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Countywide Traffic Signal Maintenance Program

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Creation of an effective traffic signal maintenance program requires gathering and analyzing a large amount of data on existing conditions and on the history of maintenance activities. A model has been developed that allows the testing of various maintenance strategies based on historical data from the system being simulated. The computer program, adaptable to almost any computer, does not require user expertise in programming. Its outputs include summary reports, which are an excellent basis for management control and planning. Labor and budget requirements for achieving various levels of accident reduction can be calculated. The model is a valuable tool both for program budgeting and for short- and long-range planning.

Developing an effective traffic signal maintenance program requires gathering and analyzing data on both the existing conditions of the system and its history of various types of maintenance activities. While such data are generally available in files and charts, retrieval and analysis can be time consuming unless the information is processed by digital computer. The benefits that can be gained from even the simplest analysis of signal maintenance data are numerous and can lead to economic savings, higher levels of service, increased productivity, and decreased liability. The law, as it relates to traffic signal maintenance, is that there is a duty to maintain the lights in a traffic control signal and that a failure to do so may lead to liability if it is a proximate cause of an injury. The erosion of sovereign immunity and the gradual increase in financial liabilities to the community have drawn attention to the maintenance of traffic signal systems.

In most areas, maintenance of the traffic signal system is left to one unit of government, be it state, county, or city. The increase in labor, material, and equipment costs in recent years has caused all such units to take a second look at increased productivity and the maintenance of proper levels of service at stable levels of spending. The effect of these spending reviews has been for those in charge of local traffic signal systems to attempt to reevaluate their current procedures in terms of various alternate maintenance strategies. The problem here, however, lies in the facts that sufficient, easily accessible data files are not available and that analysis techniques remain generally at a level too low to allow significant results or information to be gained or a sound engineering evaluation to be made.

To date, several communities have begun the implementation of computerized maintenance reporting systems that lend themselves to the analysis of maintenance-related data and the possible development of model parameters. One survey of the maintenance management of traffic signal equipment and systems (1) concluded that deficiencies in maintenance lead to signal malfunctions or breakdowns that cause delays to the traveling public, increased accident potential, increased fuel consumption, and air pollution. Thus, it is important to have a program that includes routine and preventive maintenance to ensure that problems be kept to a minimum. The lack of the ability to use such data once they are collected can lead to the improper operation of the maintenance program.

BACKGROUND AND SETTING

The Macomb County Road Commission is responsible for 2250 km (1400 miles) of highways in southeastern Michigan (northeastern suburbs of Detroit). The county covers an area of 1253 km^2 (482 miles^2) and encompasses 15 cities and 11 townships, all within the metropolitan region of Detroit. The county has a traffic signal system of approximately 500 traffic signal locations. The signals, which are under the jurisdictions of the various cities, the county, and the state highway department, are all maintained by the Macomb County Road Commission.

Traffic signal maintenance performed by the commission consists of the following types:

1. Routine maintenance: work items that must be performed on a regular basis to ensure the continued operation of the equipment;
2. Preventive maintenance: work items that should be performed at scheduled intervals to minimize the probability of failure of the signal equipment;
3. Emergency repairs: work required to restore traffic signal equipment to its original state after a service failure; and

Figure 1. Work order form.

CBO Date: ______

Nº 32100

MACOMB COUNTY ROAD COMMISSION

TROUBLE AND WORK SHEET

Reported by: ______ At: ______ A.M. P.M. Date: ______

Location: ______ Location Number: ______

Reported trouble: ______

Given to: ______ At: ______ A.M. P.M. Truck Number: ______ By: ______

Arrived at location: ______ A.M. P.M. Date: ______

Condition found: ______

Nature of repair: ______

9. CONTROLLER MAINTENANCE	20. RESET TO CBO	31. ROUTINE LAMP CHANGING
10. SIGNAL INSTALLED	21. RESET CLOCK FOR D.S.T.	32. PEDESTRIAN SIGNAL OUT
11. SIGNAL STUCK	22. RESET CLOCK FOR E.S.T.	33. CASE SIGN OUT
12. SIGNAL TWISTED	23. CLOCK INCORRECT	34. CASE SIGN DAMAGED
13. SIGNAL DAMAGED	24. TIMING INCORRECT	1. VISOR BENT
14. SIGNAL OUT	25. CHECK INTERCONNECT	2. POLE HIT
15. SIGNAL DOWN	26. CONTROL BOX OPEN	3. GUY WIRE DOWN
16. SIGNAL LOW	27. CONTACT BROKEN	4. SPAN WIRE DOWN
17. BAG SIGNAL	28. FLASHER BROKEN	5. OVERHEAD SIGN INSTALLED
18. NO BELL POWER	29. BULB OUT	6. OVERHEAD SIGN MAINTENANCE
19. NO EDISON POWER	30. LENS BROKEN	7. NO PROBLEM FOUND
		8. OTHER

Left operation: ______ A.M. P.M. Date: ______

☐ OK Perm. ☐ OK Temp. ☐ Check Timing

Parts used: ______

4. Maintenance work: work caused by relocation of signals, or scheduled or unscheduled work caused by functional inadequacy of the installed equipment or the need for physical changes in the installation brought about by pavement reconstruction or changes in signalization standards.

The development of a traffic signal maintenance program that integrates all types of maintenance at a minimum cost and also allows a budget and personnel analysis would aid in the efficient use of resources and would minimize accident liability.

Recent studies in highway maintenance have been devoted almost entirely to increasing the effectiveness of either the individual maintenance operation or the management of the maintenance organization. The problem is that highway maintenance involves a broader range of items including equipment and material types, characteristics of individual components of the system, system degradation, and system user delay. The maintenance strategy that will give the lowest total cost will not necessarily give the lowest component costs.

A study was therefore initiated to develop a reporting system to gather maintenance data that could be used to analyze the current maintenance effort and to develop a computer model for simulating the current maintenance strategy and testing alternative strategies.

METHODOLOGY

To enable the development of a model of the maintenance system, it was first necessary to develop, test, and implement a data-collection system.

In 1973 the Macomb County Road Commission instituted a signal maintenance reporting system that allows the necessary detailed data files to be built and maintained. Since that time, data for each traffic signal device under the maintenance jurisdiction of the Road Commission have been collected. The collection consists of reports of every authorized maintenance or service and repair call at all the traffic signal devices.

The reports include date and time of the reported trouble, date and time of arrival of the service technician, condition of the traffic control device, nature of the repair, and condition the location was left in. The reports are prepared by the service technicians that visit the site and are completed on a form suitable for data-processing use (Figure 1). The reports are submitted to the traffic engineer's office, where they are reviewed and the data are punched onto computer cards.

Currently three reports are being prepared from these data: a detail report listing service calls by location, a summary report of service call types by location, and a summary report of various trouble and service types (Figure 2).

Figure 2. Sample maintenance report.

```
                    LOCATION NAME
09 - CONTROLLER MAINTENANCE           2 TOTAL TROUBLE CODE
13 - SIGNAL DAMAGED                   1 TOTAL TROUBLE CODE
22 - RESET CLOCK FOR E S T            1 TOTAL TROUBLE CODE
23 - CLOCK INCORRECT                  1 TOTAL TROUBLE CODE
29 - BULB OUT                         3 TOTAL TROUBLE CODE
31 - ROUTINE LAMP CHANGING            2 TOTAL TROUBLE CODE
                           1974  1975
                              5    12 TOTAL LOCATION TR-SH
   COLE/PHLOX        TO 10 MILE RD          085

07 - NO PROBLEM FOUND                 1 TOTAL TROUBLE CODE
08 - OTHER                            1 TOTAL TROUBLE CODE
14 - SIGNAL OUT                       1 TOTAL TROUBLE CODE
22 - RESET CLOCK FOR E S T            1 TOTAL TROUBLE CODE
31 - ROUTINE LAMP CHANGING            1 TOTAL TROUBLE CODE
                           1974  1975
                             13     5 TOTAL LOCATION TR-SH
   GRATIOT           TO REMICK              086

07 - NO PROBLEM FOUND                 2 TOTAL TROUBLE CODE
08 - OTHER                           11 TOTAL TROUBLE CODE
09 - CONTROLLER MAINTENANCE           2 TOTAL TROUBLE CODE
12 - SIGNAL TWISTED                   1 TOTAL TROUBLE CODE
22 - RESET CLOCK FOR E S T            1 TOTAL TROUBLE CODE
27 - CONTACT BROKEN                   2 TOTAL TROUBLE CODE
31 - ROUTINE LAMP CHANGING            1 TOTAL TROUBLE CODE
                           1974  1975
                             12    20 TOTAL LOCATION TR-SH
   COMMON            TO GRATIOT             087

08 - OTHER                            2 TOTAL TROUBLE CODE
09 - CONTROLLER MAINTENANCE           1 TOTAL TROUBLE CODE
31 - ROUTINE LAMP CHANGING            2 TOTAL TROUBLE CODE
                           1974  1975
                              5     5 TOTAL LOCATION TR-SH
   CONNER            TO SHERWOOD            088
```

At the time that the signal maintenance reporting system was being initiated, an inventory of traffic signal devices was also being conducted. The inventory consisted of reviewing each location and determining various physical items that characterize each location, such as street location, location number, number of dials, number of circuits, cam intervals, and type of clock and flasher.

To evaluate various maintenance strategies and to determine basic system functioning parameters, the basic information required includes knowing the average number of trouble and service calls per location per year, how the average number of trouble and service calls varies with different levels of controller maintenance and lamp replacement, and how lamp life varies with respect to controller characteristics and maintenance levels.

The first object of this study was to review the basic data files and to determine what relations exist and what types of analysis and data requirements would be necessary for further study. As such, the data contained in the trouble and work report file and the location inventory file were reviewed and a number of items were chosen for review.

1. Total number trouble and work calls per location for 1974 and 1975,
2. Total number controller maintenance visits per location for 1974 and 1975,
3. Total number lamp burnout visits per location for 1974 and 1975,
4. Total number lamp replacement visits per location for 1974 and 1975,
5. Number of timing dials per location,
6. Number of circuits per location,
7. Existence of a flasher unit at a location,
8. Existence of a clock unit at a location,
9. Secondary voltage provided to the controller, and
10. Wattage rating of the location.

The analysis of the data began with a determination of the mean and standard deviation of each variable. Then a correlation analysis was conducted to evaluate the relations among variables that are commonly assumed to be related. This approach was used because we felt it would save time to test these common assumptions.

The variables that were assumed to be related were

1. Number of 1974 trouble and service calls versus 1974 controller maintenance, 1974 lampouts, and 1974 lamp charges;
2. Number of 1975 trouble and service calls versus 1975 controller maintenance, number of dials, number of circuits, number of clock units, secondary voltage at controller, and power consumption of location;
3. Number of 1974 lampouts versus secondary voltage at controller; and
4. Number of 1975 lampouts versus secondary voltage at controller.

The results of the correlation of the unsegregated data did not indicate very high levels of relations for any of the pairs of variables. It was felt that a more detailed analysis of the data base was necessary.

Next the data were segregated based on (a) the number of circuits at a location, (b) the wattage rating at a location, and (c) the number of timing dials at a location. These three items were chosen because we felt that they gave an indication of the complexity of the signal installation.

A study of these characteristics indicated a difference between locations of one circuit that consumed less than 700 watts of power and those of six or more circuits that consumed 700 or more watts. Based on this review, the data set was segregated.

Concurrently with this basic study, a number of regression analyses were performed to determine the relations among the variables of the data set. Again, variables were chosen based upon common assumptions of the signal maintenance field, in an effort to reduce the number of computer runs. Next, by using the following information, we calculated total maintenance calls per location per year, controller maintenance calls per location per year, lamp replacement visits per location per year, total nonmaintenance calls per location per year, and trouble and work calls per location per year. The existing data were plotted.

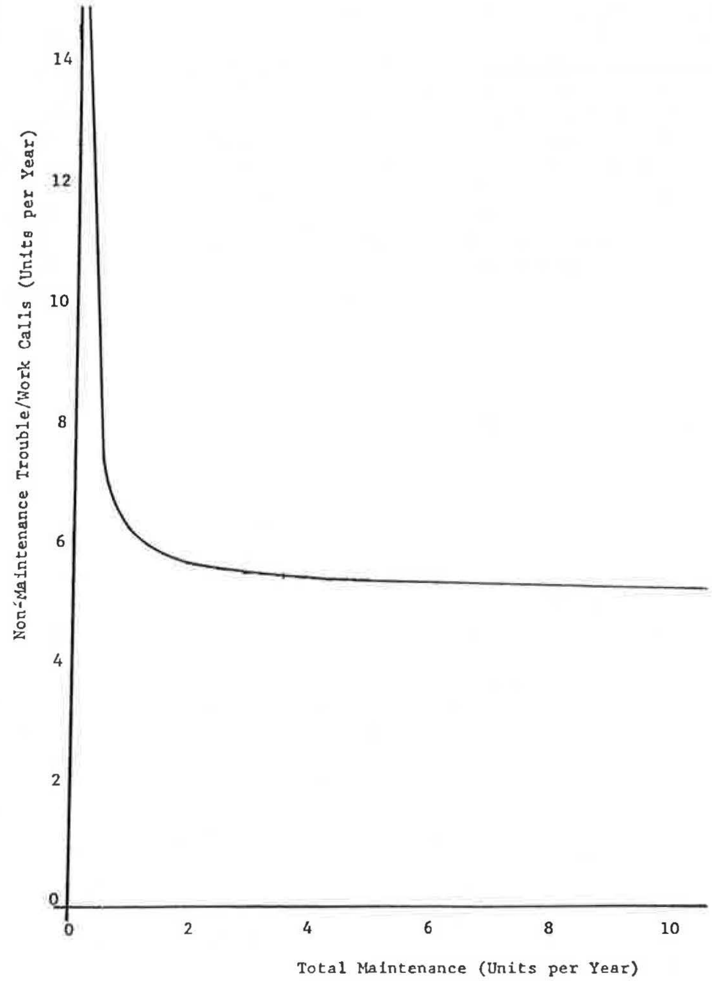
Although it was recognized that the number of data points was too small to establish valid relationships at this time, the assumptions being tested related location trouble to amounts of maintenance. Thus it was possible to determine whether further work would be worthwhile.

After plotting, an attempt was made to fit a curve to the data. The results provided a hyperbolic-type curve (Figure 3) that related maintenance to trouble calls and indicated that increasing or decreasing maintenance to extremes becomes self-defeating, either burdening the system with excessive breakdowns or excessive maintenance.

THE MODEL

In order to evaluate various traffic signal maintenance strategies and various types of signal systems in different locations in an efficient and timely manner, we

Figure 3. Maintenance versus nonmaintenance calls curve.



decided to devise a model that, from the input of various system parameters, would project accurate maintenance requirements. Such projections would be produced in a form that would enable the user to tailor the analysis for any particular traffic operations organization by using the model.

The major system components consist of the following sequential tasks:

1. Entrance and initialization,
2. Maintenance requirement generator,
3. Maintenance queue component,
4. Work time generator, and
5. System clock and termination component.

These major components provide for the general control of the program and system configuration.

Entrance and Initialization

Task 1 provides for the initialization of the system clock and the designation of the traffic signal system. The traffic signal system is initiated by the input of individual data that describe the locations by parameters that have previously been determined to be characteristic of the system. That is, the signal location could be described by the number of electrical circuits, the power consumption, the number of lamps, and other similar items.

Maintenance Requirement Generator

Task 2 provides for the setting up of the various maintenance strategies that can be tested by the model. The maintenance requirement generator responds to the input of the various types of maintenance calls and the conditions under which each type will be responded to. The maintenance requirement generator performs three separate functions in this process. First, based on the designated maintenance characteristics of the signal system, a maintenance call is generated. Second, the call is assigned to a particular location, and, finally, the actual type of the maintenance call is determined. The functions are sequenced in this particular manner so that the maintenance call will be appropriate for the time at which it is occurring and also is compatible with the characteristics of the particular location that it is assigned to. It is during the second and third functions that an iterative process may occur under certain circumstances, where the characteristics of the location may preclude the occurrence of a maintenance call at that particular time. In that case a new location would be designated and checked.

Maintenance Time Generator

The work time generator provides for the calculation of travel and actual work time based on the location of the device to be serviced and the type of maintenance work to be performed. The generator uses travel time

data supplied for each location and input as part of the location description.

The times are from the point when the maintenance service crew responds to the point when they arrive at the particular signal location.

To generate maintenance service calls and maintenance types, a method using discrete random deviates was devised. This allowed for the input of data for occurrence and type of maintenance service call that would reflect the characteristics of the system being modeled. This method also allows the input data to be modified to reflect some theoretical or future distributions.

USE OF THE MODEL

Maintenance of the traffic signal requires activities in several categories that include routine maintenance, preventive maintenance, emergency repairs, and reconstruction. Equipment malfunctions, which are more likely to occur when there is a lack of routine and preventive maintenance, can result in increased accident potential, increased fuel consumption, and environmental pollution. Signal maintenance programs include such work items as frequent visual inspections, relamping, signal head cleaning, detector inspection, and control equipment inspection.

Selection of a maintenance policy that includes all the various categories of maintenance and various maintenance programs can be approached as a problem of minimizing the cost of maintenance. Also, the level of maintenance depends on how fast malfunctions and breakdowns are detected and corrected. The dependence of both of these items on maintenance personnel and the procedure they use is critical.

The maintenance strategy used for signal maintenance involves two major areas. The first is the way various categories of maintenance are mixed in an attempt to minimize catastrophic failures. If maintenance work were subdivided into catastrophic and noncatastrophic types, the general relation given below could be described.

$$CF = f(NCF) \tag{1}$$

where CF is the level of catastrophic failures and NCF is the level of noncatastrophic failures.

In the case of this study, the routine, preventive, and reconstruction categories of maintenance would be grouped as noncatastrophic failures, while emergency repairs would be classed as catastrophic failures. In the case of most signal systems, a variety of signal types and configurations is used, along with different physical conditions of installation. The physical characteristics of a signal installation contribute to the amount of catastrophic failures and therefore Equation 1 can be changed to the more specific form given below.

$$CF = f(NCF, PC) \tag{2}$$

where PC is a factor that describes the physical characteristics of the signal.

The second area involves the actual dispatching of maintenance personnel and the procedures they use in the field. Some typical schemes used would be assigning work to a crew immediately on notification, holding work until a crew becomes available, or determining action to be taken according to the type or time of occurrence of the failure.

Deficiencies in maintenance lead to signal malfunctions or breakdowns that result in additional costs to the motoring public in both direct and indirect ways. It is important to have a signal maintenance program that includes routine and preventive maintenance that will minimize these costs.

The amount of noncatastrophic or routine maintenance performed and the procedures used to correct catastrophic failures directly affect the cost to the public. Both items can be varied to alter these costs. The amount by which each of these items is varied affects the cost to the public directly. Unfortunately, because the effects of maintenance are long term, the modification of the particular maintenance procedures being followed cannot be tested beforehand or even after a short trial period.

The model discussed in this study was used to test the effects of varying signal maintenance strategies by applying statistical tests to actual data and data generated by the model to determine whether significant changes could be detected. Tests were performed for variations in the distribution of catastrophic failures by type and time of occurrence as various maintenance strategies were applied to the system.

Two maintenance strategies were tested during the course of this study. The first consisted of routine and preventive maintenance equal to four trips per signal location per year, plus the catastrophic failure strategy below.

1. A full-time service and repair person was assigned to service catastrophic failures. During the normal working hours this person is assigned to bench work and is available for duty at any time. During all other hours of the day and on weekends he or she is on call for duty as needed. During these on-call periods a minimum call-out time is paid for whether it is needed or not.
2. As soon as notice of a catastrophic failure is received the repair person is dispatched to the site and remains there until the signal is functioning properly.
3. In all but the most extreme cases (i.e., signals completely destroyed by storm or accident), the failure is serviced by the repair person only.
4. In the case of this strategy, catastrophic failures included such occurrences as pole hit, span wire down, signal struck, signal twisted, signal damaged, signal out, signal down, signal low, no electrical power, control box open, contact broken, flasher broken, lamp out, lens broken, pedestrian signal out, case sign out, and case sign damaged.

The second maintenance strategy consisted of routine and preventive maintenance equal to four trips per signal location per year, plus the catastrophic strategy below.

1. A full-time service and repair person was assigned to service catastrophic failures during normal working hours. During periods when not on duty servicing a call the repair person is assigned to bench work.
2. As soon as notice of a catastrophic failure is received during normal working hours, the repair person, if available, is dispatched to the site and remains there until the signal is functioning properly or the regular shift ends. When the regular shift ends before completion of repairs, work resumes at the start of the next regular shift.
3. During all other nonregular shift hours in the case of the more dangerous types of failures (e.g., pole hit, span wire down, signal stuck, signal damaged, signal down, and case sign damaged), the service repair person goes to the location to move debris to the side of the road and shut off electrical service.

Figure 4. Circuits and locations.

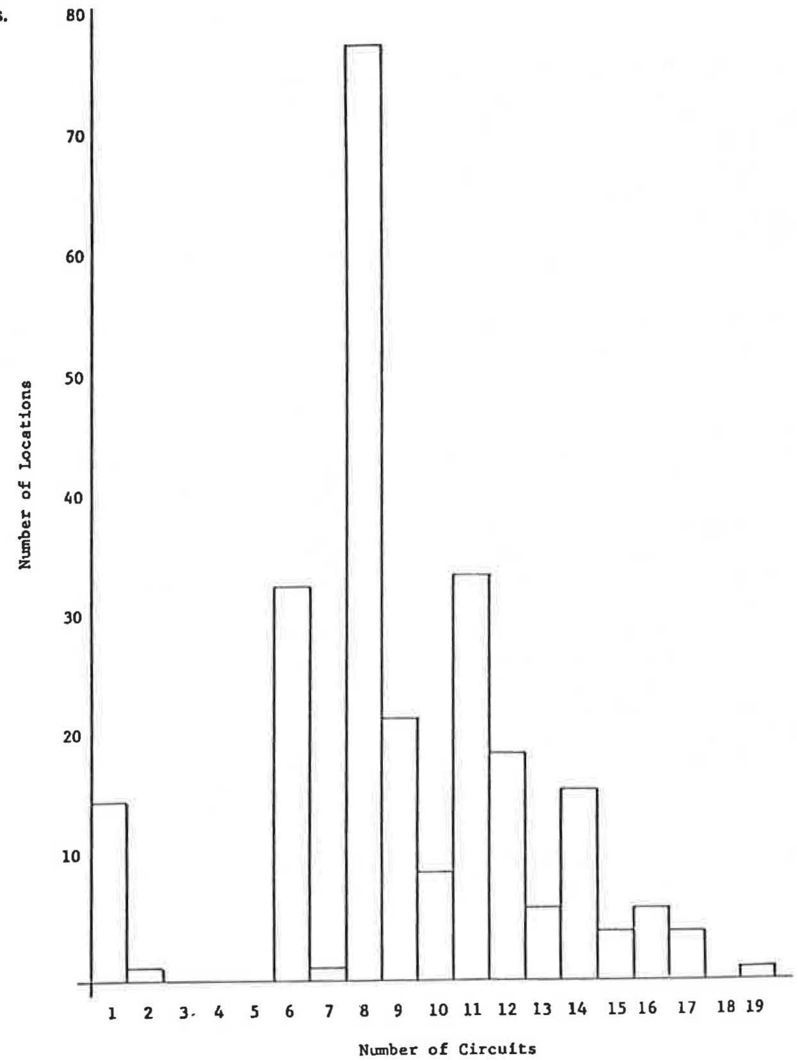
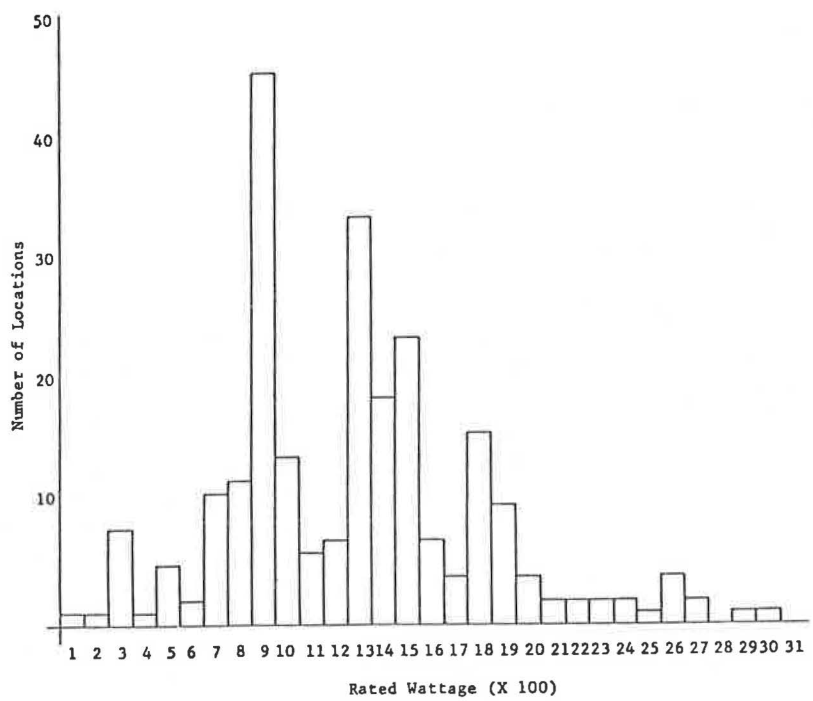


Figure 5. Wattage and locations.



Repairs would take place starting at the beginning of the next regular shift.

4. For the failure classifications signal twisted, signal out, signal low, no electrical power, control box open, contact broken, flasher broken, lamp out, lens broken, pedestrian signal out, and case sign out, the repair person would not report to the location during nonregular shift hours, and repairs would be scheduled starting at the next regular shift.

5. Reports of catastrophic failure would be screened by the dispatch personnel and handled accordingly.

The first, or full, maintenance strategy described is one that is commonly used for signal maintenance. The second, or limited, maintenance strategy, is derived from the first and has as its major difference the reduction in catastrophic-failure service.

Many agencies engaged in full maintenance strategies periodically consider the limited strategy because of economic factors. An agency engaged in a full maintenance program might, for example, have to pay the service and repair person for a 3-h minimum period even if he or she worked only a portion of that period (i.e., any period less than 3 h).

Obviously, for some periods of time, the cost of a full maintenance program would be excessive when only the economic factors were considered. But the real question lies in the minimum cost when economics, excessive delay, increased accident liability, and other associated costs are all accounted for.

RESULTS

The results from use of the model indicate that the second maintenance strategy (restricted night service) resulted in overall increases in the length of time to complete a repair to 4.3 h. The amount of overtime charged to the emergency repair of signals would be reduced by 3.5 h by use of the second strategy.

The results were obtained by running year-long maintenance simulations for a system consisting of 500 signals. System parameters reflecting the equipment configurations were as indicated in Figures 4 and 5.

CONCLUSIONS

The model developed in this study provides a useful tool for both monitoring traffic signal maintenance work and testing proposed maintenance strategies. The computer program is flexible and adaptable to almost any size computer. This program was originally developed and tested on an IBM 1130, 8K system.

A case study comparing two maintenance strategies indicated that significant changes in the factors affecting signal maintenance costs and maintenance levels could be achieved by making relatively minor strategy changes.

The model has the potential to be used for both short- and long-range planning and can contribute significant input to program budgeting by using systemwide data.

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Priority Assignment for Bridge Deck Repairs

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This paper presents, in considerable detail, an approach used to assign priorities to bridge decks for protection, rehabilitation, or replacement. The system was developed by integrating traffic use (level of service) with existing deck condition. High priority is assigned to critically deteriorated decks in heavy and moderate traffic volume locations. Medium priority is assigned to exceptionally good decks in heavy and moderate traffic volume areas to prevent chloride-induced corrosion of the rebars and subsequent spalling. Low priority is assigned to the remaining bridge decks in a descending fashion from high- to low-volume areas. The key elements needed to draft and develop the priority schedule are reviewed and discussed. The rationale for selecting protection systems to be installed and the deck preparation required for various initial deck conditions is presented. Last, a brief review of policy implementation is provided.

Perhaps the single most perplexing problem to confront bridge design and maintenance engineers in the past decade is corrosion-induced spalling of the deck. Various systems have been developed and implemented in an attempt to prevent spalling on new decks and to rehabilitate existing ones. Many bridge decks with 10-15 years of service have experienced spalling severe enough to require major repair or complete rehabilitation. As is often the case, projected maintenance needs often exceed budget limitations. There are too many bridges to fix and not enough money to go around.

Minnesota, along with many other northern central states, has been especially aware of the growing deck deterioration problem. Geographic location and somewhat severe winters necessitate extensive salting to maintain bridges and roadways in good winter driving condition. Consequently, the heavy deicer applications have resulted in an early awareness of spalling as more maintenance efforts have been concentrated on deck repair.

Installation of protection systems designed specifically to correct chloride-induced corrosion of the reinforcing steel and subsequent spalling began in 1971 and 1972. At that time, however, there was something less than consensus among staff and operations and mainte-