URFOR/SIMULATION: AN URBAN FOREST MANAGEMENT COMPUTER SIMULATION/GAME

by Robert W. Miller and Michael S. Marano

Abstract. URFOR/SIMULATION is a computerized urban forest management simulation/game designed to model a street tree population. The program utilizes actual street tree data and removes, prunes, plants, grows and kills street trees over time. The program user inputs management plans for planting, pruning and removal rates; and associated management costs. The simulation runs on an annual basis for the number of years specified by the user. Programs output describes the impact of management plans on the street tree population, calculates the value of the trees, and summarizes management costs. The simulation may be used as a game by the introduction of six random events; wind storm, ice storm, new disease, drought, budget increases, and budget cuts. The game user makes management decisions, runs the program on an annual basis, and alters management plans to compensate for random events.
Additional Key Words: Arboriculture, street trees.

Computer applications to urban forest management have come of age with the development of a number of computer based inventory systems. Sacksteder and Gerhold (5) report some 25 computer inventory systems in the U.S., with 15 being city specific and 10 being general application models adaptable to any city. The systems on line are designed to solve a most pressing problem for city foresters, how to develop comprehensive management plans for thousands of individual street and park trees. This is accomplished by many systems through data reduction, i.e. the reduction of large volumes of inventory information to a usable form which serves as a base for management decisions.

URFOR/SIMULATION* is a management simulation/game model designed to use inventory data gathered for UW/SP URBAN FOREST, one of the inventory systems described above (3). URFOR/SIMULATION may be used both as a simulation and as a game. The simulation function is used primarily for research and to project long term impacts of management decisions for cities using the UW/SP URBAN FOREST inventory system. The game function introduces random events into the simulation, and is used as an educational tool.

The Model

Development of the simulation model was based on the premise that an important management goal of an effective street tree program is to develop a high value street tree population. To accomplish this goal, it is important to know the value of street trees, the costs associated with management, and interaction of management costs and tree value.

Components of the model

I. *Inventory.* UW/SP URBAN FOREST is an inventory system designed for use in any city with a sufficient number of trees requiring data reduction. The development of this system was governed by a desire to provide an inventory program for city foresters and to serve as a data base for the management simulation model described in this paper. The inventory system describes a number of attributes for each street tree, including tree value based on the tree valuation system developed by the Council of Tree and Landscape Appraisers (1). URFOR/SIMULATION utilizes the following input data gathered for the inventory program.

A. Species and/or cultivar
B. Diameter class
C. Condition class (used to calculate tree value)

II. *Planting Table.* Inventory crews record all available planting sites on city streets and recommend a species and planting diameter for each site. All future planting in the management model draw on these data when tree planting is specified by the program user.

*The program is written in FORTRAN IV on a Burroughs 6900 and contains 3615 lines of code.

III. *Mortality Matrix.* This is based on historic mortality in the city, is input by the program user, and is species and diameter class specific.

IV. *Pruning Equation.* The tree valuation system assigns a condition class to each tree for calculating tree value. Condition class is based on the following factors; vigor, structure, crown development, insect and/or disease problems, trunk condition, and life expectancy. The frequency of pruning exerts a significant impact on condition class by influencing these factors, and subsequent tree value (4). A rigorous pruning schedule will provide a higher value tree than infrequent or no pruning.

V. *Growth.* Growth is predicted based on historic growth rates as determined from increment cores taken during the inventory, and is input by the user.

VI. *Game Function.* The simulation may be used as a game by activating the game subroutine. This subroutine will introduce one of the following random events once in each three year period.

A. Wind Storm: Increased mortality of large trees for one year.
B. Ice Storm: Increased mortality of all trees for one year.
C. New Disease: A prominent species will have its mortality rate increased in all subsequent years.
D. Drought: Planting mortality is increased for one year.
E. Budget Cut: The user is directed to cut the following year's budget.
F. Budget Increase: The user is directed to increase the next year's budget.

The model operates on an annual cycle with each of the above components interacting with the inventory (Figure 1). Cost data are summarized based on the tree management activities of planting, removal (mortality) and pruning. Costs are subtracted from tree value to obtain net forest value. The program may be run for multiple years, with output at intervals specified by the program user.

When used as a game, it is recommended the user make annual runs only. The altered street tree population is then stored each year, allowing the program user to change management plans in response to random events.

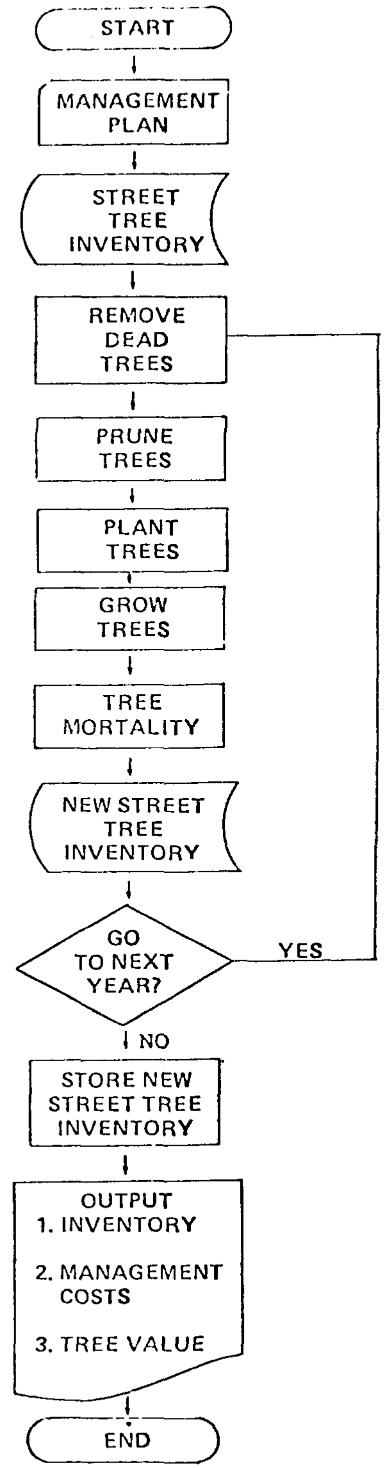

Figure 1. URFOR/SIMULATION flow chart.

Internal flow system

I. *Inventory.* The inventory data are subdivided into six condition classes by diameter and species (Figure 2). All management activities and growth interact with these tables.

II. *Planting.* Trees are planted in condition class tables based on the existing distribution of trees in these tables. The existing trees are a reflection of the interaction of planting stock and the specific urban environment, therefore, it is assumed new plantings will interact accordingly. The cost of tree planting is then calculated and summed.

III. *Mortality.* The first year of the cycle removes all trees in the 0% condition class table (dead trees). Removal costs are computed by diameter class and totaled. All subsequent cycles use the mortality matrix to kill trees in the remaining five conditions class tables (20 to 100%) based on mortality rates specified for each species and diameter class. Mortality is assigned as a percentage of the existing population and is distributed by tree frequency in the various condition tables.

All dead trees are transferred to the 0% condition class table and are removed in the next cycle. The number of trees removed in the 0% condition class table is transferred to the planting table as vacant tree spaces and distributed by the frequency within species.

IV. *Prune.* The effect of pruning cycle on condition class is described in Table 1 (4). If the existing pruning cycle is extended, then the sum of the change in condition class over the number of years of extension is used to shift trees from higher condition class tables to lower condition class tables. The reverse is true if the pruning cycle is reduced. If the pruning cycle is maintained at the status quo, no change in condition class occurs. The cost of pruning is computed by diameter class and summed for the number of trees pruned each year.

V. *Growth.* Growth shifts trees within each condition class table from one diameter class to another based on the number of trees in each diameter class. Once a tree grows to a new diameter class, it will not move to the next higher class until all original trees in the previous class have been transferred. This is to prevent some trees from being transferred to higher diameter classes prematurely.

Program input

1. Number of years program will run.
2. Output cycle, i.e., annual printout, every 5 years, etc.
3. Tree value per square inch of basal area for trees 12 inches and greater in diameter at 4.5 feet above ground. This may be influenced by location class, i.e., 70% for a street tree is usually used.
4. Replacement values for trees under 12" diameter. These values are used to compute tree values and planting costs.
5. Growth rate (from inventory output).
6. Annual planting and anticipated planting mortality. The planting table is compiled from the inventory and may be altered by the program user.
7. Anticipated annual mortality by species and diameter.
8. Specified pruning cycle and change in condition class if different from existing cycle.
9. Pruning costs** by diameter class.
10. Removal costs** by diameter class.
11. Game or no game option.

**May reflect actual field costs or include administration and overhead costs.

Table 1. Changes in condition class in relation to changes in the pruning cycle. Condition class values are summed over the number of years in which the pruning cycle is changed (2).

Pruning Cycle	*Percent change in condition class for one year change in pruning cycle*
1	
2	
3	*.09*
4	*.14*
5	*.18*
6	*.24*
7	*.28*
8	*.34*
9	*.38*
10	*.43*
11	*.48*
12	*.53*
13	*.58*
14	*.63*

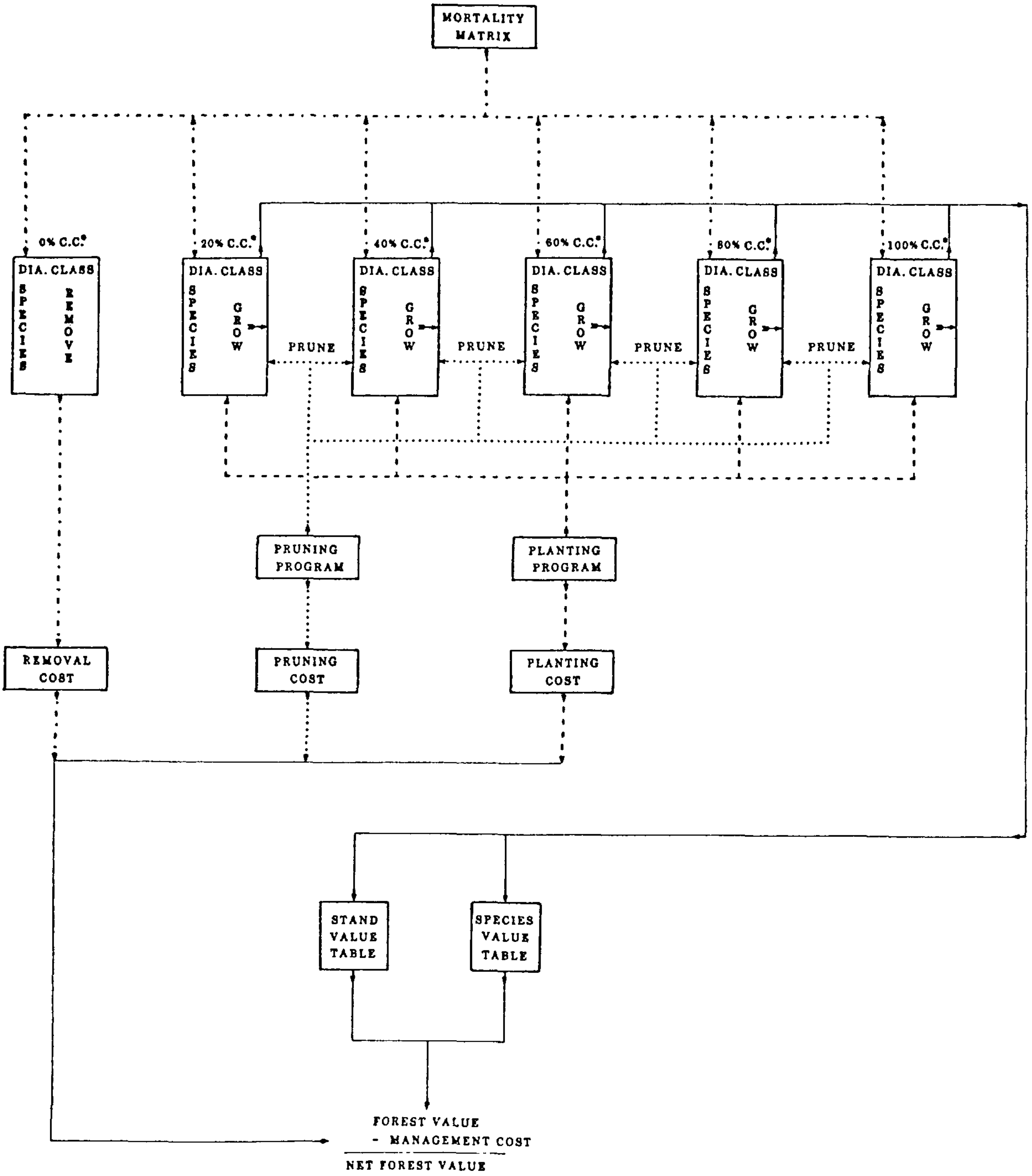

Figure 2. Internal flow chart for URFOR/SIMULATION.

*Inventory crews assign a condition class to each tree in six discreet categories: 0, 20, 40, 60, 80, or 100 percent. A perfect specimen receives 100 percent and a dead or nearly dead tree receives 0 percent.

Output-simulation. Sample output tables are based on street tree data from a city in Wisconsin. Initial conditions are described by a series of tables including a species list, summaries of input data, planting recommendations table, and mortality matrix (Table 2). The present inventory is summarized in two tables by species and by diameter (Table 3). These tables are repeated on an annual or periodic basis as specified by the program user, and reflect impact of growth and management activities over time. Each output period is accompanied by a summary table reflecting the impact of management activities since the last specified output. This table includes the number of trees affected by various management activities and the cost of each activity. The sum of the cost of all management activities is compared to the change in tree value for the period, and presented as a net loss or gain in tree value. This table is repeated at the end of the entire run and summarizes the total impact of the management plan, in this case 11 years later (Table 4).

Output-game. The game option runs the same as the simulation, with the introduction of the six previously described random events. Additional output includes the generation of a temporary mortality matrix consisting of randomly generated mortality percents for either wind or ice storms. A

*** INITIAL CONDITIONS ***

Initial Forest Value	3744172.
Number of Trees	9253
Number of Dead Trees	400
Number of Planting Sites	2931
Forest Average Condition	69.5
(After removing dead trees)	72.7
Future Average Condition	74.0

Growth Specifications:	
Gro1	0.2000
Gro2	0.0000
2 in. growth cycle of	10 years
Initial Pruning Cycle of	10 years
Desired Pruning Cycle of	5 years
Annual Planting	650 trees
Annual Planting Mortality	10.00 %
Average Planting Condition	73.50 %

Initial Cost Information

DBH Inch	Planting $ / Tree	* *	DBH Class	Removal $ / Tree	Pruning $ / Tree
1	42.00		1+	5.75	9.00
2	98.00		2	11.30	9.00
3	168.00		4	22.60	9.00
4	252.00		6	33.90	11.20
5	350.00		8	45.20	11.20
6	425.00		10	56.50	11.20
7	588.00		12	67.80	12.18
8	728.00		14	79.10	12.18
9	857.00		16	90.40	13.00
10	1050.00		18	101.70	13.00
11	1260.00		20	113.00	13.50
12	1470.00		22	124.30	14.00
			24	135.60	14.46
			26	146.90	14.46
			28	158.20	15.00
			30	169.50	15.19
			32	180.80	15.19
			34	192.10	16.94
			36	203.40	16.94
			38+	214.70	16.94

Planting Recommendation Table

Species	1	2
Ash-Gr	0	80
Ash-Wh	0	420
Basswd	0	7
Elm-Si	0	2
Poplar	0	16
Ginkgo	0	165
Hackbe	0	316
Sycamo	0	8
Honey	0	308
Horsec	0	3
Lind-L	0	308
Map-No	0	879
Map-Sl	0	11
Map-Su	0	53
Map-Cm	0	338
Oak-Rd	0	8
Oak-Bu	0	4
Oak-Wh	0	4
*** Total ***		
18	0	2930

Table 2. Initial conditions and input specifications determined by the program user. Data used in this run are from a city in Wisconsin.

statement is issued concerning the need to increase pruning for one year to repair storm damaged trees.

If a new disease is generated, a statement is issued informing the user that a permanent change is made in the mortality matrix for the species randomly selected. For a species to be selected for a new disease, it must comprise more than 5% of the street tree population. American elm cannot be selected for a new disease.

PRESENT INVENTORY OUTPUT

Combined Species - Stand and Value Table

DBH Class	Number of Trees	% of City	Avg. Cond.	Tree Value $ Average	Total
1	119	1.3	37.8	8.	969.
2	4514	48.8	67.6	57.	257591.
4	1491	16.1	75.3	164.	244541.
5	707	7.6	77.7	287.	203253.
8	355	3.8	77.0	504.	179030.
10	262	2.8	76.7	702.	184044.
12	260	2.8	68.3	760.	197627.
14	215	2.3	65.9	879.	188959.
16	222	2.4	62.4	988.	219359.
18	230	2.5	65.9	1314.	302183.
20	229	2.5	67.8	1584.	362698.
22	203	2.2	62.5	1633.	331476.
24	175	1.9	64.6	1998.	349698.
26	120	1.3	69.5	2456.	294666.
28	77	0.8	61.8	2447.	188421.
30	38	0.4	67.4	2855.	108503.
32	16	0.2	68.8	3343.	53483.
34	13	0.1	69.2	3911.	50844.
36	5	0.1	72.0	3664.	18322.
38	2	0.0	70.0	4253.	8506.
*** Totals ***					
	9253		69.5	405.	3744172.

PRESENT INVENTORY OUTPUT

Combined DBH - Stand and Value Table

Species	Number of Trees	% of City	Avg. DBH	Avg. Cond.	Tree Value $ Average	Total
Ash-Gr	580	6.3	6.5	68.9	445.	257906.
Ash-Wh	1324	14.3	3.5	70.5	123.	163461.
Basswd	264	2.9	15.6	70.5	1264.	333647.
Boxel	16	0.2	19.4	63.8	735.	11768.
Pear	8	0.1	3.0	80.0	112.	896.
Catalp	170	1.8	20.9	60.5	1121.	190497.
Crabap	1	0.0	2.0	60.0	47.	47.
Elm-Am	577	6.2	17.2	61.9	1243.	717181.
Elm-Si	28	0.3	16.6	57.1	323.	9054.
Poplar	62	0.7	1.9	37.7	36.	2216.
Ginko	10	0.1	1.9	78.0	72.	720.
Hackbe	63	0.7	3.2	69.5	185.	11669.
Sycamo	8	0.1	3.5	75.0	136.	1087.
Honey	1159	12.5	4.1	71.6	200.	231429.
Willow	1	0.0	2.0	40.0	16.	16.
Ailant	2	0.0	4.0	80.0	84.	168.
Horsec	41	0.4	20.3	75.1	2034.	83411.
Lind-L	438	4.7	3.0	69.3	134.	58630.
Buckey	5	0.1	17.6	76.0	1541.	7707.
Map-No	3030	32.7	4.5	72.0	312.	944750.
MapRed	4	0.0	13.0	65.0	1600.	6399.
Map-Sl	377	4.1	21.7	64.8	1305.	492010.
Map-Su	358	3.9	4.1	68.9	279.	99975.
Map-Cm	627	6.8	3.0	69.7	166.	103972.
Oak-Rd	10	0.1	2.0	62.0	61.	608.
Oak-Bu	33	0.4	2.7	69.1	202.	6680.
Oak-En	9	0.1	2.0	42.2	41.	372.
Oak-Pn	3	0.0	2.0	46.7	46.	137.
Oak-Wh	14	0.2	4.1	57.1	508.	7110.
H-Misc	31	0.3	1.9	51.0	21.	653.
*** Totals ***						
30	9253		6.4	69.5	405.	3744172.

Table 3. Output listing of present street tree inventory.

When drought occurs, a statement informing the user of increased planting mortality is issued. This mortality lasts for one year only, and cannot exceed 60%.

Random events are put in three categories: 1) major, including the wind and ice storms, 2) minor, including the new disease and drought induced planting mortality, and 3) budget change instructions following the major and minor events. A major event is followed in two to four years by a statement instructing the user to increase the budget for one year by 10 to 20 percent. A minor event is followed in two to four years by a statement instructing the user to cut the budget for one year by 25 to 35 percent. The entire random event subroutine takes twelve years to complete and is re-initiated in year thirteen.

Output for the game is identical to simulation output, with the addition of the above tables and statements, and the impact of the random events included in the output tables. Table 5 is a one-year summary table reflecting the impact of an ice storm.

Discussion

Simulation. The management model has been used experimentally with data from eight cities currently under inventory contract with the University of Wisconsin-Stevens Point. A number of interesting observations can be made based on the effect of various management strategies on forest value.

The long term impact of investing in street tree management invariably more than pays for itself in increased tree value. Tree planting is a sound investment in urban forestry, with the future value of street trees far exceeding establishment costs and subsequent pruning and removal costs (Figure 3). Frequent pruning is also economically viable, with shorter pruning cycles yielding higher tree values in relation to the cost of pruning (4).

City foresters from contract cities will be able to use the program to determine the long term impact of various management strategies, hopefully placing the forestry program in a more competitive position in budget requests. There has been substantial research indicating that trees, both private and public, contribute to property values. If city officials recognize this added value, then funding forestry may be a higher priority if they can see that the value of trees will exceed management costs.

The simulation has also been used as a research tool to ascertain the long-term impact of various management strategies. It has been determined that the cost of an intensive Dutch elm disease control program is more than offset by the increase in future value of the street tree population (4).

OUTPUT FOR YEAR 11

Combined Species - Stand and Value Table

DBH Class	Number of Trees	% of City	Avg. Cond.	Tree Value $ Average	Total
1+	17	0.1	75.3	18.	301.
2	3415	27.5	73.1	63.	215820.
4	4824	38.9	77.3	163.	787550.
6	1515	12.2	74.3	274.	414651.
8	620	5.0	73.8	470.	291346.
10	311	2.5	77.1	728.	226296.
12	232	1.9	76.7	949.	220147.
14	206	1.7	74.7	1110.	228752.
16	191	1.5	68.3	1172.	223782.
18	186	1.5	67.3	1393.	259117.
20	198	1.6	67.3	1638.	324370.
22	189	1.5	64.3	1758.	332237.
24	172	1.4	65.3	2120.	364627.
26	135	1.1	65.9	2318.	312983.
28	100	0.8	65.8	2639.	263850.
30	47	0.4	65.1	3038.	142786.
32	26	0.2	66.2	3356.	87261.
34	18	0.1	65.6	2733.	67186.
36	7	0.1	68.6	5162.	36135.
38	6	0.0	67.7	4631.	27786.
*** Totals ***	12415		74.4	389.	4827044.

Combined DBH - Stand and Value Table

Species	Number of Trees	% of City	Avg. DBH	Avg. Cond.	Tree Value $ Average	Total
Ash-Gr	606	4.9	7.8	81.2	619.	275351.
Ash-Wh	2208	17.8	4.2	69.9	138.	304761.
Basswd	241	1.9	17.2	72.1	1515.	365182.
Boxel	12	0.1	22.3	75.0	923.	11079.
Pear	6	0.0	5.0	80.0	231.	1394.
Catalp	152	1.2	23.0	62.1	1350.	205218.
Crabap	1	0.0	2.0	60.0	47.	47.
Elm-Am	365	2.9	19.4	64.9	1561.	569885.
Elm-Si	23	0.2	18.7	58.3	433.	9954.
Poplar	64	0.5	3.2	65.6	43.	2760.
Ginko	209	1.7	3.5	72.2	160.	33406.
Hackbe	445	3.6	3.7	78.2	159.	70932.
Sycamo	21	0.2	4.3	77.1	178.	3737.
Honey	1374	11.1	5.5	74.3	278.	382398.
Willow	1	0.0	4.0	40.0	40.	40.
Ailant	2	0.0	7.0	80.0	185.	369.
Horsec	44	0.4	19.8	73.2	2185.	93958.
Lind-L	733	5.9	4.3	75.0	191.	139845.
Buckey	5	0.0	20.0	76.0	1969.	9845.
Map-No	3704	29.8	5.5	78.0	395.	1463426.
MapRed	3	0.0	15.3	66.7	2195.	6584.
Map-Sl	354	2.9	21.5	65.9	1316.	465842.
Map-Su	379	3.1	4.2	73.1	291.	110302.
Map-Cm	1352	10.9	2.7	75.4	135.	182632.
Oak-Rd	32	0.3	2.0	85.6	84.	2685.
Oak-Bu	35	0.3	2.6	76.6	202.	7072.
Oak-En	7	0.1	2.0	48.6	48.	333.
Oak-Pn	2	0.0	2.0	70.0	69.	137.
Oak-Wh	13	0.1	4.3	70.8	556.	7227.
H-Misc	21	0.2	2.0	75.2	31.	653.
*** Totals *** 30	12415		6.2	74.4	389.	4827044.

Average Tree Condition		
Previous Forest	74.6	
Present Forest	74.4	
Change in Condition	-0.2	
	Dollars	No. of Trees
Previous Forest Value	4,687,187.	12,412
Present Forest Value	4,827,044.	12,415
Change in Value	135,857.	3
Planting Mortality		26
Other Mortality		135
Total Mortality		161
Planting Expense	16,660.	170
Removal Expense	5,322.	167
Pruning Expense	24,420	2,449
Total Expense	46,402.	
Net Gain or Loss	93,455.	

Summary for Management Period of 11 Years

Average Tree Condition		
Initial Forest	69.5	
Present Forest	74.4	
Change in Condition	4.9	
	Dollars	No. of Trees
Initial Forest Value	3,744,172.	9,253
Present Forest Value	4,827,044.	12,415
Change in Value	1,082,872.	3,162
Planting Mortality		850
Other Mortality		1,413
Total Mortality		2,263
Planting Expense	555,016.	5,664
Removal Expense	58,217.	2,502
Pruning Expense	240,038.	23,894
Total Expense	863,271.	
Net Gain or Loss	219,601.	

Table 4. Output following eleven years of management including a summary of management activities for the eleventh year and a summary of eleven years of management.

OUTPUT FOR YEAR 3

Average Tree Condition		
Previous Forest	71.2	
Present Forest	71.2	
Change in Condition	.0	
	Dollars	Number of Trees
Previous Forest Value	3,298,192.	9,253
Present Forest Value	2,650,168	9,253
Change in Value	-648,024.	0
Planting Mortality		30
Other Mortality		1,836
Total Mortality		1,866
Planting Expense	14,602.	149
Removal Expense	5,413.	149
Pruning Expense	9,303.	910
Total Expense	29,318.	
Net Gain or Loss	-677,342.	

** NOTE ** The city provided $73,558. from emergency funds to clean up the 1,836 down trees following the storm 11. This value will be included in your removal cost next year 1

Table 5. Summary table output reflecting tree losses due to a randomly generated ice storm.

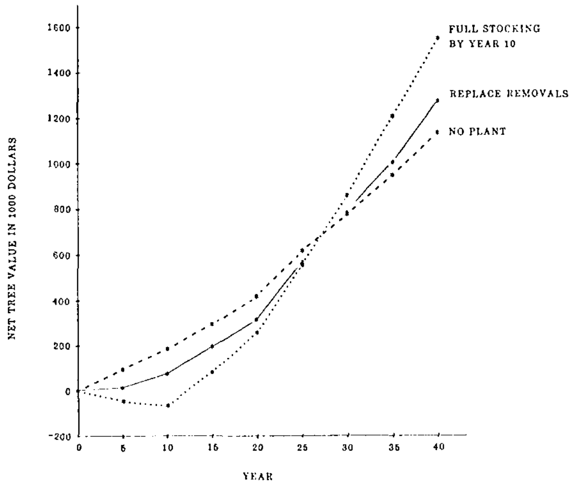

Figure 3. Net tree values (annual tree value – annual management costs) over 40 years of management for three planting scenarios in a Wisconsin community.

Game. The model is currently being used as a teaching tool in the urban forestry curriculum at the College of Natural Resources, University of Wisconsin-Stevens Point. Each student is provided a hypothetical city in a computer file. The student must develop budgets and management strategies for his/her forest and ascertain the long term impact of the various strategies through the program. Random events force the student to alter management plans to compensate for tree losses.

Summary and Conclusions

UW/SP URBAN FOREST MANAGEMENT is the first attempt to use computer simulation in the field of urban forestry. The system is based on actual inventories and predicts the impact of planting, mortality, and pruning programs on street tree populations. Future populations are described by actual numbers and by tree values in relation to management costs. The program user can establish budgets for various levels of management based on actual costs. Changes in the mortality matrix can be used to simulate the future impact of insect and disease epidemics such as Dutch elm disease.

Testing of the model has, thus far, indicated it makes reliable predictions for time periods in excess of 20 years. With the overall management objective of providing an optimum value population of street trees, the model will provide a valuable tool in assessing management strategies.

The game function introduces random events into the simulation. Students using the program may determine the long term impacts of their management strategies, and must react to natural events that cause losses of street trees.

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Professor of Urban Forestry and
Data Processing Specialist, respectively
College of Natural Resources
University of Wisconsin
Stevens Point, Wisconsin

Contributed Abstract

Biological control of the ash/lilac borer with the entomogenous nematodes, *Neoaplectana carpocapsae* and *N. bibionis*

by Harry K. Kaya

The nematodes, *Neoaplectana carpocapsae* and *N. bibionis,* were mass produced in vitro in a flask containing sterilized turkey entrails. Several hundred million *N. carpocapsae* were produced. *N. bibionis* proved more difficult to rear and only 40 million infective nematodes were produced.

During the summer of 1983, an infestation of the ash/lilac borer, *Podosesia syringiae,* in ash trees was monitored in a residential area in Sacramento. However, lining up a proper experimental design in this neighborhood was difficult because of the need to contact each homeowner with infested trees. Therefore, an effort was made to locate another infestation of borers.

During late summer of 1983, an infestation of the borer, *Synanthedon culiciformis,* was found in alder trees in a park and an apartment complex in Davis. A total of 20 trees heavily infested with this borer (15 active borers per tree) was found. Treatment with *N. carpocapsae* was initiated in late September. Before treatment, the number of active galleries per tree was counted. A gallery was considered active if fresh frass was present at the gallery entrance. The nematodes were applied with a Hudson sprayer at the rate of 0, 4000, and 8000 nematodes/ml. The average tree received 6×10^6 nematodes at 4000 nematodes/ml and 11×10^6 nematodes at 8000 nematodes/ml. In addition, active galleries were sprayed individually with a hand-held atomizer at the rate of 1.8×10^4 and 3.6×10^4 nematodes/gallery. One week after application, frass from each gallery was removed and a week later the presence or absence of frass was used as an index for control of the borer.