Field Evaluation of Highway Safety Hardware Maintenance Guidelines

BENJAMIN H. COTTRELL, JR.

The objective of this study was to use field tests to evaluate a procedure developed for the Federal Highway Administration for determining the frequencies at which highway safety hardware needs to be inspected and repaired. The selection of the frequencies that were determined was based on the accident history of the safety hardware and the level of service to be provided, which has its basis in the probability of completing the inspection and repair before a subsequent accident. It is concluded that the procedure is a useful method for determining highway safety hardware maintenance guidelines. Some problems are noted, and suggestions are made to resolve them.

In Virginia during 1984 there were 3,511 fixed-object accidents (1,726 on Interstate roads and 1,785 on primary roads) in which vehicles struck highway safety hardware, such as guardrails, sign and signal supports, and impact attenuators (*1*). These figures represent 22.5 percent and 7.4 percent, respectively, of all accidents that occurred on these types of roads. On Interstate roads, 26 (1.5 percent) of the fixed-object accidents involving highway safety hardware resulted in fatalities, 754 (43.7 percent) in injuries, and 946 (54.5 percent) in property damage. On the primary roads, 32 (1.8 percent) of the fixed-object accidents involving highway safety hardware resulted in fatalities, 802 (44.9 percent) in injuries, and 951 (53.3 percent) in property damage.

If highway safety hardware items are struck and damaged by vehicles, they can no longer fully perform their intended function, which is to protect motorists from identified hazards. Therefore an adequate level of maintenance is required to preserve the functional integrity of the safety hardware (*2*). This can be achieved by inspecting and repairing the hardware at intervals that are frequent enough to maximize its safety benefits, subject to the available resources.

The sequence of events in the damage and repair of safety hardware is shown in Figure 1. It is desirable for the restoration time (t_r) to be less than the time between accidents (t_a) for maximum safety.

A METHOD FOR DETERMINING INSPECTION AND REPAIR FREQUENCIES

The Federal Highway Administration (FHWA) has developed a method for determining the frequencies at which safety hardware should be inspected and repaired (*2*). The frequencies for the inspection and repair of hardware items are determined on the basis of the accident history of the items and the level of service to be provided, which is defined as the desired probability of completing the inspection and repair before a subsequent accident. This definition of level of service is fairly new and consequently has limited acceptance to date. The Poisson frequency distribution is used to determine inspection and repair intervals statistically.

Examples of the method may be made by using Table 1. If the average annual accident frequency is 2.0 and the probability of no accidents before completing a repair equals 0.95, then the repair must be completed in 9.4 days. For a lower confidence level of 0.90, the period for completion is 19.2 days.

The method is flexible in that it can be applied at different organizational levels for different types of hardware and for different classes of roads. Its versatility has been demonstrated by its usage for planning and managing the inspection and repair of safety hardware and other types of equipment, for preparing budgets, and for allocating funds. This method has much potential, but it had not been field tested.

OBJECTIVE

The objective of this research was to use fields tests to evaluate the method developed for the FHWA. The method was tested on five sites at which one or more of the following types of safety hardware had been installed: roadway barriers, bridge rails, impact attenuators, breakaway sign supports, and breakaway luminaire supports.

IDENTIFICATION OF HIGH-HAZARD SITES

Site Selection Criteria and Approach

The identification and selection of sites took into consideration the following factors: the highest accident frequencies involving safety hardware, a broad range of average daily traffic (ADT) volumes with a minimum of 15,000 vehicles or more, no planned construction or maintenance activities that would affect the site during the monitoring period, and the willingness of maintenance personnel to participate.

Description of Field Sites

A description of the five sites is provided in Table 2. This description includes location, length, ADT, mean number of accidents involving highway safety hardware per year for 1981–1983, roadway description, and an inventory of highway safety hardware.

Virginia Department of Highways and Transportation, Transportation Research Council, Box 3817 University Station, Charlottesville, Va. 22903.

Legend

E_i = event i
E_0 = safety hardware installation
E_1 = accident involving safety hardware
E_2 = detection of damaged safety hardware
E_3 = repair work is begun
E_4 = repair work is completed
E_5 = subsequent accident involving safety hardware

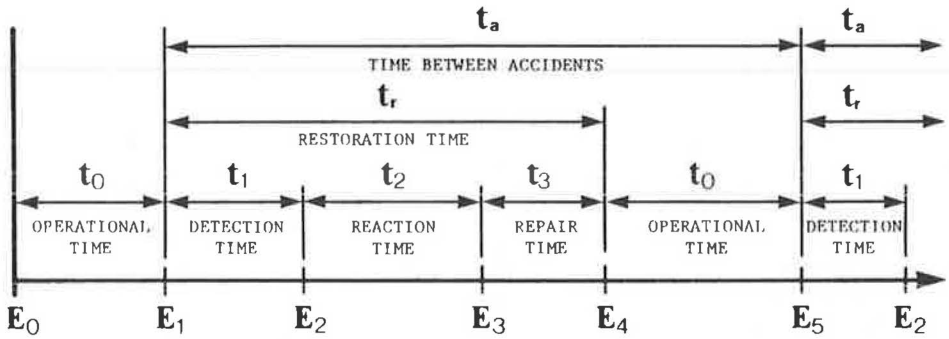

FIGURE 1 Sequence of events in damage and repair of safety hardware [source: *A Method for Determining Frequencies for Inspection and Repair of Highway Safety Hardware* (*2*)].

DATA COLLECTION PROCEDURE

The objective of the field test was to collect data on highway safety hardware inspection and repair activities at the five sites for 1 year so that the highway safety hardware maintenance guidelines could be evaluated. A monthly inspection and repair report and a damage and repair report were completed by the maintenance foreman responsible for inspection and repair at each site. The following information was collected on the forms:

- The frequency of inspection and repair activities;
- The number of times that the highway safety hardware was damaged by vehicle impact;
- The maintenance crew time in person-hours to maintain the safety hardware;
- The cost of materials and parts used to maintain the highway safety hardware;
- How the maintenance supervisor found out about the damage to highway safety hardware, the cause of the damage, and knowledge of previous damage;
- When the damage was scheduled for repair and when the repair work began and was completed.

ANALYSIS

The analysis of the data is divided into the following sections: inspection and repair activities, inspection schedule adherence, damage reporting, damage and repair report summary, and second accidents. The highway safety hardware inspection and repair activities at the field sites are discussed below for each site.

Inspection

A summary of the inspection and repair reporting activities is presented in Table 3. The two study sites on I-395 and the Route 50 site were divided by highway safety hardware and traffic signs because these roads are maintained by different area headquarters. The reporting of damaged highway safety hardware on Interstate 395 and Route 50 depends very heavily on the police because the inspector only reported severely damaged guardrails. On the basis of a two-sided *t*-test for significant difference between the actual and scheduled inspection intervals, there was no significant difference between the two intervals with a level of confidence of 0.05 (*3*).

Repair Activities

Traffic signs and impact attenuators (except on Route 50) are repaired immediately by departmental forces, but guardrail damages are repaired on contract. Ground-mounted traffic signs are repaired during inspection, and overhead signs are repaired by the district traffic staff.

Guardrail repair contracts are negotiated for each district. The basic contract provisions are as follows (*4*):

> This work shall consist of replacing and installing guardrail and median barrier in reasonably close conformity with the existing lines and grades or as directed by the engineer. Minimum repair call will be 200 linear feet per city or county and repair operations shall begin within five (5) working days after notice is received. The contractor shall advise the engineer at least 24 hours prior to commencement of work. The contractor shall not begin work at any location until the location and extent of work has been verified and approved by the engineer or his representative.

If the department is not able to perform emergency guardrail repairs, such as on Route 150 and Interstate 64, the following provision is added (*4*):

> The contractor will be expected to make an emergency response within twenty four (24) hours for locations where emergency repairs of guardrail end sections and exposed guardrail sections are necessary.

TABLE 1 MAXIMUM INSPECTION OR RESTORATION TIME IN DAYS AS A FUNCTION OF AVERAGE ANNUAL ACCIDENTS AND POISSON PROBABILITIES

$\overline{A}$ Average Annual Accidents	P(0) = PROBABILITY OF NO ACCIDENTS								$\overline{A}$ Average Annual Accidents
	0.800	0.850	0.900	0.925	0.950	0.975	0.990	0.995	
0.2	407.2	296.6	192.3	142.3	93.6	46.2	18.3	9.1	0.2
0.4	203.6	148.3	96.1	71.1	46.8	23.1	9.2	4.6	0.4
0.6	135.7	98.9	64.1	47.4	31.2	15.4	6.1	3.0	0.6
0.8	101.8	74.1	48.1	35.6	23.4	11.6	4.6	2.3	0.8
1.0	81.4	59.3	38.5	28.5	18.7	9.2	3.7	1.8	1.0
1.2	67.9	49.4	32.0	23.7	15.6	7.7	3.1	1.5	1.2
1.4	58.2	42.4	27.5	20.3	13.4	6.6	2.6	1.3	1.4
1.6	50.9	37.1	24.0	17.8	11.7	5.8	2.3	1.1	1.6
1.8	45.2	33.0	21.4	15.8	10.4	5.1	2.0	1.0	1.8
2.0	**40.7**	**29.7**	**19.2**	**14.2**	**9.4**	4.6	1.8	0.9	2.0
2.2	37.0	27.0	17.5	12.9	8.5	4.2	1.7	0.8	2.2
2.4	33.9	24.7	16.0	11.9	7.8	3.9	1.5	0.8	2.4
2.6	31.3	22.8	14.8	10.9	7.2	3.6	1.4	0.7	2.6
2.8	29.1	21.2	13.7	10.2	6.7	3.3	1.3	0.7	2.8
3.0	27.1	19.8	12.8	9.5	6.2	3.1	1.2	0.6	3.0
3.2	25.5	18.5	12.0	8.9	5.9	2.9	1.1	0.6	3.2
3.4	24.0	17.4	11.3	8.4	5.5	2.7	1.1	0.5	3.4
3.6	22.6	16.5	10.7	7.9	5.2	2.6	1.0	0.5	3.6
3.8	21.4	15.6	10.1	7.5	4.9	2.4	1.0	0.5	3.8
4.0	20.4	14.8	9.6	7.1	4.7	2.3	0.9	0.5	4.0
4.2	19.4	14.1	9.2	6.8	4.5	2.2	0.9	0.4	4.2
4.4	18.5	13.5	8.7	6.5	4.3	2.1	0.8	0.4	4.4
4.6	17.7	12.9	8.4	6.2	4.1	2.0	0.8	0.4	4.6
4.8	17.0	12.4	8.0	5.9	3.9	1.9	0.8	0.4	4.8
5.0	16.3	11.9	7.7	5.7	3.7	1.8	0.7	0.4	5.0
5.2	15.7	11.4	7.4	5.5	3.6	1.8	0.7	0.4	5.2
5.4	15.1	11.0	7.1	5.3	3.5	1.7	0.7	0.3	5.4
5.6	14.5	10.6	6.9	5.1	3.3	1.7	0.7	0.3	5.6
5.8	14.0	10.2	6.6	4.9	3.2	1.6	0.6	0.3	5.8
6.0	13.6	9.9	6.4	4.7	3.1	1.5	0.6	0.3	6.0
6.2	13.1	9.6	6.2	4.6	3.0	1.5	0.6	0.3	6.2
6.4	12.7	9.3	6.0	4.4	2.9	1.4	0.6	0.3	6.4
6.6	12.3	9.0	5.8	4.3	2.8	1.4	0.6	0.3	6.6
6.8	12.0	8.7	5.7	4.2	2.8	1.4	0.5	0.3	6.8
7.0	11.6	8.5	5.5	4.1	2.7	1.3	0.5	0.3	7.0
7.2	11.3	8.2	5.3	4.0	2.6	1.3	0.5	0.3	7.2
7.4	11.0	8.0	5.2	3.8	2.5	1.2	0.5	0.2	7.4
7.6	10.7	7.8	5.1	3.7	2.5	1.2	0.5	0.2	7.6
7.8	10.4	7.6	4.9	3.6	2.4	1.2	0.5	0.2	7.8
8.0	10.2	7.4	4.8	3.6	2.3	1.2	0.5	0.2	8.0
8.2	9.9	7.2	4.7	3.5	2.3	1.1	0.4	0.2	8.2
8.4	9.7	7.1	4.6	3.4	2.2	1.1	0.4	0.2	8.4
8.6	9.5	6.9	4.5	3.3	2.2	1.1	0.4	0.2	8.6
8.8	9.3	6.7	4.4	3.2	2.1	1.1	0.4	0.2	8.8
9.0	9.0	6.6	4.3	3.2	2.1	1.0	0.4	0.2	9.0
9.2	8.9	6.4	4.2	3.1	2.0	1.0	0.4	0.2	9.2
9.4	8.7	6.3	4.1	3.0	2.0	1.0	0.4	0.2	9.4
9.6	8.5	6.2	4.0	3.0	2.0	1.0	0.4	0.2	9.6
9.8	8.3	6.1	3.9	2.9	1.9	0.9	0.4	0.2	9.8
10.0	8.1	5.9	3.8	2.8	1.9	0.9	0.4	0.2	10.0

$$t = -\frac{365 \ln P(0)}{\overline{A}}$$

TABLE 2 DESCRIPTION OF THE FIELD SITES

Site No.	Location	Length (mi)	1984 ADT	Highway Safety Hardware Accidents, 1981–1983 (mean no./yr)	Roadway Description	Guardrail (linear ft)	Bridge Rail (linear ft)	Concrete Barrier (linear ft)	No. of Impact Attenuators	No. of Ground-Mounted Signs Exposed to Traffic
1	I-395, Part 1: from I-95 to Arlington Co. line (Fairfax Co. and Alexandria)	5.30	121,020	62.3	6 lanes with 2 reversible HOV lanes in median	58,365	1,441		4	13
2	I-395, Part 2: Arlington Co.	4.38	135,105	52.3	6 lanes with 2 reversible HOV lanes in median	19,130	4,995	16,900	9	5
3	I-64 from Route 258 (Mercury Blvd.) to Route 167 (La Salle Ave.) Hampton	2.00	61,135	19.0	4 lanes divided by grass	17,420	400	3,690	2	16
4	Route 50, Arlington County	5.20	46,765	12.0	6 lanes divided by guardrail barrier, with a short 4-lane undivided section	7,320	713	4,013	1	101
5	Route 150 from Route 360 to Route 1	5.45	28,880	9.0	4 lanes divided	37,940	5,600	0	0	32

NOTE: The typical lane width is 12 ft for Route 50; lane width varies from 11 to 12 ft. With the exception of Route 50, all sites have paved shoulders. On the two sections of I-395, luminaire posts are located behind guardrail at a spacing of 160–200 ft. Highway safety hardware on ramps to and from the test sections were not inventoried.

TABLE 3 INSPECTION AND REPAIR ACTIVITIES

Site No.	Site Description	Inspection Intervals (days)	Repairer	Repair Frequency
1	I-395, hardware, Part 1	Impact attenuator: 15	Department	Immediately
		Guardrail: special[a]	Contract	Scheduled
	I-395, signs, Part 1	3	Department	Immediately
2	I-395, hardware, Part 2	Impact attenuator: 15	Department	Immediately
		Guardrail: special[a]	Contract	Scheduled
	I-395, signs, Part 2	3	Department	Immediately
3	I-64	5	Hardware: contract	Scheduled
			Signs: department	Immediately
4	Route 50, hardware	Special[a]	Contract	Guardrail: scheduled
				Impact attenuators: immediately
	Route 50, signs	3	Department	Immediately
5	Route 150	4	Hardware: contract	Scheduled
			Signs: department	Immediately

[a]Damage reporting is provided primarily by police, who make their reports in three ways: (a) dispatcher to dispatcher for emergencies (impact attenuator damage and severe guardrail damage), (b) road hazard report (sent immediately), and (c) accident report. A maintenance foreman notes badly damaged hardware during inspection drives.

TABLE 4 RANGE OF INSPECTION AND RESTORATION INTERVALS

Expected Number of Days Between Successive Hits							
		Selected Probability Levels					
Group No.	Hits per Year	0.7	0.8	0.9	0.95	0.975	0.99
1	14.0	9.3	5.8	2.7	1.3	0.7	0.3
2	4.4	29.6	18.5	8.7	4.3	2.1	0.8
3	3.0	43.4	27.1	12.8	6.2	3.1	1.2
4	2.0	65.1	40.7	19.2	9.4	4.6	1.8
5	1.0	130.2	81.4	38.5	18.7	9.2	3.7
6	5.0	26.0	16.3	7.7	3.7	1.8	0.7
Number of Second Hits							
Interstate							
Subgroup 6	1	1	1	0	0	0	0
Subgroup 3	1	1	1	0	0	0	0
Subgroup 4	3	2	2	2	2	1	1
Subgroup 5	0	0	0	0	0	0	0
Total	5	4	4	2	2	1	1
Primary							
Subgroup 2	6	3	2	1	0	0	0
Subgroup 3	1	0	0	0	0	0	0
Subgroup 4	4	0	0	0	0	0	0
Subgroup 5	0	0	0	0	0	0	0
Total	11	3	2	1	0	0	0

The minimum repair call of 200 linear feet is included to ensure that at least a full day's work on guardrail repair is requested. The objective is to maximize the productivity of the guardrail repair crew while minimizing the travel required between locations for 1 day.

FOLLOWING THE METHOD

Five steps are suggested for applying the method:

Step 1: Obtain the frequency data on traffic accidents involving highway safety hardware. The 1-year monitoring of inspection and repair activities provided these data in lieu of department traffic accident records or special studies. In fact, the monitoring may be considered a special study. The monitoring identifies reported and unreported accidents involving highway safety hardware. The basic locational unit is typically 0.1 mi.

Step 2: Rank accident locations in decreasing order of average annual safety hardware accidents.

Step 3: Sort the locations by road class and identify accident groups (by similar accident frequencies).

Steps 2 and 3 were performed together by using Lotus 1-2-3 microcomputer software functions. The locations were sorted by Interstate and primary route sections. Six groups were formed for the 49 interstate locations and for the 30 primary-route locations.

Step 4: Identify the ranges of inspection and restoration intervals for each group. The ranges of inspection and repair intervals are presented in Table 4. The procedure to develop the ranges is based on the equation for t in Table 1. The average and maximum numbers of hits of the group are displayed, as well as the average number of hits by road class. The second part of Table 4 shows the impact of the level of service on the

TABLE 5 EXISTING LEVEL OF SERVICE AND DESIRED LEVEL OF SERVICE

	Hits per Year	Existing Restoration Interval (days)	Existing Level of Service	Desired Restoration Interval (days)[a]	Desired Level of Service
I-395, hardware, Part 1	5	7 + 26 = 33	.64	16.3	.80
I-395, hardware, Part 2	3	7 + 33 = 40	.72	27.1	.80
I-395, signs	6	3	.95	3	.95
I-64	4	5 + 121 = 126	.25	20.4	.80
Route 50, signs	18	3	.86	3	.86
Route 50, hardware	2	3 + 33 = 36	.82	36	.82
Route 150	5	4 + 42 = 46	.53	27.1	.80

[a]From Table 1.

number of hits. A level of service of 0.975 is required to minimize the number of second accidents for Interstate subgroup 4. The one accident remaining is the result of two accidents having been reported on the same day.

Step 5: Select a level of service. Because the selection of a level of service requires a policy decision, the policy was based on existing practice and contract provisions. The inspection interval required was equal to the existing average inspection interval but was not greater than 7 days. The restoration period specified in the contract for guardrail maintenance was 5 working days; this was expanded to 7 calendar days. The long reaction times are the primary factor in the level of service, and they are contingent on the requirement that there be 200 linear feet of guardrail in need of repair before the repair crews are committed to the repair work. This requirement makes the restoration period unpredictable and widely variable from county to county. Moreover, in at least one county the contractor does not have the equipment and human resources to perform the work within contract provisions. The existing levels of service calculated for the field sites and the restoration levels required to achieve a minimum level of service of 0.8 are presented in Table 5. The minimum level of service was based on the assumption that it is a practical lower limit of level of confidence in statistics.

Four of the levels of service are below 0.8. To reduce the existing restoration intervals so that the intervals required for a 0.8 level of service are obtained, substantial time reductions are needed. Obviously, changes in the contract's provisions and their enforcement would be essential to reach the minimum desired level of service, along with a reduction in inspection intervals.

PROBLEMS WITH THE METHOD

Overestimate of Second Accidents

The number of second accidents expected was significantly greater than the actual number of second accidents. According to the maintenance supervisors at the study sections, second accidents seldom occur. It is quite common, however, for accidents to occur about 50 to 100 ft from the damaged safety hardware. This problem may be resolved by applying an adjustment factor to reduce the estimate of second accidents or by basing the expected number of second accidents on the actual experience of second accidents. The value of using an adjustment factor is questionable because it lacks a theoretical basis. This problem is eliminated if the overestimate is perceived as a margin of safety.

The number of second accidents expected on the basis of the procedure is approximately equal to the annual number of accidents. This explains why the procedure predicted the actual number of second accidents poorly. It is very important in the procedure to state that the worst conditions are addressed, so that the procedure will not be expected to predict actual second accidents.

Definition of a Location

The number of accidents at a location would be significantly reduced by using 0.01 mi (52.8 ft) as the basic unit of measurement, as is done in Virginia, rather than the recommended 0.1 mi (528 ft). This change would also allow better identification of the accidents that occur near the damaged safety hardware. The next step in defining the location more specifically is to consider the direction of travel of the vehicle and the side of the road on which the damaged safety hardware is located. These changes substantially reduced the number of hits per year for each site. Consequently, when the current inspection repair activities are applied to the revised number of accidents, the level of service substantially increases. The existing level of service in Table 5 is revised in Table 6 for a 0.01-mi basic unit, direction, and side of road. The level of service increases to greater than 0.7 for all sections, compared to three sections with levels of service below 0.7 for the 0.1-mi basic unit. Consequently, the method of defining the location significantly affects the results of the procedure. The more well defined the location, the more accurately the potential for a second accident is estimated. The need for improving the accuracy in identifying accident locations by the police who complete the accident reports has been recognized.

Immediate Versus Scheduled Repairs

In practice, the damage to the highway safety hardware is assessed and is either considered for immediate repair if there is a definite hazard or scheduled for later repair if the damage is minor or less of a hazard and the guardrail is functional. The procedure does not take this classification into consideration. Moreover, severely damaged highway safety hardware is sometimes reported immediately by police. Consequently, the safety hardware may be repaired before the next inspection. These activities reduce the potential for the occurrence of a second accident. It would be helpful if this issue were taken

TABLE 6 COMPARISON OF LEVEL OF SERVICE BY LOCATION UNIT

	Location Unit = 0.1 mi			Location Unit = 0.01 mi, by Direction and Side of Road	
	Hits per Year	Restoration Interval	Level of Service	Hits per Year	Level of Service
I-395, hardware, Part 1	5	7 + 26 = 33	.64	3	.76
I-395, hardware, Part 2	3	7 + 33= 40	.72	3	.72
I-395, signs	6	3	.95	2	.98
I-64	4	4 + 121 = 126	.25	1	.71
Route 50, signs	18	3	.86	8	.94
Route 50, hardware	2	3 + 33 = 36	.82	1	.91
Route 150	5	4 + 42 = 46	.53	1	.88

into consideration in the procedure. An immediate repair may assume a level of service of 0.995.

Need for Traffic Safety Evaluation

It would be helpful if the procedure emphasized the need for traffic safety evaluations at locations with high accident frequencies. Safety improvements may be substantially effective in reducing first accidents as well as second accidents. Although safety improvements are not in the scope of the study, the procedure is remiss in not mentioning the need.

CONCLUSION

The method described in *A Method for Determining Frequencies to Inspect and Repair Highway Safety Hardware* (2) appears to have a high potential for improving highway safety hardware maintenance practices. On the basis of the findings of this field evaluation, the method has been determined to be useful for highway safety hardware maintenance guidelines.

Most maintenance guidelines are determined subjectively. This method provides statistically based quantitative guidelines that allow incremental maintenance needs (inspection and restoration intervals) and benefits (reduced number of second accidents) to be realized. Moreover, because the method determines inspection and repair intervals for the worst conditions, a substantial margin of safety is built in.

ACKNOWLEDGMENTS

This research was financed through the Federal Highway Administration.

REFERENCES

1. *Summary of Accident Data: 1982.* Virginia Department of Highways and Transportation, Richmond, 1983.
2. *A Method for Determining Frequencies for Inspection and Repair of Highway Safety Hardware.* FHWA, U.S. Department of Transportation, Feb. 1983.
3. S. C. Choi. *Introductory Applied Statistics in Science.* Prentice-Hall, Englewood Cliffs, N.J., 1978.
4. *Special Provision for Replacement of Guardrail and Median Barrier.* Virginia Department of Highways and Transportation, Richmond, Feb. 28, 1986.

The opinions, findings, and conclusions expressed in this paper are those of the author and not necessarily those of the sponsoring agencies.

Publication of this paper sponsored by Committee on Maintenance and Operations Management.