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Freight Car Reflectorization

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16. Abstract

This report examines five factors affecting the safety impact and costs associated with application of retroreflective materials to railroad freight cars to reduce the number of rail-highway crossing accidents in which motorists run into the side of a train in darkness. Measurements and observations on reflectorized rolling stock in Canada and a small-scale U.S. test are described and estimates are developed for the effect of dirt accumulation in reducing reflector brightness as a function of time. Photometric analysis of the circumstances associated with a crossing encounter in darkness is used to establish appropriate reflector characteristics for this application. Railroad industry data forms the basis of a detailed examination of reflectorization costs, including material, installation labor, and maintenance. Crossing accident/incident data for the period 1975 - 1980 is analyzed to determine the number of accidents and casualties which could potentially be affected by reflectorization. Finally, several remedial actions to improve crossing safety in darkness are discussed: locomotive reflectorization, locomotive alerting lights, and crossing illumination.

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PREFACE

The study described in this report was performed by the Transportation Systems Center (TSC) under sponsorship of the Federal Railroad Administration, Office of Safety, U.S. Department of Transportation.

As part of the study, measurements of the durability of reflectors on Canadian railroad freight cars were conducted jointly by TSC and the Canadian Transport Commission (CTC) in Montreal, PQ, Canada. Mr. Ash Hibbard initiated and arranged for Canadian participation in the tests. Mr. Peter F. Strachen, Mr. John Chemelnitsky, and Mr. Ron Eaton participated in the conduct of the tests as representatives of CTC. TSC participants in the tests included Dr. James L. Poage as team leader, Mr. Anthony Newfell, and Mr. Melvin Yaffee.

METRIC CONVERSION FACTORS

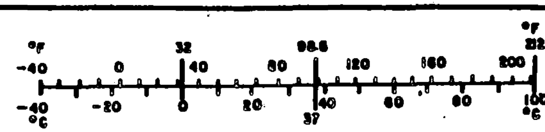
Approximate Conversions to Metric Measures

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

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

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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SUMMARY

In 1980, accidents in which motor vehicles ran into the side of a train during periods of dawn, dusk, and dark accounted for 13.5 percent of all fatalities and 20.9 percent of all injuries at rail-highway crossings. A possible remedial action is the application of reflectors to the sides of freight cars. Reflectors are widely used to improve visibility of highway signs and trucks and in other highway applications and have been considered for use on railroad rolling stock to improve rail-highway crossing safety. However, the safety benefits are difficult to quantify and the cost of installing reflective material on the nation's 1.71 million freight cars had not been determined. In addition, major questions concerning reflector lifetime and degradation of reflector performance in the railroad environment were not evaluated in the past.

In this study an analysis of the rail-highway crossing accident and incident reports in the Railroad Accident/Incident Reporting System (RAIRS) data base, from 1975 to 1980, was performed. Requirements for reflector size, shape, pattern, and color were estimated. Quantitative data was collected in the field to describe the decline in reflector performance under railroad operating conditions.

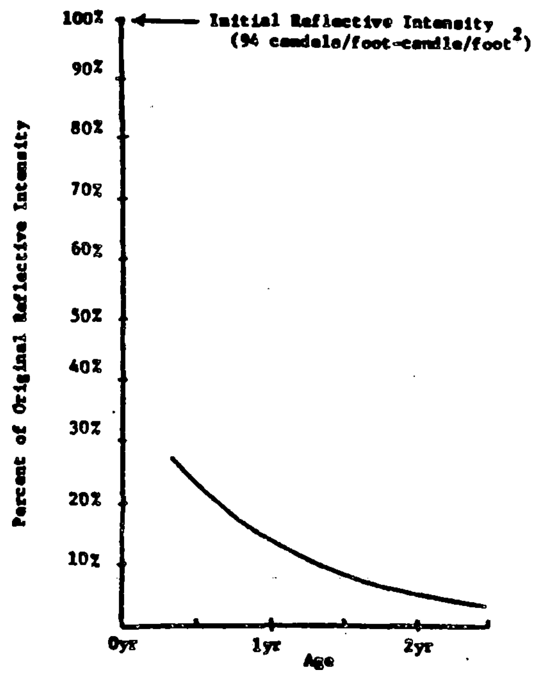
The examination of the RAIRS data base identified that a large number of accidents in which a motor vehicle struck the side of the train could not be avoided by freight car reflectorization. These accidents include: (1) accidents occurring at crossings with active warning devices, (2) accidents in

which the locomotive is struck rather than a freight car, (3) accidents in which the train is not a freight train, and (4) accidents under inclement weather conditions which would prevent reflectors from being of value.

After reductions were made for these four factors, an annual average of 340 accidents, 165 injuries, and 29 fatalities remained for further analysis of the potential of freight car reflectorization.

Several additional factors further reduce the number of accidents potentially affected by reflectorization. These include effects of driver fatigue, intoxication, or inattention; situations in which the vehicle is already too close to stop when the first freight car enters the roadway; adverse geometry of the rail-highway intersection; poor headlight aim and condition; excessive degradation of some of the reflectors; and incomplete reflectorization of the freight car fleet. No attempt has been made in this report to quantify these factors since reliable data is not extant, but it should be noted that the potential benefits fo freight car reflectorization would be significantly reduced by consideration of the unquantified factors.

Tests conducted on the Canadian railroad system, where reflectorization has been underway since 1959, and on the Boston and Maine Railroad, provided quantitative data that shows a sharp decline in reflector reflective quality with time as illustrated in the figure below.



DECLINE IN REFLECTOR REFLECTIVITY WITH TIME
UNDER RAILROAD OPERATING CONDITIONS

The average reflective intensity measurements made on 208 Canadian freight cars indicated that a reflector's reflective intensity is reduced to 23 percent of its initial value after six months in service. After one and two years in service, the reflective intensity is reduced to 14 and 5 percent, respectively, of the initial value. In the night observation of reflectors, 61 percent of the cars were observed to have reflectors which were barely visible or not visible at all. Data from the Boston and Maine reflectorization tests indicated that high intensity reflectors deteriorate in the railroad environment at a rate similar to that observed of engineer grade reflectors in use in Canada.

The rapid accumulation of dirt necessitates frequent cleaning of reflectors, which represents more than half of the total cost of freight car reflectorization. In order to assure cleaning and replacement at the required intervals, it is assumed that freight cars will be stencilled. The minimum-cost strategy was determined using photometric analysis of reflector requirements and the Canadian deterioration measurements. It would require expenditure of $67.4 million per year for the entire U.S. fleet, based on the specifications shown below. The optimal area and washing interval are very sensitive to maintenance cost assumptions.

Reflector Specifications

Reflector Area	2.75 sq. ft.
Reflector Size	12" by 33"
Reflector Material	High intensity sheeting
Number of Reflectors per Car	4 each side, 45' - 60' cars
Reflector Location	Sill
Reflector Color	Silver/White
Minimum Brightness	45 cd/ft.-candle
Washing Interval	20 months
Replacement Interval	10 years

1.0 INTRODUCTION

Rail-highway crossing accidents in which motor vehicles run into the side of a train during dawn, dusk, and dark accounted for 13.5 percent of all fatalities and 20.9 percent of all injuries at crossings during 1980. A possible response to this problem is to mount retroreflective material on freight cars which, when illuminated by vehicle headlights, may give an indication of the presence of an obstacle in the road. The safety benefits which would result from this course of action are difficult to quantify, and the cost of installing and maintaining reflective material on the nation's 1.71 million freight cars would be substantial. In addition, major questions concerning reflector lifetime and the deterioration of performance in the railroad environment have not been resolved.

This study seeks to resolve many of these uncertainties by making use of the six-year Railroad Accident/Incident Reporting System (RAIRS) data base, by examining results of the Canadian reflectorization program, and by conducting a limited test of new reflective materials on the Boston and Maine Railroad.

Chapter 2 describes the Canadian reflectorization program and the results of measurements of the reflectivity of materials installed on Canadian freight cars. Nighttime observations of reflectorized rolling stock at crossings are also reported.

Chapter 3 describes a limited test conducted with the cooperation of the Boston and Maine Railroad in which high intensity reflective material was installed on 33 sand and gravel cars.

The necessary characteristics of freight car reflectors are developed and discussed in Chapter 4, utilizing standard photometric analysis.

The installation and maintenance costs of reflectorization are described in Chapter 5, based on information from the railroad industry, Canada and suppliers of reflective material.

Chapter 6 describes the results of an analysis of the RAIRS data base and yields a determination of the number of accidents in which a motor vehicle struck the side of a freight car during dawn, dusk, and dark in non-inclement weather conditions at crossings with passive warning devices. Factors which would reduce the effectiveness of freight car reflectors are discussed.

Alternative to freight car reflectorization such as illumination, active warning devices, locomotive reflectorization, and locomotive alerting lights are discussed in Chapter 7.

2. CANADIAN FREIGHT CAR REFLECTORIZATION PROGRAM

Tests were conducted to determine the durability of reflective markings mounted on Canadian freight cars. The Canadian Transport Commission (CTC) has required reflective markings to be installed on the sides of Canadian freight cars since May, 1959 (Figure 2-1). The tests were conducted by the Transportation Systems Center (TSC) and the CTC near Montreal, Quebec, during the week of October 19, 1981. The reflective intensity of reflectors on 208 freight cars was measured. Observations of the visibility of reflectors on trains at night were made at three crossings.

The tests suggest a rapid decline in reflector reflective intensity to an average of 23 percent of initial value after six months, to 14 percent after one year, and to 5 percent after two years (Figure 2-2). The night observation tests also indicate a rapid decline in reflector reflectivity. On at least 61 percent of the Canadian cars observed, reflector reflectivity was rated poor.

2.1 THE CANADIAN REFLECTORIZATION PROGRAM

During the late 1950's, the Canadian Board of Transport Commissioners (BTC) studied rail-highway crossing data which indicated that a large percentage of accidents where motor vehicles strike a train occurred at night. The BTC concluded that the reflectorization of freight cars might reduce this type of accident. The BTC recommended to the Canadian Federal Cabinet that the Railway Act be amended to permit grants to be made from the Railway Grade Crossing Fund towards the cost of the installation of reflectors. The amount

Figure 2-1 Reflective Markings on a Canadian National Railway Box Car

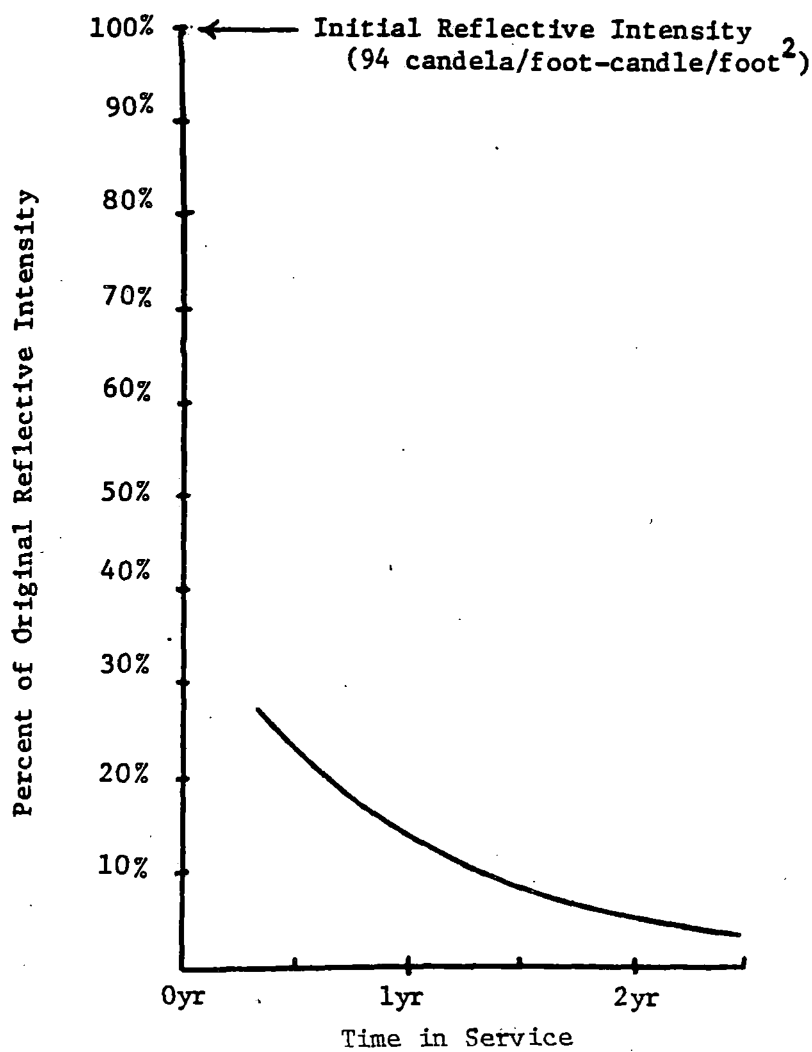


Figure 2-2 Decline of Reflector Reflective Intensity With Time (Canadian Freight Car Measurements)

of the grants was established at 80 percent of the cost which was the same percent granted for other improvements to public crossings. These recommendations were incorporated into Bill C-52 which subsequently became law.

The BTC held a Public Hearing on March 19, 1959, published its findings in a Judgement dated May 1, 1959, and issued Order No. 97788 which required each railway under its jurisdiction to apply reflective markings to the sides of all new box cars delivered to it during the period from May 1, 1959 to December 31, 1960. In addition, each railway was to apply a similar number of reflectors to old box cars. The shape, size, and material to be used would be subject to BTC approval upon application of the railway concerned.

The BTC, and later the CTC, have issued several Orders since 1959 which have continued the program and which have required 4 reflectors to be applied to each side of cars of 52 feet or less, and 6 reflectors to each side of cars of over 52 feet in length. All reflectors measured in the tests are Scotchlite Brand Reflective Sheeting manufactured by Minnesota, Mining and Manufacturing Company of Canada. The reflectors are engineer grade silver 4-inch discs used on Canadian National Railway cars (Figure 2-3) and 4-inch squares on Canadian Pacific Railway cars (Figure 2-4).

At the end of 1980, 153,783 cars of the Canadian fleet had been equipped. The CTC authorized 80 percent of the cost to be paid from the Railway Grade Crossing Fund not to exceed $8.00 per car. The total federal contribution through the end of 1980 was $660,436.60.

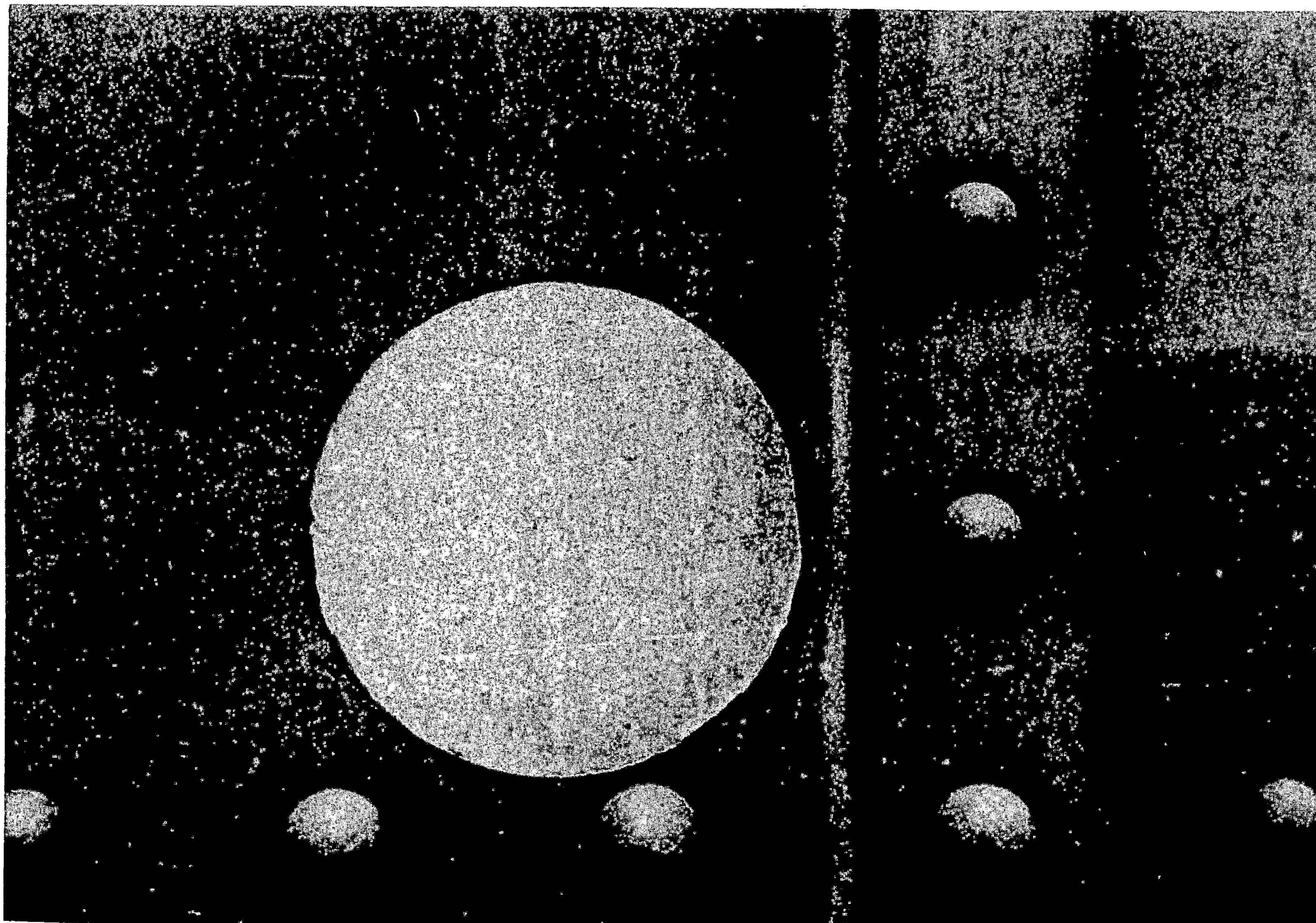


Figure 2-3 Engineer Grade Reflective 4-Inch Silver Disc Used by the Canadian National Railway

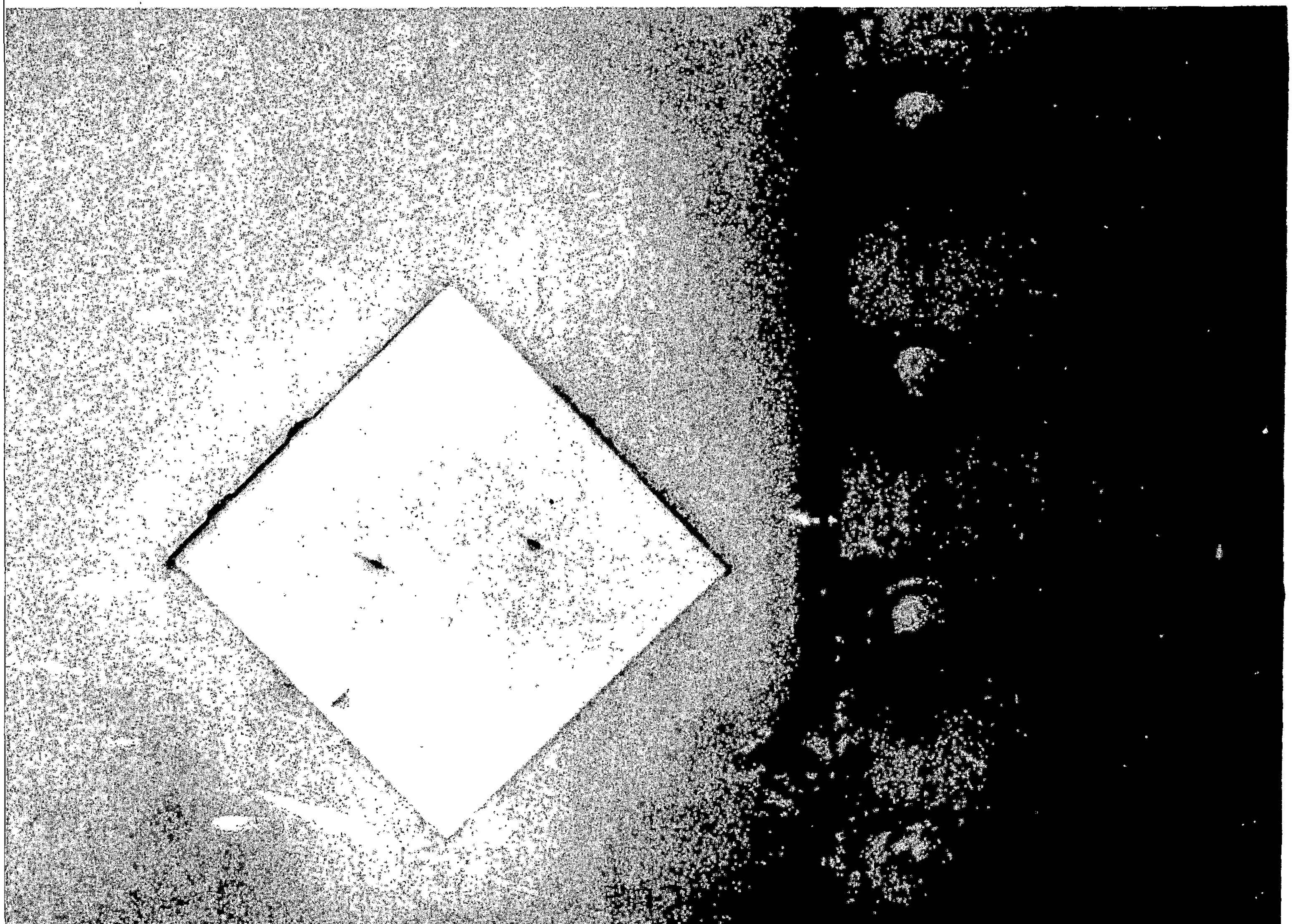


Figure 2-4 Engineer Grade Reflective 4-Inch Silver Square Used by the Canadian Pacific Railway

The CTC has, from time to time, attempted to evaluate the effectiveness of the program. The railways are required to report all accidents which occur at public crossings at grade, and the Railway Transport Committee (RTC) investigates those involving casualties. However, statistics are not maintained differentiating between those accidents in which the vehicle ran into the side of a train and those in which the train struck the vehicle.

2.2 MEASUREMENT OF REFLECTIVE INTENSITY

The reflective intensities of freight car mounted reflectors were measured in the Canadian National Railway (CN) and Canadian Pacific Railway (CP) yards near Montreal during the week of October 19, 1981. The measurements were made using a Gamma Scientific Inc. Model 910F retroreflectometer. This instrument consists of: (1) an optical head with an optical system, detector, and light source, and (2) a control unit with readout display, operating controls, and rechargeable battery power supply. The instrument is operated by pressing the optical head against the surface to be measured, which activates the device's light source. The instrument is calibrated against a secondary standard and can make measurements during either day or night. Units of reflective intensity are measured in candela/foot-candle/foot^2.

Reflectivity measurements were made on reflectors mounted on 208 freight cars using the Gamma Scientific retroreflectometer (Figure 2-5). Reflectivity of reflectors was measured on both sides of 120 cars and on one side of 88 cars. Samples of new reflective sheeting of the type installed on Canadian freight cars were measured and showed an average reflective intensity of 94 candela/foot-candle/foot^2. The data collection procedures and resulting data are given in Appendix A.

Figure 2-5 Measurement of Reflective Intensity of Reflectors on Canadian Freight Cars

For the data analysis, cabooses and work cars were excluded because the type of service of work cars and the frequent washing of cabooses provide a different environment for the reflectors than that experienced by typical freight cars. The average of reflective intensity measurements for each of the remaining 195 cars is shown in Figure 2-6. As can be seen from this figure, the reflective intensity of the reflectors decreases rapidly within a year after installation. The reflective intensity continues to decrease into the second year when it becomes a relatively constant value of less than 10 candela/foot-candle/foot^2.

To examine the rate of decline in reflectivity, an exponential curve, using natural logrithms, was fitted to the measurements obtained for reflectors which had been in service for less than 2-1/2 years. The resulting curve, Figure 2-7, shows a rapid decline in reflective intensity for reflectors in railroad revenue service with an average reflective intensity that is 23 percent of the original value after six months, 14 percent after one year, and 5 percent after two years. Figure 2-7 also shows the 95 percent confidence interval for the curve. The linear regression correlation coefficient (r) calculated for the natural logarithm of the data was 0.674.

An alternate method was used to analyze the reflectivity measurement data. The data were averaged over three-month periods and plotted at six-month intervals (Figure 2-8). As shown, these averages are similar to the exponential regression curve (Figure 2-7) and imply the same rapid decline in reflective intensity with time.

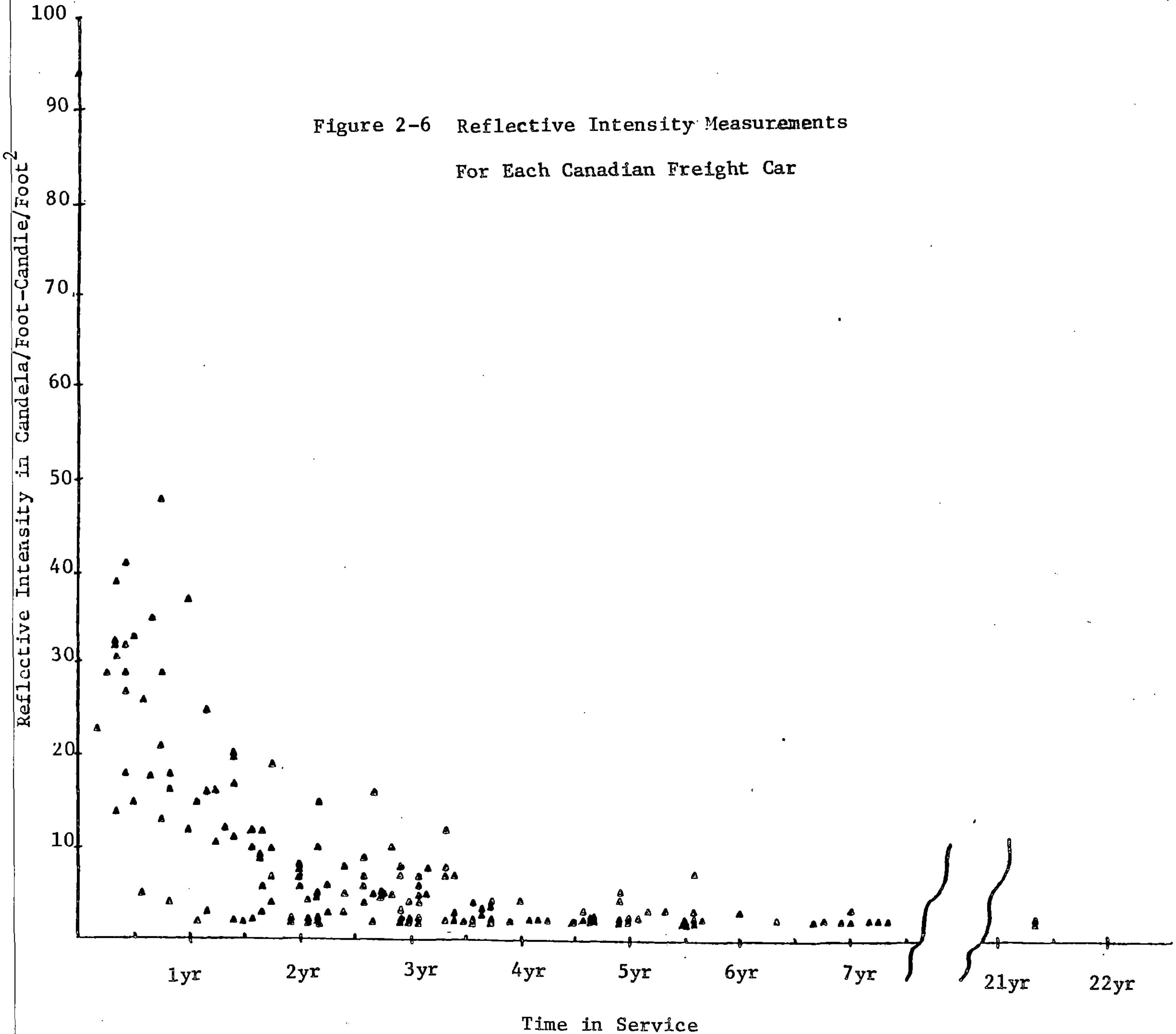


Figure 2-6 Reflective Intensity Measurements For Each Canadian Freight Car

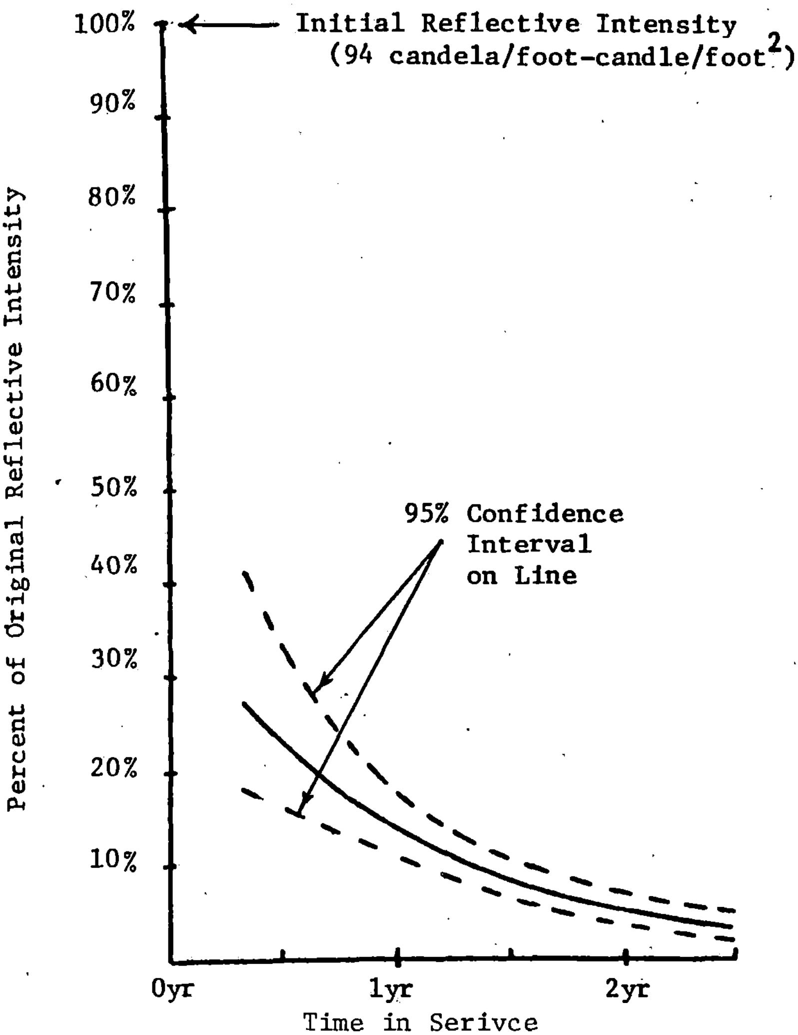


Figure 2-7 Exponential Curve Fitted to Data for Reflector Reflective Intensity Measured on Canadian Freight Cars

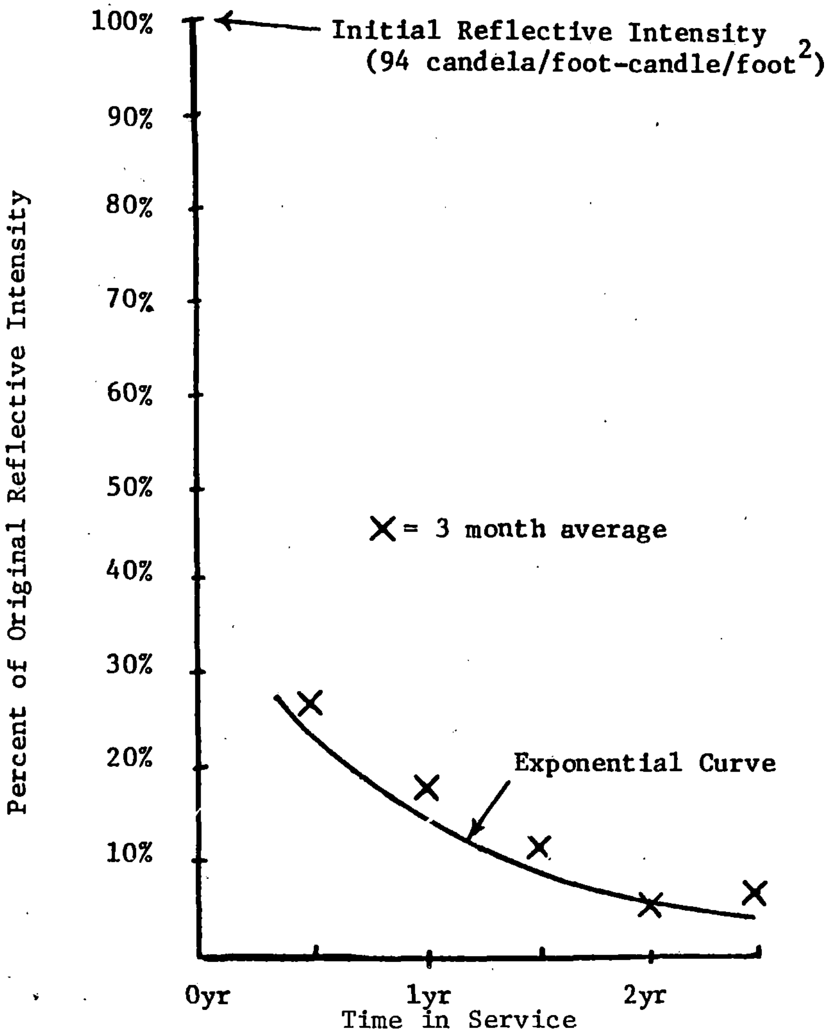


Figure 2-8 Three Month Averages of Reflector Reflective Intensity Measured on Canadian Freight Cars

After the initial reflectivity measurements, reflectors on 24 freight cars were washed and the measurements were repeated. The average reflectivity of the reflectors on each of the 24 cars before and after washing are given in Table 2-1. The average reflectivity for cars with reflectors having the same time in service was calculated and expressed as a percentage of the reflective intensity of new reflectors (Table 2-2).

The data suggest that the reflective intensity of the reflector does increase after washing as expected. The data also indicate that the reflectors deteriorate in the railroad environment at a rate such that, after three years of service, washing of the reflectors restores less than 25% of the original reflectivity.

2.3 NIGHT OBSERVATION OF REFLECTORS

To observe freight car reflector conspicuity under actual railroad operating conditions at rail-highway crossings, night observation tests of reflectors mounted on freight cars were made at three rail-highway crossings in the vicinity of Montreal, Province of Quebec, Canada during the week of October 19, 1981. The test crossings had minimal automobile traffic, an intersection angle of road and track of 90 degrees, and relatively flat approach grades.

TABLE 2-1. MEASUREMENTS OF REFLECTIVE INTENSITY BEFORE AND AFTER WASHING REFLECTORS* (Candela/foot-candle/foot^2)

Date Car Built or Rebuilt	Reflectivity Before Washing	Reflectivity After Washing
1981	37	67
	38	67
	39	64
	34	63
	45	72
	41	73
	28	82
	35	67
	51	85
1980	18	55
	8	28
	3	14
	43	66
1979	11	20
	9	16
	9	27
1978	6	16
	4	5
	8	15
1977	5	17
1975	2	2
1972	3	5
1969	3	10
	3	5

*The measurements listed are averages of the reflective intensity of all reflectors on each freight car.

TABLE 2-2. REFLECTIVE INTENSITY OF REFLECTORS BEFORE AND AFTER WASHING AS A PERCENT OF ORIGINAL REFLECTIVE INTENSITY

Year Built or Rebuilt	Number of Cars Washed by Year	Percent of Original Reflective Intensity Before Washing*	Percent of Original Reflective Intensity After Washing*
1981	9	41.2%	76.6%
1980	4	19.1%	42.7%
1979	3	10.3%	22.3%
1978	3	6.4%	22.3%
1977	1	5.3%	18.1%
1976	No Data	No Data	No Data
1975	1	2.1%	2.1%
1974	No Data	No Data	No Data
1973	No Data	No Data	No Data
1972	1	3.2%	5.3%
•			
1969	2	3.2%	8.0%

*Percentages listed are averages of all reflectors measured by year car was built or rebuilt.

An automobile was parked 300 feet from the crossing such that headlights illuminated the crossing. Figure 2-9 shows one of the crossings being set up for test observations during the day. High beams were used for all tests. An observer sat in the front seat and recorded observations of the visibility of reflectors on each car of passing trains. A new reflector was posted at the crossing to provide a reference for the observer. An observation of "good," "fair," or "poor" was recorded by the observer for each car. A car was rated "good" if the reflectors were clearly visible, "fair" if the reflectors were only moderately visible, and "poor" if barely visible or not visible at all. It must be noted that this test was conducted under the best of conditions with the observer stationary and anticipating the presence of a train.

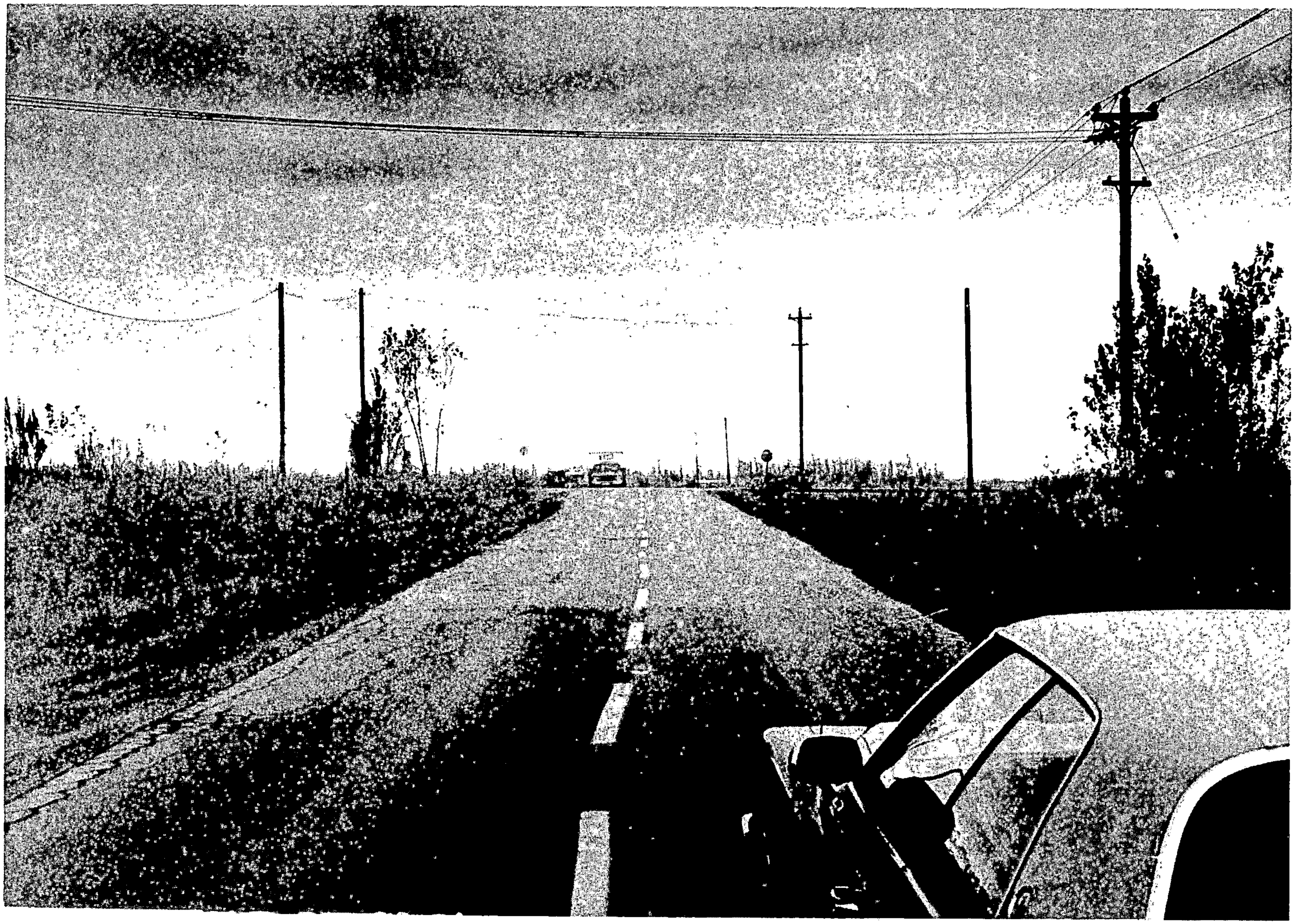


Figure 2-9 Rail-Highway Crossing Test Site for Night Observation of Freight Car Reflectors

The night observation test results are summarized in Table 2-3 which gives the percent of cars with reflectors observed as "good," "fair," or "poor" in 7 trains with a total of 480 cars. Of the cars observed, 14.2 percent had reflectors with "good" visibility, 16.7 percent "fair," and 69.1 percent "poor."

TABLE 2-3. NIGHT OBSERVATION OF REFLECTORS ON FREIGHT CARS

Test Date	Railroad	Number of Cars in Train	Ratings of Reflector Visibility by Car (Percent)		
			Good	Fair	Poor
10/19	CN	89	8.9%	3.4%	87.7%
	CN	76	15.8%	26.3%	57.9%
10/20	CP	108	18.5%	16.7%	64.8%
10/21	CP	20	15.0%	60.0%	25.0%
	CP	65	13.8%	4.6%	81.6%
	CP	74	14.9%	23.0%	62.1%
	CP	48	10.4%	14.6%	75.0%
Total for All Cars		480	14.2%	16.7%	69.1%
Totals, Modified to Show Canadian Cars Only		384	17.8%	20.9%	61.3%

United States cars, which usually do not have reflectors, are carried on Canadian railroads and representatives of CTC, CN and CP estimated that 20 percent of the cars in Canadian trains are of U.S. ownership. To account for U.S. ownership, results shown in Table 2-3 were modified to provide values for only Canadian cars. This process results in 17.8 percent of cars having reflectors with "good" visibility, 20.9 percent with "fair" visibility, and 61.3 percent with "poor" visibility.

The second line of data in Table 2-3 identifies a Canadian National Railroad train with 76 cars. The built and rebuilt dates were recorded from the cars after this train entered a receiving yard. The reflector visibility rating, "good," "fair," or "poor," is shown in Table 2-4, along with the built/rebuilt date and car type. Most of the reflectors which were rated as "good" or "fair" are less than four years old.

In summary, both the Measurement of Reflective Intensity test and the Night Observation of Reflectors test suggest a rapid rate of deterioration in the railroad environment. The average reflective intensity measurements made on 208 Canadian freight cars imply that a reflector's reflective intensity is reduced to 23 percent of its initial value after six months in service. After one and two years in service, the reflective intensity is reduced to 14 and 5 percent, respectively, of the initial value. In the night observation of reflectors, 61 percent of the cars were observed to have reflectors which were "poor," i.e., barely visible or not visible at all.

TABLE 2-4. RATINGS OF REFLECTOR VISIBILITY BY AGE AND TYPE OF CAR

DATE CAR BUILT OR REBUILT	NUMBER OF CARS BY OBSERVED REFLECTOR VISIBILITY			NUMBER OF CARS BY OBSERVED REFLECTOR VISIBILITY BY TYPE OF CAR								TOTAL NUMBER OF CARS BY TIME
				GOOD		FAIR		POOR				
	Good	Fair	Poor	Box	Tank	Box	Tank	Box	Tank	Hop.	Refr.	
1981	4	2	3	1	3	2	-	1	2	-	-	9
1980	6	-	3	4	2	-	-	1	2	-	-	9
1979	1	2	2	1	-	2	-	-	2	-	-	5
1978	1	11	2	-	1	11	-	2	-	-	-	14
1977	-	-	1	-	-	-	-	1	-	-	-	1
1976	-	1	1	-	-	1	-	1	-	-	-	2
1975	-	2	5	-	-	-	2	1	4	-	-	7
1974	-	-	2	-	-	-	-	-	1	1	-	2
1973	-	-	1	-	-	-	-	-	1	-	-	1
1972	-	2	1	-	-	-	2	-	1	-	-	3
1971	-	-	-	-	-	-	-	-	-	-	-	-
1970	-	-	3	-	-	-	-	-	3	-	-	3
1969	-	-	2	-	-	-	-	-	-	-	2	2
1968	-	-	3	-	-	-	-	-	3	-	-	3
1967	-	-	-	-	-	-	-	-	-	-	-	-
1966	-	-	4	-	-	-	-	-	3	-	1	4
1965	-	-	1	-	-	-	-	1	-	-	-	1
1964	-	-	-	-	-	-	-	-	-	-	-	-
1963	-	-	-	-	-	-	-	-	-	-	-	-
1962	-	-	1	-	-	-	-	1	-	-	-	1
1961	-	-	-	-	-	-	-	-	-	-	-	-
1960	-	-	-	-	-	-	-	-	-	-	-	-
1959	-	-	-	-	-	-	-	-	-	-	-	-
Pre 59	-	-	3	-	-	-	-	2	1	-	-	3
Sub total	12	20	38	6	6	16	4	11	23	1	3	70
Non-Canada Cars	-	-	6	-	-	-	-	2	2	-	2	6
Total	12	20	44	6	6	16	4	13	25	1	5	76

3. BOSTON AND MAINE RAILROAD REFLECTOR TEST

High intensity reflective sheeting was placed on 33 Boston and Maine Railroad (B&M) cars during the spring and summer of 1981. The test period was not long enough to develop estimates concerning the long-term wear of high intensity reflective sheeting on railroad cars. However, the results for the first six months indicate deterioration rates which are similar to those obtained from the Canadian measurements (Chapter 2).

Scotchlite Brand Reflective Sheeting, High Intensity Grade, was installed on 33 sand and gravel hopper cars on the Boston and Maine Railroad during May through July, 1981 (Figure 3-1). Four reflectors, each 4 inches by 12 inches, were installed on each side of the cars just above the side sill (Figure 3-2). The material has alternating silver and orange colors such that each 12 inch piece applied to the cars is a composite of both colors. The reflective intensity of the silver portion of the material was measured to be 290 candela/foot-candle/ foot^2. The B&M sand and gravel cars are high usage cars in dedicated service between Boston, Massachusetts and Ossipee, New Hampshire.

During October through December, 1981, reflectivity measurements were collected on 19 of the sand and gravel hopper cars (Figure 3-3). The dirt observed on the reflectors was of a sandy, dusty nature which would be expected from the type of service experienced by the cars. Table 3-1 gives the average reflector reflective intensity for each car by time in service and the lowest and highest reflector reflective intensity for each car.

Figure 3-1 High Intensity Reflectors on Boston and Maine Railroad Sand and Gravel Cars

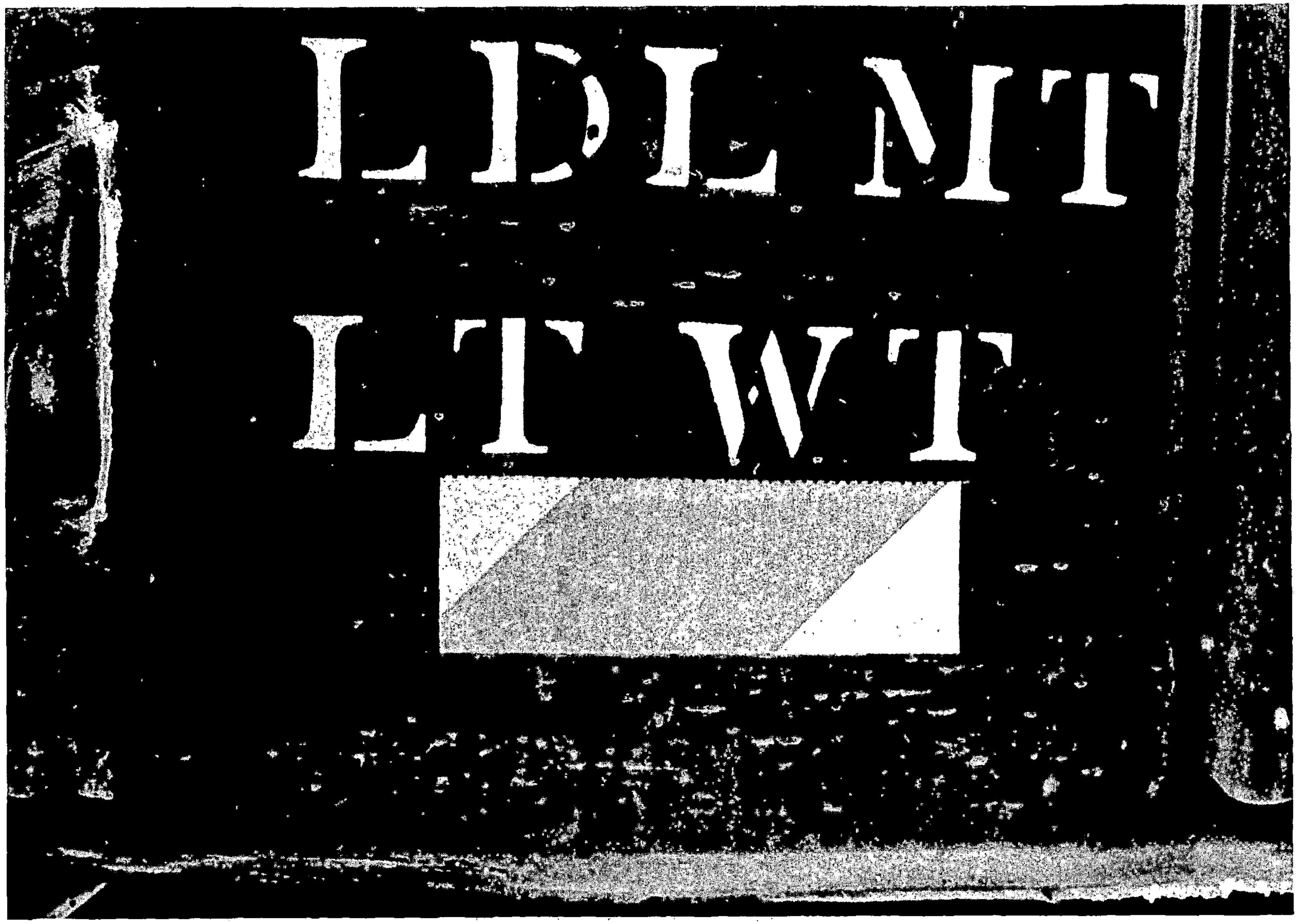


Figure 3-2 High Intensity 4-Inch by 12-Inch Reflector on Boston and Maine Railroad Freight Car

Figure 3-3 Measurement of Reflective Intensity of Reflector on Boston and Maine Railroad Freight Car

TABLE 3-1. REFLECTIVE INTENSITY OF SILVER REFLECTORS (Candela/foot-candle/foot^2)

Age (Months)	Average Reflective Intensity on Car	Range of Reflective Intensity on Car Low	High
4	196	139	232
4	15	2	45
4	29	13	42
4	163	85	202
4	103	36	164
4	97	64	127
4	221	214	227
4	70	33	98
4	135	67	168
4	117	110	123
4	58	22	102
4	72	55	89
5	28	19	38
5	94	78	119
5	44	29	56
6	11	5	17
6	19	4	25
6	2	2	2
6	58	33	87

The average reflective intensity of reflectors in service for four months was 106 candela/foot-candle/foot^2. Reflectors in service for five and six months had average reflective intensities of 55 and 22 candela/foot-candle/foot^2, respectively. These data suggest a decline in reflective intensity to 37 percent of the initial reflective intensity after four months in service; 19 percent after five months and 8 percent after six months (Table 3-2).

TABLE 3-2. REFLECTIVE INTENSITY MEASUREMENT FOR HIGH INTENSITY REFLECTORS ON B&M FREIGHT CARS

Time in Service (Months)	Number of Cars Measured	Average Reflective Intensity (candela/foot-candle/foot^2)	Average Reflective Intensity as Percent of Initial Value*
4	12	106	37%
5	3	55	19%
6	4	22	8%

*Initial reflective intensity of silver portion of reflectors was measured to be 290 candela/foot-candle/foot^2.

For comparison purposes, the reflective intensity, as a percent of initial value, of reflectors measured on Canadian cars are given in Table 3-3. The decline in percent of initial value with time is given by both the curve developed through a regression analysis (Figure 2-7) and the mathematical average of the reflective intensities measured in each month (Figure 2-6).

TABLE 3-3. REFLECTIVE INTENSITY OF ENGINEEER GRADE MATERIAL ON CANADIAN FREIGHT CARS

	Regression Analysis*	Average for Cars Measured by Month**	
Time in Service (Months)	Reflective Intensity as Percent of Initial Value	Number of Cars Measured	Reflective Intensity as Percent of Initial Value
4	27%	5	32%
5	25%	4	29%
6	23%	2	26%

*Figure 2-7.
**Figure 2-6.

An insufficient amount of data and the limited time available for the Boston and Maine Reflectorization tests prohibit the development of absolute conclusions regarding the durability of high intensity reflectors in the railroad environment. However, the data indicate that high intensity reflectors deteriorate in the railroad environment at a rate similar to that observed of engineer grade reflectors in use in Canada.

4. REFLECTOR CHARACTERISTICS

Selection of the reflector characteristics for freight car reflectorization involves the specification of six critical parameters. They are:

1. Reflector material
2. Reflector location and number per car
3. Reflector color
4. Reflector brightness
5. Reflector size, washing cycle, and replacement interval
6. Reflector shape

The subsections that follow analyze the interrelation between these parameters and select optimum values for each.

4.1 REFLECTOR MATERIAL

Materials which reflect light directly back toward the light source, regardless of the angle from which the light comes, are technically known as "retroreflectors" or "reflex reflectors." For simplicity, these materials and devices will be referred to as "reflectors" in this report.

Reflective materials are characterized in terms of reflective intensity, which is the ratio of the intensity of the reflected light per unit area (candela/sq ft) to the illuminance of the incident light (foot-candles). For a fixed source of intensity I (candela) at a distance d (feet), the illuminance received by the reflector is I/d^2 ft-candles. The intensity of the reflected light in clear air is $A \times B \times I/d^4$ (candela), where B is the reflective intensity of the material and A is the reflector area. A desired brightness can be achieved by any appropriate combination of area A and reflective intensity B for a stated source intensity I and distance d. Thus, less area (a smaller reflector) is needed when a reflector material having a higher value of B is used.

The reflective intensity of the material, B, is dependent on two angles, the incidence angle and the divergence angle. The incidence angle is the angle formed by the path of the light source and a line perpendicular to the surface of the reflector. The divergence angle is the angle formed by the path of the light source and the line of sight of the observer (Figure 4-1). The reflective intensity, and hence the intensity of the reflected light, is very sensitive to the divergence angle and is moderately sensitive to the incidence angle (Figure 4-2). The reflective intensity of the material and its sensitivity to divergence and incidence angles varies with each type of reflective material.

There are three materials which could be used: (1) molded prism reflectors (usually plastic), (2) reflective liquid (typically applied over paint), and (3) reflective sheeting.

Molded prism reflectors, commonly used on motor vehicles, require mechanical attachments, such as rivets, and are more vulnerable than other types of reflectors to destruction if struck by a hard object. Molded prism reflectors can provide more reflective intensity than sheeting. However, the reflective intensity is strongly dependent on the angle of incidence, such that the reflected intensity decreases rapidly as the light source becomes less perpendicular to the reflector surface. This means that a molded prism reflector which provides adequate visibility at a crossing having an intersection angle of 90 degrees would be much less conspicuous at a crossing with an intersection angle markedly different from 90 degrees.

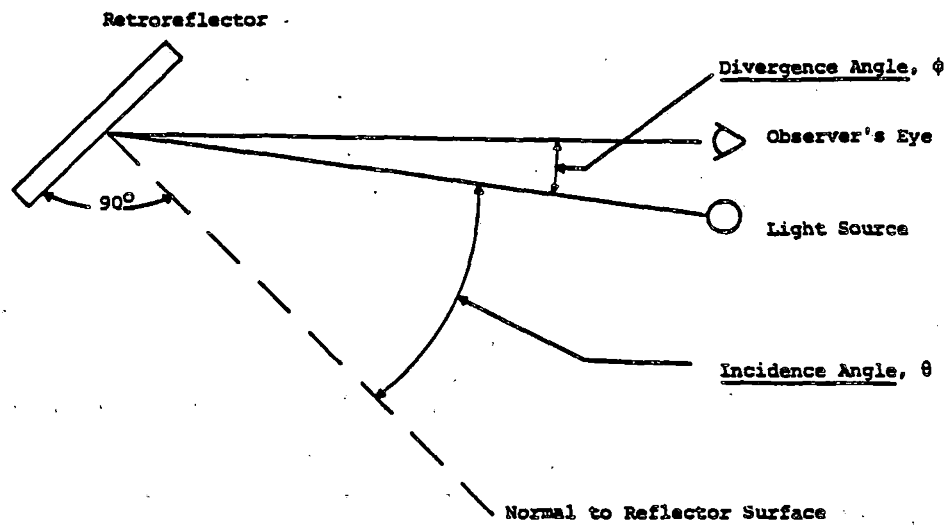


FIGURE 4-1. REFLECTOR DIVERGENCE AND INCIDENCE ANGLE

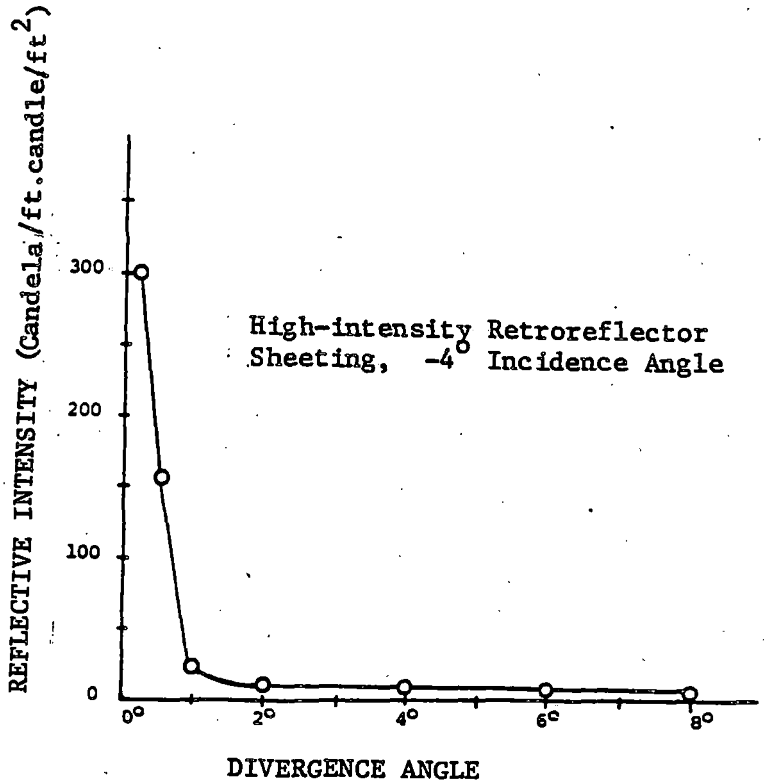


FIGURE 4-2. VARIATIONS OF REFLECTIVITY WITH DIVERGENCE ANGLE

Reflective liquid contains many tiny reflective spheres which are applied as a final coat on top of a layer of paint of an appropriate color. Reflective liquid provides less reflective intensity than sheeting and molded reflectors. The tiny reflective spheres can readily accumulate dirt and are particularly vulnerable to abrasive wear. In addition, the reflective property of the exposed material is seriously diminished when it is wet, so that performance in rain is severely degraded.

Reflective sheeting has an adhesive backing which permits application directly to a newly-painted or cleaned freight car surface. In comparison to molded prism reflectors and reflective liquid, the sheeting is relatively insensitive to incidence angle and has a lower lifetime cost. In a particular situation other materials may be preferred, but in the context of size determination and cost analysis for this study, reflective sheeting is the selected material.

There are two forms of reflective sheeting: engineer grade and high intensity. The engineer grade material consists of enclosed glass lenses, whereas the high intensity uses either encapsulated lenses or microprisms. In general, the engineer grade is designed for less demanding and shorter-life uses. The high intensity material combines substantially longer service life with a greater than three-fold increase in brightness, and is significantly less sensitive to incidence angle.

The specified reflective intensity of silver/white high intensity material is 250 cd/ft-candle/sq ft, compared to 70 for engineer grade. Therefore, 3.6 times as large an area is required to produce a given overall intensity of reflected light with the engineer grade as with the high intensity. Engineer grade material is specified to retain at least 50 percent of its initial reflectivity after 7 years, whereas high intensity material remains above 80% for at least 10 years in normal service (Appendix B). The basic cost for high intensity material is only 1.8 times greater than for engineer grade material. Thus, high intensity reflective sheeting has been selected as the basis for this analysis of freight car reflectorization.

4.2 LOCATION OF REFLECTORS AND NUMBER PER CAR

Normal practice in establishing the location of highway traffic warning devices calls for one device per lane of traffic, with lane widths typically between 9 and 12 feet.[1] Similarly, Federal Highway Administration requirements for side marker lamps and reflectors on trailer trucks specify a reflector at each end of the trailer and an additional marker halfway between for trailers exceeding 30 feet in length.[2] Therefore, under the assumption of a maximum spacing of 15 feet, the required number of reflectors is a function of car length, and varies between four and seven reflectors per side of car (Table 4-1).

[1] Baerwold, John E. (Ed.), Transportation and Traffic Engineering Handbook Englewood Cliffs, NJ: Prentice Hall, 1976, page 328.

[2] Code of Federal Regulations, Title 49, Part 571.108, "Lamps, Reflective Devices and Associated Equipment"; Washington, DC, Government Printing Office 1980, pps. 183-194.

TABLE 4-1. REQUIRED NUMBER OF REFLECTORS PER SIDE OF CAR

Car Length (feet)	Required Number of Reflectors
Less than 45	3
45 to 60	4
60 to 75	5
75 to 90	6
Over 90	7

Reflector location at approximately eye level places the material at the center of the motorist's field of view and assures sufficient intensity of incident light. The best location closest to eye level is the side sill of the freight car. On rolling stock such as flatcars, no other position is available.

4.3 REFLECTOR BRIGHTNESS

The determination of the brightness required to attract the attention of a motorist is based on the principles of photometry. Under the assumption of a 90 degree intersection angle between the roadway and track, the amount of light received by an observer from a retroreflector is given by the equation below:[3]

$$E_e = \frac{I_s \; A \; B \; t^{2d} \; WH}{d^4} \text{, where}$$

E_e = illuminance received by the observer (foot-candles)
I_s = intensity of the light beamed toward the reflector (candela)
A = area of the reflector (square feet)

[3]McGinnis, R.G., "Reflectorization of Railroad Rolling Stock", Transportation Research Record 137, Transportation Research Board, 1979, p. 31.

B = reflective intensity of the reflector (candela/foot-candle/ft^2)

t = transmissivity of the atmosphere per foot

W = windshield transmittance

H = headlight transmittance

d = distance between the observer and the reflector (feet)

Under the assumption of a 2.5 second driver reaction time, a level approach grade, a wet pavement, and a vehicle speed of 50 miles per hour, the motorist must become aware of the obstacle when the vehicle is approximately 500 feet from the crossing so that the vehicle can be brought to a safe stop before reaching the crossing.

Based on Federal Aviation Administration (FAA) levels for detection of lights in darkness, an illumination level of 2.3×10^{-6} ft-candles is required to assure that the reflector is sufficiently visible.[4]

Studies have shown that motorists typically use the low headlight beam even when the high beam would be appropriate.[5] For a properly-adjusted headlight, the aim for the low beam is seen to be 2 degrees down from the horizontal plane (Figure 4-3). Under the assumption of a level approach grade, a reflector location on the side sill, 3-1/2 feet above the rail will be one foot above the vehicle headlight, which is assumed to be 2-1/2 feet above the surface of the roadway.[6] Thus, at 500 feet from the crossing, the

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[4] _Ibid._, p. 33.

[5] _Ibid._, page 32.

[6] Association of American Railroads, "Car and Locomotive Cyclopedia," New York: Simmons Boardman; 1974.

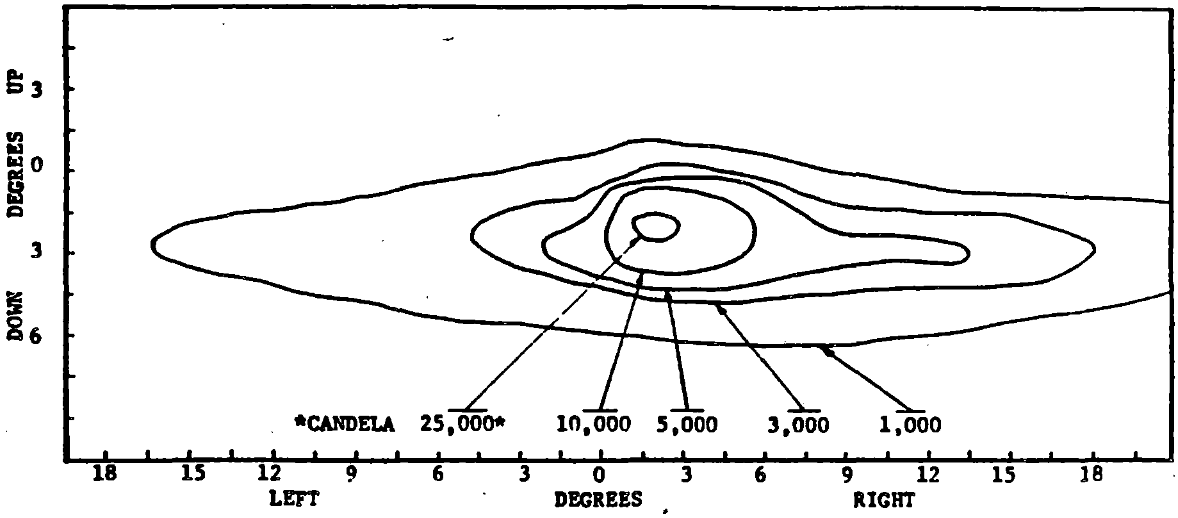

FIGURE 4-3. LOW BEAM HEADLAMP LIGHT INTENSITY DISTRIBUTION

reflector will be illuminated light of the intensity which occurs 2 degrees above the aiming point. As Figure 4-3 shows, this intensity is approximately 3000 candela.

Atmospheric conditions are assumed to be clear, with light attenuated 50 percent due to haze in a distance of 5 miles. This implies an atmospheric transmittance of 94.5 percent (one-way) at the assumed range of 500 feet.

Based on a previous study, a 30 percent reduction of light by the windshield and a 15 percent reduction of light by dirt on the headlights is assumed.[8]

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[8] Op. Cit., McGinnis, p. 33

The required reflector brightness (A x B) can be determined from the equation given on page 32 with the assumed values summarized below in Table 4-2. The results indicate that for a straight and level roadway, the reflector must have an overall reflective intensity of at least 45 cd/ft-candle in order to attract the attention of virtually all motorists at a distance from the crossing sufficient to permit a safe stop.

TABLE 4-2. OPTICAL PARAMETERS

E_e, Required Level of Illuminance	2.3×10^{-6} foot candles
d, Required Detection Distance:	500 feet
W, Windshield Transmittance:	.70
H, Headlight Efficiency:	.85
I_s, Headlight Intensity (per light):	3000 cd
t, Atmospheric Transmittance:	.945

The practical validity of this theoretical finding can be confirmed by reviewing the specifications for two devices used to warn motorists of obstacles in the highway: the emergency triangle and vehicle marker lights.

The emergency triangle "is to be carried in commercial motor vehicles and used to warn approaching traffic of the presence of a stopped vehicle."[10] Triangular in shape, it includes both orange fluorescent material for daytime visibility and red reflective material for night visibility. The basic specification for the reflective portion is that it have a total reflective intensity of 80 cd/ft-candle. Dirt accumulation is assumed to reduce the effective intensity by a factor of 2; thus, the reflectivity perceived by the motorist would be 40 cd/ft-candle.

A variety of white and amber lamps are required on motor vehicles to serve as side marker lights, parking lights, and clearance lights. These all have the basic function of alerting drivers to the presence of a vehicle in the road. The intensity required for these lights is 1 candela for white devices and .68 cd for amber.[11] A reflector with reflective intensity of 45 cd/ft-candle has a brightness of .87 cd, which is midway between the specified intensity for white and amber vehicle lights.

4.4 REFLECTOR COLOR

Silver/white reflective material has a much higher reflective intensity than colored materials. The next brightest, yellow, has a reflective intensity of 170 cd/foot-candle/ft^2, compared to 250 cd/foot-candle/ft^2 for silver-white. Red, with the desirable connotations of "stop" and "danger," has a reflective intensity of only 35 cd/foot-candle/ft^2. The lower the initial reflectivity of the material, the larger the area needed to yield a specified overall intensity. Given the rapid deterioration rate of reflectors in the railroad environment and the requirement that reflectors in service must have an overall reflective intensity of 45 cd/foot-candle, a silver/white color is chosen to maximize efficiency.

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[10] Code of Federal Regulations, Title 49, Part 571.125, "Warning Devices", Washington, DC: Government Printing Office, 1980, pp. 290-294.

[11] Op. cit., Code of Federal Regulations, Title 49, Part 571.108, pp. 183-194.

4.5 REFLECTOR SIZE, WASHING INTERVAL, AND REPLACEMENT INTERVAL

High intensity silver/white reflector material is specified to have a reflective intensity of 250 cd/ft-candle/ft^2 when new. Therefore, the required overall reflective intensity of 45 cd/ft-candle could be met with a 5-inch by 5-inch square of clean new high intensity silver/white sheeting. However, the required size must be determined on the basis of real conditions of use.

The reflective intensity of a reflector will decrease with time as a result of two factors: aging and the accumulation of dirt. Eventually, a reflector will age to a degree such that the accumulation of dirt after washing will cause its reflective intensity to be reduced to a value which is less than the required minimum of 45 candela/foot-candle. The reflector must then be replaced with a new reflector.

Under the assumption that a reflector is washed several times at specified intervals, the reflector will be replaced at the end of one of these washing intervals. Figure 4-4 illustrates this scenario. At time X_0, a reflector which has been in service has just been washed and has a reflective intensity of Y_0. At time X_1, the reflector is washed and its reflective intensity is increased to a value of Y_1. Y_1 is less than Y_0 because of the reduction in reflective intensity caused by aging. At time X_n the reflective intensity has been reduced to a value slightly greater than or equal to the minimum acceptable value. If the reflector is merely washed at time X_n, the reflective intensity would fall below the minimum value before the next washing period. Therefore, the reflector is replaced at time X_n.

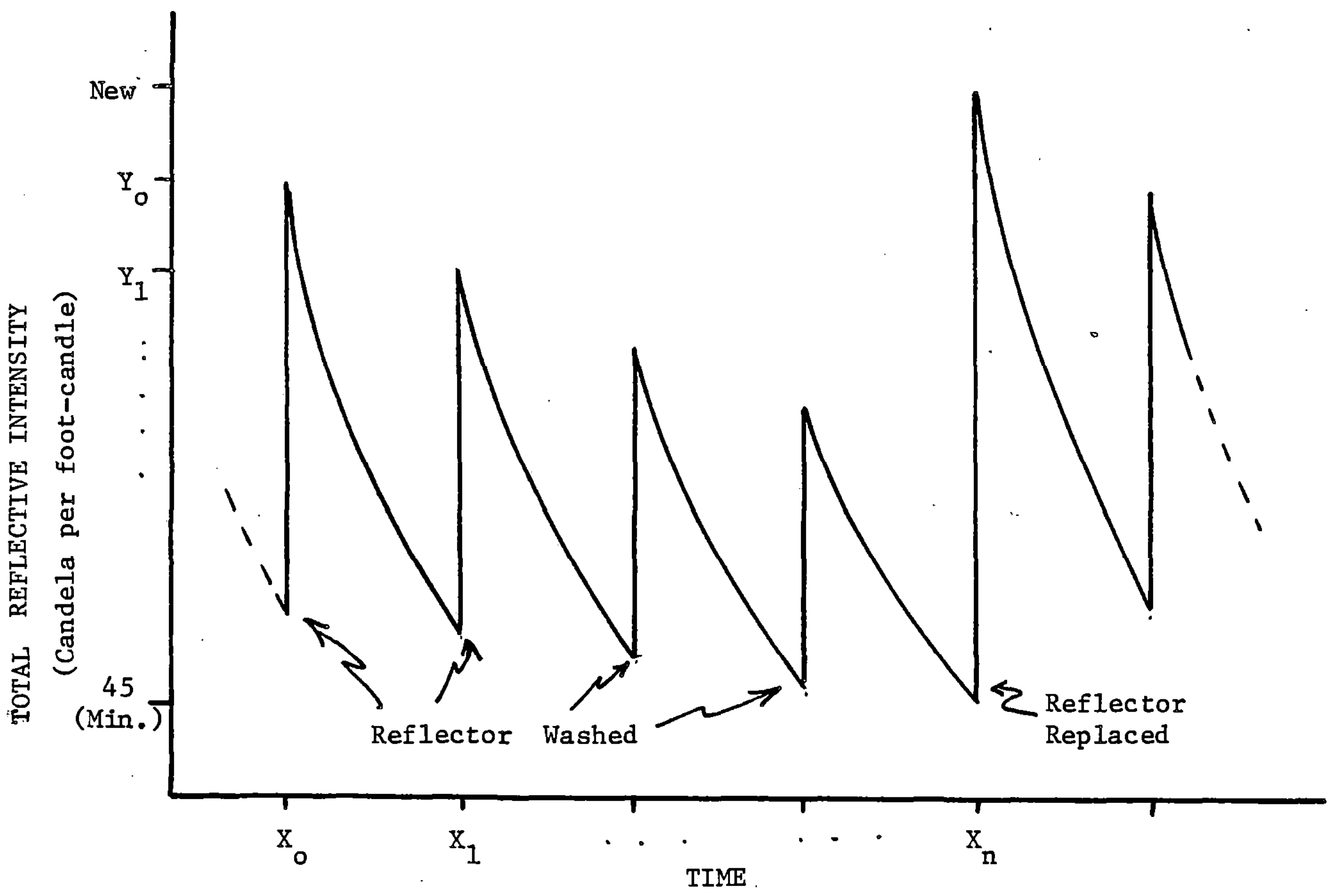

FIGURE 4-4. VARIATION OF REFLECTIVE INTENSITY WITH TIME

The size of the reflector must be large enough so that at time X_n the overall reflective intensity, which has decreased from its initial value when it was new, is greater than or equal to 45 candela/foot-candle.

The size of the reflector, washing interval and replacement interval are interrelated with the material, installation and maintenance costs.

The use of larger reflectors increases material costs, but maintenance expense is lowered because less frequent washing is necessary to prevent reflective intensity from falling below the required 45 cd/ft-candle. The optimum choice of reflector size is that which balances these two effects to attain the lowest total expense. The life-cycle cost to reflectorize a freight car can be written in terms of three components:

Cost = Material Cost
+ Installation Labor Cost
+ Maintenance Cost

A detailed description of the analysis used to define the required size, washing interval and replacement interval while minimizing costs is presented in Appendix C. Values for each cost element are as determined in Chapter 5. The Canadian measurements provide information describing the deterioration of reflectors. Material specifications are used to separate the effects of aging and dirt, based on the assumption that material deterioration due to age is twice as rapid in the railroad environment as in highway use.

The results of the analysis described in Appendix C indicate that a reflector area of 2-3/4 sq ft is needed to achieve the required visibility under the expected conditions of dirt accumulation and age deterioration. Reflectors would be washed every 20 months and replaced at 10-year intervals.

4.6 REFLECTOR SHAPE

For a given observation distance, if the largest dimension of a reflector subtends an angle greater than approximately 0.3 degrees a less-than-proportional increase in visibility is produced.[12] For a distance of 500 feet, this constraint implies that the largest dimensions of the reflector should not be larger than 3 feet. Reflector height of 1 foot with a length of 2-3/4 feet (12" x 33") is recommended in order to meet the 2-3/4 ft. area requirement in a manner which facilitates mounting procedures.

4.7 SUMMARY OF REFLECTOR CHARACTERISTICS

The required reflector characteristics, based on standard photometric theory and minimization of costs, assuming stenciling with each washing, are summarized in Table 4-3.

TABLE 4-3. SUMMARY OF REQUIRED REFLECTOR CHARACTERISTICS

Reflector Characteristic	Value
Reflector Area	2.75 sq ft
Reflector Size	12" x 33"
Reflector Material	High Intensity Sheeting
Number of Reflectors per Car	4 each side, 45 to 60-ft cars
Reflector Location	Sill
Reflector Color	Silver/white
Minimum Brightness	45 cd/foot-candle
Washing Interval	20 months
Replacement Interval	10 years

[12] Aurelius, John P. and Norman Korobow, The Visibility and Audibility of Trains Approaching Rail-Highway Grade Crossings, Washington, DC: U.S. Department of Transportation, May 1971, p. 36.

An overall reflective intensity of 45 cd/ft-candle is required in order to be sufficiently visible to a motorist 500 feet from a crossing having a level and perpendicular approach. Considerations of cost and durability indicate that silver/white high intensity reflective sheeting is the preferred material for freight car application. For typical headlights and operational circumstances, the reflective area needed to provide 45 cd/ft-cd depends primarily on the frequency with which the reflectors are washed. An area of 2-3/4 sq ft, with washing and stenciling at 20-month intervals, is found to meet the visibility requirement at the lowest cost. Four reflectors are needed on each side of a 45 to 60 foot car. The preferred shape is a 12-inch by 33-inch strip, mounted on the side sill of the freight car.

5. COSTS OF REFLECTORIZATION

The costs for reflectorization of freight cars are presented in this chapter. These costs include: (1) material costs, (2) installation costs, (3) maintenance costs, (4) stenciling costs.

Chapter 4 presented the conclusion from Appendix C that for the stated assumptions the minimum cost scenario for reflectorization consists of installing new reflectors every 10 years and washing reflectors every 20 months. The results in Appendix C are based in part on cost factors developed in the following analysis. The annual average cost of reflectorization is computed by determining the total cost over one 10-year cycle and dividing by 10. This is a steady-state average which is realized after an initial implementation period of 10 years.

The information for cost calculations was gathered from manufacturers, railroads, the Association of American Railroads (AAR), and field observations. All costs developed in this section are given in 1981 dollars.

5.1 MATERIAL COSTS

Analysis of reflective material requirements discussed in Chapter 4 established a requirement for initial reflective intensity of 250 candela/foot-candle/foot^2. The silver reflective sheeting of Avery International's Durabrite and 3M's Scotchlite high intensity products are guaranteed by the manufacturer to have an initial reflective intensity of 250 candela/foot-candle/foot^2 (Appendix B). The prices shown in Table 5-1 include both cutting to size and transportation and result in an average cost of $2.62 per square foot.

TABLE 5-1. REFLECTIVE MATERIAL COSTS

Manufacturer	Unit Price
Avery International	$2.23
3M Corp.	$3.00

In addition to the direct cost of retroreflective material, railroads will incur administrative costs associated with ordering the material. Rule 72 of the AAR Interchange Rules[1] states that 15% should be added to the material price to cover these costs; therefore an average cost of $3.01 per square foot is used for this analysis.

It was recommended in Chapter 4 that the reflector should be 2.75 square feet with a maximum spacing of 15 feet. The number of reflectors per car depends on the length of the car. The length distribution for freight cars[2] and reflective material costs for cars in each length category are given in Table 5-2. The cost for each car length is combined with the percentage of cars of that length to give a weighted sum that is the average reflective material cost per car. This weighted sum is the following:

$$(.10) \times (\$49.67) + (.75)(\$66.22) + (.08)(\$82.78) + (.01)(\$99.33) + (.06)(\$115.89) = \$69.23$$

[1] Field Manual of the Interchange Rules Washington, DC: Association of American Railroads, 1981, p. 313.

[2] Nayak, P.R. and D.W. Parker, Issues and Dimensions of Freight Car Size: A Compendium, Washington, DC: U.S. Department of Transportation, April 1980, pp. 3-9.

Thus, the average cost per car for reflective materials is $69.23.

TABLE 5-2. CAR LENGTH DISTRIBUTION AND REFLECTIVE MATERIAL COSTS PER CAR

Car Length ft	Percent of Fleet	Number of Reflectors	Material Requirements Sq. ft	Cost Per Car
Less than 45'	10%	6	16.5	$49.67
45 - 60'	75%	8	22.0	$66.22
60 - 75'	8%	10	27.5	$82.78
75 - 90'	1%	12	33.0	$99.33
Over 90'	6%	14	38.5	$115.89
Average		8.36	23.0	$69.23

A material cost of $69.23 per car results in a total cost for reflective material for the 1,710,000 freight cars in the U.S. fleet[3] of $118.4 million.

The analysis in Appendix C utilized indicated that 10 years is the optimal practical reflector replacement period; for this scenario 1/10th of the fleet, 171,000 cars, will have reflectors replaced each year. The annual reflective material cost for these cars is (171,000 cars) x ($69.23) = $11.8 million. The annual material requirement is 3.93 million square feet.

5.2 INSTALLATION COSTS

Normal application of reflective sheeting involves cleaning the surface, peeling off a protective backing and applying the reflector with a plastic squeegee or a rubber roller. The Canadian Transport Commission indicates that 20 to 30 minutes are required to apply eight 4" by 4" reflectors to a car, or

[3] Yearbook of Railroad Facts - 1981 Edition (Washington, DC: Association of American Railroads), p. 49.

2.5 to 3.75 minutes per reflector. Experience with applying 6" x 12" reflectors on Boston and Maine Railroad (B&M) freight cars resulted in an average installation time of 3.75 minutes per reflector. Tests showed that the average time for installing a 6" x 30" reflector to be 5 minutes per reflector. Extrapolation of these results shows that reflectors having an area of 2.75 square feet would require 8 minutes to install (see Appendix C). Assuming that the time required to clean the surface may vary, a range from 6 minutes to 10 minutes per reflector is used in this analysis. Total installation time required for each car length is given in Table 5-3.

TABLE 5-3. TIME FOR REFLECTOR INSTALLATION ON FREIGHT CARS

Car Length (feet)	Number of Reflectors	Average Time Per Reflector (minutes)	Time Per Car (minutes)	Time Range (minutes)
Less than 45'	6	8	48	36 - 60
45 - 60'	8	8	64	48 - 80
60 - 75'	10	8	80	60 - 100
75 - 90'	12	8	96	72 - 120
Over 90'	14	8	112	84 - 140

Using the car length distribution given in Table 5-2, the average time per car for installation of reflectors is calculated by a weighted sum as follows:

$$(.10)(48) + (.75)(64) + (.08)(80) + (.01)(96) + (.06)(112)$$
$$= 66.9 \text{ mins per car.}$$

This is equivalent to 1.11 hours per car. Since there are 1.71 million freight cars, this represents a total of (1.11)x(1.71) = 1.9 million hours of labor. Similarly, using the range from 6 to 10 minutes per reflector, the total numbers of labor hours would range from 1.4 to 2.4 million.

For the 10-year replacement cycle, in which 1/10 of the total number of freight cars will require new reflectors each year, the annual number of labor hours required for installation would be 190,000 labor hours, with a range from 140,000 to 240,000 labor hours.

Labor charges for installing reflectors on freight cars are covered under the AAR's job category 4450 which has an interchange labor rate of $39.28 per hour. According to AAR Interchange Rule 111,[4] this labor rate includes the following:

- Wages of foreman, assistant foreman, gang foreman, inspectors, clerks, messengers, watchmen, janitors, laborers, etc., working in connection with car repairs.
- Proportion of salaries and expenses of Chief Mechanical Officers and their office and supervisory forces, regional supervisory and accounting forces.
- Proportion of expense of operating power plants, power purchased, shop switching, wages of operators, and direct operators of crane and tractors, tool room attendants, machinery oilers, and other facility operators, tools, fuel, lubrication, water, other supplies, etc.
- Proportion of expense of maintenance of facilities (tracks, buildings and machinery) and fixed charges on facilities such as interest, taxes, depreciation and insurance on land, track, buildings and machinery.
- Workman's compensation, carriers, taxing act of 1937, railroad unemployment act, supplemental pension benefits, vacations with pay, health and welfare benefits, and hospital, medical, and surgical benefits and group life insurance expenses.

Therefore, rates for labor based on AAR Interchange Rules include all direct and indirect costs for the installation of reflective material on freight cars.

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[4] Office Manual of the Interchange Rules, Washington, DC: Association of American Railroads, 1981, p. 65.

Since 190,000 labor-hours are required annually for installation of reflectors, the total annual labor cost for installation is

($39.28) x (190,000) = $7.5 million.

Similar calculations using a minimum time requirement of 140,000 hours and a maximum time requirement of 240,000 hours result in costs of $5.6 million and $9.4 million, respectively.

Since the nominal labor hour requirement per car is 1.11 hours, the labor cost per car is (1.11)($39.28) = $43.60 with a possible range of from $32.21 to $54.99.

The annual costs for materials and labor to install retroreflectors on 171,000 freight cars are summarized in Table 5-4.

TABLE 5-4. ANNUAL MATERIAL AND INSTALLATION COST OF REFLECTORIZATION

Material Cost (millions)	Range of Labor Costs (millions)			Range of Annual Costs for Installation (millions)		
	Min	Nominal	Max	Min	Nominal	Max
$11.8	$5.6	$7.5	$9.4	$17.4	$19.3	$21.2

The total cost per car for material and installation labor is $69.23 + $43.60 = $112.83 with a possible range from $101.44 to $124.22 depending on labor requirements.

5.3 MAINTENANCE COSTS

Tests conducted with high intensity material mounted on B&M sand and gravel cars indicate that a washing time of 1 minute per reflector is sufficient to remove dirt. The actual labor time required per car, however, is assumed to be twice this figure in order to allow for the collection of materials and walking from car to car. Time required for each car length is given in Table 5-5. The average time required for washing is given by the weighted sum as follows:

$$(.10)(.20) + (.75)(.27) + (.08)(.33) + (.01)(.40) + (.06)(.47) =$$
$$.28 \text{ hours per car.}$$

TABLE 5-5. CLEANING TIMES

Car Length	Number of Reflectors	Cleaning Time Per Car (hours)
Less than 45'	6	0.20
45 - 60'	8	0.27
60 - 75'	10	0.33
75 - 90'	12	0.40
Over 90'	14	0.47
Average		0.28

The optimal maintenance policy determined in Appendix C calls for cleaning reflectors every 20 months and replacing reflectors every 120 months (10 years). During each 20-month period, 5/6 of the reflectors would be cleaned and 1/6 would be replaced. This implies a cleaning rate of 1.425 million cars per 20 months which is equivalent to an annual rate of 855,000 cars per year. Since the average cleaning time is 0.28 hours per car, this represents an annual requirement of (.28) x (855,000) or 239,400 labor-hours.

Washing time can be expected to vary. The Canadian ore car experience, considered to be a worst case, yielded a total labor time of 3 minutes per reflector.[5] Tests using special teflon coated OACI labels showed a wash time of .5 minutes per reflector, or a total labor time per reflector of 1 minute. Repeating the above calculations using the range of 1 minute and 3 minutes per reflector yields annual cleaning requirements of from 119,700 labor-hours to 359,100 labor-hours.

In a previous study of reflectorization,[6] it was determined that 5% of reflectors would be found to be damaged or missing each year. This implies an equivalent of 85,500 cars will require replacement of reflectors each year. It was shown in Section 5.1 that the average cost to install reflectors on cars is $112.83, which indicates an annual cost of $9.6 million to replace defective reflectors with a range from $8.7 million to 10.6 million.

To calculate the total annual maintenance cost, the cost of replacing defective reflectors is added to the cost of washing reflectors. Cleaning reflectors mounted on freight cars is covered in AAR job category 4450 which has a fully burdened labor rate of $39.28 per hour.[7] Since 5% of the 855,000 cars scheduled for washing will receive new reflectors, only 812,250 will be washed which gives an annual cleaning cost of:

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[5] Ingrao, Hector C., Optimal Automatic Car Identification, Vol. III, Washington, DC: U.S. Department of Transportation, June 1977, pp. 159-162.

[6] Op. Cit., McGinnis, p. 38

[7] Op. Cit, Office Manual of the Interchange Rules, p. 97.

(.28 hrs per car) x (812,250 cars) x ($39.28 per hour)

= $8.93 million.

Allowing for the range of time requirements, the annual cost range for cleaning is from $4.46 million to $13.38 million. The cost to clean a car is (.28) x ($39.28) = $11.00 with a range from $5.50 to $16.50.

Table 5-6 summarizes annual maintenance costs and displays the possible range in these values.

TABLE 5-6. ANNUAL MAINTENANCE COST OF REFLECTORIZATION

Cleaning Costs (millions)			Cost of 5% Annual Replacement (millions)			Total Maintenance Cost (millions)		
Min	Nominal	Max	Min	Nominal	Max	Min	Nominal	Max
$4.5	$8.9	$13.4	$8.7	$9.7	$10.6	$13.2	$18.5	$24.0

5.4 STENCILING COSTS

In addition to the costs described in Sections 5.1 and 5.2, there are costs associated with recording the date of application and the date of cleaning of reflectors on freight cars. These two dates must be stenciled on freight cars so that cars requiring reflector service can be located in yards and appropriate action taken.

The AAR Office Manual of Interchange Rules states that stenciling both sides of a freight car carries a fully burdened rate of $28.83 per car.[8] Over a 10-year period, a freight car will be stencilled six times: when reflectors are first installed, and one after each of the five cleaning periods. Thus, the total 10-year stenciling cost for a single car is 6 x ($28.83) = $172.98, or an annual average of $17.30 per car. Since there are 1.71 million freight cars, the total annual cost for stenciling is (1.71) x ($17.30) = $29.58 million.

5.5 TOTAL REFLECTORIZATION COSTS

Within the assumptions previously indicated, the reflectorization of freight cars will have an estimated total annual cost of $67.4 million for a replacement-wash policy that incorporates a 10-year replacement period and a 20-month wash cycle. If the minimum and maximum time requirements for installing and washing reflectors are incorporated into the total annual cost, a range from $61.1 million to $73.8 million results as shown in Table 5-7.

TABLE 5-7. ANNUAL REFLECTORIZATION COST

Cost Component	Annual Cost (millions)		
	Min	Nominal	Max
High Intensity Material	$11.8	$11.8	$11.8
Installation Labor	$5.6	$7.5	$9.4
Cleaning Labor	$4.5	$8.9	$13.4
Replacement Cost	$8.7	$9.6	$10.6
Stenciling	$29.6	$29.6	$29.6
TOTAL ANNUAL COST	$61.1	$67.4	$74.8

[8] Op. Cit., Office Manual of the Interchange Rules, p. 104.

6. ANALYSIS OF RAIL-HIGHWAY CROSSING ACCIDENTS

6.1 TOTAL VEHICLE-RAN-INTO-TRAIN ACCIDENTS UNDER CONDITIONS OF DARKNESS, DAWN OR DUSK

The basic subset of accidents and casualties potentially affected by freight car reflectorization consists of all collisions in which the motor vehicle runs into the train under conditions of darkness, dawn, or dusk. For convenience these will be referred to as "RIT" (ran-into-train) accidents. Table 6-1 shows the annual number of these accidents and associated casualties for the period from 1975 to 1980.

TABLE 6-1. ANNUAL NUMBER OF ACCIDENTS, INJURIES, AND FATALITIES FOR MOTOR VEHICLES STRIKING TRAINS UNDER CONDITIONS OF DAWN, DUSK, OR DARKNESS, 1975-1980

Year	Accidents	Injuries	Fatalities
1975	1766	790	121
1976	1835	810	81
1977	1861	781	95
1978	1963	799	140
1979	1883	818	117
1980	1641	765	106

The accidents which make up Table 6-1 were 14.6 percent of all accidents occurring at railroad-highway crossings from 1975 to 1980, and caused 19.0 percent of the injuries and 11.2 percent of the fatalities. However, not all of these accidents could have been affected by freight car reflectorization. The RAIRS data base can be used to eliminate from consideration those accidents and casualties which would not have been affected by reflectorization: (1) accidents occurring at crossings with active warning devices, (2) accidents in which the locomotive is struck, rather than a freight car, (3) accidents in which the train is not a freight train, and (4) accidents under inclement weather conditions which would prevent reflectors from being of value.

6.2 ACCIDENTS AT CROSSINGS WITH ACTIVE WARNING DEVICES

Crossings equipped with active warnings (usually train-activated flashing lights alone or flashing lights with automatic gates) would be expected to have few accidents arising solely from visibility problems of the type potentially affected by freight car reflectorization. In this analysis it is assumed that only accidents occurring at crossings with passive warnings are relevant to reflectorization. Table 6-2 shows the result of excluding from Table 6-1 all accidents and casualties for crossings with active motorist warnings.

TABLE 6-2. ANNUAL NUMBER OF ACCIDENTS, INJURIES, AND FATALITIES FOR MOTOR VEHICLES STRIKING TRAINS UNDER CONDITIONS OF DAWN, DUSK, OR DARKNESS AT CROSSINGS WITH PASSIVE WARNING DEVICES, 1975 - 1980

Year	Accidents	Injuries	Fatalities
1975	1013	415	79
1976	981	449	53
1977	1028	439	55
1978	1077	448	65
1979	1006	454	66
1980	807	365	52

6.3 VEHICLE-STRIKES-LOCOMOTIVE ACCIDENTS

From 1975 to 1980, sixty percent of vehicle-ran-into-train accidents occurring in darkness, dusk or dawn were collisions with locomotives, and would not have been affected by freight car reflectorization. When crossing collisions in which locomotives are struck are eliminated from those enumerated in Table 6-2, the accidents, injuries and fatalities for 1975 through 1980 are as shown in Table 6-3.

TABLE 6-3. ANNUAL NUMBER OF ACCIDENTS, INJURIES, AND FATALITIES FOR MOTOR VEHICLES STRIKING TRAINS TO THE REAR OF THE LOCOMOTIVES UNDER CONDITIONS OF DAWN, DUSK, OR DARKNESS AT CROSSINGS WITH PASSIVE WARNING DEVICES, 1975-1980

Year	Accidents	Injuries	Fatalities
1975	391	178	54
1976	370	184	24
1977	405	197	24
1978	444	198	32
1979	451	240	40
1980	355	171	30

6.4 TYPE OF TRAIN

Freight car reflectorization is also not relevant to collisions involving passenger trains and work trains which normally do not include freight cars. Table 6-4 shows the number of accidents, injuries and fatalities in which a freight train was struck to the rear of the locomotive consist in conditions of darkness, dawn or dusk.

TABLE 6-4. ANNUAL NUMBER OF ACCIDENTS, INJURIES, AND FATALITIES FOR MOTOR VEHICLES STRIKING FREIGHT CARS UNDER CONDITIONS OF DAWN, DUSK, OR DARKNESS AT CROSSINGS WITH PASSIVE WARNING DEVICES, 1975-1980

Year	Accidents	Injuries	Fatalities
1975	376	170	54
1976	366	181	24
1977	399	194	24
1978	431	195	32
1979	437	230	40
1980	349	168	29

6.5 WEATHER CONDITIONS

Additional RIT accidents are not relevant to freight car reflectorization because of weather conditions at the time of the accident. Snow and fog generally interfere greatly with visibility. The brightness of the headlight illumination reflected back from snow or fog makes reflectors much less conspicuous. In addition, headlight intensity and reflected light returned from the reflector are strongly scattered and attenuated by fog and snow, thereby reducing the visibility of the reflectors still further. Thus, accidents occuring under conditions of snow and fog are not included among those potentially affected by reflectorization. The result of eliminating snow and fog accidents from Table 6-4 is shown in Table 6-5.

TABLE 6-5. ANNUAL NUMBER OF ACCIDENTS, INJURIES, AND FATALITIES FOR MOTOR VEHICLES STRIKING FREIGHT CARS UNDER CONDITIONS OF DAWN, DUSK, OR DARKNESS AT CROSSINGS WITH PASSIVE WARNING DEVICES, EXCLUDING ACCIDENTS OCCURRING IN SNOW OR FOG, 1975-1980

Year	Accidents	Injuries	Fatalities
1975	334	143	51
1976	336	167	23
1977	353	171	23
1978	365	160	26
1979	369	199	25
1980	306	147	24

6.6 OTHER FACTORS AFFECTING THE SAFETY EFFECTIVENESS OF FREIGHT CAR REFLECTORIZATION

The accidents and casualties identified in Table 6-5 provide an upper limit on the number of collisions which potentially could have been affected by freight car reflectorization. However, some of these accidents are likely to have resulted from causes unrelated to the visibility of the freight cars. Even among the accidents which were related to visibility, some may have involved specific circumstances (other than those already considered) such that freight car reflectorization would not have helped. Factors of this nature are discussed below. However, data sufficient to permit rigorous and precise quantitative characterization of these aspects are not available.

6.6.1 Accidents Not Affected by Freight Car Visibility

The fact that some vehicles run into trains at positions far from the front of the train even in daylight conditions and at crossings with automatic gates, indicates that RIT accidents can sometimes happen for reasons unrelated to visibility. Driver intoxication, fatigue, inattention, or other incapacitation often associated with highway accidents in general, explain some crossing accidents. Such factors are particularly likely to be related to accidents at night. In addition, some of the accidents in which vehicles strike one of the first few freight cars are cases in which the vehicle is too close to the crossing to stop safely at the time the first freight car enters the crossing and is illuminated by the vehicle headlights. These accidents cannot be affected by improvement of freight car visibility through reflectorization.

6.6.2 Factors Limiting the Degree to Which Reflectorization Can Improve Freight Car Visibility

Even for crossing accidents which could in principal be beneficially affected by better visibility of freight cars in darkness, there are several factors which limit the degree to which reflectorization can be effective in achieving sufficient improvement in visibility. These include (1) excessive reflector degradation, (2) incomplete reflectorization of the fleet, (3) the geometry of the rail-highway intersection, and (4) headlight aim and condition.

(1) Excessive Reflector Degradation. Some freight car reflectors, due to exposure to particularly severe conditions, will become substantially dirtier than average or will age more rapidly than expected. Others may be damaged through vandalism. In some cases these factors can reduce reflectivity to such a degree that the visibility improvement and the associated safety effectiveness are seriously diminished.

(2) Cars Not Equipped With Reflectors. Even with a commitment to install reflectors, practical impediments can be expected to prevent implementation from reaching 100%. This was demonstrated by the industry's experience with labels for optical automatic car identification where a major effort over several years was unable to achieve complete labeling.

(3) Roadway And Track Geometric Factors. The angle at which the roadway crosses the track is often considerably less than 90 degrees. For example, the angle is less than 60 degrees at approximately 30 percent of all crossings.[1] Due to the strong dependence of reflective intensity on incidence angle, the light reflected will be seriously diminished in these situations. In other cases, the road may turn near the crossing, so that freight car reflectors will not be made visible by illumination from vehicle headlights until the vehicle is quite near the tracks. Variations in vertical level of road and tracks can also have a marked detrimental effect, since motor vehicle headlights focus most of their light below the horizontal plane. If topographic or geometric factors cause the lights to be aimed below the freight car, the reflected brightness may be very small.

(4) Headlight Aim and Condition. A small misalignment of motor vehicle headlights in the vertical plane will sharply reduce the light incident on the reflector, with a commensurate decrease in reflected intensity. Also, some vehicles can be expected to have accumulated dirt on the headlights to a degree which reduces headlight efficiency below 85% assumed in the analysis in Chapter 4.

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[1] Rail-Highway Crossing Accident/Incident and Inventory Bulletin, No. 3, Calendar Year 1980, Washington, DC: U.S. Department of Transportation, June 1981, p 69.

7.0 ALTERNATIVES TO FREIGHT CAR REFLECTORIZATION

There exist alternative approaches to achieve the objective of reduced rail-highway crossing accidents in which the vehicle strikes the train under conditions of dawn, dusk or darkness. Five such alternatives are discussed below:

1. Train-activated motorist warnings devies.
2. Locomotive reflectorization as specified for freight cars.
3. Extensive reflectorization of locomotives
4. Installation of alerting lights on locomotives.
5. Illumination of crossings

7.1 TRAIN-ACTIVATED WARNINGS

Train-activated motorist warning systems differ from the other alternatives identified in this section in that they are beneficial in reducing all types of crossing accidents, not only those in which the vehicle runs into the train in dusk, dawn or darkness. In the absence of quantitative data on this subject, it is assumed that the effectiveness of train-activated warnings against the dark-RIT accidents is the same as for other classes of accidents, approximately 65% to 90% accident reduction.[1] However, considerations of cost-effectiveness limit the number of crossings at which active warning devices can be used. Thus, this alternative is not applicable to a large number of low-traffic-density crossings.

[1] Morrissey, J., The Effectiveness of Flashing Lights and Flashing Lights with Gates in Reducing Accident Frequency at Public Rail-Highway Crossings 1975-1978, (Washington, DC: U.S. Department of Transportation, April 1980), p. 9.

7.2 LOCOMOTIVE REFLECTORIZATION

Most crossing accidents involve motor vehicles colliding with locomotives or with freight cars located immediately behind the locomotives. Approximately 60% of the dark, dawn and dusk RIT accidents involve vehicles running into the locomotive. However, locomotive reflectorization would affect only a portion of those accidents. Accidents in which the motorist is already too close to the crossing to stop at the time the locomotive enters the roadway will not be prevented. All of the unquantifiable limitations on the safety effectiveness of freight car reflectorization discussed in Section 6 also apply to locomotive reflectorization. Two categories of locomotive reflectorization are considered:

1. Limited locomotive reflectorization, identical to that previously discussed for freight cars.
2. Extensive locomotive reflectorization.

7.2.1 Limited Locomotive Reflectorization

The simplest case of locomotive reflectorization is that in which the locomotive is treated as described earlier for freight cars: application of four strips of high intensity reflective sheeting to each side of the locomotive.

The costs for this type of locomotive reflectorization would be less than that for freight car reflectorization. There are only 28,483 locomotives in the U.S. fleet, as compared to 1.7 million freight cars.[2] Since locomotives receive scheduled maintenance at intervals no greater than one year,

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[2] Yearbook of Railroad Facts - 1981 Edition, Washington, DC: Association of American Railroads, 1981, pp 48-49.

reflectors could be washed more frequently and the requirement for stencilling at the time of washing might not be necessary. This would significantly reduce the cost of reflector maintenance. Also, since more frequent washing would permit use of a smaller reflector, material costs per locomotive could be less than that per freight car.

7.2.2 Extensive Locomotive Reflectorization

Extensive reflectorization would mean the application of a 5 to 10 times as large an area of reflective sheeting than would be applied in the limited case. An example of extensive reflectorization is the use of a 6- to 12-inch reflectorized strip running the length of the locomotive. This would require approximately 50 to 100 square feet of material per locomotive.

The primary advantage of extensive rather than limited reflectorization is the increased likelihood that the locomotive will be seen before entering the roadway so that there will be some reduction of accidents in which the train strikes the vehicle and in which the train does not enter the roadway until the vehicle is too close to stop. This could substantially increase the potential safety benefits. Extensive reflectorization is also less vulnerable than limited reflectorization with respect to poor headlight aim, disadvantageous crossing geometry, and excessive dirt buildup. On the other hand, the material and labor costs of installation would be significantly greater than for limited locomotive reflectorization.

7.3 LOCOMOTIVE ALERTING LIGHTS

Many railroads have equipped some or all of their locomotives with alerting lights to make them more conspicuous. The flashing or rotating alerting lights are intended to attract motorists' attention before a locomotive enters a roadway and before it leaves. Railroads hope this safety program will reduce the number of struck-by-train accidents, as well as accidents in which railroad cars immediately behind the locomotive are struck.

7.4 CROSSING ILLUMINATION

Illumination of crossings by special lighting has long been used as a preventive measure for nighttime accidents. Crossing illumination, when effectively implemented, increases visibility for rolling stock about to enter a crossing, as well as for trains already occupying a crossing. Also, illumination can increase awareness of the presence of a crossing. Thus, there are significant safety benefits for accidents involving vehicles struck by a train as well as for those striking a train. The benefits are obtained for all types of trains, including work trains and passenger trains, and in almost all weather conditions. The only constraint on overall effectivness of crossing illumination is the possibility that road topography may prevent direct observation of the crossing and a train until it is too late for a motorist to stop.

APPENDIX A

MEASUREMENT OF REFLECTIVITY OF REFLECTORS ON CANADIAN FREIGHT CARS

Measurements of the reflectivity of reflectors on 208 Canadian freight cars were taken jointly by the Transportation Systems Center (TSC) and the Canadian Transport Commission (CTC) at Canadian National Railway and Canadian Pacific Railway yards in Montreal, Quebec, Canada, during the week of October 19, 1981. Of the 208 freight cars, 140 were box cars, 19 were covered hoppers, 13 were flat cars, 11 were gondolas, 8 were tank cars, 4 were refrigerator cars, 11 were cabooses and 2 were work cars.

The following data were collected from each of the 208 cars examined:

a) Owner of car
b) Car number
c) Date car built or rebuilt
d) Measurement of reflectivity
e) Reflectivity measurement after washing for 24 cars
f) Type of car
g) Yard where measurement was made.

Table A-1 contains the reflectivity measurements for the 208 freight cars. The table contains the average of the measurements made on the reflectors on each car, and, in parentheses, the lowest reflector reflectivity measured on the car and the highest reflector reflectivity measured on the car. The units of each measurement are candela per foot-candle per foot^2. The data are listed by the date the car was built or rebuilt which is stenciled on the side of the car. This date is assumed to be the date the reflectors were installed on the car. The data are also listed by type of car.

TABLE A-1. REFLECTIVE INTENSITY MEASUREMENTS FOR REFLECTORS ON FREIGHT CARS

DATE CAR BUILT OR REBUILT	REFLECTIVE INTENSITY FOR CAR* CANDELA/FOOT-CANDLE/FOOT^2							
	BOX	COVERED HOPPER	FLAT	GONDOLA	TANK	REFRIG-ERATOR	CABOOSE	WORK
8-81					23(21,26)			
7-81	29(2,44)							
6-81	32(28,36); 39(33,50) 32(28,36)	14(12,15)		31(29,32)				
5-81	32(25,42); 18 (14,22) 29(15,42)	27(25,27)					41(35,48)	
4-81	15(6,22)	33(22,42)					46(40,50) 20(15,27)	
3-81	26(22,32)			5(3,7)				
2-81	35(26,52)			18(6,27)				
1-81	29(26,36); 48(38,57) 13(8,24)				21(18,24)			2(2,2)
12-80		4(3,9)		18(16,20)				
11-80							10(7,17)	
10-80	12(9,15)					37(19,50)		
9-80	15(24,5); 2(2,2)							
8-80	3(3,3); 25(21,31)		16(14,22)					

*Measurement listed for each car is: average of reflectors measured on car (lowest reflector measured, highest reflector measured).

TABLE A-1. REFLECTIVE INTENSITY MEASUREMENTS FOR REFLECTORS ON FREIGHT CARS (CONTINUED)

DATE CAR BUILT OR REBUILT	REFLECTIVE INTENSITY FOR CAR,* CANDELA/FOOT-CANDLE/FOOT^2							
	BOX	COVERED HOPPER	FLAT	GONDOLA	TANK	REFRIG-ERATOR	CABOOSE	WORK
7-80	16(15,19)							
6-80	12(9,15)						70(68,75)	2(2,2)
5-80	2(2,3); 11(8,16) 17(15,20)		20(15,23) 20(14,24)				6(4,9)	
4-80						2(2,3)		
3-80	12(6,15); 2(2,3)	10(10,11)						
2-80	6(4,8); 9(4,16) 9(6,10); 12(4,18) 3(3,3)						53(41,63); 4(3,5)	
1-80	19(14,25); 7(6,7) 10 (8,14); 4(3,5)							
12-79							35(27,42)	
11-79	2(2,2); 2(2,2)						36(20,47)	
10-79	8(7,10); 8(6,12); 7(5,9); 6(5,7)							
9-79	2(2,2)		2(2,2)					

*Measurements listed for each car is: average of reflectors measured on car (lowest reflector measured, highest reflector measured).

TABLE A-1. REFLECTIVE INTENSITY MEASUREMENTS FOR REFLECTORS ON FREIGHT CARS (CONTINUED)

DATE CAR BUILT OR REBUILT	REFLECTIVE INTENSITY FOR CAR,* CANDELA/FOOT-CANDLE/FOOT^2							
	BOX	COVERED HOPPER	FLAT	GONDOLA	TANK	REFRIG-ERATOR	CABOOSE	WORK
8-79	2(2,2); 2(2,2); 10(8,11); 2(2,2) 5(5,9)		5(2,7)		15(10,21)			
7-79	6(4,8); 3(3,3)							
5-79	5(5,7); 8(7,11) 3(3,3)							
3-79	6(5,8); 4(3,5); 7(7,9)				9(3,18)			
2-79	5(3,6); 2(2,3)			16(11,20)				
1-79	5(4,5); 5(4,6)	5(4,8)						
12-78	5(3,7); 10(8,12)							
11-78	8(2,15); 7(7,9); 3(3,3)			2(2,2)				
10-78	2(2,4); 2(2,4) 4(3,4)							
9-78	4(3,6); 5(4,6); 2(2,3); 2(2,2)	7(3,9)				6(3,11)		

*Measurement listed for each car is: average of reflectors measured on car (lowest reflector measured, highest reflector measured).

TABLE A-1. REFLECTIVE INTENSITY MEASUREMENTS FOR REFLECTORS ON FREIGHT CARS (CONTINUED)

DATE CAR BUILT OR REBUILT	REFLECTIVE INTENSITY FOR CAR,* CANDELA/FOOT-CANDLE/FOOT^2							
	BOX	COVERED HOPPER	FLAT	GONDOLA	TANK	REFRIG-ERATOR	CABOOSE	WORK
8-78	5(1,9); 8(5,14)							
6-78	8(5,9); 2(2,2); 7(5,12)				12(10,14)			
5-78	2(2,2); 7(6,8) 3(3,3)							
4-78	2(2,2)						15(3,31)	
3-78	2(2,2); 4(3,4) 2(2,2)							
2-78	3(3,4); 3(2,5)							
1-78	2(2,2); 2(2,2); 4(3,4)		4(3,6)					
1977	2(2,3); 2(2,2); 2(2,2); 2(2,2); 4(4,5); 2(2,3); 2(2,2); 2(2,2); 2(2,2); 2(2,2)	2(2,3)		3(3,4)				
1976	2(2,2); 3(3,4); 2(2,2); 2(2,2); 4(4,5); 2(2,2);	7(6,10)	2(2,3); 5(4,6); 3(2,4)	2(2,2)				

*Measurement listed for each car is: average of reflectors measured on car (lowest reflector measured, highest reflector measured).

TABLE A-1. REFLECTIVE INTENSITY MEASUREMENTS FOR REFLECTORS ON FREIGHT CARS (CONTINUED)

DATE CAR BUILT OR REBUILT	REFLECTIVE INTENSITY FOR CAR,* CANDELA/FOOT-CANDLE/FOOT^2							
	BOX	COVERED HOPPER	FLAT	GONDOLA	TANK	REFRIG-ERATOR	CABOOSE	WORK
1976 (cont)	2(2,2); 3(2,4); 2(2,2); 2(2,2); 2(2,2); 2(2,2);							
1975	2(2,2); 2(2,2); 2(2,2); 2(2,2)		3(2,4)					
1974	2(2,2); 2(2,2); 2(2,2); 2(2,2)				3(3,3); 2(2,2)			
1973	2(2,2)		2(2,2)	2(2,3)				
1972	2(2,2)		3(3,3)	2(2,2)				
1971	2(2,2)				3(2,7)			
1970		2(2,2); 2(2,2); 2(2,2); 3(3,3)						
1969	2(2,2); 2(2,2) 2(2,4); 2(2,2) 2(2,2); 3(3,3); 2(2,5); 3(3,3); 3(3,4)							
1968		4(2,10); 2(2,3); 4(3,5)						

*Measurement listed for each car is: average of reflectors measured on car (lowest reflector measured, highest reflector measured).

TABLE A-1. REFLECTIVE INTENSITY MEASUREMENTS FOR REFLECTORS ON FREIGHT CARS (CONTINUED)

DATE CAR BUILT OR REBUILT	REFLECTIVE INTENSITY FOR CAR* CANDELA/FOOT-CANDLE/FOOT^2							
	BOX	COVERED HOPPER	FLAT	GONDOLA	TANK	REFRIG-ERATOR	CABOOSE	WORK
1967	2(2,2); 2(2,3); 3(3,3); 2(2,2); 2(2,2)							
1966	2(2,2); 2(2,2)	3(3,4); 2(2,3); 4(3,8)						
1965			2(2,2)	2(2,2)		4(2,5)		
1961	2(2,4); 2(2,2)							
1960	2(2,2); 2(2,2)							

*Measurement listed for each car is: average of reflectors measured on car (lowest reflector measured, highest reflector measured).

APPENDIX B

RETROREFLECTIVE PRODUCTS

Information, characteristics, and prices of retroreflective products have been supplied by Advanced Vacuum Systems (Info, Inc.), Avery International, and the 3-M Corporation.

Product Bulletin

30

TRAFFIC CONTROL MATERIALS DIVISION

3M COMPANY

DATE: AUGUST 1, 1976

BARRICADE SHEETING FABRICATED FROM "SCOTCHLITE" BRAND RETRO-REFLECTIVE SHEETING HIGH INTENSITY GRADE, 5870 SILVER

I. GENERAL

This Product Bulletin describes the physical and optical properties of Barricade Sheeting fabricated from "SCOTCHLITE" Brand Reflective Sheeting High Intensity Grade, 5870 Silver. It is designed to reflectorize warning and safety devices used at construction or maintenance worksites.

Specific information on fabrication, maintenance, effective performance life, and other supportive data is found in the literature reference in Section IV.

II. DESCRIPTION

The Barricade Sheeting consists of "SCOTCHLITE" Brand Reflective Sheeting, 5870 Silver, with alternative six inch orange and silver (white) colored stripes that slope downward at an angle of 45° in the direction traffic is to pass. The alternating silver and orange stripes are similar in color when viewed in the daylight or as a retro-reflector under headlight illumination.

The design is in conformance with the design criteria for barricades in Section 6, C-2 of the Manual on Uniform Traffic Control Devices (MUTCD). The orange day colors conform visually with the appropriate Color Tolerance Chart issued by the Federal Highway Administration.

The entire area of silver (white) and orange is reflectorized so as to be visible under normal atmospheric conditions from a minimum distance of 1000 feet (304.8m) when illuminated by the legal low beams of standard automobile headlights.

Barricade Sheeting fabricated from "SCOTCHLITE" Brand Reflective Sheeting High Intensity Grade, 5870 Silver is available in 4", 6", 8", and 12" widths by 10 foot lengths (10.2 cm, 15.2 cm, 20.3 cm, and 30.4 cm by 3.05 m). The barricade sheeting with the right hand slope is coded HTBR-1R while the barricade with the left hand slope is coded HTBR-1L. Order must specify slope or code number.

III. PROPERTIES

This type Barricade sheeting is commonly used on Type I, Type II, or Type III barricades as described in the Manual on Uniform Traffic Control Devices, Section 6C, and may be used on marker panels.

A. Adhesive

5870 Sheeting barricade material has an aggressive pressure sensitive adhesive particularly suited for hand application at temperatures as low as -10°F (-23°C) and for application to moderately rough or porous, properly painted wood, metal, and plastic surfaces.

The adhesive will support a one (1) pound (0.45 Kg) weight, hung downward at 90° from the free end of a 1" x 6" (2.54 cm x 15.24 cm) strip. Four (4) inches (10.1 cm) of the strip is applied to a properly prepared, smooth aluminum surface and conditioned for 24 hours at standard conditions* after which the strip will not peel back more than 2 inches (5.0 cm) during the 5 minute test period.

B. Photometric

The brightness values of Barricade Sheeting fabricated from "SCOTCHLITE" Brand Sheeting, 5870 Silver, 0.2° and 0.5° observation angles** are expressed in average candlepower per foot candle per square foot (candelas per lux per square meter) at -4° and 30° entrance* angles in accordance with the testing procedure for reflective sheeting found in the Federal Highway

*Unless otherwise specified 73.4° ± 2°F (23° ± 1.1°C) and 50 ± 4% R. H.

** Observation Angle. The acute angle formed by lines drawn between the light source, a point on the reflector and a point on the receiver.

* Entrance Angle. The acute angle formed by a line drawn between the light source and [illegible]

Administration Specification FP-74, Section 718.01(a). Measurements must be made with the entrance and observation angles in the same plane.

	Silver		Orange	
Observation Angle	0.2°	0.5°	0.2°	0.5°
Entrance Angle				
-4°	250.0	95.0	70.0	25.0
30°	140.0	55.0	40.0	15.0

The barricade sheeting will show no appreciable loss in brightness when viewed at night with water (rain) totally wetting its surface.

C. Application

High Intensity Grade, Barricade Sheeting fabricated from "SCOTCHLITE" Brand Reflective Sheeting 5870 Silver is applied by hand using a plastic squeegee or a two (2) inch (5 cm) rubber roller.

Depending on application and exposure conditions, properly applied 5870 sheeting may wrinkle slightly. Cold, hand applications tend to wrinkle more than machine applications that use heat. The condition may occur immediately or during exterior exposure. Such wrinkling is not progressive and should not adversely affect the performance of the sheeting for its intended use.

For further information on substrate preparation and application procedures, refer to the information in the literature listed in Section IV.

The smooth surface of the Barricade Sheeting may be cleaned by rinsing first, then washing the surface with a mild detergent, followed by a final rinse. STEAM CLEANING IS NOT RECOMMENDED. Use cleaning materials that will not abrade the surface. To remove oil, or road film wipe the sheeting with a cloth dampened in heptane or mineral spirits, then rewash and rinse with clean water.

D. Effective Performance Life

The Effective Performance Life of Barricade Sheeting fabricated from 5870 sheeting will depend on the surface to which it is applied, the preparation of the surface prior to application, compliance with recommended application procedures, and exposure conditions and maintenance.

Applications to unpainted, or excessively rough or non-weather resistant surfaces or exposure to severe or unusual conditions may shorten the effective performance life. The user should be satisfied that such application is adequate for the intended use.

Application of this type Barricade Sheeting to surfaces exposed in other than vertical positions, such as the sides or backs of tank trucks, decks or roofs of vehicles will result in reduced effective performance life.

Properly applied applications made to recommended plastic substrates will have an effective performance life of up to two years. 5870 sheeting applied to sign base materials according to recommendations for traffic control signs will give effective performance for up to three years.

IV. LITERATURE REFERENCE

Application	
Cutting and Matching Instructions	LM-1F50
Sign Base Materials	LM-1F40
Maintenance	
Storage Maintenance and Removal Instructions	
Sign Fabrication and Maintenance Manual	LM-IF150 SMAINT
Cleaners, Strippers, and Maintenance Equipment for Reflective Sheeting	LM-IF151
Federal Specification, Section 633; Traffic Control Signs, Section 718.01(a), Testing Procedures	FP-74 (FHWA)
Sign Shop Practices Manual	LM-SSPM

GIJ 192 (1.6.0)

Traffic Control Materials Division 3M COMPANY
3M CENTER · SAINT PAUL. MINNESOTA 55101

Avery International

December 2, 1981

Reflective Products

250 Chester Street
Painesville, Ohio 44077
Phone 216/352-4444

Massachusetts Dept. of Transportation
TSC-DTS 732
Kendall Square
Cambridge, Massachusetts 02142

Attn: Jim Pomfret

Dear Jim:

As a follow-up to our conversation yesterday, I am enclosing some 1982 costs on our Durabrite™ High-Intensity reflective product. The price list attached is the typical pricing on the market. For large volume, and this would be in the nature of 25,000/sf and over, the price on colors would drop to $2.14/sf; colors include white.

In the matter of furnishing 6 x 18" pieces, if they were square cut we would be looking at an upcharge of $.05 per square foot. If on the other hand, we were talking about die-cut pieces that had rounded corners, and this I think is preferable for long-term adhesion, the price increase would be in the nature of $.08 or $.09 per square foot.

In the matter of the teflon overlay; as I mentioned, our company does not currently make a pressure-sensitive construction of this nature. However, in the volume that we are talking about we would certainly entertain the idea of providing such a protective sheet with an appropriate long life acrylic pressure-sensitive clear adhesive. On this construction at this time I can only give you a ballpark figure. The product: a 2 mil teflon with the long life acrylic adhesive would be in the nature of $.85 to $.95 per square foot. Should the project move along, I would, of course, be more than happy to arrange for lab samples and the like to demonstrate the effectiveness of the teflon coat.

One other thought comes to mind in that teflon is offered by several companies in a liquid container ususally a spray container that might be appropriate to apply once the reflective is installed on the car. This would serve the purpose of dirt prevention and also edge sealing at the same time.

I certainly want to thank you for your continued interest in our product and apologize for the delay that we have caused.

Cordially,

Robert M. Juckett
National Sales Manager

RMJ/amw

Advanced Vacuum Systems 30 Faulkner Street, Ayer, Massachusetts 01432 (617) 772-0712 Boston (617) 893-3476

29 October 1981

Mr. James C. Pomfret
U.S. Department of Transportation
Research & Special Programs Admin.
Kendall Square
Cambridge, MA 02142

Dear Mr. Pomfret:

In response to your inquiry I have done some further analysis of costs.

In large quantity production I estimate that we could supply retroreflective material of a grade equivalent to that used on the ACI program with a teflon coating for about $3/square foot.

Enclosed are samples of teflon coated material for your test. We would be pleased to provide up to 50 square feet of material at no charge and larger quantities at $5.00 per square foot for evaluation purposes.

If I can be of further assistance, please let me know.

Yours truly,

Norman R. Buck
President

NRB:gb

Encl: Samples

Avery International

October 27, 1981

Reflective Products

250 Chester Street
Painesville, Ohio 44077
Phone 216/352-4444

Mr. Bruce George
U.S. Federal Railroad Administration
Washington, D.C.

Dear Bruce:

I want to thank you for the time you were able to spend with Ralph Lundregan and me during our initial meeting. At that time, I mentioned that I would forward a letter to you outlining the capabilities of Durabrite™ high brightness reflective sheeting and a comparison of "Durabrite" versus Engineer Grade sheeting.

The basic performance difference between the two products can be broken down to two specific areas -- brightness and durability.

Brightness:

The obvious difference here is exemplified by the "head-on" SIA reading (candelas per footcandle per square foot).

White "Durabrite" - 250   White Engineer Grade - 70

Thus, "Durabrite" has approximately 3.5 times the specific brightness of the Engineer Grade product. I am enclosing the appropriate sections of FHWA Specification FP-79 so that you can make your own comparison of the two products at the various angles and in different colors. Table IV (page 271) is Engineer Grade and Table V-B is "Durabrite."

While it is obvious that there is a large gap in brightness between the two products initially, this difference will be compounded as the products accumulate the dirt and grime associated with railroad use. Should the products accumulate a surface layer that reduces their effectiveness by 50%, the resultant comparison of SIA values would read white "Durabrite" - 125 and white Engineer Grade - 35. Readings of 35 and lower may not be truly effective in the boxcar conspicuity program.

This "falloff" of Engineer Grade values is further complicated in the next section.

Mr. Bruce George
U.S. Federal Railroad Administration
October 27, 1981
Page Two

Durability:

By referring now to the chart on page 272 of FP-79, you will see the comparison of the materials classified as Type II (Engineer Grade) and Type III ("Durabrite"). This section describes the performance standard of the two products when submitted to accelerated weathering in a weatherometer. (Note: 1,000 hours of testing is equivalent to approximately 5 years of outdoor use; 2,200 hours is approximately 10 years.)

Again, a comparison of the two products after 5 years of simulated outdoor exposure would be white "Durabrite" - 200 (minimum) and white Engineer Grade - 35 (minimum). To pass the spec, "Durabrite" must have an SIA value of 200 at the end of 2,200 hours.

Because of the harsh environment in which the material will be used, I believe that these 5-year and 10-year time periods will be impossible to meet, but I am convinced that "Durabrite" will further widen the performance gap in a "real world" situation.

I hope this information is of interest and benefit to you, and I want to again mention Avery International's desire to work with you on this safety program.

Regards,

R. S. Macioci
Durabrite Market Manager

RSM:pg
Enc.

RETRO-REFLECTIVE SHEETING

DURABRITE™ REFLECTIVE SHEETING — December 1, 1981

STANDARD ROLLS LIST PRICES

PRESSURE-SENSITIVE

CODE	COLOR
7100	White
7101	Yellow
7102	Red
7104	Orange
7105	Blue
7107	Green

SIZE	PRICE
1″ × 50Y	$33.00
2″	66.00
3″	99.00
4″	132.00
5″	165.00
6″ × 50Y	198.00
7″	231.00
8″	264.00
9″	297.00

SIZE	PRICE
10″	$330.00
11″	363.00
12″ × 50Y	396.00
13″	429.00
14″	462.00
15″	495.00
16″	528.00
17″	561.00
18″ × 50Y	594.00

DISCOUNT SCHEDULE: (Based on single shipment to one destination)	Order Value at List Prices:	Discount
	$	List
	1,500-2,499	List less 5%
	2,500 +	List less 10%

Stock Assorting Privilege: All "Fasign" reflective sheetings may be combined to obtain best quantity pricing.

Minimum Order: $100.00

Terms: Net 30 days

Transportation Charges: Prices are F.O.B. Shipping Point with transportation charges allowed and prepaid via lowest cost routing to destination within the 48 continental states and District of Columbia.

Prices subject to change without notice.

See reverse side for complete Terms & Conditions of Sale.

AVERY INTERNATIONAL, Reflective Products / 250 Chester Street / Painesville, Ohio 44077 / Phone (216) 352-4444

FASIGN® REFLECTIVE SHEETING
TERMS AND CONDITIONS OF SALE

PRICE AND PAYMENT: All prices, unless stated otherwise herein, are F.O.B. shipping point and are exclusive of any present or future federal, state, local or other taxes applicable to the sale of products listed herein. Any such taxes shall be added to the price and paid by PURCHASER unless PURCHASER provides Avery International Corporation (AVERY) with a valid exemption certificate acceptable to AVERY and the appropriate taxing authorities. All prices are subject to change without prior notice; however, prices shall be those contained in the appropriate AVERY price list covering the products ordered and in effect on the "Entry Date" noted on the face of AVERY's Sales Order. Orders calling for future delivery shall be billed at prices in effect on the shipping date. Except as herein specifically provided, different products on an order may not be combined to obtain quantity pricing. Shipments which are more or less than the actual quantity ordered shall constitute filling the order if such variance does not exceed the following percentages: (i) 10%, for stock and custom orders where AVERY purchases standard materials; and (ii) 20%, for custom orders where AVERY purchases non-standard materials. PURCHASER shall be billed only for the quantity actually shipped plus, if applicable, trim loss.

The net amount of invoice shall be payable in full within thirty days following the date of invoice. A one percent discount is available if payment is received within fourteen days of date of invoice. Amounts not paid within thirty days of date of invoice will be subject to a late payment charge (charge) of 1.0% per month on the unpaid balance to be included on each month's invoice until paid. The imposition of such charge is not intended to infer any consent, acquiescence or other agreement, express or implied, on the part of AVERY to forbear or otherwise defer collection of such amounts when due. To the contrary, AVERY expects payment on or before the due date of each invoice and intends to take all necessary and feasible action to enforce prompt payment. PURCHASER confirms, acknowledges and agrees that it would be impracticable, extremely difficult and unduly expensive to attempt to determine the actual damage sustained by AVERY as the result of the default in payment of any individual account and that the charge of 1.0% per month referred to above represents a reasonable endeavor to fix AVERY's minimum probable loss resulting from delinquent payment, that such charge bears a reasonable relation to such loss and that such charge is reasonable in amount. It is expressly intended by AVERY and PURCHASER that this provision for late payment charges shall constitute a valid, binding and enforceable agreement for the payment of liquidated damages pursuant to Section 1671(b) of the California Civil Code and Section 2718)1) of the California Uniform Commercial Code. If in AVERY's opinion PURCHASER's financial condition does not justify continuance of production or shipment on the terms of payment specified, AVERY may require payments in advance. Failure of PURCHASER to pay any AVERY invoice by its due date makes all subsequent invoices immediately due and payable irrespective of terms and AVERY may withhold subsequent deliveries until the full account is settled.

ACCEPTANCE: An order once placed with and accepted by AVERY (all orders are subject to acceptance by AVERY's home office) may be cancelled only with AVERY's consent and upon terms that will indemnify AVERY against loss.

TITLE AND RISK OF LOSS: Title and risk of loss to all products purchased shall pass to PURCHASER upon delivery by AVERY to a common carrier, regardless of the freight terms stated or method of payment of transportation charges.

SHIPMENT AND TRANSPORTATION CHARGES: AVERY reserves the right to specify routing of shipments. AVERY shall attempt to ship within the time specified in AVERY's Sales Order, if indicated, and if not then within a reasonable time; and PURCHASER acknowledges that no claim may be made for delays in shipment where PURCHASER accepts the products. Unless specified in AVERY's Sales Order, freight charges shall be prepaid and billed.

COMPLIANCE: AVERY products are manufactured in compliance with all applicable requirements of the Fair Labor Standards Act, as amended, and all other applicable laws. Except as otherwise agreed in writing, normal tolerances in specifications shall not be cause to reject products.

RETURNS: Products sold by AVERY are returnable only in accordance with the warranty provisions hereof. Before returning any product, PURCHASER must obtain AVERY's written material return authorization and instructions.

LIMITED WARRANTY: All statements, technical information and recommendations concerning products sold or samples provided by AVERY are based upon tests believed to be reliable but do not constitute a guarantee or warranty. All products are sold and samples of products provided with the understanding that PURCHASER has independently determined the suitability of such products for its purposes. AVERY warrants the products to be free from defects in material and workmanship. Should any failure to conform to the warranty appear within one year (or the time period stated on the specific product specification sheet, if any, and if not then on the specific product information literature in effect at time of shipment, if longer than one year) after the initial date of shipment, AVERY shall, upon notification thereof and substantiation that the products have been stored and applied in accordance with AVERY's standards, correct such defects by suitable repair or replacement without charge at AVERY's plant or at the location of the products (at AVERY's election); provided, however, if AVERY determines that repair or replacement is not commercially practical, AVERY shall issue a credit in favor of PURCHASER in an amount not to exceed the purchase price of the products.

THIS WARRANTY IS EXCLUSIVE AND IS IN LIEU OF ANY IMPLIED WARRANTY OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR OTHER WARRANTY OF QUALITY, WHETHER EXPRESS OR IMPLIED, EXCEPT THE WARRANTY OF TITLE AND AGAINST PATENT INFRINGEMENT. NO WAIVER, ALTERATION, ADDITIONS OR MODIFICATIONS OF THE FOREGOING CONDITIONS SHALL BE VALID UNLESS MADE IN WRITING AND MANUALLY SIGNED BY AN OFFICER OF AVERY.

LIMITATION OF LIABILITY: In no event shall AVERY be liable for any incidental or consequential damages, including but not limited to, loss of profit, loss of use or production or loss of capital. The remedies of PURCHASER set forth herein are exclusive and the total liability of AVERY with respect to any contract, or anything done in connection therewith such as the performance or breach thereof, or from the manufacture, sale, delivery, resale, installation or use of any products whether arising out of contract, negligence, strict tort, or under any warranty, or otherwise, shall not exceed the purchase price of the products upon which liability is based.

ASSIGNMENT: Any assignment of this agreement or of any rights hereunder or hypothecation thereof in any manner, in whole or in part, without the prior written consent of AVERY shall be void.

NON-WAIVER: Failure by AVERY to insist upon strict performance of any of the terms or conditions hereof, failure or delay to exercise any rights or remedies provided herein or by law or to properly notify PURCHASER in the event of breach, or the acceptance of payment for any products hereunder, shall not be deemed a waiver of any right of AVERY to insist upon strict performance hereof or any of its rights or remedies, or as to any prior or subsequent default hereunder, nor shall any termination of this agreement operate as a waiver of any of the terms hereof.

FORCE MAJEURE: AVERY shall not be liable for any loss, damage, delays, changes in shipment schedules or failure to deliver caused by accident, fire, strike, riot, civil commotion, insurrection, war, the elements, embargo, failure of carrier, inability to obtain transportation facilities, government requirements, acts of God or public enemy, prior orders from others or limitations on AVERY's or its suppliers' products or marketing activities or any other cause or contingency beyond AVERY's control.

CHOICE OF LAW: This agreement shall be governed by and construed in accordance with the laws of the State of California.

ENTIRE AGREEMENT: These terms and conditions embody the entire agreement and understanding between the parties, are intended as a complete and exclusive statement of the terms of agreement regarding the products set forth on AVERY's Sales Order between the parties, and supersede any prior or collateral agreement or understanding between the parties relating to the subject matter hereof. PURCHASER acknowledges that AVERY has not made any representation to PURCHASER other than those which are specifically referred to or contained herein. Each paragraph and provision hereof is severable and if any provision is held invalid or unenforceable, the remaining provisions shall nevertheless remain in full force and effect.

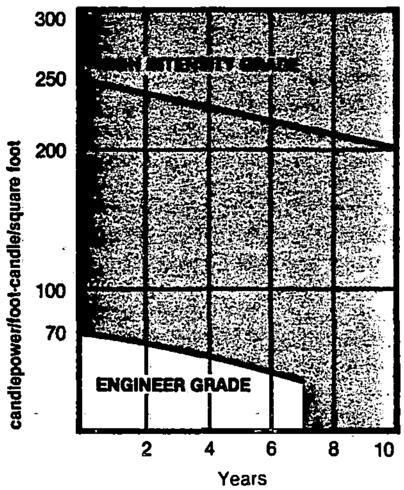
No salesman, representative or agent of AVERY is authorized to give any guarantee or warranty or make any representation contrary to those contained in these terms and conditions of sale.

Durability

High Intensity Grade sheeting is nearly three times brighter after ten years exposure than Engineer Grade enclosed-lens sheeting was on the day it was installed. At the point where the Engineer Grade sheeting retains 50 per cent of its original brightness, High Intensity Grade retains 80 per cent. High Intensity Grade reflective sheeting provides greater sign visibility both initially and during the life of the sign.

BRIGHTNESS RETENTION

MINIMUM SPECIFICATION BRIGHTNESS VALUE — SILVER



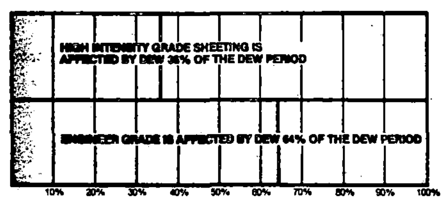
Dew resistance

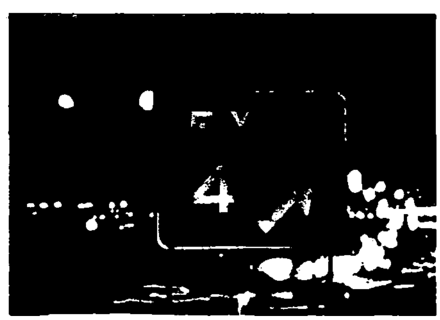
In areas where dew is common, moisture condensation can cause a blackout of sign legends and backgrounds. The tiny droplets of dew scatter the incoming light before it is reflected back to the driver.

High Intensity Grade sheeting slows the collection of moisture because the air pockets in the honeycomb structure beneath the sheeting's surface act in much the same manner as the air in a double-paned storm window. This reduces the temperature difference between the sign face and the surrounding atmosphere and minimizes condensation. Thus High Intensity Grade offers a tremendous safety advantage over other types of sheeting in areas highly affected by dew.

DEW RESISTANCE

TOTAL DEW AFFECTED PERIOD





Source: Traffic Control Materials Division/3M

Pamphlet LM-HIBCB (71.75) MP
3-M Corporation
St. Paul, MN

APPENDIX C

DETAILED ANALYSIS OF REFLECTORIZATION COST AS A FUNCTION OF AREA

This appendix contains determination of the reflector area which minimizes the life-cycle costs of washing and replacing reflectors.

C.1 REFLECTOR DEGRADATION EQUATION

The engineer grade material tested in Canada (Chapter 3) was found to have an initial retroreflectance of 94 cd/ft-cd/ft^2 which dropped almost immediately to 35.8 cd/ft-cd/ft^2 and then appeared to diminish exponentially with time. Letting R(t) stand for reflective intensity and t for time (in years), the reflective intensity at time t, based on a least squares fit of the Canadian data is given by

$$R(t) - R_o(\frac{35.8}{94}) \exp (rt) = R_o(.3809) \exp (rt) = R_o(.3809) \exp (-.9872t)$$

where R_o is the initial reflective intensity.

The decay coefficient of -.9872 combines the effects of dirt accumulation and material aging. In order to determine the effect of dirt alone, the deterioration with age must be quantified. The reflective intensity of engineer grade material is specified to drop to no less than half its original value in seven years under normal conditions of use. This implies decay at a rate given by

$$R = R_o \exp (-.099t) \qquad \text{(engineer grade; normal conditions)}$$

It is assumed that deterioration of reflectors in the railroad environment occurs twice as rapidly as for the highway conditions for which the specifications are intended. Thus, in railroad use, as in Canada, deterioration can be expected to be according to

$$R = R_o \exp[2(-.099)t] = R_o \exp(-.198t) \text{ (engineer grade; railroad conditions).}$$

Thus, the Canadian result, which shows a total deterioration time constant of -.9872, is assumed to be composed of an age effect which contributes -.198, and a dirt effect which contributes -.7892.

These results show that material with initial reflectance of R_o deteriorates due to dirt alone according to the equation

$$R(t) = R_o [(.3809 \exp(-.7892t)].$$

High intensity reflective material also shows decay due to ultraviolet light and other aging effects, but at a substantially slower rate than engineer grade. Federal Highway Administration (FHWA) specifications for high intensity sheeting require that it retain 80% of its original reflective intensity after 10 years of service. In view of the harshness of the railroad environment, it is again assumed that deterioration with age is twice as fast for reflectors on railcars as it is for reflectors in highway applications. The drop to 80 percent in 10 years implies a decay constant of -.0223; doubling this value to adjust for the railroad case yields the equation

$$R(t) = R_0 \exp(-.0446t) \quad \text{(high intensity, railroad environment).}$$

Reflectors mounted on freight cars will be subjected to periodic cleaning and less frequent periodic replacement. Letting t_w denote the time in years since the last cleaning and t_r the time in years since the last replacement, the reflective intensity for reflectors with initial intensity of R_0 is given by

$$R(t_w, t_r) = R_0 \, (.3809) \exp(-.7892t_w) \exp(-.0446t_r).$$

FHWA specifications and manufacturers' guarantees state that the initial reflectance of high intensity material will be 250 cd/ft-cd/ft^2. Thus, for high intensity reflectors

$$R(t_w, t_r) = 250(.3809) \, [\exp(-.7892t_w)] \, [\exp(-.0446t_r)]$$

$$= 95.23 \exp(-.7892t_w - .0446t_r).$$

C.2 REFLECTOR AREA

The requirement for total reflectivity (established in Chapter 4) is that the reflector must return at least 45 candelas per foot of incident light. Thus, the area of the reflector, A, must satisfy the condition that

$$A \times \text{(reflective intensity)} \geq 45.$$

Using the results of the previous section, it follows that

$$A \times 95.23 \exp(-.789t_w - .0446t_r) \geq 45$$

or

$$A \geq .4725 \exp(.7892t_w + .0446t_r)$$

where t_w represents the time since the last wash and t_r represents the time since the last replacement.

C.3 DETERMINATION OF OPTIMAL REFLECTOR SIZE

Determination of the optimal reflector size consists of balancing installation costs and maintenance costs. Large reflectors have high material and installation cost but require less frequent cleaning. Small reflectors have low initial cost but high maintenance costs. The following analysis identifies the area that has the minimum total cost for material, labor, and maintenance.

The annual cost of reflectorization, C, is given by the following expression, where T_w is the maintenance period and T_r is the replacement period:

$$C(T_w,T_r) = \text{material costs} + \text{installation costs} + \text{maintenance costs.}$$

In the following analysis we require that the replacement interval be a multiple of the wash interval. This is not strictly necessary, but in light of implementation practicalities is highly desirable. For a given pair (T_w,T_r) the area is determined so that the reflectivity constraint,

$$A \geq .4725 [\exp(.7892t_w + .0446t_r)],$$

is met as an equality immediately prior to replacing the reflectors, that is, when $t_w = T_w$ and $t_r = T_r$.

Figure C.1 is a graph of the intensity of a reflector with area A that is replaced after T_r years and washed every T_w years, where in this example, $T_r = 6T_w$.

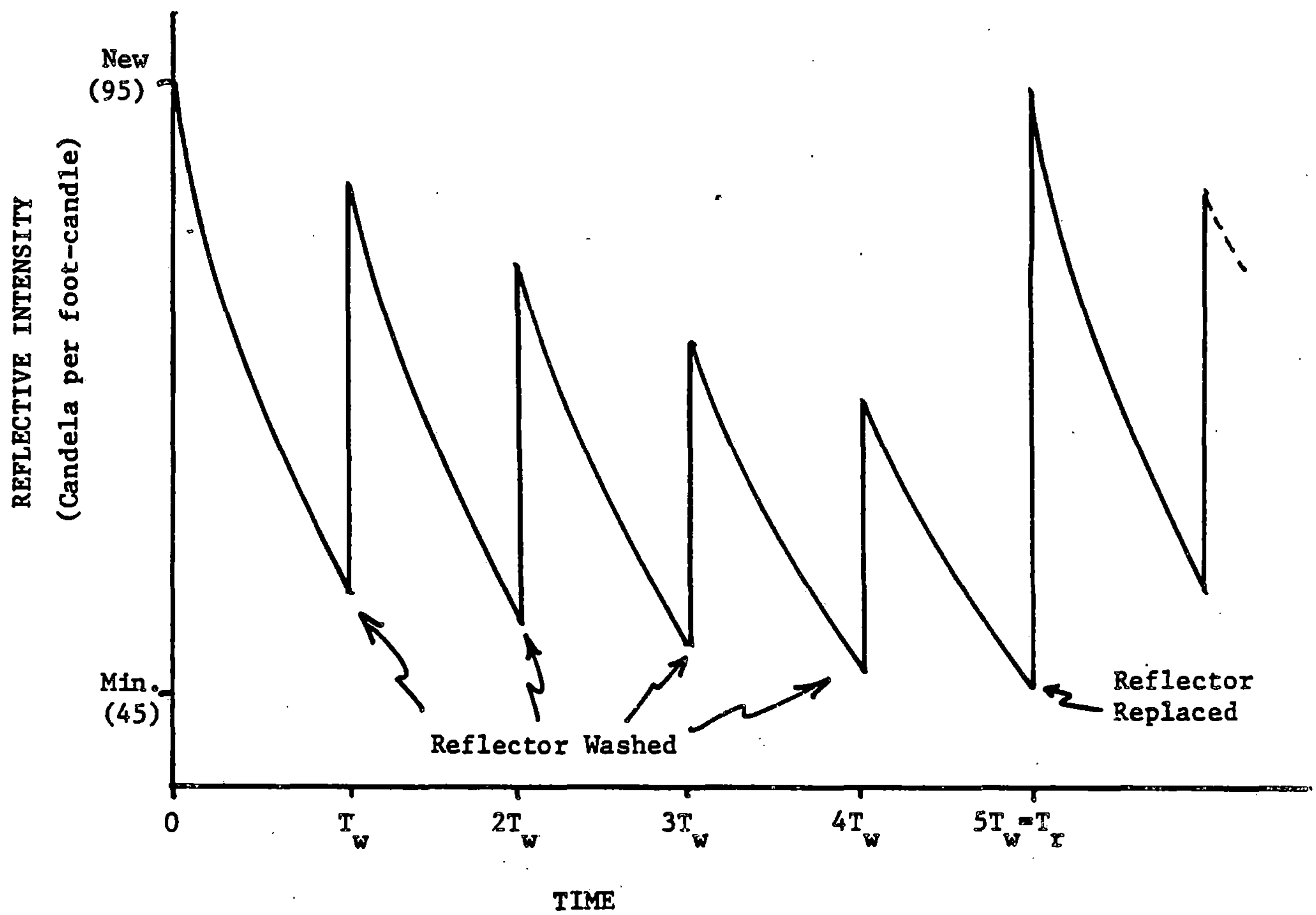


FIGURE C-1. REFLECTOR BRIGHTNESS VERSUS TIME FOR A WASH PERIOD OF T_w AND A REPLACEMENT PERIOD OF T_r

At time T_r the intensity has degraded to 45 and the reflector is replaced. thus, as a function of T_r we have for area,

$$A \times [95.23 \exp(-.7892T_w - .0446T_r)] = 45$$

or

$$A = .4725 \exp(.7892T_w + .0446T_r).$$

In the following sections the combination of values for T_w and T_r that results in the lowest annual cost will be determined. Also, the equation for area derived above will be used to calculate the optimal reflector size.

C.3.1 Material Costs

Average cost of reflective material, including cutting, transportation and railroad handling costs, is \$3.01 per square foot. Analysis of the distribution by length of the 1.71 million cars in the U.S. freight car fleet shows that an average of 8.36 reflectors are needed per car. Thus, the total reflective material required is (1.71) x (8.36) x A, where A is the area of a reflector. The total cost is (1.71 million cars) x (8.36 refl. per car) x \$3.01 per foot^2) x A (area), or \$43.03A millions. If this material is left in place for T_r years, then the average annual cost is

$$\text{Annual Material Cost} = \frac{43.03A}{T_r}.$$

C.3.2 Installation

Tests with 1.25 ft^2 reflectors have shown that the average time per car assumed necessary for application in the field is .69 hours. Larger reflectors will require more time, although a certain amount of setup time is required which is independent of reflector size. The average time required to install reflectors having area A can be expressed as

$$T = (.69)\ (.5 + \frac{.5}{1.25}A)$$

which assumes that .34 hours of setup time are required per car and that the remaining time is proportional to the area.

The AAR Office Manual of Interchange Rules indicates that a total labor rate of \$39.28 is appropriate for the job of installing reflectors. Thus, the total cost for installation, expressed in millions of dollars, is

$$C = (1.71) \times (.69)\ (.5 + \frac{.5}{1.25} A) \times (39.28),$$

which reduces to

$$C = 23.17 + 18.54A$$

The annual cost is found by dividing by the replacement period, T_r,

$$\text{Annual Installation Cost} = \frac{23.17 + 18.54A}{T_r}$$

C.3.3 Maintenance Costs

The average time required to clean the reflectors on freight cars is assumed to be .28 hours per car (Chapter 3) and is not sensitive to variation of area within the range considered in this analysis. In the steady-state situation, the proportion of cars requiring cleaning each year is $(1/T_w - 1/T_r)$ since a fraction $1/T_r$ of the reflectors will be replaced rather than washed. Thus, the annual washing cost is

$$\text{Annual cost of Washing} = (1.71)\left(\frac{1}{T_w} - \frac{1}{T_r}\right) \times (.28)\ (39.28)$$

$$= \frac{18.81}{T_w} - \frac{18.81}{T_r}$$

Under circumstances in which it is necessary to assure compliance with the stated washing and replacement intervals, the freight car must be stenciled to indicate action taken and the date each time a reflector is washed or replaced. The AAR Office Manual of Interchange Rules states that stenciling both sides of a freight car costs \$28.83 per car. Thus, the annual stenciling cost is

$$\text{Annual Stenciling Cost} = \frac{28.83 \times 1.71}{T_w} = \frac{49.30}{T_w}$$

C.3.4 Annual Cost Equation

In a previous study of reflectorization, it was estimated that 5 percent of reflectors would be found to be damaged or missing each year. Thus, when maintenance is done an annual average of 5 percent or 85,500 freight cars will require new reflectors each year. Since each car requires an average of 8.36 reflectors which cost \$3.01 per square foot, replacement adds

$$\text{Annual Material Replacement Cost} = (.0855)\ (8.36)\ (\$3.01)A - 2.15A$$

to the annual material costs. Similarly, the annual installation labor costs are increased by

$$\text{Annual Material Installation Cost} = (.0855)\ (.69)\ \left(.5 + \frac{.5}{1.25}A\right) \times 39.28 = 1.16 + .93A$$

Thus, the annual costs for replacing 5 percent of the reflectors are,

$$\text{Total Annual Replacement Costs} = (2.15A) + (1.16 + .93A) = 1.16 + 3.08A$$

Since the replaced reflectors will not have to be washed, the annual maintenance (washing) costs are reduced by 5 percent, becoming

$$\text{Maintenance Cost} = .95\left[\frac{18.81}{T_w} - \frac{18.81}{T_r}\right] = \left[\frac{17.87}{T_w} - \frac{17.87}{T_r}\right]$$

By combining the costs of replacing reflectors with the previously determined costs, the following equations for annual costs result:

$$\text{Material \& Installation} = \left[\frac{43.03A}{T_r} + \frac{23.17 + 18.54A}{T_r}\right] + 3.08A + 1.16$$

$$\text{Maintenance} = \left[\frac{17.87}{T_w} - \frac{17.87}{T_r}\right]$$

$$\text{Stenciling} = \frac{49.30}{T_w}$$

Adding these three terms together results in the annual cost equation,

$$C(t_r,t_w) = \frac{60.90A}{T_r}\ \frac{5.30}{T_r}\ \frac{67.17}{T_w} + 3.08A + 1.16.$$

Substituting in that $A = .4825 \exp(.7891T_w + .0446T_r)$, it is found that

$$C(T_R,T_W) = \frac{28.78 \exp(.7892T_W + .0446T_R)}{} + \frac{5.30}{T_r} + \frac{67.17}{T_w}$$

$$+ (1.46) \exp(.7892T_w + .0446T_r) + 1.16$$

is the annual cost of maintaining reflective markings on freight cars, with T_r an integer multiple of T_w. Table C-1 displays values of C for different combinations of T_r and T_w.

TABLE C-1. ANNUAL COST AND REFLECTOR AREA FOR DIFFERENT COMBINATIONS OF WASH AND REPLACEMENT PERIODS

Replacement Period (months)	Wash Period (months)	Reflector Area (sq. feet)	Annual cost ($ millions)
96	12	1.49	84.9
96	16	1.93	72.9
96	24	3.27	70.4
108	12	1.55	84.2
108	18	2.31	69.2
120	12	1.62	83.8
120	15	1.98	73.6
120	20	2.75	67.4
120	24	3.58	68.1
132	12	1.70	83.5
132	22	3.28	66.5
144	12	1.78	83.3
144	16	2.31	70.8
144	18	2.64	67.9
144	24	3.91	67.1
156	12	1.86	83.1
156	13	1.98	79.0
168	12	1.94	83.1
168	14	2.23	75.6
168	21	3.51	66.0
168	24	4.28	66.9

Figure C-2 shows the annual cost curves for both a 120-month (10-year) replacement cycle and a 168-month (14-year) replacement cycle where the cost is determined for different wash periods.

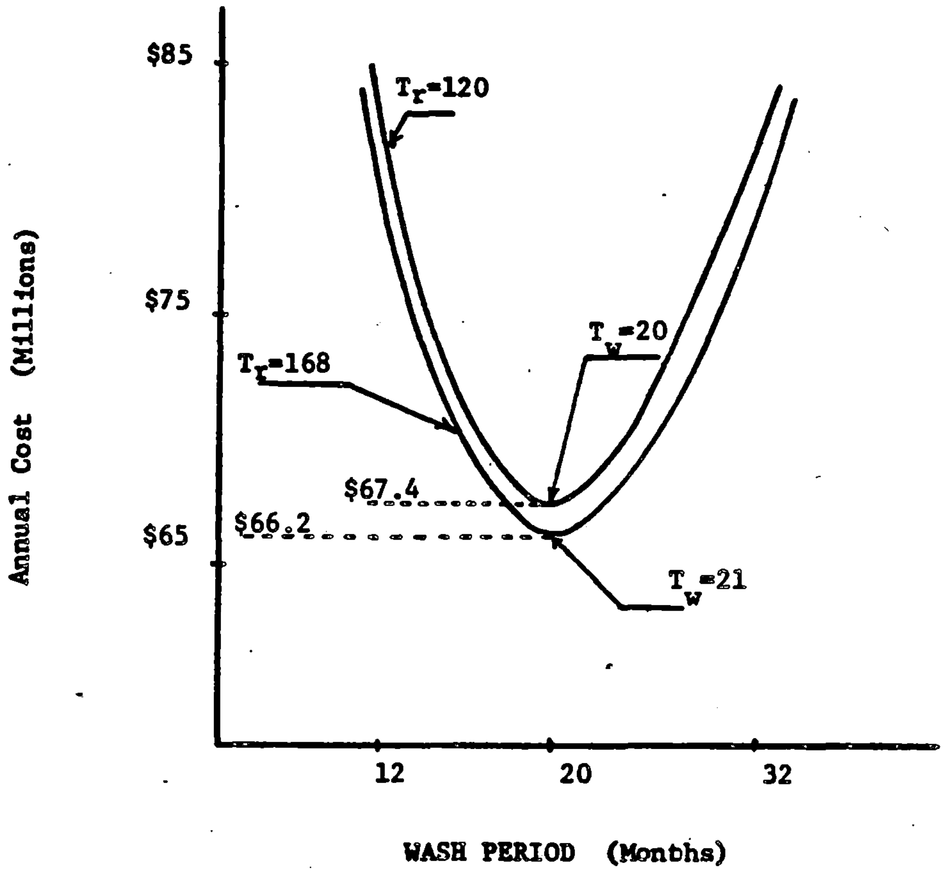


FIGURE C-2. ANNUAL REFLECTORIZATION COST AS A FUNCTION OF WASH PERIOD

If no further constraints are placed on T_w, T_r, or the area of a reflector, then the annual cost function has a minimum value of $66.2 million which occurs when T_w = 21 months and T_r = 168 months. For this combination of T_w and T_r the necessary area would be 3.51 square feet.

However, manufacturers of high intensity material guarantee performance only up to 10 years in a highway environment, which implies that ten years is an upper bound on the useful life of high intensity material in railroad use. Thus, the constraint on T_r is

$T_r \leq 120$ months

With this constraint, the cost function has a minimum value of \$67.4 million when $T_w = 20$ and reflector area is 2.75 square feet. Thus, based on the assumptions described above the minimum cost reflectorization policy calls for reflectors with an area of 2.75 square feet, to be replaced after 120 months and washed every 20 months.