 43 modeling years

possible to see from the graph than by using the progressive technology there is a gradual improvement of the landscaping state even in the most difficult conditions. The calculations, based on the suggested model, allow arriving at the conclusion that approximately starting from the 60th year these frost cracks will not lead to the size of the tree population being less than the set standard.

CONCLUSIONS

The developed model of the vegetation park development allows comparing various technologies of landscaping (in particular, comparing the technologies of planting and taking care of plants, imitating the changes in the composition of the tree type park) and evaluating the dynamics of a tree plantations park in the long-term perspective, including the impact of unusual weather conditions and extraordinary events (frost cracks, fire, drought, etc).

The model application is the development of an effective strategy of city landscaping.

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