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OPERATIONAL PARAMETERS IN ACOUSTIC SIGNATURE INSPECTION OF RAILROAD WHEELS

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16. Abstract

This report describes revenue-service tests of locomotive-mounted strobe lights used to make trains more conspicuous to motorists ar rail-highway crossings. The testing, conducted in cooperation with four railroads, had the objectives of assuring practicality compatibility with normal operations, validating previous cost estimates, and obtaining a measure of safety effectiveness. Prior research underlying the tests is reviewed briefly.

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PREFACE

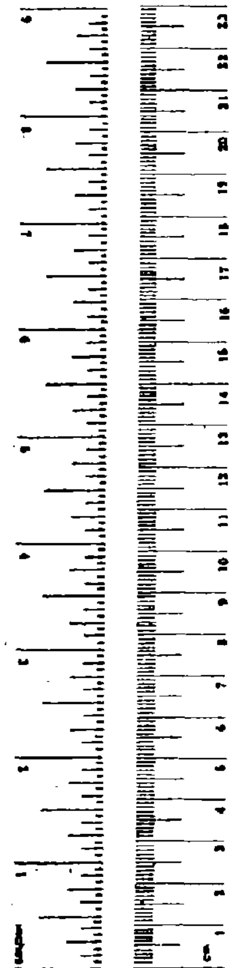
The research described in this report was performed as part of a program at the Transportation Systems Center to provide the technical basis for the improvement of grade crossing safety. The program is sponsored by the Federal Railroad Administration, Office of Research and Development. The program is part of a more general activity designed to promote greater safety in railroad freight and passenger service.

The work reported here has benefitted greatly from the extensive participation of numerous individuals associated with the railroads and equipment suppliers involved in these tests. Their cooperation and efforts are much appreciated. A. Newfell, T. McGrath, and T. Hayes of TSC have been major participants in the effort and have contributed greatly to it. Mr. Newfell has had primary responsibility for arranging and coordinating actual implementation of all equipment-related aspects of the tests. Mr. McGrath has played a principal role in gathering and analyzing data. Mr. Hayes' involvement was critical in dealing effectively with equipment aspects of one test.

METRIC CONVERSION FACTORS

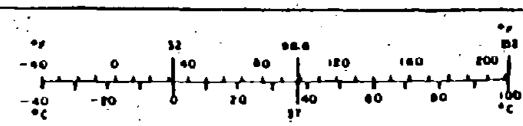
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

The Federal Railroad Administration (FRA) has sponsored numerous studies directed toward identifying the most effective and practical means of making trains more conspicuous to motorists near grade crossings. This previous research led to a recommendation that one effective approach would be installation on locomotives of clear (white) xenon strobe lights to be flashed in the vicinity of crossings. In order to obtain some confirmation of early research findings under realistic conditions, limited testing in revenue service operations was undertaken with the cooperation of four railroads. In these tests, the FRA, acting through the Transportation Systems Center, reimbursed the participating railroads for the purchase of 20 to 40 strobe lights per carrier; the railroads took responsibility for installation and maintenance of the lights and for collection of data regarding costs and accident experience of strobe-equipped locomotives and a pool of unequipped units exposed to similar service.

The specific details of each test were left to be determined by each railroad. As a result, the tests varied in both structure and time frame. One carrier had completed a full year of testing by March 1, 1978, while by January, 1980, one railroad had not yet formally begun taking data. Nevertheless, a substantial amount of information has been acquired regarding the use of strobe lights. The following points highlight the major results of the testing:

- In all tests the strobe-equipped locomotives experienced fewer accidents per locomotive mile. However, the measured difference varied substantially from one railroad to another. This fact, combined with the relatively small sample size, precludes using this test as a sole means of drawing any firm conclusions on a nationwide basis.
- On Santa Fe, the test involved train service for which accident rates were well below the national average. In this test, the strobe equipped locomotives had only slight-

ly fewer accidents than a control group when compared on an accident per locomotive mile basis; the control group locomotives had sequentially-flashing amber alerting lights.

- On Amtrak and on the Chessie System, the strobe lights were used on locomotive routes with accident rates which were near or above the national average. Under the limitations of these tests, the strobe equipped locomotives showed fewer accidents on an accident per locomotive mile basis than a similar control group without strobe lights. Although the difference in accident rates between the equipped and unequipped groups was greater than in the Santa Fe test, the sample was still too small to draw valid conclusions on a wider basis.

- The data available from each of the railroads involved very few accidents with either group. Accordingly, one accident more or less in either group would make a substantial difference in the number of accidents per locomotive mile.

- The apparent reliability of the strobe lights varied widely among railroads. From available information it is not possible to determine whether this is due to variations in basic equipment, operating conditions, or installation and maintenance practices.

- In testing which included over 1-1/2 million train miles, no adverse effects were reported from railroad crews, motorists, or other persons near railroad rights of way. No specific efforts were made to solicit reactions one way or the other.

- Based on the limited data available, the strobe lights tended to show maximum effectiveness at night and in areas of high grade crossing accident rates.

- Due to test limitations and substantial differences among the participating railroads, a quantitative estimate of costs or benefits is not possible without additional sources of data and further analysis.

The results of these tests indicate that there is a good possibility that increased locomotive conspicuity may contribute to a reduced number of grade crossing accidents under some conditions. In addition, it appears that there were no widespread adverse effects which resulted from the use of the strobe lights with the frequencies and intensities used in the tests. Any real variations in effectiveness among the railroads can mean that the benefits derived are dependent on the nature of the environment and the type of railroad operation. This precludes any simple extrapolation of the results of this testing to a nationwide basis without knowing the relationship of the routes covered in this study to the national rail network.

The strobe light reliability experienced was not as good as expected. One test experienced maintenance requirements and reliability problems which were much more severe than had been estimated in previous research efforts. The maintenance required and the ability to keep the lights operating varied substantially among railroads. One railroad experienced severe problems. The degree to which the reliability and maintenance requirements of a particular piece of hardware are "satisfactory" is a judgment which must be made by the railroad involved. However, it was evident during the test that hardware intended for universal application in a railroad environment must be more rugged than the equipment used in the tests.

1. INTRODUCTION

In recent years, the Federal Railroad Administration (FRA) has undertaken a continuing study of means of making trains at railroad-highway grade crossings more conspicuous to motorists. This work, conducted in large part by the Transportation Systems Center (TSC) with the cooperation of several railroads and equipment suppliers, has led to the conclusion that the conspicuity of trains as seen by motor vehicle operators approaching crossings can be significantly enhanced by visual alerting devices on the locomotive. The installation of clear ("white") xenon strobes can accomplish this objective. Extension of application to the railroad situation is not a radical innovation since the highly-conspicuous and attention-getting short-duration flash of such beacons has previously been adopted in a variety of transportation safety applications, particularly on highway vehicles.

Subsequent testing has now been conducted in cooperation with revenue-service railroads in order to obtain detailed information concerning operational considerations, practicality, costs, and safety effectiveness. This report describes the tests and their results.

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2. BACKGROUND

In 1970-71, FRA sponsored a study of the visibility of trains approaching grade crossings (Reference 1). A major part of this effort consisted of observations of available beacons of several types mounted on a captive locomotive operating at a rail-highway crossing. Xenon strobe lamps were tried in addition to a variety of lights using incandescent lamps: revolvong bulbs, alternately flashing lights in a single housing, single lamps with a rotating reflector, and a single bulb with a revolving lens system. These tests indicated that among the roof-mounted units tested, a pair of emergency-vehicle xenon strobe lights had particular advantages in making the locomotive more conspicuous to motorists during daylight conditions. It was noted in this study that the very narrow beamwidth of conventional locomotive headlights restrict their use in the alerting function except for vehicles near the crossing. An additional recommendation from this study was that the pair of roof-mounted clear ("white") xenon strobe lights should be flashed alternately.

During 1971-72, FRA made additional studies at the National Bureau of Standards. In this research several innovative devices were conceived and constructed. In 1973, the Transportation Systems Center, acting for FRA, arranged testing of these devices along with strobes at the Naval Ammunition Depot in Crane, Indiana. (A captive railroad operation was located at this facility, which also had a capability for human-factors research.) Observers in those tests found the standard xenon strobes to be the most conspicuous among the lights tried.

In 1974 a thorough literature review was undertaken at TSC, accompanied by further limited observational tests (Reference 2). This study confirmed the previous findings. Key conclusions were that any adverse personal effects would be minimized within reasonable intensity and flash rate limits, and that the lights were highly conspicuous and apparently well-suited to the crossing-safety application. Central to the high conspicuity of strobes is a very short flash duration, which is well under the basic response time of the human eye (0.1 second). The result is an alerting effectiveness which has led to use of strobes in a wide range of safety applications, including aircraft, emergency and highway-maintenance motor vehicles, and tall fixed structures such as TV towers and smokestacks.

Further TSC studies focused on the determination of the most appropriate type of lamp. The basic short-flash specification could be met with either a xenon flash tube or a rotating incandescent lamp of sufficiently narrow beamwidth. (A stationary flashing incandescent bulb cannot achieve the short duration and high repetition rate required.) The xenon lamp was found to be preferable. An electromechanical beacon involving physical motion is inherently more complex, more prone to mechanical failure, and generally more expensive. Comments from railroad personnel at the time of the earlier study indicated concern over the initial expense and maintenance requirements of such devices. On the other hand, the xenon lamp has no filament to break, and instead of moving parts it relies on solid state circuits, which have proven to be rugged in some applications. Xenon flash tubes age by gradually darkening; they do not generally fail abruptly and unexpectedly as do lamps with filaments. The advantages in effectiveness, durability, and user acceptability of strobes were supported by the experience of the Maine Highway Department, which used strobes not only on the roof of snowplow trucks, but also mounted on the tips of sidewing plow blades.

The overall conclusion drawn from integration of these research efforts was that xenon flash lamps mounted on the roof of locomotives had promise of being a simple, practical and potentially effective visual warning system.

As a result of these findings strobes were installed on a small number of locomotives used in mainline service by several railroads during 1973 and 1974. In each case they were used for at least several months. Basic durability and crew response were noted. Results led to some modifications such as masking of the top and rear portions of the lights, incorporating two-level "day-night" intensity control, etc.

The FRA research described above was summarized in a technical report entitled "Guidelines for Enhancement of Visual Conspicuity of Trains at Grade Crossings", Report No. FRA-ORD/75-71, published by TSC in May, 1975 (Reference 3). It concluded that installation of an acceptable strobe light system would make locomotives much more conspicuous at crossings. The report also presented guideline performance specifications for such beacons in terms of location, color, intensity, beam patterns, and flash rate.

3. OBJECTIVES

Although these past studies investigated the practicality and potential effectiveness of strobes, additional information was needed. First, it was necessary to confirm under circumstances of large-scale railroad operations over an extended period that no special problems would be encountered and that no adverse effects on crews or the public would be associated with these devices. Second, it was important to refine and strengthen earlier estimates of installation and maintenance costs and of equipment reliability for realistic revenue-service conditions. Finally, the observed apparent increase in train conspicuity, particularly at night, was basically a subjective finding which did not definitively establish safety benefits. It was judged desirable to seek specific information regarding safety performance.

For these reasons testing was planned with the three-fold objective of determining (1) suitability and reliability of the concept and available equipment in normal railroad operations and practices; (2) validity of prior estimates of installation and operating costs; and (3) a measure of safety effectiveness.

4. APPROACH

As a consequence of the considerations described above, discussions were initiated with several railroads concerning implementation of a revenue-service test intended to be of sufficient scope and structure to provide data which would effectively address the operational use of these devices. Preliminary TSC analyses showed that testing on a very large scale over an extended period of time would be necessary to be sure of demonstrating safety effectiveness in a statistically rigorous and convincing manner, since grade crossing collisions are a relatively infrequent occurrence for any particular locomotive. (Typically 2 to 3 years elapse between accidents.) On the other hand, the desirability of testing under diverse conditions characterized by variety in terrain and operations, coupled with practical and economic constraints, dictated the choice of running experiements of modest size on several railroads. Of necessity, the primary selection criterion was willingness to participate, with secondary consideration for locomotive crossing exposure, accident rates, data collection procedures, and general experience in conducting research of this nature. Ultimately, arrangements were made with four railroads: Chessie System, Amtrak, Santa Fe, and Boston & Maine. Due to differences among the several tests, data from them cannot be combined or directly compared. In each case the test was to consist of:

1. Selection of approximately 20 to 40 locomotives to be equipped with strobe lights and an equal number to serve as a control group;
2. Installation of the lights by the railroads;
3. Collection of detailed data concerning operations (miles of service), installation costs, maintenance costs, and accident experience.

The Government provided funds for purchase of the lights; all other expenses, including labor of installation and data collection, have been borne by the railroads involved. Actual structuring and performance of the tests, including equipment maintenance and data collection, has been completely their responsibility and under their control. In some cases FRA and TSC have acted to facilitate resolution of maintenance problems.

5. RAILROAD TESTS

5.1 CONSTRAINTS & LIMITATIONS

Movement from basic agreement to actual initiation of the tests proved to be a lengthy and difficult process. This was primarily due to the challenge of accomodating the installation and data-gathering activities within a framework of normal railroad operations. In view of the completely voluntary and cooperative nature of the tests and the substantial contribution in time and effort made by all of the railroads, only limited special requests were imposed on them. The Government had no direct role in maintenance of equipment, utilization of strobe-equipped locomotives, and collection and validation of data.

5.2 EQUIPMENT

The lights in use are relatively simple devices. Construction of them requires only expertise in the design and fabrication of strobe-light circuits for moderate intensities, coupled with appreciation for the demanding circumstances of the railroad application. Two manufacturers have for some years been the successful bidders in procurements of small quantities of available strobes meeting TSC performance guidelines. Their lights are variations of designs originally developed for motor-vehicle applications. No specific development has been carried out; minor modifications appropriate to different cases were included by the suppliers within the normal hardware price. Within a particular model designation, the user specifies details such as the desired intensity, supply voltage, and flash rate. Special control switches and use of multiple intensity levels are also considered to be minor options. A summary of equipment installed as part of the tests is presented in Table 5-1.

The lights thus supplied have shown continual small changes in the power supply design, construction, and components as experience has been gained with the railroad application, but the model numbers

TABLE 5-1. TEST CONFIGURATION

Railroad	No. of Loco's	Intensity (Day/Night)	Intensity Control	Means of Activation
Santa Fe(I)	18	800-1200/ 200-400	Manual	Continuous
Santa Fe(II)	25	800-1200/ 200-400	Headlight Switch	Bell/Whistle
Chessie	41	1600/ 200-400	Headlight Switch	Bell/Whistle
Amtrak	13	800-1200/ 200-400	Headlight Switch	Bell/Whistle
B&M	21	800-1200/ 200-400	Manual	Bell/Whistle

have remained the same. Lights used in the tests were manufactured in 1976-77.

5.3 CURRENT STATUS

As of January 1, 1980, the Chessie test has been completed and the data analyzed. Substantial data was also collected and supplied to TSC by the Santa Fe and was subsequently analyzed. The Amtrak test, which required extensive coordination with operating railroads and posed special equipment installation problems, began only in July, 1979. While the accident rate for strobe-equipped locomotives has been lower than for unequipped units in each case, the results obtained in all three cases are based on very limited samples - three to five accidents for the strobe-equipped locomotives in each test - so that considerable caution is warranted in inferring conclusions from the results. The random occurrence of one or two more collisions would have markedly altered the percentage differences between the strobe-equipped and control groups.

A number of difficulties have so far prevented successful implementation of the test on the Boston & Maine. Details of the performance of each test follow.

5.4 THE CHESSIE SYSTEM TEST

The Chessie System, which had already been investigating this subject independently for several years, was able to purchase the lights and begin installation quite rapidly. The test was conducted on the Western Maryland Railway, a component of the Chessie. The region involved is basically that between Baltimore and Hagerstown, Maryland. It is predominantly mountainous and rural, and is characterized by low train speeds. There are 217 public crossings and 209 private crossings on the 167 route miles involved in the test. At the time of this test 128 of the public crossings had only passive warnings. In 1976, the year prior to the test, the Western Maryland as a whole experienced 22 accidents per million train miles.[1] Strobe lights automatically activated by use of the bell or whistle were installed on 41 locomotives (GP-9's, GP-35's, and GP-40's) which normally operate on four subdivisions of the railroad. High (day), low (night), or intermediate intensity was automatically selected corresponding to the position of the headlight intensity switch. Data were collected as to total locomotive mileage and accident experience for each group and provided to TSC on a monthly basis for the fourteen-month period from March 1, 1977 until April 30, 1978.

In the course of the test, 304,054 train miles were accumulated with strobe-equipped locomotives in the lead position, compared to 137,631 train-miles for a smaller fleet of unequipped units which conducted equivalent operations. The equipped group experienced 3 rail-highway crossing accidents, all in daylight, for a rate of 9.9 accidents per million train miles. The unequipped control group suffered 5 accidents, 3 of which were during daylight, for a rate of 36.3 accidents per million train miles. Thus, for this test the accident rate for the strobe-equipped locomotives was only 27 percent of that for the unequipped group. However, due to possible variations in service conditions, the small sample size, and the possibility that the test results could be affected by random chance, this value cannot be taken as a direct measure of strobe light effectiveness.

Chessie reported costs in 1977 as follows: Materials, $394 per unit; Labor, 49 hours at $10/hour; Total, $885 per locomotive. This was based on 36 installations. They also purchased 5 new locomotives equipped with strobes at an additional cost of $1040, and ordered 50 more for which the price differential was $1400. Sufficient data to arrive at a reliable estimate of life cycle costs is not available. With regard to maintenance, Chessie indicated that a few fuses required replacement in early units. No units were reported to have failed.[2]

[1] Letter from Chessie System to TSC, June 13, 1978.
[2] Letter from Chessie System to TSC, November 14, 1977.

Subsequently Chessie continued to utilize and evaluate strobes independently. The accident history for all strobe-equipped locomotives was compared to the rest of the system fleet over an extended period. It is assumed that all locomotive units were used interchangeably without regard for the presence of strobes. Chessie System analyzed 1314 freight train crossing accidents and the overall night/day effectiveness of strobes on 95 locomotives involved in some of these accidents. They reported finding "a range of effectiveness in preventing accidents roughly comparable to that of the Amtrak locomotive strobes."[1]

5.5 THE SANTA FE TEST

Strobe lights were installed on 43 SD-45 locomotives operating primarily on ATSF main lines between Chicago, Los Angeles, and Houston. A large portion of the route is open country, and operating speeds are often above 50 mph. The Santa Fe system accident rate in 1977 was on 13.3 accidents per million train miles, about half the overall U.S. average, and very close to that of other railroads with a similar route structure. The equipped group was sub-divided into two parts. Eighteen locomotives had strobe lights which ran continuously, while the remaining 25 were activated automatically with use of the bell or whistle. Those running continuously allow the engineer to choose high or low (day or night) intensity; on the other units the strobe setting matches the headlight switch position. A control fleet of 43 locomotives which are exposed to comparable service was also designated. However, these locomotives are equipped with the standard flashing amber incandescent beacons normally used by the Santa Fe. The intensity of these lights is not known, and they do not have the very short flash duration which is characteristic of strobes. Locomotive usage has been recorded by means of the ATSF management information system. The entire network is divided into 44 segments, and all locomotives in the test are tracked in terms of each passage (in lead position) over each segment. Monthly accident and mileage data were provided to TSC.

[1]Letter from Chessie to TSC, February 20, 1980.

Significant hardware-related problems were encountered in this test. These included both equipment failures and vandalism.[1] Data collection began in July, 1977, before all installations had been completed. In October of that year, TSC staff members spent two weeks at the ATSF shops in Barstow, California, checking the status of lights on each test locomotive and carrying out repairs or replacement as necessary. A total of 17 units required some attention, mostly replacement. Problems included physical destruction or unauthorized removal of the power supplies, malfunctions of control switches or lights, unorthodox installation or repair practices, and mis-matching between power supplies and lights. Difficulties included procurement of proper replacement parts from the strobe parts suppliers.

Failures of lights to operate continued to be reported after these repairs. An independent consulting firm under contract to FRA examined various facets of the question. Measurements of the surge characteristics of the locomotive electrical systems revealed the possibility of failure due to severe but infrequent surges in power. By the late summer of 1978, a substantial number of additional failures had been reported. Subsequently, 33 non-operative strobes were removed and examined by the consulting firm to detect common modes of failure. Of the 17 returned power supplies made by one manufacturer, 9 worked under isolated laboratory conditions, and 2 more flashed but gave the same intensity on both "high" and "low" settings. Two had vibration-related defects, two suffered from short-circuited transistors, and two had major defects. For the 16 supplies made by the other manufacturer, 5 worked in the lab tests with 4 having deficient electrical contacts and connectors. Three had defects apparently resulting from inadequate resistance to vibration. Two supplies flashed only one of the two lamps connected to them. Of the other units, one had two shorted diodes and one had a bad capacitor contact. Other tests showed that the capacitors used were potentially vulnerable

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[1] Letter from Santa Fe to Association of American Railroads with copy to TSC, October 28, 1977.

to overheating in one model or chemical leakage in the other.[1]

Thus, of the 33 "failed" units, 14 functioned when tested independently in the lab. Intermittent problems in the total locomotive system were apparently responsible for the in-service problems. No common failure mode was identified with inoperative units. The examination did show the desirability of increased product improvements such as sturdier construction, high-quality connectors, and critical component modifications to achieve higher temperature ratings.

The problems encountered restricted the number of locomotives operating at any given time with strobes. During the test, Santa Fe had difficulty in producing records which contained all necessary details as to periods when the lights on a given locomotive were working, or, if inoperative, the precise time when they had failed.[2] Data collection was ended in July, 1978. Consequently, for each strobe equipped locomotive, Santa Fe reported data only covering time periods during which they were confident that the strobes had been operating. Between July 1, 1977 and June 20, 1978, the locomotives equipped with strobes accumulated 1,094,940 train miles and were involved in 5 accidents, for a rate of 4.6 collisions per million train miles. The control group, with incandescent beacons, traveled 2,623,740 miles in lead position, experiencing 13 crossing accidents, for a rate of 4.9 collisions per million train miles. Although this is eight percent higher than that for strobe-equipped units, valid statistical inferences cannot be made with a high level of confidence.

In 1977, the Santa Fe reported costs as follows: Materials, \$300 to \$325; Labor, \$49.[3] They have experienced major maintenance problems and high costs associated with the difficulties just described.

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1 Report to FRA by Arthur D. Little, Inc., April, 1979.
2 Letter from Santa Fe to TSC, September 18, 1978.
3 Letter from Santa Fe to TSC, October 28, 1977.

5.6 THE BOSTON & MAINE TEST

The Boston & Maine selected as the test group 21 locomotives (7 GP-38's, 3 GP-18's, and 11 GP-9's) used for general linehaul operations between Mechanicville, NY; Boston, MA; Concord, NH; and Portland, ME. The 1529-mile B&M system has 1254 public grade crossing, 60 percent of which have train-activated warnings. In 1977, the B&M experienced 30.8 accidents per million train miles. Strobe installations were made during the spring and summer of 1978, and the test was to begin in October 2 of that year. Lights were to be activated manually by the engineers in advance of all grade crossings. After several months B&M decided in favor of automatic operation and the test was suspended so that the strobes could be connected for operation with activation of the bell or whistle.

However, due to a heavy workload on B&M maintenance forces, as well as a serious locomotive shortage, the railroad has still been unable to carry out this change. In the interim, the lights have seldom been used. As a result, no meaningful data have been obtained, although locomotive mileage and accident experience has been reported. No cost figures have been reported.

5.7 THE AMTRAK TEST

Strobes have been standard on new Amtrak equipment for several years. For some locomotive types clearance limitations have required use of relatively small lights of reduced intensity. However, a number of difficulties impeded attempting to utilize this situation to evaluate strobes. Except for the Northeast Corridor, which has few crossings, Amtrak neither owns the track nor operates the equipment which comprise its system. Thus, when the FRA/TSC tests were being initiated it was not found to be practical to gather system-wide data concerning locomotive operations, accident experience, or strobe light usage. Further, in most cases it was not feasible to define an equivalent group of locomotives, with similar operating circumstances, to which the strobe-equipped locomotives could be compared. Instead, it was necessary to structure a controlled experiment involving only one specific portion of Amtrak's operation. Full-size strobes were added to 13 SDP-40 locomotives. These are used on trains numbered 81, 82, 87, 88, 91, 97, and 98 which run between Washington, DC, and Florida. On many parts of the route speeds are in the range of 50 to 70 mph; in Florida the timetable average is approximately 40 mph. A control group of six similar but non-equipped locomotives also used in this service was designated. In addition, F-40PH and P-30CH locomotives which have factory-installed low-profile strobes are also used on these runs, primarily in the summer. Data have also been collected and reported for this group. A variety of test implementation delays were encountered, partially due to changes in Amtrak routes and operations and to the requirement for acceptability to the operating railroads.

The test was initiated July 1, 1979. In accordance with past Amtrak policy, the strobes are operated automatically when the bell or whistle is activated, and the intensity settings correspond to the low and high headlight switch positions. Amtrak has reported that as of December 31, 1979, unequipped locomotives have been in lead position for 166,568 miles and experienced 4 accidents, for a baseline rate of 30.0 accidents per million miles. (This particular route was chosen in part because of its high accident rate.) Units equipped with full-size strobes have had 2 accidents in this service in 304,404 miles.[1] This yields a rate of 6.6 per million miles, only 22 percent (again on a raw basis) of that for the unequipped locomotives.

The locomotives with the low-profile lights are little used during the winter on these runs, but have accumulated 79,184 miles and in that distance suffered 2 crossing collisions. They thus have a rate of 25.3 accidents per million miles. On closer examination, it is found that both accidents for the 13 locomotives with full-size strobes occurred at night and both group accidents concerned a stopped car, and none for the small-strobe group.

[1] Data supplied by Amtrak in monthly letters.

6. TEST RESULTS

6.1 OPERATIONAL CONSIDERATIONS

A major purpose of these tests was identification of any possible problems in train operation which might be associated with strobe lights in this application. In particular, concern has been expressed in the past that strobe lights, or their reflections, would have an annoying or adverse effect upon train crews and others. This has not been a serious problem during widespread use of very similar units on a variety of highway vehicles, and no significant deleterious effects were reported in these tests. The effective intensities of the locomotive strobes are normally less than 2000 candela (cd, formerly called candlepower) in the daytime and 200 to 400 cd at night. These values can be compared to those for locomotive headlights (200,000 cd), automobile headlights (up to 75,000 cd per pair), and motor vehicle brake lights (200 cd maximum). The flash repetition rates used are well below the values at which disorienting effects can occur. Even with these facts known, however, it is reassuring to have obtained operational evidence that no problems occurred in using these devices. In over 1-1/2 million miles of testing, corresponding to an estimated 35,000 hours of exposure involving hundreds of train crews, no railroad has reported to TSC complaints of crew irritation of difficulties, nor have there been any problems reported by motorists or others. Many locomotive engineers did report the subjective impression that motorist behavior is characterized by more caution at crossings than had previously been observed.

Assurance that crew disturbance will not be a factor is strengthened by the use of multiple-intensity strobes, so that high brightness levels can be used in the daytime with much lower values at night, and by interconnection with the bell and whistle, thereby limiting the crew's exposure.

6.2 COST CONSIDERATIONS

In the past, the units have typically cost $300 to $500 with additional expense for bell/whistle interconnection. TSC staff members have carried out many installations, and scheduling costs, and find 4 to 8 labor hours to be a reasonable allotment once efficient procedures are established. Of course, shop practices and labor agreements differ among railroads. Consequently, figures reported by railroads in the test vary considerably; installation labor ranges from $50 to $1000 per locomotive. This is consistent with expenses incurred in previous work in this area; in 1974, the out of pocket costs by another railroad were reported to TSC as $188 for each of 2 installations. Locomotive manufacturers have reportedly quoted prices to railroads for $1400 to $2000 for strobes as original equipment. No substantive quantitative data has been received relating to maintenance costs. Reliability of the basic system is discussed in the following section.

6.3 RELIABILITY CONSIDERATIONS

The tests do not present a clear picture regarding operational reliability of the strobe units. Chessie has indicated minimal equipment reliability problems during the test period and in operating a fleet of over 90 equipped locomotives for several years. Amtrak, with 184 units, has experienced a repair rate somewhat higher than expected for this type of equipment but has tolerated it. The Santa Fe has experienced considerable difficulties in keeping strobes operating properly. The situation on the Boston & Maine does not permit any conclusions to be drawn. Difficulties with reliability on the Santa Fe appear to have been primarily due to the lack of sufficient ruggedness in the system to survive the conditions of the test.

Detailed engineering examination of the hardware by TSC and an FRA consulting firm revealed no fundamental defects in circuit design. It has been suggested that for the 1976-77 equipment used in the test, the lifetime (resistance to harsh operating conditions) could be significantly increased by design improvements such as minor circuit changes, use of electrical components with higher temperature ratings, more rugged packaging, and higher-quality connectors. (Good tolerance of high temperatures is particularly important if the strobes are to be operated continuously, rather than only at crossings.)

6.4 SAFETY EFFECTIVENESS

For each group of locomotives, accident rates were calculated on the basis of accidents per train mile within the reporting constraints. For the FRA-sponsored portion of Chessie testing, the strobe-equipped locomotives had an accident rate 73 percent lower than the control group; on the Santa Fe the equipped locomotives experienced an 8 percent lower accident rate; and on Amtrak the rate was 78 percent less for the full-size strobes, and 16 percent less for the smaller low=profile lights. Table 6-1 summarizes these results and compares them to the system average on each railroad. With the exception of the unequipped Santa Fe group, each group of locomotives had five or fewer accidents. With a sample of this size a single additional accident in any of the groups would result in a relatively large change in accident rate and possibly a very large change in the apparent effectiveness. This precludes making any generalizations concerning the results of the tests, and severely limits the confidence which could be placed in any statistical analysis.

6.5 DIFFERENCES AMONG THE TESTS

Each test - Chessie, Amtrak, and Santa Fe - represents a particular combination of types of train, locomotive color, speeds, terrain, region of the country, maintenance practices, etc. All of these can conceivably have a significant impact upon safety effectiveness or observed reliability. Thus, in interpreting the results and in judging the degree to which they can be generalized (if any), one must be aware of these differences. No small group of tests of limited extent can accurately simulate the potential results of universal application. In order to provide

TABLE 6-1. TEST RESULTS AND RELATED SYSTEM DATA

Railroad	Locomotives	Train-Miles	Accidents	Acc/Million Train-Miles
Chessie	Equipped	304,054	3	9.87
Chessie	Unequipped	137,631	5	36.33
Chessie	System Average (1977 W. Md. Ry.)	1,247,117	21	16.84
Chessie	System Average (1976 W. Md. Ry.)	1,354,955	31	22.88
Santa Fe	All Equipped	1,094,940	5	4.57
Santa Fe	Unequipped	2,623,740	13	4.95
Santa Fe	System Average (1977)	44,519,259	591	13.28
Amtrak	Equipped (Large)	304,404	2	6.57
Amtrak	Equipped (Small)	79,184	2	25.26
Amtrak	Unequipped	166,568	5	30.02
Amtrak	System Average (Excluding NEC) (1977)	28,149,563	247	8.77

perspective and to facilitate judgments as to the relevance of these tests to general conclusions, the differences among them are now summarized. Table 6-2 presents approximate characterizations of the Chessie, Amtrak, and Santa Fe test circumstances in terms of some of the factors potentially relevant to safety. Given the relatively limited understanding which currently exists concerning causation of grade crossing accidents, the relative importance of any of these factors becomes judgmental. Each case may embody differences in the exposed motorist population, and in the experience, expectations, and behavior of drivers.

A special factor affecting Amtrak is the likelihood that motorist experience and behavior patterns will be based primarily on experience with more-numerous and typically lower-speed freight trains.

With respect to reliability, several differences may contribute to the varying results of the tests.

(1) Approximately half of the strobes in the Santa Fe test were operated continuously, rather than with sounding of the bell or whistle. This is a much more demanding mode than is intermittent use, increasing running time substantially and typically leading to considerably higher circuit temperatures. (Chessie and Amtrak used the lights only at grade crossings.)

(2) The Santa Fe operating conditions - predominantly in the southwestern U.S. - contribute to higher operating temperatures, which are especially demanding of solid state circuitry. Of the 33 units removed and examined, 15 had been reported to have failed during the month of August, which suggests ambient heat as a factor.

(3) Procedures for coordination and management of the tests, including maintenance practices, were necessarily different among the three cases.

Chessie was able to exercise special individual control and attention to a greater degree than would probably be the normal

TABLE 6-2. CHARACTERISTICS OF TEST ROUTES

	Chessie	Amtrak	Santa Fe
Terrain	Hilly, curves	Level, Straight	Open, Straight
Population Density	Low to Moderate	Moderate to High	Low
Rail Traffic Density	Low to Moderate	Moderate	High
Train Speeds	Low	Moderate to High	High

practice in actual operations on many other railroads. Amtrak has unique characteristics requiring work through operating railroads with a wide distribution of maintenance facilities. For the Santa Fe, the test was coordinated and directed from headquarters in Chicago, and most of the actual implementation occurred in Barstow, California.

7. SUMMARY AND CONCLUSIONS

The tests reported here provide much useful information bearing on the relevance of strobes to crossing safety, but are not sufficient in scope or precision to support definite conclusions concerning safety effectiveness or practicality. The apparent contrast between effectiveness results for Chessie and Amtrak, on the one hand, compared to those for Santa Fe on the other, may or may not be real. The results should be viewed in the context of the major differences which exist among the three cases and the high degree of uncertainty inherent in the limited data collected. The Santa Fe locomotives, unlike other groups in the tests, normally experience a very low baseline accident rate, presumably arising in part from the totally different terrain and operational patterns involved. Amtrak, Chessie, and Santa Fe had all previously adopted paint schemes intended to make locomotives highly conspicuous at grade crossings. The open terrain in the West may pose a substantially smaller obstacle to the unambiguous sighting of a train than is the case in the East. The ATSF Control group also presumably benefitted significantly from the use of incandescent beacons, particularly at night. It is noteworthy that the Chessie data, showing no nighttime accidents for strobe-equipped locomotives, suggests that this is the condition under which strobes have their major effect. In other words, for the Santa Fe case those accident situations for which conspicuity is most relevant may occur less often, and a significant degree of enhancement -- perhaps even equivalent to that for strobes -- may already have been achieved with other forms of visual alerting: existing beacons. It is noteworthy that the two tests which showed comparatively favorable results -- Chessie and Amtrak -- represented quite different operating speeds, terrain, rolling stock, and baseline accident rates. It can be seen in Table 6-1 that the Western Maryland Railroad experienced a significant drop (still subject to question as to statistical validity) in the system-wide accident rate from 1976 (22.0 per million train miles) to 1977 (16.8). Conceivably, the strobe light test may be a factor in this.

For instance, if the accident rate for the unequipped locomotives had applied to the train miles run during 1977 by equipped locomotives in the test, there would have been 5 more accidents, for a system average of 20.8 per million train miles. (The difference between the system averages and the rate for unequipped units could mean that the test was run on the more hazardous portion of the system, than was originally intended.)

In conclusion, although complaints were not actively solicited, minimal adverse effects have been found in 1-1/2 million train miles of testing. Although the costs for each railroad varied widely, they are consistent with prior cost estimates. It appears that greater hardware durability and ruggedness are needed to allow operations in usual railroad modes and in order to be compatible with routine maintenance procedures. Such design improvements would extend the life of the units and increase the acceptability for universal use.

The tests taken together, while not quantitatively precise regarding the possible magnitude of accident reduction, lend support to the finding that visual alerting systems in general, and, more specifically, locomotive-mounted strobe lights, have the potential to provide safety benefits under a range of circumstances. However, the data do not permit estimation of the magnitude of the benefits to be expected if strobes or other alerting lights were used universally. Generalization of that nature would require both more precise measurement of effectiveness in specific cases, and careful analysis of the degree to which those cases were representative of the national rail network. In the case of the test in which no difference could be definitively established between strobes and other alerting beacons, it is not possible to judge the degree to which both types of light may have contributed to the observed accident rates.

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