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 maintenance personnel on exactly what the problem was and how it should be corrected.

Initial guidelines, which amounted to little more than a list of approved membranes selected from a study (1) and some recommendations for deck preparation before system installation, were implemented as a stopgap measure in November 1974. These, it was felt, would buy time until the problem could be more fully reviewed and a comprehensive policy developed to correct it.

During the closing months of 1975, a task force made up of personnel from the offices of bridge design and construction, materials, research, and standards was assembled to review the state of the art for both problem and solution technology and to develop a new policy for bridge deck repair and protection. The following approach to assigning priorities to decks for repair is one of the cornerstones of that policy.

OBJECTIVE

The objectives of this paper are to present in a clear and detailed manner the approach used to (a) select bridge decks in need of repair by means of a systematic and rational procedure that takes into account as nearly as possible the many variables involved, (b) identify the elements needed to develop a realistic and practical policy of this type, (c) select protection systems installed on various decks, and (d) review the policy's implementation and exceptions.

Minnesota began a program of annual bridge inspection to determine physical condition and identify deficiencies in 1970. By 1973, the inspection procedure had been upgraded to include detailed information on items such as percentage of deck areas patched with either bituminous (temporary) or concrete (permanent) patches that showed spalling or delamination. These checklist items were then lumped together as unsound concrete. A condition code number, based on current inspection inventory rating, was also incorporated into the process.

TRAFFIC CATEGORY GROUPING

The first approach to developing a workable format that would identify bridges for early deck repair resulted in agreement among all parties that repair should be reserved for those bridges with the most severe deck condition (largest amount of unsound concrete). It was further agreed that traffic use should be considered in deciding which severely deteriorated bridges should be repaired first, second, third, and so on.

It was around the simple concept that repair should be dictated by deck condition and traffic use that the format evolved. Furthermore, it was agreed that the concept of use versus condition would be best incorporated into a meaningful policy if kept simple. With this in mind, the Minnesota group agreed on the division of traffic categories. This assignment was not arbitrary. Rather, it generally reflected three levels of service.

Category A encompasses all bridges on urban Interstate systems with volumes of 10 000-100 000 vehicles per day average daily traffic (ADT). It is significant that those roadways and bridges that carry the highest volumes of traffic, as a general rule, are those that are subject to the most frequent and heaviest amounts of salting. Subsequently, they have also exhibited earlier and more severe deterioration than bridges in less heavily trafficked areas.

Category B (2000-10 000 ADT) encompasses all bridges located on rural Interstate highways and state trunk highways. These bridges are not salted as often and exhibit less severe premature deterioration than those in category A.

Category C (less than 2000 ADT) encompasses all remaining bridges on lower-volume state trunk highways. They are generally salted less and are in better condition with regard to incidence of surface spalling than bridges in categories A and B.

DECK CONDITION GROUPS

Several task force sessions were devoted to reviewing the state of the art relative to probability of successful permanent repair versus initial deck condition. This review showed that only very few factual data were available to support various methods and procedures for repairing or rehabilitating decks.

Research by others (2-6) using half-cell potentials and chloride analysis of simulated concrete decks has suggested that corrosion and spalling may continue even after special protection systems are in place if care has not been taken to remove all salt-laden concrete or areas of active corrosion (defined by half-cell testing) before system placement. Field investigations of actual structures performed by California and Iowa (6,7) indicate that this concept, although theoretically sound, was not firmly supported by field data and observations.

Iowa reports that high-density concrete overlays installed on decks contaminated above the chloride threshold have not shown significant spalling since placement.

Stratfull (6) has identified structures where half-cell potentials fall below the accepted corrosion threshold even though chloride at the rebars is in the range of roughly three times that needed to cause corrosion. He attributes this occurrence to insufficient moisture for the corrosion cell to remain active. In addition, review of repairs on five decks showed corrosion potential reductions on the order of 50 percent of the pre-repair level. Stratfull did caution, however, that this reduction did not necessarily reflect on the probability of continued corrosion in areas where contaminated concrete was not removed.

Other investigations (8) of special concrete deck protection systems, some now in place for five and six years on decks with threshold-level chloride, show only minor evidence of continued spalling at present. Thus it would seem that the current understanding of the corrosion phenomenon and possible solution technology should call for considerable flexibility in a policy intended to deal with the situation.

After much discussion, task force members decided to use four deck condition groups. Initially, they were identified subjectively by the levels of deterioration listed below.

		Deterioration	
Group	Rating	Percentage	Code No.
1	Slight	0-5	9
2	Moderate	5-20	7-8
3	Severe	20-40	5-6
4	Critical	40+	4 or below

Further review led to defining the percentage of unsound concrete, as identified earlier, that was associated with each level of deterioration. Finally, the code designation used in annual inspections was assigned to its respective group. One ought to keep in mind that there is nothing absolute about assigned percentage of unsound area or code condition. Condition and traffic

Table 1. Bridge and area assignments by deck condition and traffic category.

Group	Category A		Category B		Category C	
	No. of Bridges	Area Affected (m^2)	No. of Bridges	Area Affected (m^2)	No. of Bridges	Area Affected (m^2)
1	14	51 740	91	115 348	52	44 935
2	97	775 182	641	506 539	556	254 436
3	111	207 120	214	209 078	236	100 503
4	13	48 014	7	2 819	10	25 662

Note: $1 m^2 = 1.2 yd^2$.

use were grouped, categorized, and integrated as shown in Table 1.

As all bridge inspection reports are logged in a central computer inventory system, the next step in policy development was fairly easy. A program was written to identify all bridges by number and surface area and to assign them to their respective positions in the matrix. A more definite picture of current and future needs began to develop. When this task was complete, the next one, that of assigning priorities for programming and scheduling work, began.

PRIORITY ASSIGNMENT FOR CONTRACT REPAIR

As was mentioned previously, assigning the first priority was easy. Those bridges with critical deck spalling in traffic category A should be repaired first and were appropriately identified as priority one. In a similar manner, critical bridges in category B were assigned priority two. It was in assigning priorities three and four that major disagreement among task force members surfaced. Part of the group felt that priority three should be assigned to severely deteriorated (group 3 bridges in category A), while others felt that priority three should be delegated to protecting the slightly deteriorated bridges in category A.

It seemed reasonable to implement the old axiom that an ounce of prevention would in fact be worth a pound of cure. If a deck was in excellent condition with only a minimum amount of chloride contamination, then there was no good reason not to protect it from further salting and eventual deterioration by adding an additional 50 mm (2 in) of special concrete. This would provide the additional cover needed to prevent salt from ever reaching the rebars in threshold level quantities during the expected life of the structure.

Disagreement persisted until an economic analysis was performed to better understand the cost-benefit ratio for each course of action. In addition, chloride analysis was performed on those decks in category A group 1 to ensure that threshold chlorides had not reached the level of the rebars. Major items for consideration in cost-benefit analysis were cost of removing concrete and preparing the deck for new overlay, cost of new overlay per square meter at the specified thickness, and approximate life expectancy of the system on the deck being repaired. It seemed reasonable to expect that, for a given system, the life expectancy would be the longest if the deck to which it was applied was in the best possible condition. Extending this concept further led to developing crude estimates of system life and to assessing costs based on dollar per square meter of deck per year of service. Such figures, though based on little more than engineering guesses, provided a relative ordering of system costs versus anticipated performance. With the cost-benefit study complete, it was apparent that assigning priority three to category A group 1 was justified by a ratio of at least 2:1 and in some instances 3:1.

After reviewing cost-benefit data, priorities three and four were thus assigned to group 1 traffic categories A and B, respectively. Priority five was assigned to group 4 category C. The priority assignment shown below continued in a similar manner until all groups were completed.

Group	Priority Assignment		
	Category A	Category B	Category C
1	3	4	10
2	6	7	11
3	8	9	12
4	1	2	5

EXCEPTIONS

As is often the case with policy development, exceptions arise that must be dealt with. There were several in our case, and these will now be reviewed.

The first exception involves bridges in which the deck is a portion of the main structural support member. This includes concrete box girders, slab spans, and deck girder bridges. Because decks on these structures cannot be removed without supporting the structure on falsework, the amount of unsound concrete in the severe category was changed to 20-60 percent and critical assessment was reserved until 60 percent or more of the surface is unsound. Every effort should be made to protect these decks before deterioration begins or to repair them as soon as programming allows. Within any category, these structures should receive priority over other bridges.

Another exception occurs when a bridge that does not necessarily warrant immediate repair (but in all probability will during the foreseeable future) is located near bridges being repaired as a strip project. In this case, it is economically justified to include the random bridge in the strip project, as opposed to repairing it several years later as a single project. Also, from a traffic control standpoint, there is less adverse public reaction to multiple restrictive lane closures year after year on the same section of highway.

The last exception is also associated with traffic conditions in that, when some bridges are repaired, it is more time efficient to close the bridge to all traffic and make detours. Other structures that might by priority assignment require repair are delayed to accommodate detoured traffic.

REPAIR SYSTEM SELECTION

Presenting an approach for assigning repair or rehabilitation priorities would be incomplete without some discussion of protection system selection. There is also a need to review the various deck preparations, or, more specifically, concrete removal procedures with regard to extent and depth.

The two classes of systems currently used for deck protection and rehabilitation are membranes with bituminous overlays and special concrete overlays. The three basic deck preparation methods are

1. Scarify, spot remove, patch, and overlay;
2. Remove 100 percent of the concrete to the top of the upper rebar mat and overlay; and
3. Remove entire deck.

Predicting probable system performance was difficult enough with systems installed on new decks. There was early consensus on the contention that traffic

Table 2. Summary of 1976 policy for contract bridge deck restoration.

		Deterioration		Category A				Category B				Category C			
Group	Rating	Percentage	Code	No. of Bridges	Area (m^2)	Priority	Procedure	No. of Bridges	Area (m^2)	Priority	Procedure	No. of Bridges	Area (m^2)	Priority	Procedure
1	Slight	0-5	9	14	51 737	3	Spot removal and concrete overlay	91	115 348	4	Spot removal and concrete or membrane and bituminous overlay	52	44 936	10	Spot removal and concrete or membrane and bituminous overlay
2	Moderate	5-20	7-8	497	775 183	6	Spot removal and concrete overlay	641	506 593	7	Spot removal and concrete overlay	565	254 436	11	Spot removal and concrete or membrane and bituminous overlay
3	Severe	20-40	5-6	111	207 121	8	100 percent removal to reinforcing bars, minimum spot removal below bars, concrete overlay	214	209 078	9	Spot removal and concrete overlay	236	100 502	12	Spot removal and concrete or membrane and bituminous overlay
4	Critical	40+	4 or lower	13	48 014	1	Program new deck	7	2 819	2	Spot removal and concrete overlay	10	25 663	3	Spot removal and concrete or membrane and bituminous overlay

Note: 1 m^2 = 1.2 yd^2.

volume is directly related to the level of chemical use. More highly trafficked areas are salted more heavily and frequently than lower-volume areas. Pursuing this rationale led to recognizing that some decks require the maximum protection possible, while others need considerably less protection. In short, system selection should be based initially on anticipated exposure to deicing chemicals.

A second and more elusive aspect of probable system performance was the influence of initial deck condition. It was mentioned earlier that only limited data were available to support a decision regarding which system to install on a deteriorated deck.

It seemed reasonable to expect that a specific system installed on a new deck may well out-perform the same system installed on a badly deteriorated deck. There was also a very real possibility that the extent of concrete removal preceding overlay placement could influence system performance.

In an attempt to balance the benefits accrued from protecting relatively good in-service decks against the risk associated with premature protection system failure, the following format for deck preparation and system selection was developed.

Group 1

Priority 3
- Spot removal and concrete overlay

Priority 4
- Spot removal and concrete overlay or membrane and bituminous overlay

Priority 10
- Spot removal and concrete overlay or membrane and bituminous overlay

Group 2

Priority 6
- Spot removal and concrete overlay

Priority 7
- Spot removal and concrete overlay

Priority 11
- Spot removal and concrete overlay or membrane and bituminous overlay

The decision to use concrete overlays in high-volume areas is based in part on the marginal performance of early membrane and bituminous overlay systems and partially on the apparent long-term durability of concrete overlays in Iowa. In addition, using scarification for decks with less-than-threshold chlorides at rebar level and spot removal on decks with a few spalls seemed reasonable in terms of cost. This procedure was thus selected for implementation in all traffic categories for deck condition groups 1 and 2.

For decks where deterioration has advanced to the severe stage, group 3, it is generally agreed that total removal to the top of the upper mat of rebars is the most effective procedure. Concrete overlays were again selected as the system most likely to provide the best long-term, cost-effective protection, as shown below.

Group 3

Priority 8
- 100 percent removal to reinforcing bars and minimum spot removal below bars, concrete overlay

Priority 9
- 100 percent removal to reinforcing bars with minimum spot removal below bars, concrete overlay

Priority 12
- 100 percent removal to reinforcing bars and minimum spot removal below bars, concrete overlay

Group 4

Priority 1
- Program new deck

Priority 2
- Program new deck

Priority 5
- Program new deck

For those bridges classified as critical, total deck removal and replacement is economically justified. When this situation arises, the replacement deck is given the same protection as a new deck. New decks are designed with protection systems intended to provide the longest maintenance-free life for the level of traffic and exposure anticipated. New decks in category A are constructed with epoxy-coated rebars in the top mat of reinforcing steel and a special concrete overlay—in effect, a dual system. Decks in category B receive either epoxy-coated rebars, a special concrete overlay, or a membrane and bituminous overlay. Finally, new bridges built in areas subject to low traffic volumes will have decks designed with a high-quality minimum water/cement ratio concrete and 76 mm (3 in) of clear cover over the top mat of rebars.

For cases where decks are carrying low traffic volumes but are still subject to heavy deicing chemical application, consideration should be given to placing a system corresponding to the next higher traffic volume category. Cases of this type arise in urbanized areas and intersections and ramps.

IMPLEMENTATION

Early in 1976 implementation of the new policy (see Table 2) began with its being incorporated into bridge repair and rehabilitation plan preparation. During that year approximately 100 bridges were either built or repaired. Considerable attention and effort were focused on rehabilitating bridges assigned priorities one and two. By 1977, bridges assigned priorities three and four were protected in accordance with provisions of the new policy. As deficiencies or omissions in the policy were identified during the first year of implementation, revisions were necessary and were made early in 1977. No major problems developed, and all changes were minor in nature.

One of the major advantages of this policy is that it delegates repair effort to decks where the need is greatest (priorities one, two, and four). Another feature of the approach is that it provides a fairly accurate picture of the distribution of decks (and surface area) by condition and traffic use. Reviewing the distribution gives considerable insight into where present and future repair efforts will need to be focused. The number of decks and their surface areas involved are categorically defined. A basis for predicting future funding needs is also now established.

Other significant benefits provided by the policy are found in the rationale of protecting good bridge decks now instead of repairing them later (priorities three and four). Specific advantages and several disadvantages associated with this aspect of the policy are listed below.

Advantages

1. Structures can be protected with today's dollars at a much lower cost than that required to repair them after deterioration begins.

2. Duration of lane closures can be minimized by limiting concrete removal before protection. Normal closures take half the time it would take to repair and overlay.

3. Effectiveness of this procedure is superior to any repair or rehabilitation short of removing the entire deck.

4. The problem deterioration is being controlled to the highest degree possible by attacking the affected group of structures from two directions, the top (newer decks) and the bottom (critical decks).

Disadvantages

1. The public uproar caused when motorists see workers apparently repairing "new" decks is significant (an obvious and glaring example of make-work).

2. Current funding of bridge repairs is often inadequate to cover the costs of repairing critically deficient bridges, let alone trying to protect the newer ones.

3. A program of testing and evaluation for identifying which bridges should be protected is a prerequisite to initiating this policy.

SUMMARY

Since implementation, nearly 250 bridge decks have been built, protected, or rehabilitated in accordance with the provisions of the original policy. By using a system that allocates a certain portion of the annual construction budget to protecting in-service structures in good condition, in addition to rehabilitating critically deteriorated decks, we are in effect burning the candle from both ends. It is overly optimistic to expect complete success with such an approach. What is assured, however, is that premature deterioration of structures that can be saved will be prevented. This in itself will serve to compress the deteriorating decks into a manageable group.

Integral to the success of this policy is the annual reassessment of deck conditions based on a reliable inspection program and an inventory rating system. Protection system selection should be largely based on anticipated level of service and use of chemical deicers. Repair or rehabilitation procedures should be based on the present physical condition or should be expected to fully extend the remaining service life.

Every effort should be made to integrate the bridge deck repair and protection policy with any existing bridge replacement program. It has been noted, however, that by and large most of the decks requiring repair of damage due to spalling seldom belong in a replacement program. Successful implementation hinges on providing some flexibility where anticipated or unusual exceptions occur.

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