SIMULATION MODELING OF HIGHWAY MAINTENANCE OPERATIONS APPLIED TO ROADSIDE MOWING

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This paper presents a simulation model by which a mowing operation is analyzed on a day-to-day basis. Included in the model are the effect of rainfall-speed distributions for tractor-mower production as related to terrain features; hourly cost distributions for tractors, mowers, and service trucks; and time distributions for nonproduction activities that occur during the daily mowing operation. The speed and time measurements were observed on 169 acres of a 10.6-mile section of I-95 in the New Castle maintenance district in Delaware. The simulation model is described in the general purpose simulation system language. Output showing the simulated variation in total project times and costs for 20 observations of various amounts of assigned mowing area are shown. The model provides a tool by which the highway maintenance engineer can evaluate short- and long-range planning decisions that involve a series of highly variable time-consuming activities. Suggestions of other highway maintenance operations to which the model can be applied are presented.

•WITH the growing size and complexity of the nation's highway system and ever-increasing traffic volume, it is necessary that highway maintenance be given more attention in the overall development of the highway system to ensure safety and driving ease for the motoring public.

The highway maintenance engineer, as any other engineer, is dedicated to satisfying the needs of society by using modern planning and decision-making techniques that not only improve day-to-day operations but also provide for long-range planning to reduce the cost of highway maintenance operations.

Operations research techniques are not used in the highway maintenance field to anywhere near their full potential for cost reduction. Yet the problems of maintaining a highway are not significantly different from other types of maintenance operations to which operations research techniques have been successfully applied. An effort to apply linear programming for the optimal assignment of tractor-mower units for roadside mowing was developed in 1966 (1), but the model was incomplete in its development and thus is not used today for highway maintenance planning (2).

One of the most significant improvements for updating the planning and budgeting of highway maintenance operations has been obtained through the standardization of quality, quantity, and production that was initiated only 4 to 5 years ago (3, 4, 5).

Several state highway departments and the Federal Highway Administration have made comprehensive studies in an effort to determine a procedure for evaluation of the time and cost associated with grass cutting (6-17). The results of the studies indicated that the times and costs were highly variable. Thus, the use of average values of time and cost for budgeting and equipment assignment led to erroneous decisions.

Many questions to which quantitative comparisons can be applied for management decisions related to mowing can be answered quickly and at a relatively low cost with a simulation model. Simulation is a process by which logic models, which are too complex for an analytical solution, can be solved numerically. The simulation process in-

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volves the performing of controlled experiments on the model and observing the performance of the model under a given set of conditions.

Among the questions that might be proposed are the following:

1. What would be the expected change in time and cost if a different size and/or type of mower was used to cut the grass?
2. What would be the expected savings in time and cost if all 3:1 side slope mowing were eliminated?
3. What would be the expected time and cost for cutting grass on a new section of highway?

The mowing simulation model developed in this study can be represented by a block diagram (Fig. 1) showing the logical flow of the activities that an operator of a tractor-mower unit performs in a daily mowing operation. The simulated operator has associated with him attributes in the form of frequency distributions obtained from field measurements that, through random number generators, describe the probabilistic status of the operator at any point in time during the working day. The simulated speed of the mower is controlled by randomly sampling the speed distributions that are associated with various terrain features of the highway right-of-way. Included in the model are travel times, delay times, equipment operating costs, and speeds that relate to the production capacity of the mower.

The computer programming language used for the model is the general purpose simulation system (GPSS) language, which is applicable to the IBM 360 series of digital computers. The output of the computer program provides the following information about a mowing operation:

1. The total completion time of the project including the effect of rainfall;
2. The total time to complete the project excluding the effect of rainfall (sometimes called the scheduled completion time of the project);
3. The total production time in the project;
4. The total project cost including equipment, transportation, and labor;
5. The total cost in the project for the tractor-mower unit;
6. The total cost in the project for transportation to and from the field; and
7. The subsection of the highway where the tractor-mower unit stopped cutting each day.

The model can be used effectively to determine the expected cost for mowing the grass cover on new sections of highway, analyze highway beautification programs in which only certain portions of the grass cover are to be cut, compare the differences in expected times and costs related to various cutting assignments using different sizes and/or types of tractor-mower units, analyze the effects on production time if more management control of the field operation is provided, and aid in the establishment of mowing standards for sections of highway.

Data for the model were obtained from field studies of tractor-mower production speeds and nonproductive time-consuming activities as observed on I-95 in Delaware. The study encompassed 169 acres of mowed grass area that was divided into seven subsections with each subsection having six terrain classifications related to the mower production speeds.

The model was used to predict the expected times and costs for a 6-ft flail type of mower to mow the grassed areas associated with the northbound lane, southbound lane, and median.

SIMULATION MODEL

The simulation model consists of a core program and four data packs. The data packs, which contain information relevant to determining mowing project costs and times, are as follows:

1. Speed functions that relate mower production to terrain features,
2. Cost functions that relate to hourly equipment costs,
3. Delay functions that are associated with nonproductive activity times, and

4. Area distribution functions that describe the subsections of the highway right-of-way and the respective percentages of each type of terrain classification.

The core program, through random number generators that select random variables from cumulative probability density functions within each of the data packs, determines mowing project times and costs.

The model considers the probability of rainfall delays, and variations in daily nonproductive times such as travel to and from the field, preventive maintenance, personal delays, and equipment breakdowns.

OPERATION OF THE MODEL

The model contains six speed functions relating to the production capacity of the mower, three cost functions that reflect equipment cost, 16 functions of nonproductive time activities occurring during a normal workday, and seven functions that relate to the proportional amounts of area to be mowed under each of six speed distributions (Table 1).

Random variables were selected from the functions listed in the program by means of eight pseudorandom number generators. The generators were assigned sequentially to the functions because they were listed at the beginning of the program to make the entire model random.

Simulation began by setting the simulated clock time within the program to zero. The simulated time unit in the model was equivalent to 1 min of actual time.

As a transaction, which represented the driver of a tractor, proceeded from one component to another in the system, the clock time was updated by variate time increments that were added to the clock time.

The simulation model accrued time on a day-to-day basis until all grass areas within the section of highway were mowed. This approach required that a sufficient number of daily work sequences be run to ensure that all the grass areas were cut. From previous observations of mower production in the example study and several trial runs with the computer program, it was established that 12 cycles of daily work sequences per observation of project completion time was adequate.

At the end of every 12 cycles, the clock time was reset to zero. Also, all "savevalues" that serve to retain the values of attributes such as total project time, total project cost, total equipment cost, and other times and costs associated with morning and afternoon production in the simulation model, were reset to zero except for those "savevalues" that designated the areas of the subsections and terrain classifications.

The seeds of the eight random number generators were not reset. Thus, each 12-cycle run was an independent observation of the project completion time.

Three time interruptions within a daily work sequence were instituted from field studies. The first interruption was the time to stop cutting in the morning and go to lunch. The second was the time to leave the field and return to the maintenance division headquarters. The third was the time at which the transaction was to leave the system.

As shown in Figure 1, the first consideration in the model was to ascertain if rain had occurred. Rain determined whether the driver was sent to the field or assigned to another task. On the first of each 12 cycles, the probability was 0.73 that a clear day would randomly occur. A random variable was selected by means of a random number generator and compared with the probability of 0.73. If the variate was less than or equal to 0.73, the driver was assigned to the field. If the variate was greater than 0.73, the driver was assigned another task, and the simulated clock time was advanced 480 min without a cost being charged to mowing.

After the first day, the probability of forecasting a clear day fluctuated from 0.78, which was the probability that, if today was clear, tomorrow would be clear, to 0.60, which was the probability that, if today was rainy, tomorrow would be clear.

The work sequence was divided into two sessions: morning and afternoon (Fig. 1). In the morning, six variates associated with each of six nonproductive activities were generated and added to the clock time in proper sequential order, as follows:

Figure 1. Flow diagram for simulation model.

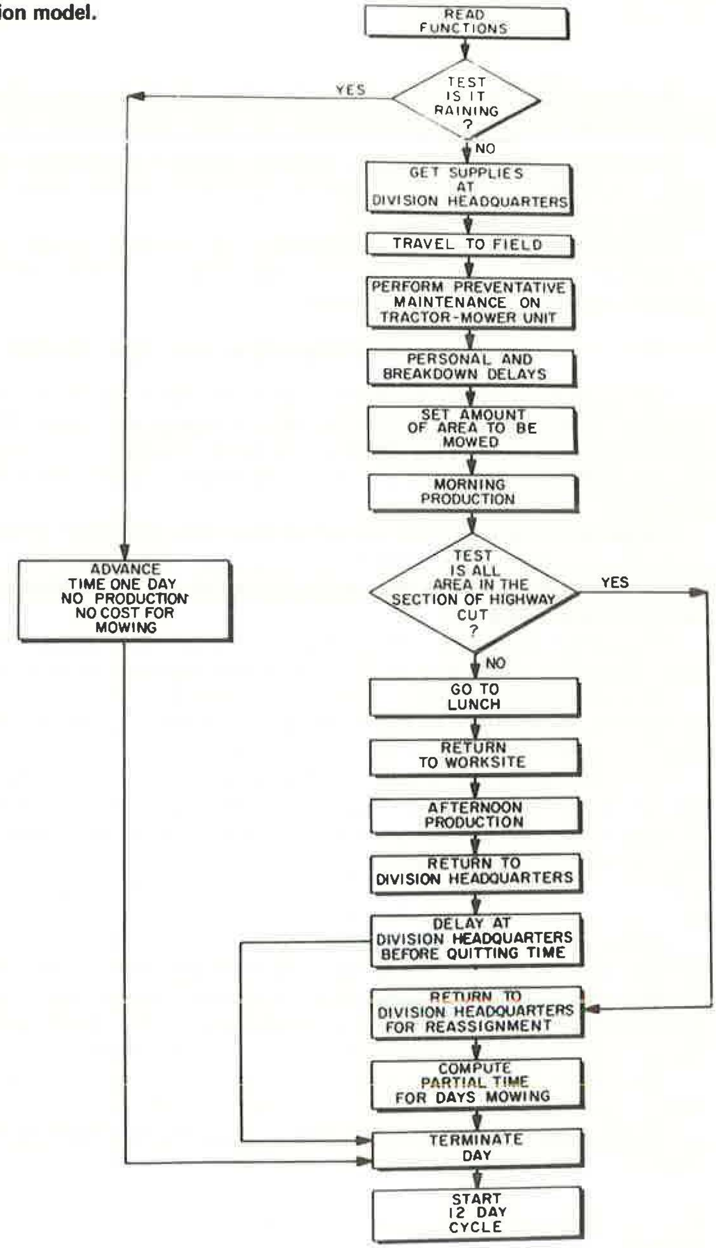


Table 1. Model functions.

Function	Description	Function	Description
1	Flail mower speeds, 0- to 8-deg side slope	17	Personal delay times in a. m.
2	Flail mower speeds, 9- to 12-deg side slope	18	Travel times from site to truck at lunch
3	Flail mower speeds, 13- to 16-deg side slope	19	Lunch times
4	Flail mower speeds, 17- to 22-deg side slope	20	Travel times from truck to site in p. m.
5	Obstacle mowing speeds	21	Number of personal delays in p. m.
6	Roading speeds	22	Personal delay times in p. m.
7	Hourly operating costs for flail mowers	23	Travel times from site to truck in p. m.
8	Hourly operating costs for tractors	24	Travel times from field to headquarters
9	Hourly operating costs for trucks	25	Turn times
10	Number of breakdowns for flail mower	26	Area, Naamans Road Interchange
11	Times per breakdown for flail mower	27	Area, Naamans Road to Harvey Road
12	Delay times at division headquarters	28	Area, Harvey Road Interchange
13	Travel times from headquarters to mower	29	Area, Harvey Road to Marsh Road
14	Preventive maintenance times	30	Area, Marsh Road Interchange
15	Travel times from truck to site in a. m.	31	Area, Marsh Road to Route 202
16	Number of personal delays in a. m.	32	Area, Route 202 Interchange

1. The delay time at the maintenance division headquarters to secure supplies, such as water, gas, and repair parts;
2. The travel time from the division headquarters to the work site;
3. Preventive maintenance and minor repairs prior to beginning work;
4. Travel time from the truck to the mowing area;
5. Personal delay times, such as getting a drink of water, picking up trash, and personal relief; and
6. Mower breakdown delay times for removing objects that had become lodged in the mower, adjusting cutting height of the blades, and so forth.

The morning production period began after the simulated clock was advanced for the six nonproductive time variates, some of which might have been zero. The production period was subdivided into 10-min work intervals.

The subsections of the highway were called sequentially, whereas the speed classifications within each subsection were called randomly. A discrete random variable was generated to select the terrain classification within a subsection. The terrain classification was designated by a 2-digit number. For example, in subsection 30 given in Table 2, if the discrete random variable 12 was selected by the random number generator, then the class B terrain classification had been designated for parameter 7. Modulo division by 10 gave a remainder of 2, which signified that a speed variate was selected from function 2 and placed in FN*7.

The amount of area mowed in a 10-min interval was given by 1 FVARIABLE = FN*7 (5,280/60)*(55/10)*10 where FN*7 is a speed variate expressed in miles per hour, 5,280/60 is a constant that changes miles per hour to feet per minute, 55/10 is the effective width of cut that was assumed as 5.5 ft for a 6-ft rear-mounted flail mower, 10 is the interval of time over which the speed was assumed constant, and 1 FVARIABLE is the total number of square feet of grass cut in 10 min in the terrain classification specified by parameter 7.

After each 10-min work interval, a series of checks was performed. First, the simulated clock was checked against the time to stop work for lunch. If the clock time was later than 11:40 a.m., the morning work period ended, and the driver went to lunch. If the clock time was earlier than 11:40 a.m., the model checked to see if all the area of the subsection had been cut. If more than 100 ft^2 of area remained, the driver returned to work for another 10-min work interval. If 100 ft^2 or less of area remained in the subsection, the area was set to zero, and a check was made to determine if the subsection was the last subsection on the highway. If all sections had been cut, the driver returned to the truck and then to the division headquarters for another assignment.

During a normal day, the driver went to lunch, and areas of uncut grass remained for the afternoon work session. When the driver went to lunch, the simulated clock was advanced five variate time intervals, each associated with a nonproductive activity. The five nonproductive activities were travel time from the work area to the truck, lunch time, travel time from the truck to the work site after eating, personal delay times, and equipment breakdown delays.

The afternoon production period began after the simulated clock was advanced for the five nonproductive time variates, some of which might have been zero. The work cycle in the afternoon session was the same as that described for the morning session.

After each 10-min work interval in the afternoon, the model performed a series of checks. First, the simulated clock was checked against the time to stop work and return to the truck for transportation to the division headquarters. If the clock time was later than 3:10 p.m., the driver returned to the division headquarters. The simulated clock was advanced two time-variate intervals, each associated with nonproductive activities. The two intervals were travel time from the work area to the truck and travel time from the job site to the division headquarters.

The last nonproductive time variate, which was the delay time at the division headquarters before going home, was developed by the model. The clock time at which the truck arrived at division headquarters was called in the program and subtracted from 4:00 p.m. to obtain the variate delay time.

If the clock time was earlier than 3:10 p.m., the model performed the same set of area completion checks that it did during the morning session. If all the area was cut before 3:10 p.m., the driver returned to the division headquarters, and a partial day's work was indicated in the program printout.

DESCRIPTION OF EXAMPLE APPLICATION

The mowing simulation model was developed with the IBM 360 computer facility at Drexel University. Data for the model were obtained from a 12-week study of the mowing operation on a 10.6-mile section of I-95 in the New Castle maintenance division.

All mowed areas on the section of I-95 from the Pennsylvania line to the intersection of I-95 and I-295 (Fig. 2) were detailed on landscape plans of the area. The detailing included the field checking of degrees of side slope, and the location of guardrails, trees, lampposts, delineation markers, and other mowing obstructions. The layout of the area and field checking the accuracy of the plans required 45 man-hours. The quantity take-off of the area required 56 man-hours. A typical detailed section is shown in Figure 3.

The terrain features associated with the mowed area were classified according to six conditions. These conditions were 0 to 8 deg (less than 5:1) side slope or class A, 9 to 12 deg (5:1) side slope or class B, 13 to 16 deg (4:1) side slope or class C, 17 to 22 deg (3:1) side slope or class D, obstacle areas of class E, and roading or class F.

Obstacle mowing included traffic islands, cutting along lines of delineation markers and lamppost standards, and cutting adjacent to guardrails and fences.

Roading was travel between grass plots where the areas become asphalt or concrete.

The simulation model required that the section of highway be divided into subsections with each subsection being divided into a set of terrain classifications. For this study, the section of I-95 was divided into seven subsections with a set of six terrain classifications per subsection as given in Table 2.

TIME STUDY OF TRACTOR-MOWER UNITS

Time studies were conducted on nine drivers and three types of tractor-mower units. Times were measured for each of the tractor-mower units to determine their speeds when cutting on slide slopes classified as 0 to 8 deg, 9 to 12 deg, 13 to 16 deg, and 17 to 22 deg.

The distances over which time intervals were measured varied according to the distances between natural and man-made obstructions that required the driver to turn the mower around. The distances ranged from 250 to 1,000 ft with the most frequent distances occurring between 450 and 550 ft. Distances were determined by pacing, referencing to guardrail post spacing, or scaling distances from the plans. All speeds were for a grass height interval of 6 to 20 in.

Typical histograms of the distribution of mower speeds and nonproduction activity times are shown in Figures 4 and 5.

COST DATA

The hourly costs for operating tractors, mowers, and trucks were obtained from monthly cost records. The data were obtained from the Oklahoma Department of Highways, the Delaware Department of Highways and Transportation, and the Pennsylvania Turnpike Commission. The data contained the hourly rates for 24 trucks, 47 tractors, and 18 flail mowers.

Histograms of the distribution of hourly cost rates for operating tractors, flail mowers, and trucks are shown in Figures 6, 7, and 8.

RAINFALL DATA

The effect of rainfall as a factor in extending the completion time of a mowing project was incorporated as a part of the simulation model.

Table 2. Lane area distribution.

Section	Class A Ft²	Class A Per-cent	Class B Ft²	Class B Per-cent	Class C Ft²	Class C Per-cent	Class D Ft²	Class D Per-cent	Class E Ft²	Class E Per-cent	Class F Ft²	Class F Per-cent	Total Area (ft²)	Save-Value
Naamans Interchange	141,285	45	36,360	11	40,460	14	48,650	16	36,850	12	3,880	2	307,485	X30
Naamans Road to Harvey Road	139,875	28	102,180	21	116,300	24	104,000	21	—	—	27,610	6	489,965	X31
Harvey Interchange	28,150	33	10,065	12	8,200	9	15,980	18	11,620	13	12,595	15	86,610	X32
Harvey Road to Marsh Road	56,185	14	76,130	19	127,800	32	122,745	31	—	—	16,225	4	399,085	X33
Marsh Interchange	—	—	—	—	—	—	—	—	10,980	81	2,530	19	13,510	X34
Marsh Road to Route 202	229,355	46	46,380	9	112,150	23	76,770	15	—	—	32,570	7	497,215	X35
Route 202 Interchange	243,810	41	140,130	24	103,955	17	78,830	12	25,335	4	4,620	2	596,680	X36
Average	838,660	35	411,245	17	508,865	21	446,975	19	84,785	4	100,020	4	2,390,500*	

*Total area equals 54.9 acres.

Figure 2. Site location of study on I-95.

Figure 3. Typical layout of mowing areas by terrain classifications.

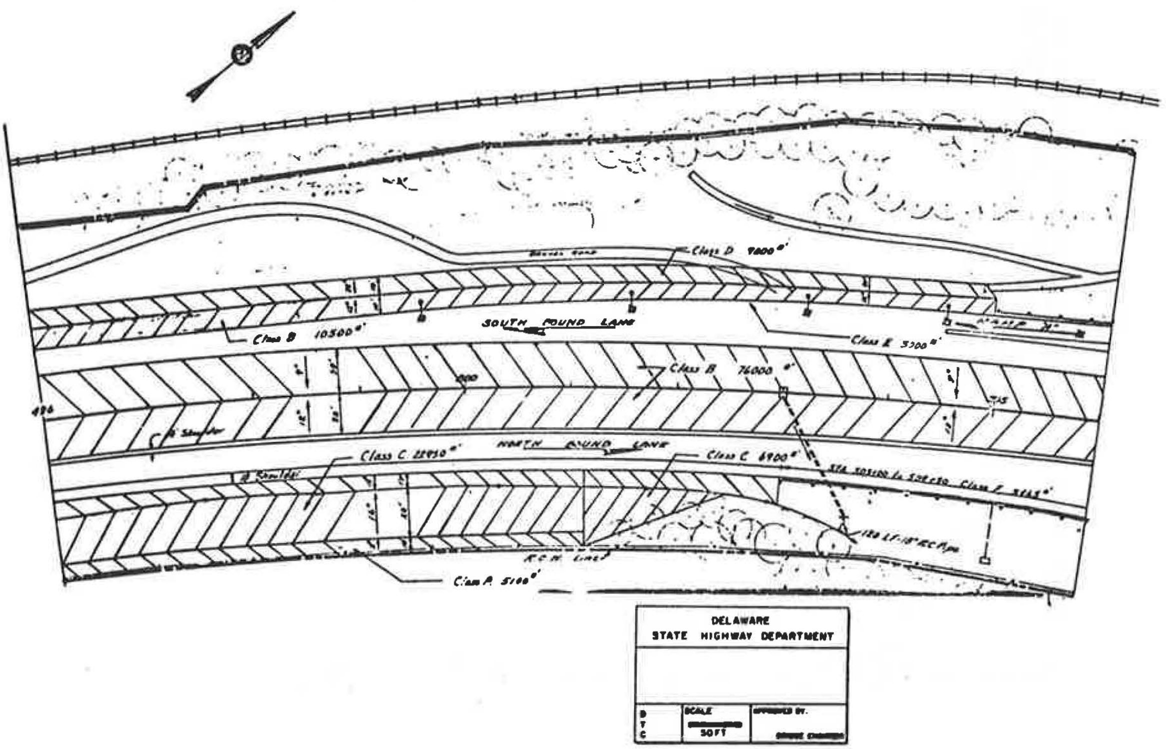


Figure 4. Speeds of flail mower, 0- to 8-deg side slope.

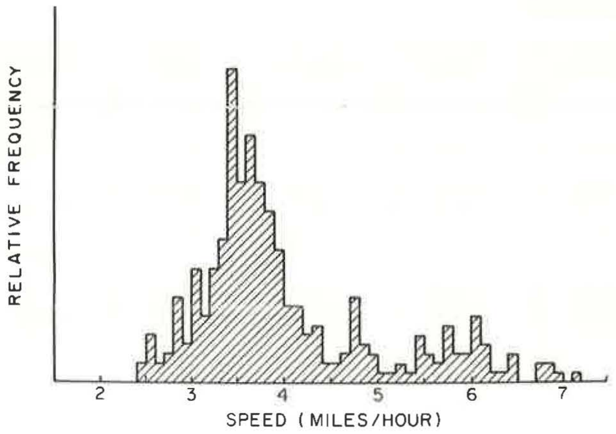


Figure 5. Times for each breakdown of flail mower.

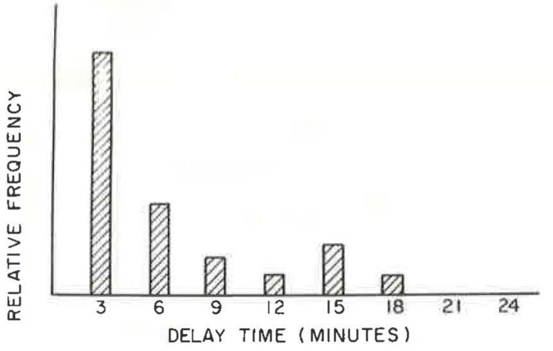
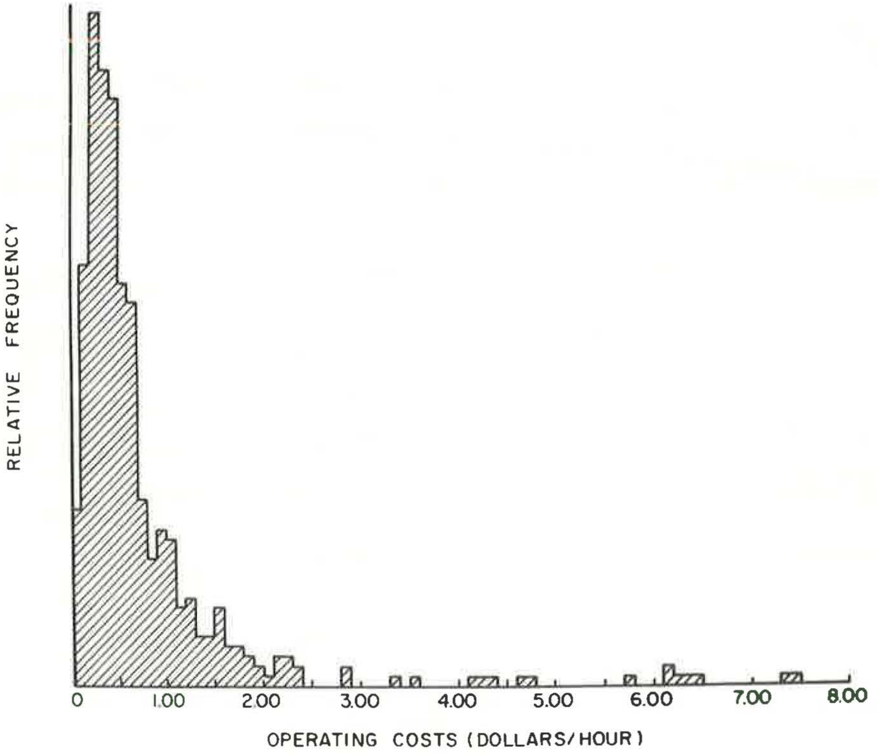


Figure 6. Hourly operating costs for tractors.



The rainfall data were obtained from the weather station at the Philadelphia International Airport, which is located 18 miles from the study area on I-95 in Delaware. Twenty years of rainfall data, dating from 1951 through 1970, were used in the forecast analysis. The data were further reduced to 5-day workweek conditions.

From the analysis of the data, the following probabilities were obtained: $P(B_1) = 0.73$ where $P(B_1)$ is the probability that a clear day will occur between May 1 and November 1; $P(B_2) = 0.27$ where $P(B_2)$ is the probability that a rainy day will occur between May 1 and November 1; $P(X_1/B_1) = 0.78$ where $P(X_1/B_1)$ is the conditional probability that, if today is clear, tomorrow will be clear; $P(X_2/B_1) = 1 - P(X_1/B_1) = 0.22$ where $P(X_2/B_1)$ is the conditional probability that, if today is clear, tomorrow will be rainy; $P(X_1/B_2) = 0.60$ where $P(X_1/B_2)$ is the conditional probability that, if today is rainy, tomorrow will be clear; and $P(X_2/B_2) = 1 - P(X_1/B_2) = 0.40$ where $P(X_2/B_2)$ is the conditional probability that, if today is rainy, tomorrow will be rainy.

Bayes' theorem for forecasting clear weather, given that a clear condition exists, is given by the following formula:

$$P(B_1/X_1) = \frac{P(B_1)P(X_1/B_1)}{P(B_1)P(X_1/B_1) + P(B_2)P(X_2/B_2)}$$

where $P(B_1X_1)$ is the posterior probability of clear weather, and $P(B_1)$, $P(X_1/B_1)$, $P(B_2)$, and $P(X_1/B_2)$ are the prior probabilities as defined previously. Therefore,

$$P(B_1/X_1) = \frac{(0.73)(0.78)}{(0.73)(0.78) + (0.27)(0.60)} = \frac{0.5694}{0.7314} = 0.779$$

Bayes' theorem for forecasting clear weather, given that a rainy condition exists, is given by the following formula:

$$P(B_1/X_2) = \frac{P(B_1)P(X_1/B_1)}{P(B_1)P(X_2/B_1) + P(B_2)P(X_2/B_2)}$$

where $P(B_1/X_2)$ is the posterior probability of clear weather, and $P(B_1)$, $P(X_2/B_1)$, $P(B_2)$, and $P(X_2/B_2)$ are prior probabilities. Therefore,

$$P(B_1/X_2) = \frac{(0.73)(0.22)}{(0.73)(0.22) + (0.27)(0.40)} = \frac{0.1606}{0.2686} = 0.598$$

APPLICATION OF THE MOWING SIMULATION MODEL

It was proposed by the author that 10.6 miles of the southbound lane from edge of roadway to right-of-way fence on I-95 be mowed with a single 6-ft flail mower. The time was estimated from a field observation to be approximately 1 workweek. Based on this knowledge, a simulated sample size of 20 observations was selected. This size sample was analogous to making field measurements of the project times for a full mowing season that extended from May 1 to November 1. It was further proposed that the model represent the recording of these measurements for five mowing seasons. Thus, the mowing model consisted of five samples, each of which included 20 observations.

All eight random number generators that are available in the GPSS simulation language were assigned sequentially to the functions to develop complete randomization within the model.

The results of the simulated project times and project costs for sample 1 are given in Tables 3 and 4. The simulated times compare favorably with the observed completion time of 1 week.

A comparison was also made in which all class D or 3:1 side slope mowing was eliminated from the cutting assignments for the southbound lane. The results of this comparison, as given in Tables 4 and 5, indicate that, on the average, the scheduled

Figure 7. Hourly operating costs for flail mower.

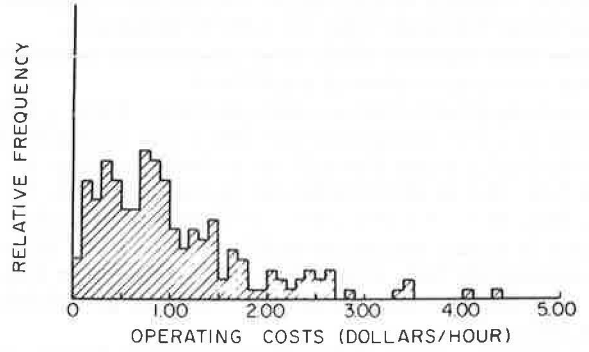


Figure 8. Hourly operating costs for trucks.

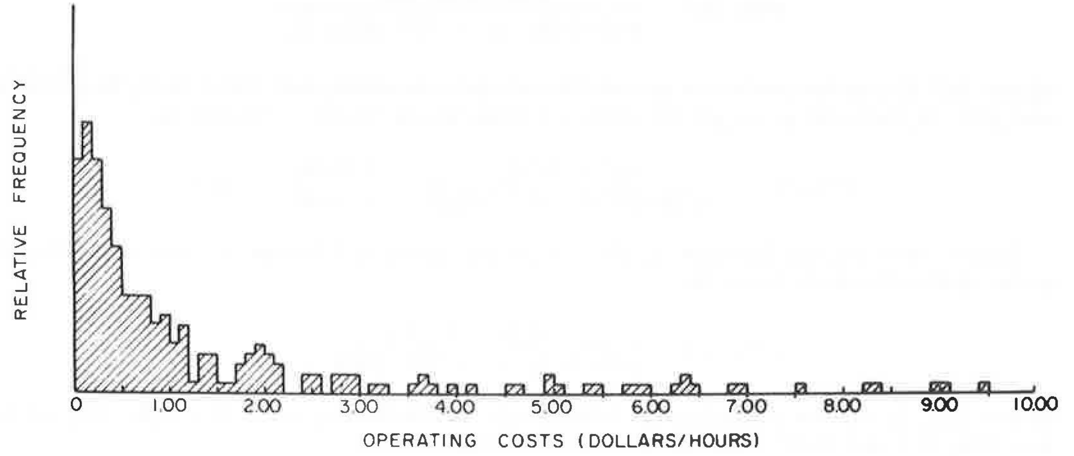


Table 3. Sample 1 project times.

Observation	Total Project Time With Rain		Total Product Time Without Rain Effect		Rain Factor[a]	Total Production Time in Project	
	Min	Hours	Min	Hours		Min	Hours
1	2,582	43.03	2,582	43.03	1.00	1,472	24.53
2	3,544	59.07	2,584	43.07	1.37	1,378	22.97
3	3,060	51.00	2,580	43.00	1.19	1,406	23.43
4	3,840	64.00	2,400	40.00	1.60	1,359	22.65
5	3,506	58.43	2,546	42.43	1.38	1,388	23.15
6	2,604	43.40	2,604	43.40	1.00	1,434	23.90
7	2,705	45.08	2,705	45.08	1.00	1,447	24.12
8	2,814	46.90	2,814	46.90	1.00	1,544	25.73
9	2,535	42.25	2,535	42.25	1.00	1,399	23.32
10	3,987	66.45	2,547	42.45	1.57	1,387	23.12
11	2,969	49.48	2,489	41.48	1.19	1,429	23.82
12	4,095	68.25	2,655	44.25	1.54	1,432	23.87
13	2,648	44.13	2,648	44.14	1.00	1,461	24.35
14	2,582	43.03	2,582	43.03	1.00	1,435	23.92
15	2,605	43.42	2,605	43.41	1.00	1,384	23.07
16	3,095	51.58	2,615	43.58	1.18	1,452	24.20
17	3,240	54.00	2,760	46.00	1.17	1,442	24.03
18	2,583	43.05	2,583	43.05	1.00	1,443	24.05
19	3,994	66.57	2,554	42.56	1.56	1,388	23.11
20	4,286	71.43	2,366	39.43	1.81	1,408	23.47
Mean	3,164	52.73	2,588	43.14	1.23	1,424	23.47
Standard deviation	603	10.05	104	1.74	0.26	42	0.70

[a]Derived from preceding two columns.

Table 4. Sample 1 project costs.

Observation	Project Cost (in dollars) With Class D	Project Cost (in dollars) Without Class D	Observation	Project Cost (in dollars) With Class D	Project Cost (in dollars) Without Class D
1	101.13	79.34	12	104.54	83.66
2	103.56	82.80	13	106.31	87.08
3	106.12	91.42	14	109.47	83.17
4	104.10	84.50	15	106.69	93.02
5	102.45	90.82	16	106.47	83.36
6	106.10	87.31	17	104.36	90.95
7	106.49	83.57	18	107.12	83.65
8	105.11	87.70	19	102.45	88.33
9	100.00	82.67	20	96.57	85.95
10	103.09	84.35	Mean	104.27	86.06
11	103.71	87.59	Standard deviation	2.86	3.57

Note: Figures represent total cost per mowing, including transportation and labor.

Table 5. Project times (without class D).

Observation	Total Project Time With Rain		Total Project Time Without Rain Effect		Rain Factor[a]	Total Production Time in Project	
	Min	Hours	Min	Hours		Min	Hours
1	2,315	38.58	1,835	30.58	1.26	1,094	18.23
2	2,352	39.20	1,872	31.20	1.26	1,103	18.38
3	3,076	51.27	2,116	35.27	1.45	1,177	19.62
4	3,068	51.13	2,108	35.13	1.46	1,101	18.35
5	2,123	35.38	2,123	35.38	1.00	1,101	18.35
6	2,764	46.07	2,284	38.07	1.21	1,130	18.83
7	3,781	63.02	1,861	31.02	2.03	1,056	17.60
8	4,480	74.67	2,080	34.67	2.15	1,111	18.52
9	2,827	47.12	1,867	31.12	1.51	1,089	18.15
10	3,549	59.15	2,109	35.15	1.68	1,099	18.32
11	2,046	34.10	2,046	34.10	1.00	1,079	17.98
12	2,540	42.33	2,060	34.33	1.23	1,059	17.65
13	3,106	51.77	2,146	35.77	1.45	1,087	18.12
14	3,980	66.33	2,060	34.33	1.93	1,091	18.18
15	2,618	43.63	2,138	35.63	1.22	1,144	19.07
16	2,045	34.08	2,045	34.08	1.00	1,086	18.10
17	3,999	66.65	2,079	34.65	1.92	1,088	18.13
18	2,534	42.23	2,054	34.23	1.23	1,085	18.08
19	3,052	50.87	2,092	34.87	1.46	1,100	18.33
20	2,558	42.63	2,078	34.63	1.23	1,090	18.17
Mean	2,941	49.01	2,053	34.21	1.43	1,099	18.31
Standard deviation	702	11.69	112	1.87	0.35	27	0.45

[a]Derived from preceding two columns.

completion time and cost per mowing of the southbound lane would be reduced 12.5 percent for the scheduled completion time and 12.1 percent for the cost per mowing. The analysis required ½ man-hour to collate the results of the computer output at a cost of $24 for computer time.

CONCLUSIONS

As demonstrated in this study, the mowing simulation model gives the highway maintenance engineer an effective tool by which he can make quantitative decisions about mowing programs for various sections of the highway system. The model is easily modified to handle any mowing situation that involves the production of a tractor-mower unit.

If the highway maintenance engineer is of the opinion that his work force performs more efficiently than the one represented in the model, he can remove the set of delay data from the data deck and replace it with a set of data that is applicable to his work force.

To apply the model to another section of highway, one needs to remove from the present program that portion of the data deck that refers to the subsections and terrain classifications and, also, the set of data in the core program that initializes the subsections and terrain classification areas. These data are replaced with data that describe the new section of highway according to its subsections and terrain classifications.

The model can be modified to handle any size or type of mower. This modification requires that the speed data in the data deck be replaced with speed data that are applicable to the performance of the new mower on the terrain classifications. If the effective width of the new mower is other than 5½ ft, the width factor in the production capacity equation must be specified in the core program.

The GPSS program developed for the mowing model is a utility program that can be extended to other highway maintenance operations such as road patching, in which the variance in the number of square feet of patching laid per day by a paver can be estimated; snowplowing, in which the number of square feet per hour of cleared road surface can be estimated for different size plows and depth of snow; or a ditching operation, in which the cubic yards of excavated material per hour can be estimated as a function of the density of the material.

With the development of the simulation model, the highway maintenance engineer now has a means by which time study data can be used effectively to make quantitative comparisons among alternatives for cost reduction decisions.

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