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TECHNICAL REPORT

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U. S. ARMY TARADCOM

Framework for Ultrasonic Inspection in the Army Tire Retread Process

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FOREWORD

The work described in this report was performed by the GATX Corporation, GARD, INC., 7449 N. Natchez Avenue, Niles, Illinois 60648 for the U.S. Army Tank-Automotive Research and Development Command under Contract No. DAAK30-78-C-0034. The work was administered under the direction of Army Project Engineer Robert Watts of TARADCOM, Warren, Michigan.

The work covered by this report was performed at GARD in the contractor's NDT Systems Group under W. Lichodziejewski, Manager, by I. R. Kraska, Project Engineer and Principal Investigator, with the assistance of T. A. Mathieson, Research Engineer. The authors gratefully acknowledge the technical assistance provided by the Army Project Engineer and the field testing assistance of Mssrs. Crews and Wallraven of the Red River Army Depot (RRAD) and of Reginald Bragg, Director of Quality, U.S. Army Depot Activity, Ober-Ramstadt, Germany.

This report covers work conducted during the period of October 1978 to April 1979. It was submitted by the authors in May 1979.

This project has been accomplished as part of the U.S. Army Materials Testing Technology Program, which has for its objective the timely establishment of testing techniques, procedures or prototype equipment (in mechanical, chemical, or nondestructive testing) to insure efficient inspection methods for materiel/material procured or maintained by DARCOM.

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ABSTRACT

The reported work is part of a larger Army program to evaluate the benefit from using ultrasonic tire inspection, a Tire Degradation Monitor (TDM), in the Army Tire Retread System.

The objectives of this work were to:

a) develop a closed loop test plan to direct the Army ultrasonic tire inspection evaluation of the TDM,

b) perform a field test of the plan at RRAD,

c) analyze resultant RRAD inspection data to determine tire suitability for retreading and the corresponding TDM ultrasonic measurement correlation, and

d) develop the mathematical model for a cost analysis to be performed with the data obtained in the closed loop evaluation (scheduled for the Army Depot Activity, Ober-Ramstadt).

This final report presents (a) the results of a field evaluation of the test plan (the plan was completed earlier in the program and submitted under separate cover), and (b) a model for an economic analysis to be performed with the data obtained in a subsequent closed loop evaluation (scheduled for June 79 in Ober-Ramstadt).

In summary, we show that a viable evaluation plan was developed, field tested and is ready for use in the planned evaluation. The RRAD ultrasonic tire inspection data analysis verifies previous data (Yuma Proving Grounds (YPG)*) and indicates the potential for cost savings. The framework for the cost savings analysis provided herein delineates the suggested analysis rationale and indicates the data required to provide a viable economic analysis.

* Mathieson, T. A., "Using Ultrasonics to Establish Maintenance Expenditure Limits for Tires", November, 1974.

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Section 1

OBJECTIVE

This reported work is part of a larger program to evaluate the benefit from using ultrasonic inspection (TDM) in the Army Tire Retread System.

The objectives of this reported work were to:

a) develop a closed loop test plan to direct an Army ultrasonic tire inspection evaluation of the TDM,

b) perform a preliminary field test of the plan at RRAD,

c) analyze resultant RRAD tire inspection data and use the data to verify the developed cost analysis model, and

d) develop the model for a cost analysis to be performed with the data obtained at RRAD and in the closed loop evaluation (scheduled for Ober-Ramstadt).

The overall objectives of the TARADCOM inspection program are to:

1) determine the ultrasonic inspection-related savings which can be attributed to reduced tire failures during the retread process or to fewer rejected tires after retreading, and

2) determine the effectiveness of the Tire Degradation Monitor (TDM) as both pre and post-retread inspection equipment by determining the degree of correlation between the digital ultrasonic tire reflection measurements to both tire casing quality and remaining useful tire life.

Section 2

SUMMARY AND CONCLUSIONS

2.1 Summary

2.1.1 Evaluation Test Plan

A TDM Evaluation Test Plan was developed earlier in the program and submitted under separate cover. The test plan included a brief discussion of previous work leading to the development of the TDM, identified various parameters which affect TDM readings, and recommended approaches for controlling or eliminating their influence. To aid Army personnel in the TDM evaluation, it also provided the following: TDM operating instructions, test procedures, instrument calibration procedures, inspection guidelines, and information on the process effects on retread quality.

2.2.1 Training and Demonstration

Visits were made to RRAD and Ober-Ramstadt Depot Activities to provide in-plant demonstration of the inspection equipment and training of candidate operating personnel. In addition, reviews were held with Ober-Ramstadt Activity personnel and field test activities, and modifications to the test plan were accomplished to reflect the inputs.

2.3.1 Test Plan

Following the development of the Test Plan, a TDM was placed in the RRAD retread facility to verify the plan prior to implementing it at Ober-Ramstadt. The verification test was to identify any interface problems or usage restrictions, determine equipment maintenance support requirements, and provide quantitative and qualitative performance data for the economic analysis.

2.4.1 Cost Analysis Model

To provide a cost justification for the implementation of a new inspection procedure (i.e., use of the TDM), an economic analysis related to the procedure should be established. Therefore, the model for a cost analysis procedure was developed. It describes the suggested rationale for cost saving analysis and indicates the information required to provide a viable economic analysis to show the potential net savings which could be realized by eliminating code H* tires from the retreading process. This work was done during Phase I of the program to insure that all data input requirements were identified before the Test Plan was developed and field evaluated.

2.5.1 RRAD Data Results

1525 tires were inspected at RRAD by Army personnel both prior to and after retreading using the test plan procedures. The RRAD data had been analyzed and shows a direct correlation between low TDM measurements, 0 to 40% (TDM digital reading of 6) of the TDM calibration point, and Code H tires (that is, tires not suitable for retreading). The RRAD ultrasonic inspection results also support a previous ultrasonic inspection of tires performed at YPG. Data from the YPG evaluation showed that tires which gave an ultrasonic measurement of less than 40% of the calibration point failed more frequently or had a shorter tread life expectancy than tires which had ultrasonic signals greater than the 40% calibration point. The data showed a natural grouping of tires into 0-6 and 6 - 20 ranges.

Table I summarizes the results of 1489 tires. Not included in the summary are tires which had bead damage or excessive section repairs. The data show for the 0 to 3 or 0 to 6 range the total number of tires correctly identified as Code H by the TDM was 35 to 53%. The table also indicates that about 49%

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* Code "H" Unserviceable - Uneconomically repairable.

TABLE 1 - INSPECTION RESULTS

TDM DIGITAL READING (N)	NO. OF CODE H TIRES W/READING ≤ N.	NO.OF RETREADED TIRES W/READINGS ≤ N	TOTAL NO.TIRES W/READINGS ≤ N	CORRECT TDM PREDICTION OF CODE H TIRES W/READINGS ≤ N %	TOTAL NO. CODE H TIRES	PERCENT CODE H IDENTIFIED
3	121	227	348	34.8	349	34.8
6	185	390	575	32.2	349	53

TDM DIGITAL READINGS	NO.OF CODE H TIRES NOT IDENTIFIED BY TDM	TOTAL NO.OF TIRES W/READINGS > N	% OF CODE H TIRES W/DIGITAL READINGS > N	PERCENT OF TIRES RATED CODE H BY TDM %	PERCENT CODE H TIRES CURRENT INSPECTION
3	228	1141	20	38.7	23.4
6	164	914	17.7	49.6	23.4

of the candidate retread tires would be rejected, designated Code H, based on a combination of both TDM and current screening process. The current screening process identified 23% of the tires as Code H. Thus, for every 100 casings turned in for retreading an additional 16 to 26 casings would be designated Code H and would have to be replaced by new assets. This requirement of new assets based on ultrasonic tire inspection may appear excessive with only the RRAD data as supporting evidence. However, what is not known from the current data is the life expectancy of the additional 15 to 26 tires in a hundred that would be rejected. If these tires were to be expected to fail prematurely or have low remaining useful life, then the ultrasonic decision to reject them would be justified. For example, of 89 tires from the YPG test, 53 tires experienced either road hazard or casing failures. Of the 53 tires, 77% had ultrasonic measurements below 40% of the calibration point. Without prior knowledge of the anticipated operational environment of the tire, ultrasonic inspection of tires may not be a predicator of road hazard failures. However, it is felt that casing failures due to tire degradation can be predicted with ultrasonics. Unfortunately, the YPG data summary did not differentiate between road hazard and casing failures. However, the 77% correct failure prediction provides an initial guideline for the Ober-Ramstadt evaluation. The determination of the expected remaining life of these ultrasonically inspected and designated Code H tires will be made from data generated from the Ober-Ramstadt evaluation during Phase II of the program.

2.2 Conclusions

2.2.1 Test Plan Evaluation

The initial evaluation of the Test Plan as conducted at RRAD demonstrated that the evaluation of the TDM on military tires can be accomplished most satisfactorily. With detailed procedures (i.e., test plan) it is possible to train field personnel to perform the calibration, inspection, and data record keeping required for the TDM evaluation. Based on the RRAD work, there were no serious problems encountered with the test plan and it is ready for field use.

2.3.1 Cost/Benefit Structure

An economic analysis model was developed and is ready for TDM evaluation results from Ober-Ramstadt. This test plan will enable TARADCOM to assess presently used (visual) quality control inspection compared to the advanced (pulse-echo ultrasonic) inspection, on a cost-effectiveness basis.

2.4.1 RRAD Data Evaluation

The inspection of 1525 tires at RRAD (both prior to and after retreading) have in addition to checking out the Test Plan provided two principal conclusions:

The first is that TDM inspection can preferentially select out Code H casings (especially those so-classified by ozone or weather checking) and that the average TDM indications of Code H and of code-acceptable casings are significantly different with a confidence level in excess of 97%. Nothing can be said about those casings which were visually code-acceptable but TDM-rejectable because once Red River releases a retread, it loses all control and knowledge of that retread's fate.

The second conclusion of this evaluation is that the TDM "red-light" indication has not been proved to be a reliable predictor of casing quality. Although this indication tends to preferentially select out Code H casings judged so by having separations, it rejects less than 30% of such casings and does so by also rejecting a large number of code-accepted casings of unconfirmed quality. In summary, this evaluation, by the limited extent of the data has demonstrated more that a correlation exists between the TDM measurements and tire suitability for retreading than it has identified the quantitative criterion by which to perform the rejection of tire casings prior to retreading.

In addition to the above, the results of this field test uncovered some potential problem areas. When calibrating the instrument, an inspector not familiar with the operation of electronic equipment may have problems in reliably setting the calibration. The operator must be completely familiar with the unit and with the inspecting techniques. When the signals which the TDM probe generates inside a tire are displayed on an oscilloscope, an experienced operator is required to detect, locate, and evaluate such irregularities as poor tread bonds and local defects.

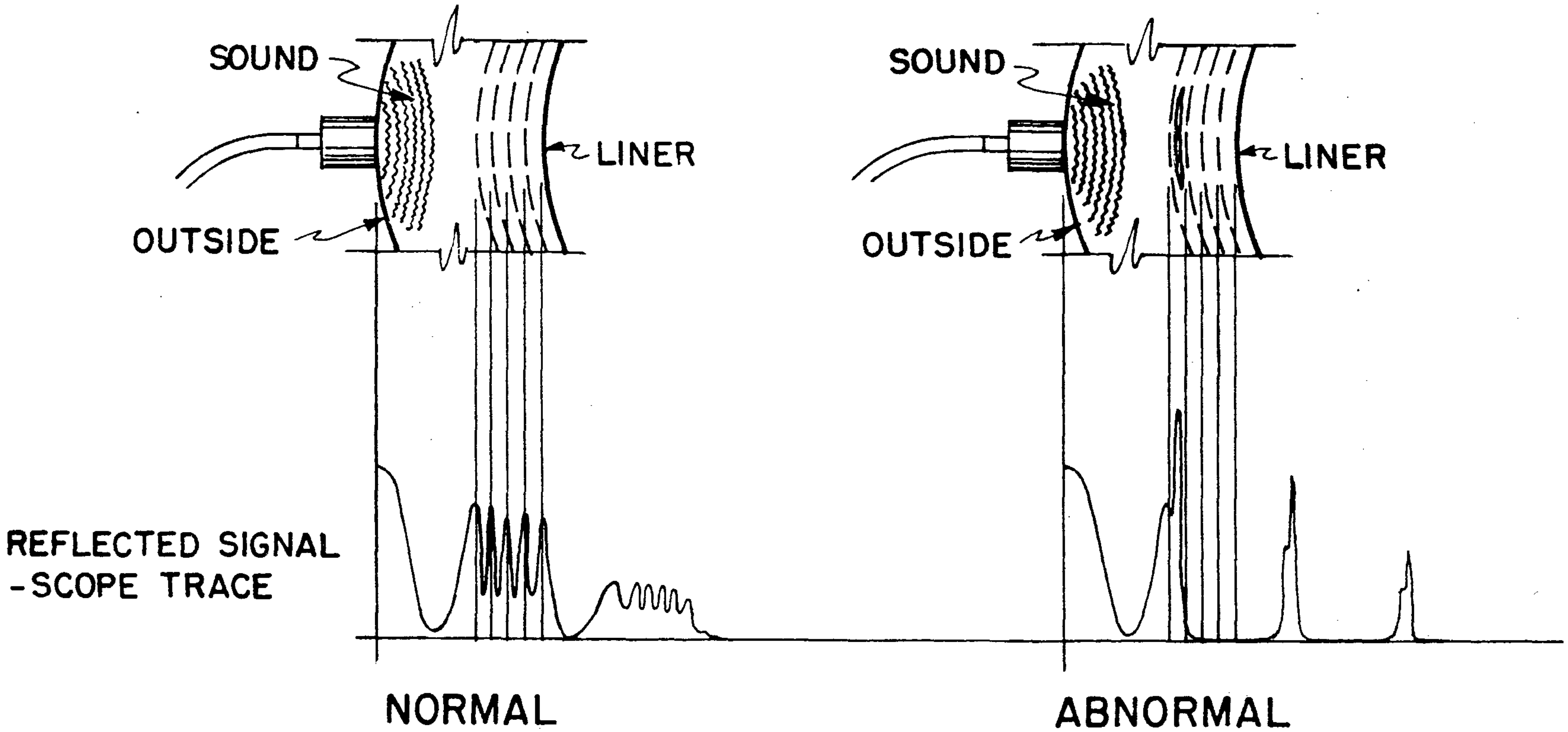
Further, it was observed that when tire testing is performed in an area where there is a large temperature variation (about $30^{o}F$ to $110^{o}F$) and on tires with large rubber thickness range (i.e., pre vs. post-retread), there is a need for automatic temperature compensation of the automatic gain control circuitry. This is due to the fact that tread rubber thickness and temperature affect the ability of the tread rubber to transmit sound.

Section 3

RECOMMENDATIONS

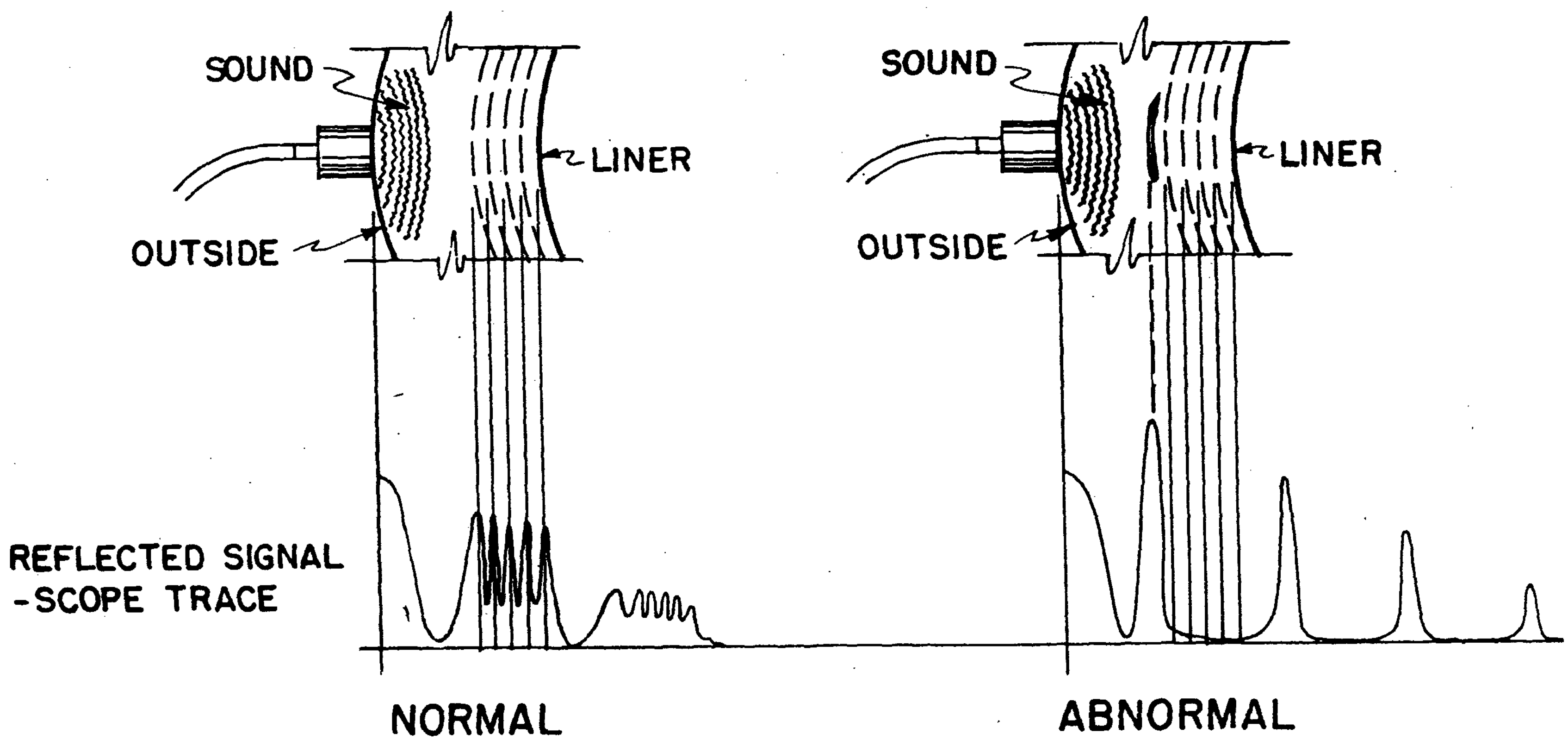
Because Red River Army Depot had no facility to keep track of the monitored casings after retreading, a great deal of ambiguity exists concerning the nature and fate of those casings visually judged code-acceptable and exhibiting TDM readings low enough to effectively reject a substantial fraction as Code H casings. Similar statements can be made concerning those casings exhibiting "red-light" indications and those casings having post-retread TDM readings increased over their pre-retread inspection value. Therefore, the first recommendation is that the subsequent service life of each casing inspected be recorded during the evaluation at Ober-Ramstadt. The TDM should be capable of predicting the remaining service life of a casing, but the present evaluation has only demonstrated its ability to selectively reject Code H casings.

A second recommendation relates to the modes of behavior of the "red-light" indications. With the TDM properly calibrated, the "red-light" indication will appear only when the energy of the reflected beam is about 100% in excess of that reflected from a tightly-bound cord-rubber matrix typical of the ply layers of a new, sound tire. This can happen when the rubber separates from the cord creating a highly-reflective rubber-to-air interface or when the adhesion between the buffed casing and the tread rubber is so poor as to create another highly-reflective surface. Figure 1 illustrates the first case with the corresponding oscilloscope pattern of the reflected signal. Likewise, Figure 2 illustrates the second case with its corresponding oscilloscope pattern of reflection. If the second condition is present in a retread candidate tire, it is possible that this poorly bonded tread could yield a "red-light"



A-8 **COMPARISON OF NORMAL TIRE ULTRASONIC SIGNATURE WITH INCORRECT TIRE — SEPARATION BETWEEN FIRST & SECOND PLIES**

Figure 1



A-7 **COMPARISON OF NORMAL TIRE ULTRASONIC SIGNATURE WITH INCORRECT TIRE — SEPARATION**

Figure 2

indication which could possibly mask the recognition of an otherwise sound casing. To prevent this, pattern recognition must be employed by either having a highly skilled and experienced inspector interpret the return echo, or by designing a machine to process and classify the echo.

As a consequence of this, we recommend that the TDM be further developed to incorporate control and signal processing using microprocessor technology. Such a TDM could, in addition to processing and bond-line and ply-layer discriminations discussed above, maintain its own calibration by compensating for tread-depth and temperature variations in the intensity of the return signal. In fact, by designing the TDM to run under the control of a microprocessor, it could not only be self-calibrating but could also have access to a repertoire of automatic search procedures to be used in the event it sensed an unusual return echo pattern. GARD's experience in developing microprocessor-controlled systems for field use indicates the feasibility of our developing a sturdy microprocessor-based TDM capable of battery or power-line operation and automatic compensation for ambient temperature and tread depth.

Based upon the favorable results obtained at RRAD, the start of Phase II of the program is recommended. It includes the closed loop data collection on about 1500 tires in a range of tire sizes and construction. The ultrasonic data generated from the test will be analyzed and the current RRAD results consolidated with this new data. Together, the data generated from the field tests will be used with the economic analysis framework to determine the economic benefits of pre- and post-retread ultrasonic predictions of remaining useful tire life.

Section 4

INTRODUCTION

4.1 Background

GARD, INC. has over the past several years conducted a series of research projects and built an electronic nondestructive test system for TARADCOM for measuring casing quality of worn tires prior to retreading. The first system developed was an ultrasonic pulse-echo tire scanner shown in Figure 3. This system can find both localized defects (i.e., nail holes, breaks, separations, etc.) and a generalized casing quality we have called degradation. This scanning system has been used at GARD to examine more than 500 tires and at the Red River Army Depot and the Army Depot Activity in Germany in the military retread plants.

During the course of the Army program, GARD discovered a phenomenon which research has shown to be a fundamental mechanism of tire failures: tire degradation. The first contact with the tire degradation mechanism came during another Army Contract (DAAAE07-73-C-0271) which was an investigation of moisture effects on tire retreadability. This program demonstrated that approximately 10% of the nylon cord tires (truck-type) would absorb moisture into the ply area if the ply area were exposed directly to water (from cuts or holes). There were no consistent patterns as to manufacturer, year, cord size, tire size, wear, etc. to explain this 10%. These hygroscopic tires were compared ultrasonically to the normal 90%. Tire data analysis identified consistent ultrasonic differences (although very subtle) to the extent that it was possible to non-destructively predict which nylon tires would be hygroscopic. Mechanical testing showed substandard cord and interply peel strengths for these 10% compared to the remaining 90% of the nylon tire population. Subsequent road

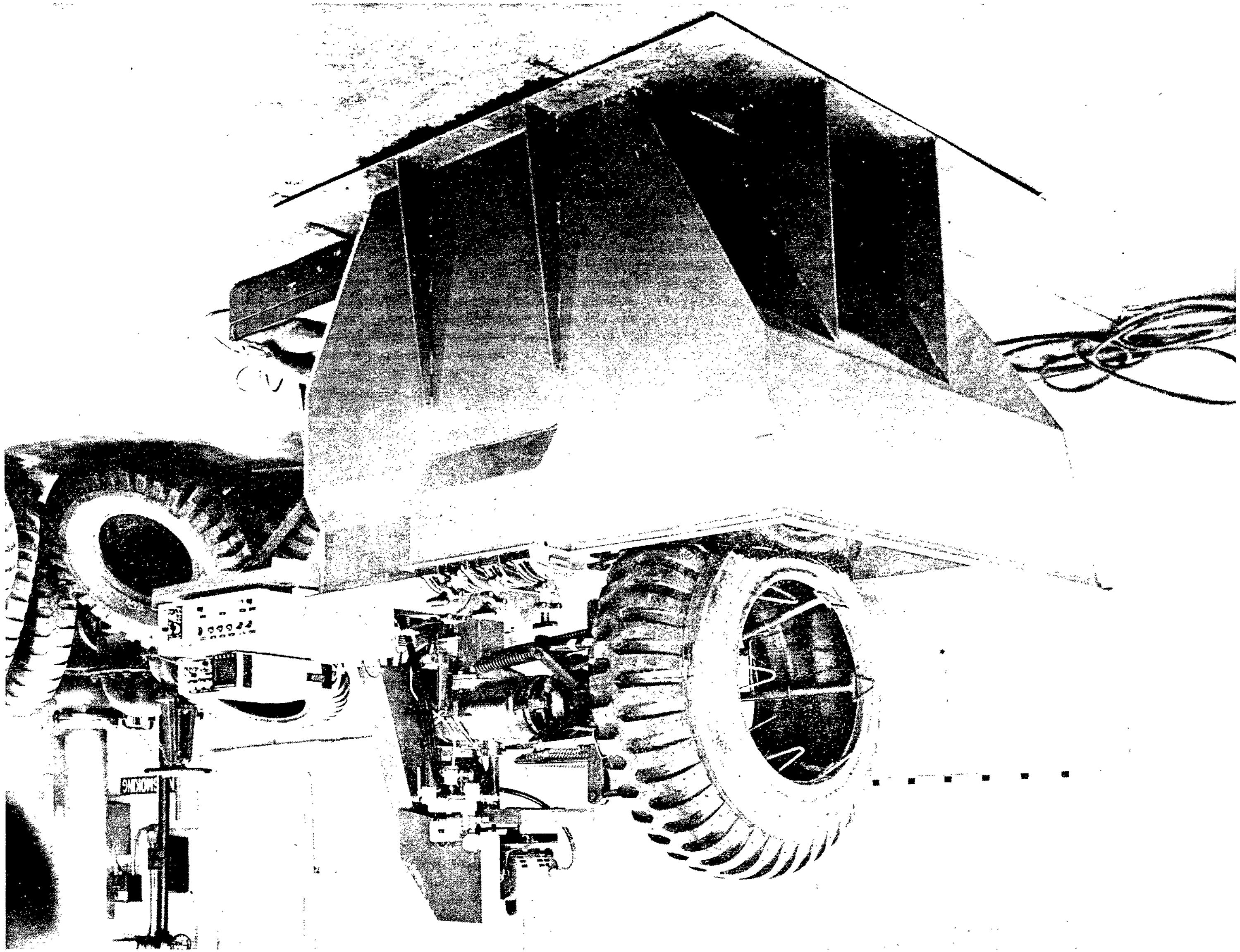


Figure 3 ULTRASONIC TIRE INSPECTION SYSTEM

testing has shown the poor service life of such hygroscopic tires.

During the inspection of 500 retread candidate tires with the scanning system, a sizable percentage (approximately 20%) of the tires indicated the same unusual ultrasonic characteristics but to varying degrees. These changes were fairly uniform around the circumference of the tire (which led to the definition of circumferential defects) and thus seemed to represent a basic property of the tire. Subsequent road testing of hundreds of military tires has confirmed that indeed these circumferential defects can be correlated to ultimate tire failure and thus be used as a predictive tool. The general industry impression that separations cause the majority of non-road hazard failures has been shown to be on over-simplification. Some separations will indeed cause tire failure but only if they are either very large (and thus generate a great deal of frictional heating) or if the residual casing strength, or state of degradation, is such that small defects can materialize and grow to ultimate failure. Thus the presence or absence of separation is not by itself a good prediction of tire failure expect in specific situations.

The outcome of GATX/Army and GATX/in-house research is the GARD Tire Degradation Monitor (TDM) shown in Figure 4. This portable instrument which measures degradation on a digital scale can also be used with an oscilloscope to find a number of other types of defects. The TDM is available for commercial sale and has been purchased by a number of retreaders and tire manufacturers.

Based upon the favorable results of this work, the U.S. Army Tank-Automotive Research and Development Command, sponsored this program to provide a test plan to evaluate TDM use on military tires for tire quality assurance, both before and after retreading.

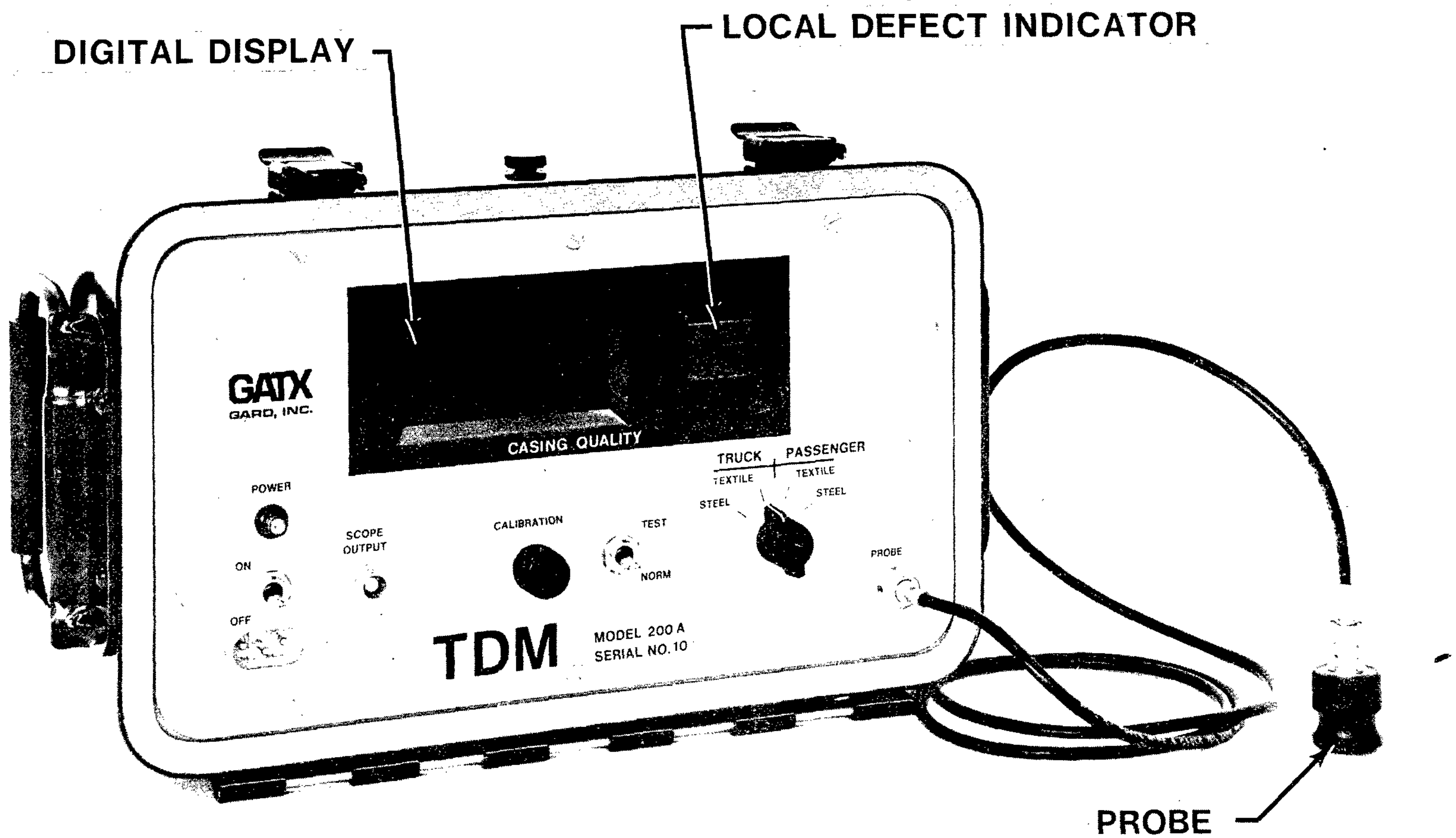


Figure 4 TIRE DEGRADATION MONITOR

4.2 TDM Evaluation Plan

The overall objective of this program was to provide the Army with a test plan* to evaluate the instrument in an efficient and controlled manner. The subsequent evaluation will verify the TDM's performance on military tires, generate statistical data to perform an economic analysis, define any interface or usage restrictions, determine equipment maintenance and support requirements, and provide quantitative and qualitative performance data.

A test plan evaluation was carried out in two subsequent activities: a check of the Test Plan at the Red River Army Depot tire retreading shop, and the development of a tire inspection economic analysis framework.

The RRAD inspection objectives were to field-evaluate the developed Test Plan, collect data on pre- and post-retread ultrasonic inspection and to determine ultrasonic inspection savings related to reduced tire casing failures during the retreading process and to fewer rejected tires after retreading. Some 1525 tires were inspected (both prior to and after retreading) by Army personnel trained in the use of the TDM. Some analysis of this data is included, but the analysis is incomplete due to the unavailability of on-the-road monitoring data. On-the-road data are unavailable from RRAD because they do not have a closed loop system (i.e., control or knowledge of final disposition of tires). Retreaded tires can either be returned to RRAD, retreaded commercially, or sent to a PDO yard.

The economic analysis framework addresses: 1) The mission-related goals of the TDM inspection procedure, 2) the limitations of and assumptions used for this analysis, 3) the alternative procedures possible by use of the TDM, 4) the benefits associated with each of the alternative inspection procedures, 5) estimation of costs for each feasible procedure, 6) any cost-to-benefit index for each inspection procedure, and 7) the parameters which must be recorded

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* Kraska, I.R., "Tire Degradation Monitor Evaluation Plan", GARD/GATX, GARD No.1704, November, 1978.

during the actual inspection.

Phase II of the program will include closed loop data collection (at U.S. Army Depot Activity, Ober-Ramstadt) on about 1500 tires in a range of tire sizes and construction. The tires will be graded by an Ober-Ramstadt inspector, so subsequent TDM data will be relatable to current inspection procedures. Following the initial TDM degradation measurements, the tires will go through the normal retreading process. Upon completion of final inspection, the tires again will be inspected with the TDM for manufacturing defects (undercured tread rubber and poor tread adhesion).

Data on the degradation readings in relation to tire casing quality and post-retread quality will be generated. Tires that have passed final inspection will undergo on-the-road testing. Tires that fail will be carefully analyzed by qualified Army personnel for the exact cause of failure and the data will be recorded. In the final step of Phase II, the ultrasonic data generated from the Ober-Ramstadt test will be analyzed. The RRAD results compiled during Phase I of the program will be consolidated with the above Ober-Ramstadt data. Together, the data generated from the field tests will be used with the economic analysis framework to determine the economic benefits of pre- and post-retread ultrasonic predictions of remaining useful tire life.

Section 5

RRAD EVALUATION

5.1 Test Plan Evaluation

To evaluate the utility of the test plan in the hands of inspection personnel, GARD provided in-plant demonstration of the equipment in operation and an inspector was trained to operate the inspection equipment. The inspectors then inspected 1525 tires both prior to and after retreading, following procedures in accordance with the Test Plan.

From the results of this field test the following conclusions may be drawn. With a detailed inspection procedure (i.e., Test Plan) and reference standard it is possible to train field personnel to perform the calibration, inspection and interpretation of the results in most cases.

Further, it was observed that when tire inspection was performed in an area where there is a large temperature variation (about $30^{\circ}F$ to $110^{\circ}F$) and on tires with a large rubber thickness range (i.e., pre- vs. post-retread) there is a need for finer calibration of the Automatic Gain Control Circuitry. This is due to the fact that tread rubber and temperature affects the ability of the tread rubber to transmit sound. This automatic AGC compensation can be accomplished with the use of microprocessor technology.

Based on the RRAD work during which no serious test plan problems were encountered, the Test Plan was deemed ready for field use.

5.2 Tire Test Results

The TDM evaluation at Red River was limited to testing the monitor's capability of rejecting in a pre-retread inspection those casings likely to fail during the retread process. No attempt was made to track each successfully retreaded casing to ascertain its performance in its post-retread service life. Of the 1525 candidate casings monitored, 1140 were successfully retreaded. The 385 retread failures were composed of 24 product casings which were unable to pass a post-retread inspection and of 360 candidate casings unable to pass a pre-retread visual inspection. Of these latter, 12 were rejected because of bad or broken bead, 263 because of the presence of weather checking (Code H1), and 86 because of separations (Code H2). Only these last two failure classifications will be treated as they are potentially correlatable to TDM inspection.

Figure 5 shows the normalized distribution of TDM readings monitored from all the casings studied. It is presented here as illustrative of a typical distribution of TDM readings in the retread candidate pool. Note that approximately 15% of the candidates are "red-light" indicators. These casings give this type of indication for any of three reasons, all of which result in a higher-than-standard reflection of the ultrasonic energy. One cause of the "red-light" indication is that the casing has degraded to the point that it has developed separations between rubber and ply cord which provide strong reflecting surfaces to the ultrasonic beam. Another cause of the "red-light" indication is the presence of an acoustic impedance mismatch between tread rubber and undertread rubber. This mismatch can be caused by poor bond adhesion or by differences in the acoustic properties of the adhesive and the rubbers. It has been observed in prior work that certain classes of "red-light" tires are retreadable for light-duty service while others are not retreadable despite presenting a quality visual appearance. A third cause of the "red-light" indication is the presence of a layer of microporosity in the tread or undertread. There are also a number of cases of "red-light" indications for which no cause could be determined. In the Red River evaluation, it was found that of a total of 233 "red-light" indicators, only 52 were code-rejectable with 181 passing through

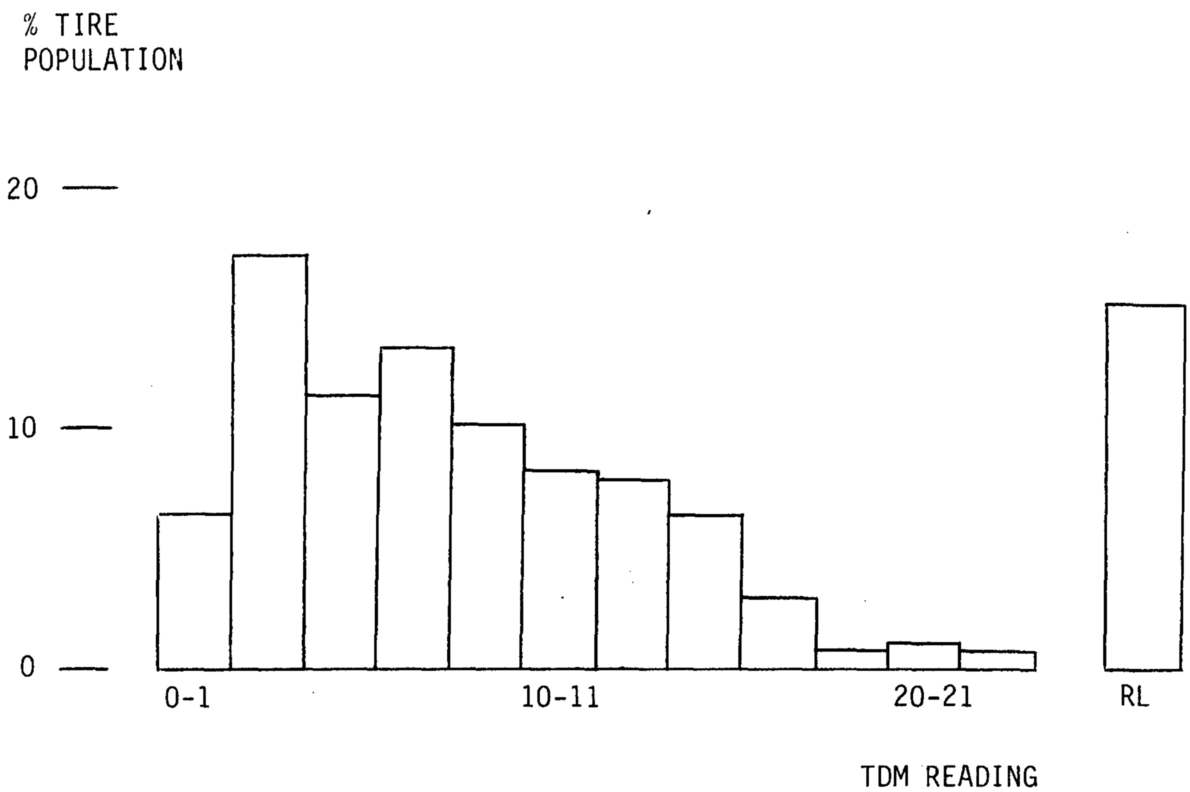

Figure 5 DISTRIBUTION OF INITIAL TDM READINGS

the retread inspection and process intact. This seems to imply that if the "red-light" indication is used for preemptory rejection of candidate casings, nearly 78% of these rejections may have been good and would certainly have been retreadable. However, retreadability is not serviceability and, because the monitored casings were not tracked into their next service life, no information is available to answer the question of whether the "red-light" indication was a useful predictor of retread utility.

Ignoring, for the purpose of this discussion, those casings with "red-light" indications and concentrating on casing grading by the TDM digital readings, the normalized distribution of such casings for the 959 code-acceptable casings is shown in Figure 6. In comparison, similar distributions for Code H1 (weathered) and Code H2 (separated) rejects are shown in Figures 7 and 8 respectively. The statistics for these distributions are summarized in Table 2. Because certain aspects of present TDM use (such as temperature compensation, calibration checks, and inspector motor skill) are uncontrolled, the data collected exhibits a large variability. It is apparent by both visual inspections and by tests of significance that Code H rejects can be selectively culled by TDM inspection. For example, referring to Figures 6 thru 8, a rejection of casings with TDM indications of 3 or less will cull 38% of the Code H2's and 39% of the Code H1's at a cost of falsely culling 23% of the code-acceptables. Once again it should be noted that these code-acceptable tires with TDM readings of 3 or less have only proven process-survivable. Because they were not followed into subsequent service no data is available concerning their utility.

A more accurate picture of TDM correlation with code rejectability is given in Table 3a which outlines how well TDM inspection can select out Code H tires from the casing population as a function of TDM readings. In this table,

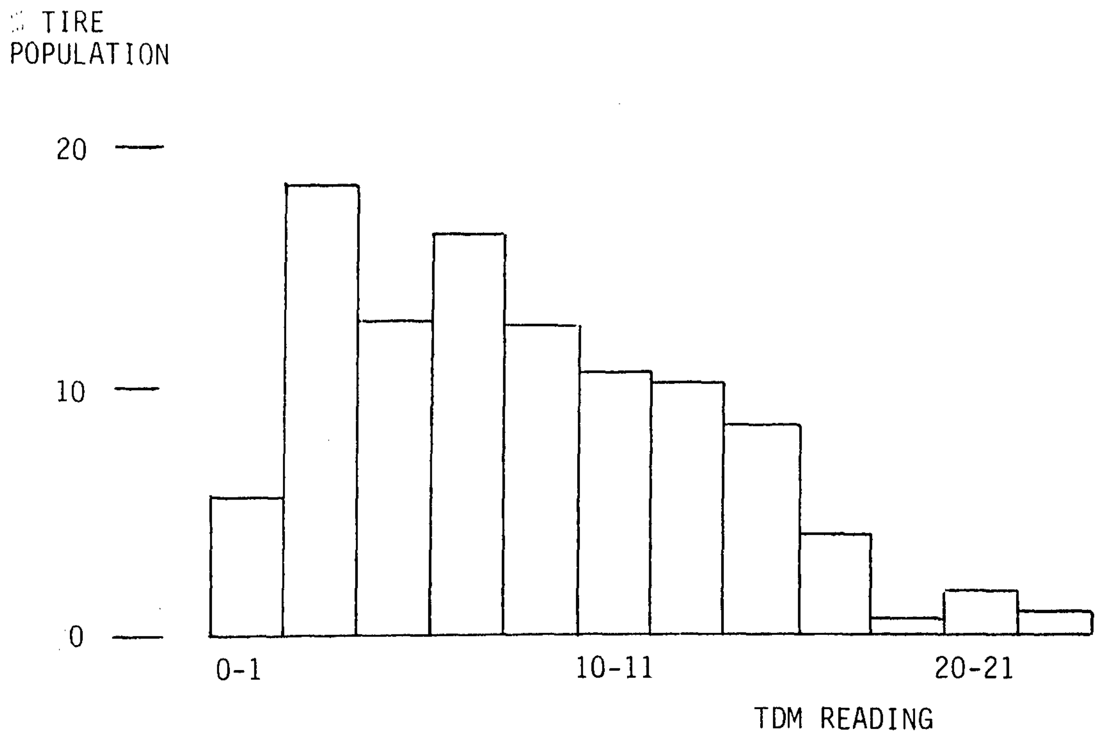

Figure 6 DISTRIBUTION OF TDM READINGS FOR CODE ACCEPTABLE NON-"RED LIGHT" TIRES

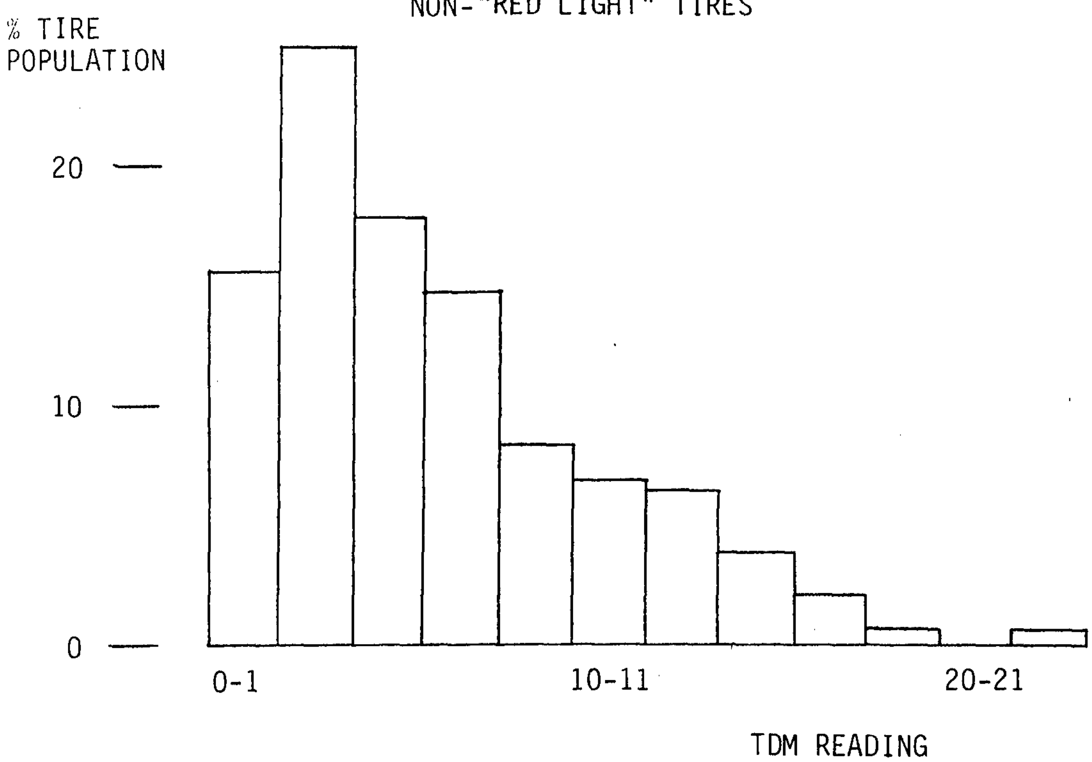

Figure 7 DISTRIBUTION OF TDM READINGS FOR CODE H1 TIRES

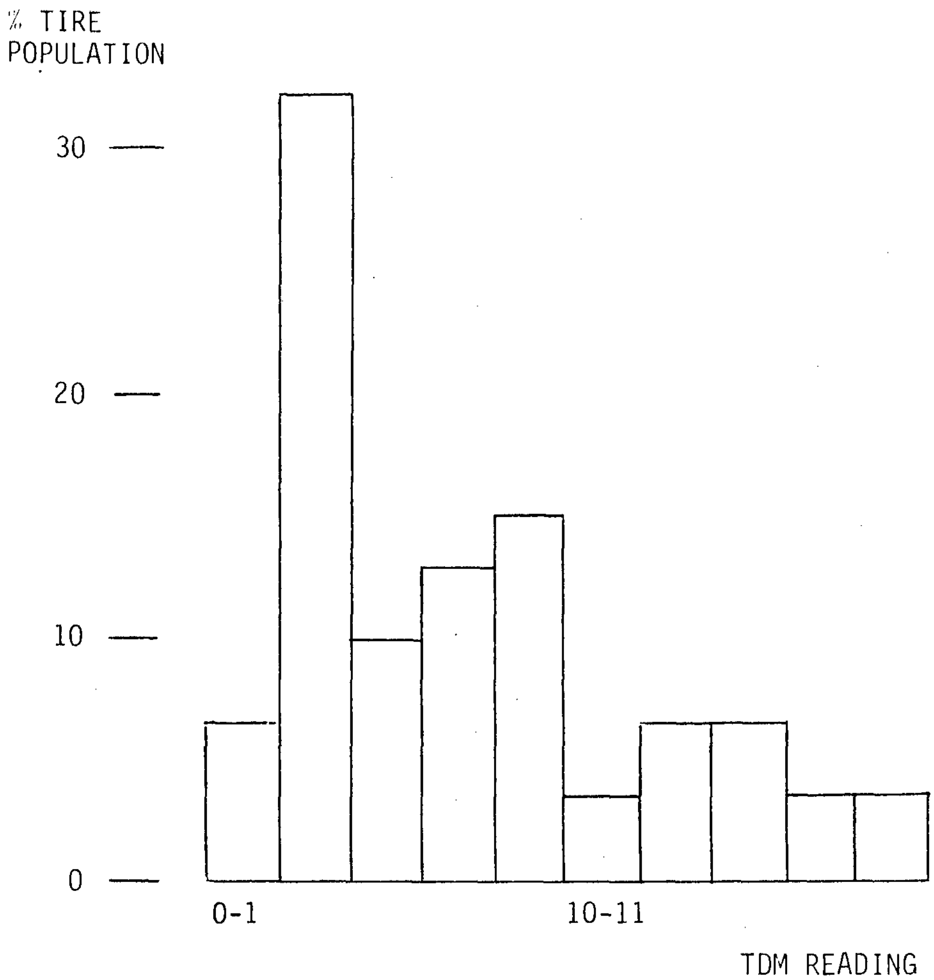

Figure 8 DISTRIBUTION OF TDM READING FOR CODE H2 TIRES

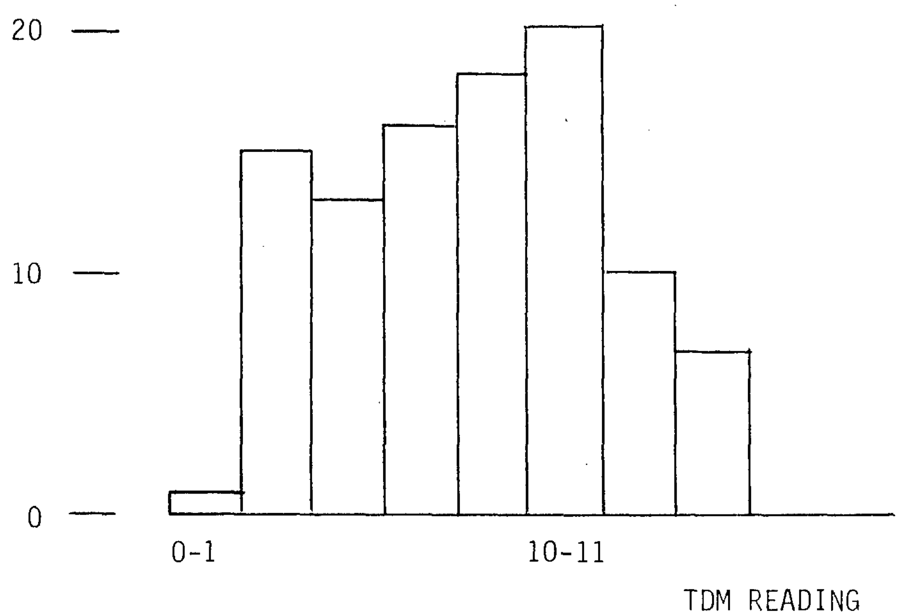

Figure 9 DISTRIBUTION OF TDM READINGS OF TIRES WHOSE READING IS UNCHANGED THROUGH THE RETREAD PROCESS

TABLE 2

Statistical Summary of Non-"red-light" Indicating Casings

	μ	σ	N
Code H1	5.917±	4.540	(241)
Code H2	7.033±	4.953	(61)
Code accepted pre-retread	8.217±	4.992	(959)
Code accepted post-retread	9.414±	3.998	(995)
		t	P(not same)
Code accepted pre-retread: Code H1		6.888	P> 99.9%
Code accepted pre-retread: Code H2		1.809	P> 97.8%
Pre-retread: post-retread		5.837	P> 99.9%

TABLE 3a

Summary of Number of Casings Having a Given TDM Level Reading

TDM	H1	H2	TOTAL CODE H	INITIAL OF RETREADED TIRES	TOTAL OF ALL TIRES	PERCENT CODE H
0	18	1	19	18	37	51.4
1	19	3	22	34	56	39.3
2	17	4	21	54	75	28.0
3	43	16	59	121	180	32.8
4	10	0	10	35	45	22.2
5	32	6	38	86	124	30.6
6	14	2	16	42	58	27.6
7	21	6	27	110	137	19.7
8	1	0	1	5	6	16.7
9	18	9	27	114	141	19.1
10	0	0	0	1	1	0
11	16	2	18	99	117	15.4
12	2	0	2	9	11	18.2
13	13	4	17	86	103	16.5
14	1	0	1	6	7	14.3
15	8	4	12	73	85	14.1
16	3	0	3	14	17	17.6
17	3	2	5	22	27	18.5
18	0	1	1	3	4	25.0
19	1	1	2	3	5	40.0
20	0	0	0	11	11	0
21	0	0	0	5	5	0
22	1	0	1	5	5	16.7
23	0	0	0	3	3	0
RL	22	25	47	181		20.6

TABLE 3b

Summary of Fraction of Casings

Having a Given TDM Level Reading

TDM REJECTION READING	WEATHER CHECKING (H1)	SEPARATIONS (H2)	BOTH (H1+H2)	ACCEPTED FOR RETREAD	TDM REJECTIONS EFFICIENCY
0	6.8%	1.2%	5.4%	1.6%	3.38
1	14.1%	4.7%	11.7%	4.6%	2.54
2	20.5%	9.3%	17.8%	9.3%	1.91
3	36.9%	27.9%	34.7%	19.9%	1.74
4	40.7%	27.9%	37.5%	23.0%	1.63
5	52.9%	34.9%	48.4%	30.5%	1.59
6	58.2%	37.2%	53.0%	34.2%	1.55
7	66.2%	44.2%	60.7%	43.9%	1.38
8	66.5%	44.2%	61.0%	44.3%	1.38
9	73.4%	54.7%	68.8%	54.3%	1.27
10	73.4%	54.7%	68.8%	54.4%	1.26
11	79.5%	57.0%	73.9%	63.1%	1.17
12	80.2%	57.0%	74.5%	63.9%	1.17
13	85.2%	61.6%	79.4%	71.4%	1.11
14	85.6%	61.6%	79.7%	71.9%	1.11
15	88.6%	66.3%	83.1%	78.3%	1.06
16	89.7%	66.3%	84.0%	79.6%	1.06
17	90.9%	68.6%	85.4%	81.5%	1.05
18	90.9%	69.8%	85.7%	81.8%	1.05
19	91.3%	70.9%	86.2%	82.0%	1.05
20	91.3%	70.9%	86.2%	83.0%	1.04
21	91.3%	70.9%	86.2%	83.4%	1.03
22	91.6%	70.9%	86.5%	83.9%	1.03
23	91.6%	70.9%	86.5%	84.1%	1.03

those casings with "red-light" indications are included in the population although no attempt is made to reject them on that basis. Two important features of the Red River evaluation are highlighted in Table 3b. First, it should be noted that the fraction of Code H2 casings that are TDM-rejected is very nearly the fraction of code-acceptable casings that are TDM-rejected for any TDM reading used as the rejection level. That is, rejection based on TDM reading does not preferentially select out separations. This is consistent with the hypothesis that the TDM digital indication, being an inspection procedure which samples the condition of global tire wear, is largely blind to the presence of separation. The "red-light" indicator was incorporated to detect separations and, although it has not proved to be useful in culling out Code H tires in general, it does exhibit a preferential selection toward Code H2 casings. Whereas 15.9% of the good* casings and 8.4% of the Code H1 casings were "red-light" indicators, as much as 29.1% of the Code H2 casings were "red-light" indicators.

If account is taken of not only the presence of "red-light" indications, but of the number that occur during the inspection of a casing, a better rejection of Code H2 casings can be made. For example, the Red River evaluation showed that there are as many casings indicating "red-light" in only one place on the circumference as there are indicating "red-light" at every inspected point on the circumference. However, the latter type casing suffers in-process failures at a rate almost twice that of the former type casing. Based on the Red River data, if only those casings indicating "red-light" at more than one point on their circumference were rejected, the total number of "red-light" rejections would have been less. In addition, tires which exhibit so-called "local" red-light indications (only one per casing) will show a finite TDM level at other inspected points. Such readings were not always taken at Red

River, leaving a number of gaps in the data set. This is the type of data which an "intelligent" TDM with memory can acquire routinely and is a further justification for developing a microprocessor-based TDM.

The second item noted in Table 3b is the behavior of the TDM rejection efficiency. This, a ratio of the fraction of bad casings rejected to the fraction of good* casings rejected, is an index of TDM selectivity and is shown in Table 3b as it relates to rejection of Code H casings. Using TDM readings of 5 or 6 as rejection points, approximately half of the Code H casings are rejected at a cost of about 30% of the good* casings also being rejected. This gives a rejection efficiency of 1.55 which means that for every 1.55 bad casings rejected, a good* casing is also rejected. To optimize the usefulness of TDM inspection, a rejection level should be selected that maximizes the rejection efficiency. Table 3b shows that for TDM rejection levels of 1, 2.54 bad casings can be rejected at the cost of rejecting a good casing and that for TDM rejection levels of 0, 3.38 bad casings can be rejected at the cost of rejecting one good casing. Thus, based on the present state-of-the-data, it appears that although only five to twelve percent of Code H casings will be rejected, a TDM rejection level of 0 to 1 will give the best return for inspection cost.

Comparison of RRAD ultrasonic test results with visual inspection and failures during the retread process confirmed a direct correlation between low TDM readings 0-6 (or 0 to 40% of the calibration point), and Code H tires. These tires are not suitable for retreading. These results support

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* It cannot be repeated too often that these casings we have been classifying as "good" are only good in the sense that they survived the retreading process. The tire inventory control at Red River did not allow for post-retread documentation of each casing's service record so that, although we feel that many of these low-TDM "good" retreads would not survive in use, there is no way to prove this contention.

a previous ultrasonic test performed at the Yuma Proving Ground (YPG). Data from YPG indicated that tires which gave ultrasonic measurements less than 40% of the calibration point failed more frequently and had lower tread life expectancy than tires which had measurements greater than 40%.

From the data collected at Red River an interesting observation was noted. Over half the candidate casings accepted for retread exhibited a higher TDM reading after retreading than they possessed before.

To investigate this, the data from code-accepted retread candidates was separated into three classes: those casings whose TDM level continued to fall through the retread process, those whose TDM level was unaffected by the retread process, and those whose TDM level increased through the retread process. The normalized distributions of TDM readings for each of these three classes is shown in Figures 9-11. It can be noted right away that the casings which exhibited post-retread TDM increase tend to have lower pre-retread TDM readings than do casings which exhibit through-process TDM decrease This corresponds well with an idea that the post-retread increase in TDM reading is the next stage in degradation of a tire already well-degraded. A delta histogram of the data (Figure 12) shows that post-retread TDM increases are distributed differently from post-retread TDM decreases. TDM increases of 4 to 7 units appear more prevalent than TDM decreases of the same amounts, but this is an artifact of the histogram display and is due to there being a larger population of casings with post-retread TDM increases than there are of casings with post-retread TDM decreases. When both tails of the delta histogram are independently normalized to their respective populations, the distributions remain dissimilar but the difference is that post-retread TDM decreases of 2 to 5 units predominate over post-retread increases of the same amounts.

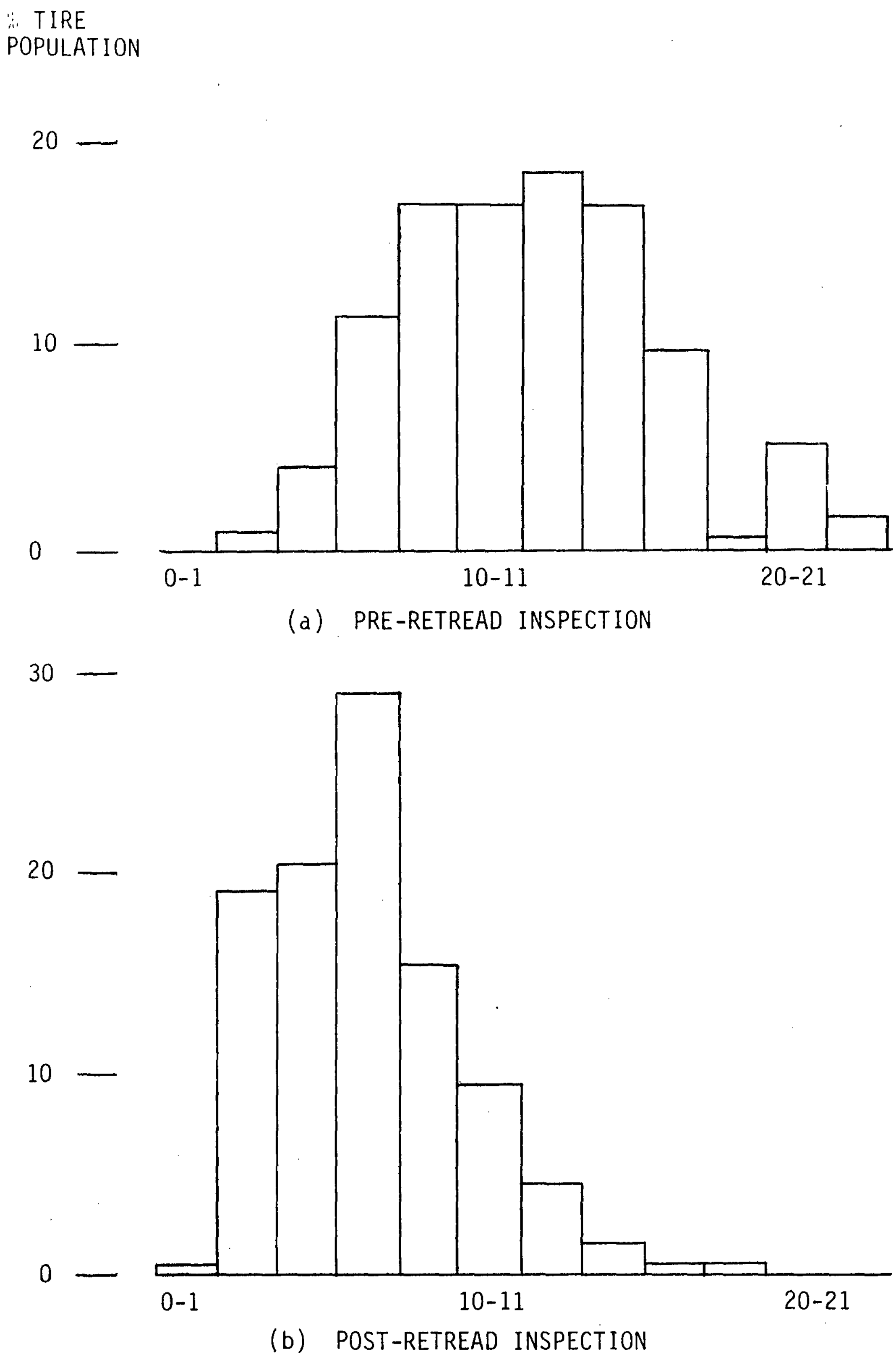

Figure 10 DISTRIBUTION OF TDM READINGS FOR TIRES WHOSE READING DECREASES THROUGH THE RETREAD PROCESS

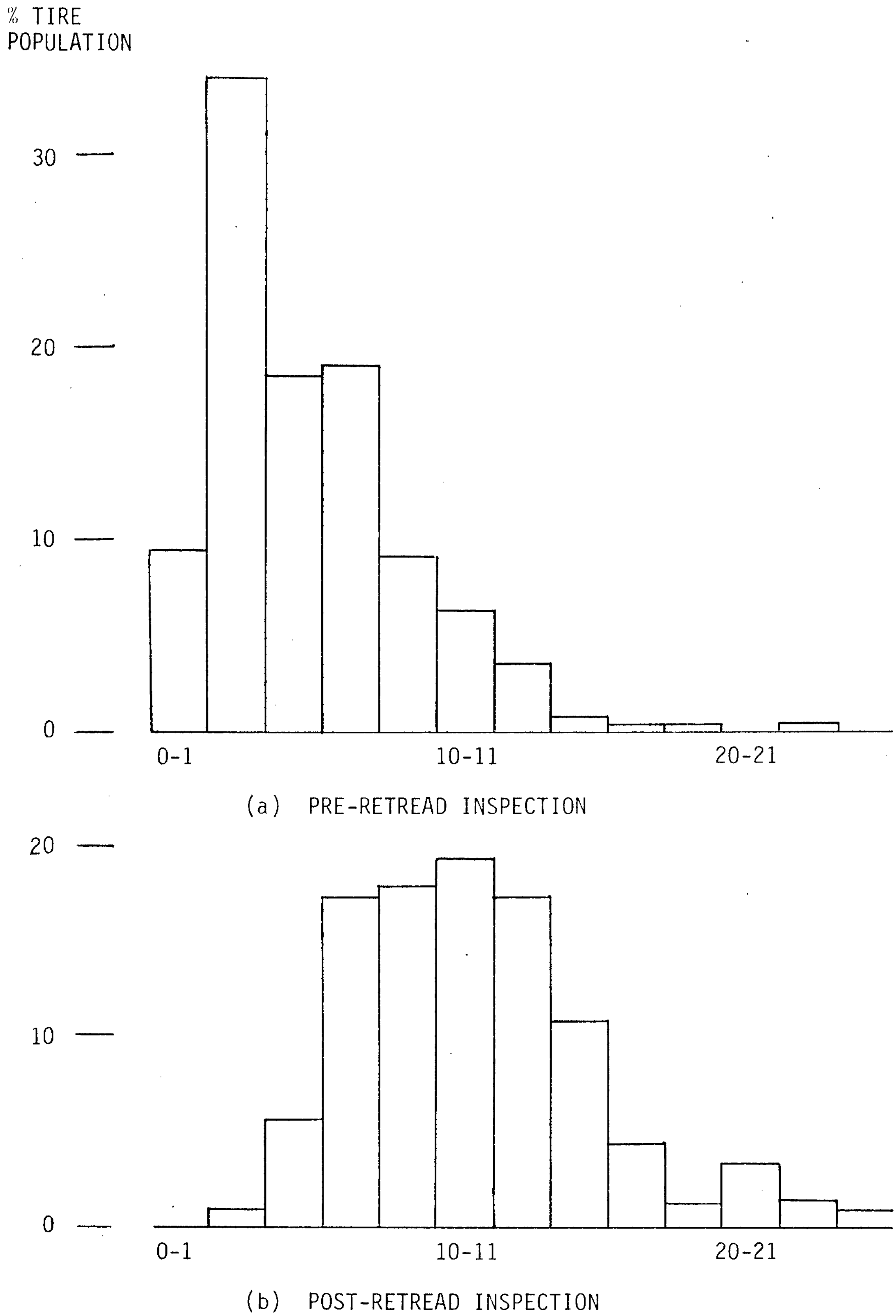

Figure 11 DISTRIBUTION OF TDM READINGS FOR TIRES WHOSE READING INCREASES THROUGH THE RETREAD PROCESS

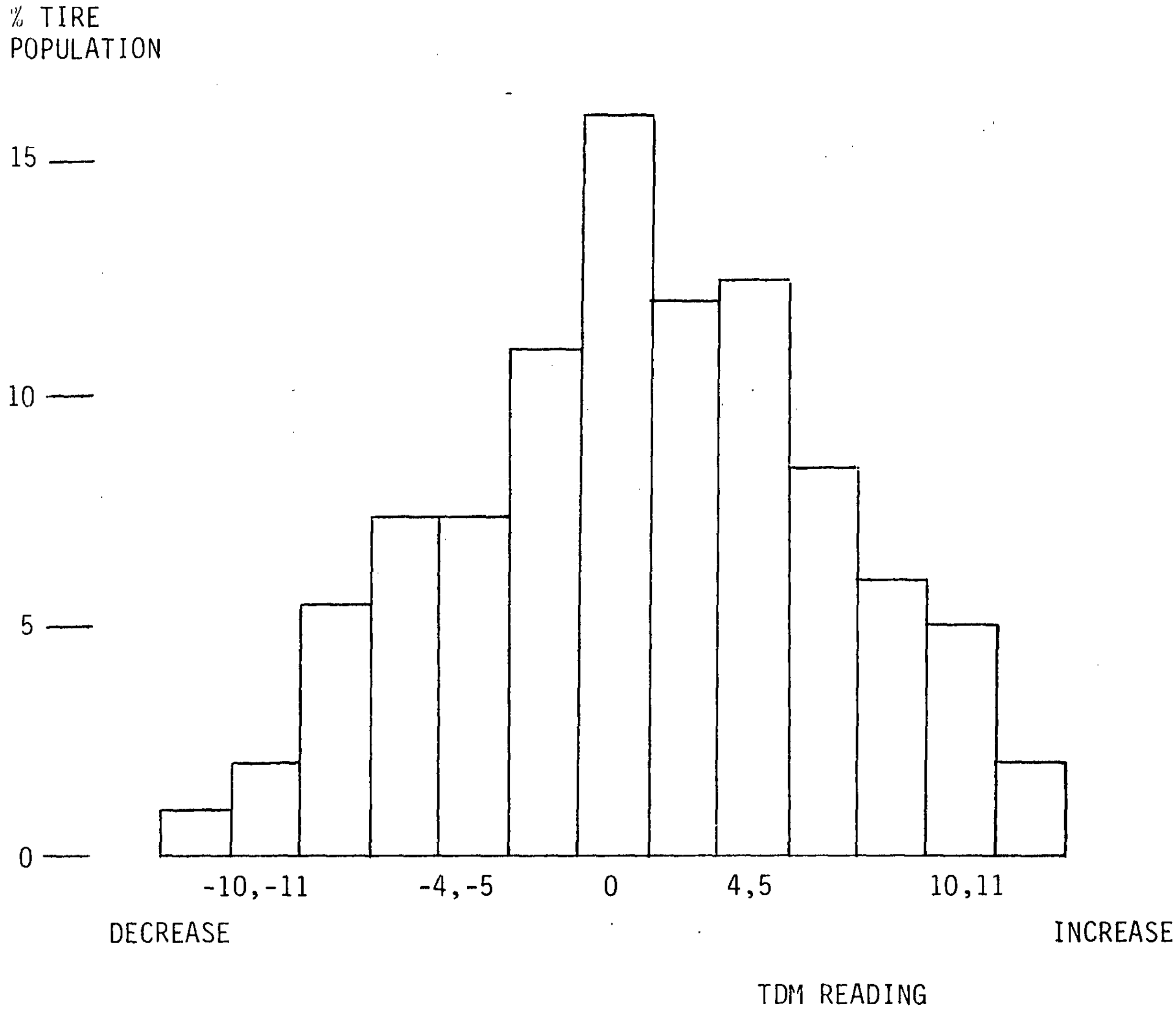

Figure 12 DELTA HISTOGRAM OF TDM READING CHANGES THRU THE RETREAD PROCESS

TABLE 4

Statistical Summary of Retreaded Casings Classified According to Their Through-Process Behavior

	μ	σ	N
Degrading Casings			
Pre-retread inspection	12.36 $\pm$	4.04	
Post-retread inspection	6.87 $\pm$	3.09	(343)
Unaffected Casings			
Pre-retread inspection	8.36 $\pm$	3.65	
Post-retread inspection	8.36 $\pm$	3.65	(100)
Retrograding Casings			
Pre-retread inspection	5.20 $\pm$	3.46	
Post-retread inspection	11.27 $\pm$	4.21	(457)

That this is so could arise from the condition of the casing which exhibits a post-retread TDM rise changing more rapidly than that of the casing widely distributed, the standard deviation of the post-retread TDM readings of these tires is larger, and the physical mechanism underlying this stage of casing degradation implies a rapidly accelerating deterioration in the condition of the casing. All these factors are consistent with the picture of a rapidly deteriorating tire carcass except that the majority of the tires examined exhibited this phenomenon! This implies two things; 1) the majority of the Red River data may have been collected under conditions of questionable calibration and is therefore misleading, or 2) the Army has a larger population of poor casings than heretofore suspected. The possibility of questionable calibration need not have been due to operator error. As has been previously mentioned, there is a temperature dependence of the TDM reading. During lab calibration tests, high readings (10-20) decreased with increased temperature. Low readings (0-5) increased with increased temperature. This dependence not only affects the level of each TDM reading itself, it has been observed to affect the depth-amplitude correction (DAC) factor which is used to compensate ultrasonic reflection levels for the various tread depths encountered. When a tire is inspected at temperatures in excess of those for optimum DAC response, the TDM level obtained reads higher than it actually is if the tread is thin and reads lower than it actually is if the tread is thick. Thus, tires with relatively thick treads inspected on warmer-than-normal days could show, when inspected at normal temperatures after retread, an apparent increase of TDM reading over its pre-retread level. By the same effect, tires with thin treads inspected on normal or colder-than-normal days could show, when inspected on warmer-than-normal days after retread, the same apparent through-process increase in TDM reading. If this effect is the sole explanation for this type of TDM level behavior, then the use of a properly programmed microprocessor-based TDM should be able to compensate for this and for any other complex temperature or depth dependence of the ultrasonic reflections. To find out what is really happening, it will be necessary to keep track of these tires after retreading to find out if they are truly in the last stage of their utility, are being affected by temperature, or if there is some other reason for the observed post-retread increase in TDM reading.

Section 6

COST/BENEFIT STRUCTURE

To provide a cost justification for the implementation of a new inspection procedure such as use of a Tire Degradation Monitor (TDM), an economic analysis related to the procedure should be established. Such an analysis must address 1) the mission-related goals of the TDM inspection procedure, 2) the limitations of and assumptions used for this analysis, 3) the alternative procedures possible by use of the TDM, 4) the benefits associated with each of the alternative inspection procedures, 5) estimation of costs for each feasible procedure, and 6) any cost-to-benefit index for each inspection procedure. Having established such an economic analysis for TDM use, selections of and justifications for a particular inspection procedure or procedures will be a relatively simple task. The following discussion outlines how we propose to establish an economic analysis of TDM inspection using information obtained from tires at Ober-Ramstadt as a data base.

The principal mission-related goals of any TDM inspection procedures are to reduce the amount of labor, material, and energy lost in the retreading of a tire casing that will not subsequently perform as an acceptable retread, and to increase the safety and reliability of the retreaded product by reducing weak-casing failures in the field. Secondary goals of TDM procedures are to reduce or make more efficient the handling of unfit casings, and to retain control of such casings for more efficient disposal. These goals can be measured by reduction in the number of tires failing during the retread process or later in field use, or by the reduction in the costs of retreading tires for the Army in general.

The economic analysis herein outlined assumes:

1) The closed loop data collection population (at Ober-Ramstadt) is a good sample of the general Army casing population.

2) Closed loop casing inspectors (at Ober-Ramstadt) are equal in skill and conscientiousness to Army casing inspectors elsewhere.

3) Each post-retread or in-process failure is replaced by a new tire rather than a retread. If actual replacement is by retread, that replacement must ultimately be reflected by the purchase of a new tire to replenish the casing pool.

4) General tire usage in the Army will not diminish.

The alternative inspection procedures to be subjected to economic analysis are combinations of TDM use at field and at post inspection facilities, and of inspections before or after retreading. It is assumed that a microprocessor-based TDM capable of pattern recognition will be considered. Specifically, the alternatives are:

1) TDM inspection of casings at field sites only

2) TDM pre-retread inspections of casings at post or retreader's only

3) TDM pre-retread and post-retread inspections of casings at post or retreader's only

4) TDM inspections of casings at field sites and post-retread inspections at post or retreader's

5) TDM inspections of casings at field sites and pre-retread inspections at post or retreader's

6) TDM inspections of casings at field sites and pre-retread plus post-retread inspections at post or retreader's.

Before discussing in detail the benefits and costs associated with each of the above alternatives, a general benefit and cost structure useful for

TDM economic analysis will be outlined. The benefits of the most elaborated use of TDM inspections are outlined in Table 5. The savings realized in shipping from a field site when bad casings are rejected is a product of the average weight of all casings shipped, the unit weight cost of shipping (which include handling), the percentage of failure-bond casings predicted by TDM, and the number of casings inspected by one TDM at the field sites.

This saving can be expressed as:

$$\left[\frac{\sum_{i=1}^{n} X_i W_i}{\sum_{i=1}^{n} X_i}\right] (C_S) \left[P_p(t) + P_f(t)\right] N \qquad (1)$$

Examples of how this and the following cost and savings relations are used are presented in the appendix.

The savings realized by not inspecting on a spreader those casings which have already been rejected by TDM inspection is a product of the labor cost of spreader inspections, the percentage of bad casings predicted by the TDM, and the number of casings inspected by one TDM.

This saving can be expressed as:

$$T_S \, C_{LS} \, P_p(t) \, N \qquad (2)$$

Similarly, the savings realized by not buffing those casings which have been rejected by the TDM as potential separation failures is the product of the labor cost of buffing a tire, the percentage of separations rejected by TDM, and the number of casings inspected by one TDM. This saving can be expressed as:

$$T_B \, C_{LB} \, P_p(t) \, P_s \, N \qquad (3)$$

The savings realized by not retreading a tire that will fail in service

TABLE 5 Economic Analysis Cost-Benefit Parameters

SAVINGS	COSTS
Shipping	TDM Purchase
Spreader Inspection	Inspection
Buffing	TDM Support
Casing Failures	Incorrect Code H Rejection
Recovered Casings	

PARAMETERS REQUIRED

N	Annual number tires inspected per TDM		
X_i	Number of tires of type i		
W_i	Average weight of a tire of type i		
T_B	Buffing process time (hours)	mc	Average mileage accumulated by a failed tire
T_I	TDM inspection time (hours)	mp	Average mileage accumulated by a useable tire
T_S	Spreader inspection time (hours)		
C_i^N	Average cost of a new tire of type i	$P_f(t)$	Fraction of in-service tire failures rejected by TDM
C_i^R	Average cost to retread a tire of type i	$P_i(t)$	Fraction of incorrect rejections by TDM
C_s	Average shipping cost per unit weight	$P_p(t)$	Fraction of in-process failures rejected by TDM
C_{LB}	Hourly wage of buffer operation	$P_r(t)$	Fraction of incorrect PDO's recovered by TDM
C_{LS}	Hourly wage of spreader inspection	P_F	Fraction of casing population that fails
C_{FI}	Hourly wage of TDM inspection	P_H	Fraction of casing population that is Code H
C_{TDM}	Purchase cost of TDM unit	P_S	Fraction of casing population that is Code H2
		P_{PDO}	Fraction of casings incorrectly consigned to PDO

before it returns its retread investment is a product of the average fraction of unused service life at failure, the average cost of retreading a tire, the percentage of in-service failures predicted by the TDM, and the number of casings inspected per TDM. This saving is expressed as:

$$(1 - \frac{mc}{mp})\left[(\frac{\sum_{i=1}^{n} X_i C_i^R}{\sum_{i=1}^{n} X_i})\right] P_f(t)\ N \qquad (4)$$

Finally, it has been observed that a number of retreadable casings are sitting in PDO yards to which they had been unjustifiably consigned. A savings can be realized by using TDM inspection to assure that such tires are never sent to PDO in the first place. Such savings is a product of the net cost of average new tire procurement over average retread tire processing (including shipping), the fraction of tires consignable to PDO without TDM inspection, and the number of casings inspected by one TDM. This saving is expressed as:

$$\frac{\sum_{i=1}^{n} X_i(C_i^N - C_i^R - W_i C_s)}{\sum_{i=1}^{n} X_i}\ P_r(t)\ .\ P_{PDO} \cdot N \qquad (5)$$

The principal item to note is that all these benefits are a function of the value of TDM reading (t) at which the casing accept/reject decision is made. Specifically, casings with a reading equal to or less than the value t are rejected as being unfit for retreading. It can thus be seen that the benefits structure of our economic analysis plan provides for optimization of the benefits by selecting a proper value of TDM accept/reject limit.

The costs of the most elaborate use of TDM inspections are outlined in Table 5. The cost of a TDM unit is self-explanatory and should be the purchase cost of the field version of a microprocessor-based "intelligent" TDM.

The cost of inspections is a product of the labor cost to do a TDM inspection and the number of tires inspected per TDM. This cost is expressed as:

$$T_i \cdot C_{fi} \cdot N \qquad (6)$$

The annual cost of supporting the TDM includes replacement of accessories, procurement of couplant, and unscheduled maintenance. This annual cost is presently assumed to be 25% of the TDM purchase price.

Use of the TDM for inspecting retread candidate casings increases the risk of rejecting a percentage of casings which would be acceptable retreads. This must be considered as a cost of incorrect rejection and is a product of the net cost of average new tire procurement over average retread tire processing (including shipping), the fraction of acceptable casings wrongly rejected, and the number of tires inspected per TDM.

This cost can be expressed as:

$$\frac{\sum_{i=1}^{n} X_i \left(C_i^N - C_i^R - W_i C_s\right)}{\sum_{i=1}^{n} X_i} (1-P_H)\cdot(1-P_F)P_i(t)\cdot N \qquad (7)$$

Having outlined the costs and benefits associated with TDM inspection, the discussion will now consider comparisons of cost: benefit performance among the alternative implementations of TDM inspection.

Alternative 1. Inspection at field sites only.

Each casing is inspected once per retread cycle for disposition to a retreading facility or to scrap. All the cost and savings factors presented in equations (1) to (7) are appropriate and the cost justification for using a TDM at a particular field site will depend on that site's inspection volume and on the TDM's ability to reject a large enough fraction of unacceptable casings to overcome the cost of misclassifying acceptable casings.

Alternative 2. Pre-retread inspection at retreader's only.

Each casing is inspected once per retread cycle for disposition to scrap or to the next stage in retreading. No shipping costs or misconsigned PDO losses are saved. Cost and savings relations (2) to (4), (6), and (7) are appropriate and the large volume to be expected at a retread facility helps to lower the effective criticality of TDM false rejections.

Alternative 3. Pre-retread and post-retread inspection at retreaders' only.

Each casing is inspected twice per retread cycle. The first inspection determines disposal to retreading or to scrap and the second inspection is a quality assurance measure to intercept subtle in-process faults. The pattern-recognition capabilities in a microprocessor-based TDM will allow accurate post-retread assessment of retread process-induced errors. No shipping costs or misconsigned PDO losses are saved and equations (2) to (4) and (7) are appropriate. Because of the double TDM inspection, equation (6) is modified to:

$$T_i \; C_{fi} \left[2-P_p \; (t)\right] N$$

Alternative 4. Inspection at field sites and post-retread inspection at retreader's.

To save the cost of shipping unretreadable casings to the retreading facility, pre-retread TDM inspections of casings are performed at field sites and all post-retread quality assurance TDM inspection is performed at the retreader's. Relations (1) to (5) and (7) and the above modification of (6) are appropriate to describe the cost-savings structure of this alternative.

Alternative 5. Inspection at field sites and pre-retread inspection only at retreader's.

This alternative at first appears to offer a duplication of inspection cost with no resultant benefit. However, if the concept of inspected tire volume per TDM (N) is examined more closely, it becomes apparent that whereas virtually any retread facility is able to draw a casing volume large enough to support at least one TDM, there will be many field sites which do not handle even the minimum one-TDM support volume. In a retreading system composed of a number of retread facilities each supplied by a number of field sites, a fraction u of the casings has been supplied by those field sites with individual throughput volumes large enough to support TDM inspection and that fraction u has therefore already been inspected. On the other hand, the fraction 1-u of the retreader's volume has come from those field sites which individually do not have the throughput volume to support TDM use. If each casing can be identified by its source or by its state of prior inspection, then only those casings not inspected in the field will be inspected at the retread facility and inspection effort will not be duplicated. In that case, this alternative becomes economically similar to alternative 1 with some retained loss due to the cost of shipping unretreadable tires unable to be TDM inspected at field sites.

However, if each casing cannot be identified by source or preinspection, then the fraction 1-u of the retreader's volume will be doubly inspected and the cost of inspection will increase accordingly. In fact, every equation (1) to (4), (6), and (7) of the cost-benefit structure will be augmented by the fraction 1-u.

Alternative 6. Inspection at field sites and pre-retread plus post-retread inspection at retreader's.

This alternative combines the features of alternative 3 or 4 and alternative 5. Every casing that arrives at the retreading facility may or may not be doubly inspected depending on whether it can be established that the casing had been TDM inspected at the field site. Shipping costs are saved only on those tires that are field-inspected and every casing that passes inspection at the retreader's will be inspected again after retreading. Without knowing the nature of the given retread system or volume of casing flow from field sites to retreader, it is difficult to measure the exact cost-benefit factors involved in relations (1) to (7). However, a specific example is outlined in the appendix for a simple field site inspection.

APPENDIX

This appendix gives an example of an economic analysis of the type outlined in the text for a simple application of ultrasonic TDM casing inspection of 1100x20 and 1100Rx20 tires at a field site. Based on composite data taken from this report on the RRAD evaluation, from prior studies conducted at YPG, and from information supplied by TARADCOM, the parameter N (annual volume of casing inspection required to cost-justify procurement of one TDM) can be determined. Knowledge of this N, the other parameters outlined in Table 5, and the average service life of the TDM will allow a computation of a reasonable payback period and a net cost benefit of TDM casing inspection.

The first stage in performing the economic analysis is the computation of the costs and the savings of TDM use on a casing volume per annum per-TDM basis. Such savings are computed using equations (1) to (5) in the text. Related costs are computed using equations (6) and (7) and the purchase and support costs of each TDM. Values for the underlying parameters listed in Table 5 are given as follows:

N = figure of merit to be derived (casing volume/year/TDM)

X_1 = 18000 Volume of 1100x20 tires retreaded

X_2 = 1800 Volume of 1100Rx20 tires retreaded

W_1 = 103 lb. Average weight of 1100x20 tires

W_2 = 143 lb. Average weight of 1100Rx20 tires

T_B = 0.125 hr. Buffing time

T_I = 0.009 hr. TDM inspection time (assumed)

T_S = 0.125 hr. Spreader inspection time

C_1^N = $135. Average cost of new 1100x20 tires

C_2^N = $226. Average cost of new 1100Rx20 tires

C_1^R = \$ 56. Average cost of retreading 1100x20 tires

C_2^R = \$ 62. Average cost of retreading 1100Rx20 tires

C_S = \$236.25 ton^{-1} Average shipping cost

C_{LB} = \$25. hr.$^{-1}$ Labor cost of buffing

C_{LS} = \$25. hr.$^{-1}$ Labor cost of spreader inspection

C_{FI} = \$25. hr.$^{-1}$ Labor cost of TDM inspection (assumed) (will be less for field inspection)

C_{TDM} = \$10,000. Purchase cost of TDM

mc = 3688 miles Average mileage on failed tire (YPG data)

mp = 7506 miles Average mileage on useable tire (YPG data)

$P_f(t) = 0.77$ In-service failures caught (YPG data)

$P_i(t) = 0.34$ Incorrect TDM rejections (RRAD data in Table 3b.)

$P_p(t) = 0.53$ In-process failures caught (RRAD data)

$P_r(t) = 0.23$ PDO recoveries (Ober-Ramstadt estimate)

$P_F = 0.27$ Tire failure ratio (YPG data)

$P_H = 0.23$ Code H classification ratio (RRAD data)

$P_S = 0.06$ Code H2 fraction (RRAD data)

$P_{PDO} = 0.10$ Incorrect PDO consignments (TARADCOM estimate)

TDM performance data are taken from the present RRAD evaluation study when it is available and appropriate and from prior YPG studies otherwise. For example, no field failure data could be obtained at RRAD but was the entire point of the YPG studies and whereas no in-process failure data was available at YPG, the present report supplies it. Therefore, the YPG data are used to measure TDM capability of rejecting in-service failures and the RRAD data are used for in-process failures. In addition, a TDM reading of 6 (or 40% of a new tire reading) has been used as the accept/reject criterion.

Shipping Savings

Equation (1) in the text becomes:

$$\frac{(18000)(103\text{lb}) + (1800)(143\text{lb})}{18000 + 1800} \left(\frac{\$236.25 \text{ ton}^{-1}}{2000 \text{ lb.ton}^{-1}}\right) (0.53)\ N$$

$$= \$6.676\ N$$

This saving is rather large due to the heaviness of this size tire and the fraction of casings rejected.

Spreader Inspection Savings

Equation (2) in the text becomes:

$$(0.125 \text{ hr.}) (\$25.00 \text{ hr.}^{-1}) (0.53)\ N$$

$$= \$1.656\ N$$

This saving is relatively large because of the high TDM rejection rate.

Buffing Savings

Equation (3) in the text becomes:

$$(0.125 \text{ hr.}) (\$25.00 \text{ hr.}^{-1}) (0.53) (0.06)$$

$$= \$0.099\ N$$

This is an insignificant contribution to the cost-benefit structure largely because so relatively few casing failures are due to separations.

Casing Failure Savings

Equation (4) in the text becomes:

$$\left(1 - \frac{3688}{7506}\right) \frac{(18000)(\$56.) + (1800)(\$62.)}{18000 + 1800} (0.77)\ N$$

$$= \$22.467\ N$$

This saving has been computed using YPG data which reflect high failure rates in a harsh road surface environment. Translation of this analysis to a more commonly encountered environment should not reduce the amount of savings because averages are used. The mileage ratio of retread vs new should remain relatively constant but computation of the actual saving will require results of tests run at Ober-Ramstadt.

PDO Recovery Savings

Equation (5) in the text becomes:

$$\frac{18000\,(\$135-\$56-103(\frac{\$236.25}{2000})) + 1800(\$226-\$62-143(\frac{\$236.25}{2000}))}{18000 + 1800}\,(0.23)(0.10)\ N$$

$$= \$1.705\ N$$

This saving is relatively large because of the high cost of the material being recovered.

TDM Inspection Cost

Equation (6) in the text becomes:

$$(0.009\ \text{hr.})\ (\$25.\ \text{hr.}^{-1})\ N$$

$$= \$0.225\ N$$

This relatively small cost assumes the use of the pattern-recognizing TDM in an inspection environment with minimal additional tire handling by the inspector. Tires are normally inspected visually, and TDM inspection would be made during the visual inspection. Handling requirement should therefore not be changed.

Incorrect Rejection Cost

Equation (7) in the text becomes:

$$\frac{(18000)(\$36.-\$56.90\ -(\frac{\$236.25}{2000})\ 103) + (1800)(\$226.\ -\ \$62.\ -(\frac{\$236.25}{2000})\ 143)}{18000\ +\ 1800}$$

$$\times\ (1-0.23)(1-0.27)(0.34)\ N$$

$$= \$14.434\ N$$

The magnitude of this cost is directly attributable to the large number (34.2%) of so-called good* casings rejected at a TDM reading of 6 or less in the RRAD population. This percentage is based on the ratio of code-accepted casings with the lower-than-acceptable TDM reading to the total number of code-accepted casings. It is probable that an unknown number of these casings were bad in the sense that they would not return full service after retreading and that the ratio of incorrectly rejected casings could be less than 34.2%. This example is assuming that all the TDM rejectable but code-acceptable casings are truly good casings so that the ratio of 34.2% represents the worst case.

Finally, if the TDM Purchase Cost is $10,000.00, if the TDM service life is assumed to be six years, and if the TDM Support Cost is assumed to be 25% per year of the purchase cost (or an annual cost of $2,500.00), then the TDM support volume N of casings inspected annually can be found by equating the present value net benefit of TDM use with the present value cost of TDM purchase:

$$D_y \, (\$17.944N - \$2500.00) = \$10{,}000.00 \, D_1$$

The number $17.944 is the difference between savings and costs per inspected casing for the alternative being considered in this example and D_y is the cumulative uniform discount factor for y years as presented in Figure 2-4 of AR 11-28. D_1 is, of course, the first year single amount discount factor applied to the purchase of the TDM. This relation implies that for a TDM service life of six years, six values of TDM support volume can exist depending on how the purchaser selects his payback period. Selection of this period is influenced by the relation between discounted savings and discounted costs. The discounted savings are computed after the cost-justification volume (N) for TDM procurement is determined and are expressed as:

$$S = D_6 \, (\$17.944 \, N - \$2500) - \$10{,}000 \, D_1$$

The discounted costs are computed on a similar basis and are expressed as:

$$C = D_6 \, (\$14.659 \, N + \$2500) + \$10{,}000 \, D_1$$

The cumulative uniform discount factor for six years (D_6) is given in Figure 2-4 of AR 11-28 as 4.570 and, as the equations imply, there are six values of discounted savings and costs for a TDM service life of six years. The pay back period, associated annual casing inspection volumes required to justify TDM procurement, and the related discounted savings and costs are summarized in the following table:

Payback Period (years)	Minimum Annual Inspection Volume Justifying TDM Procurement (casings)	Six-year Accumulated Discounted Savings	Six-year Accumulated Discounted Costs
1	697	$ 36,192	$ 67,658
2	432	14,460	49,905
3	342	7,080	43,876
4	300	3,636	41,062
5	273	1,422	39,254
6	256	28	38,115

The resultant savings to cost ratio is low because of an assumption that the incorrect TDM rejection rate $P_i(6) = 0.34$ is a realistic representation of TDM false rejections. This is a worst case assumption and has been made because of our ignorance of the post-retread performance of casings with low TDM readings that survived retreading. If it is now assumed that as many as 50% of these retreads failed to provide adequate post-recap service, then the true false rejection rate would be 50% of 0.34, or 0.17. Repeating the foregoing economic analysis using an assumed $P_i(6) = 0.17$, the minimum casing volumes and related discounted savings and costs become:

Payback Period (years)	Minimum Annual Inspection Volume Justifying TDM Procurement (casings)	Six-year Accumulated Discounted Savings	Six-year Accumulated Discounted Costs
1	497	$ 36,183	$ 37,868
2	308	14,451	31,440
3	245	7,207	29,297
4	213	3,527	28,209
5	195	1,457	27,597
6	182	-38	27,155

The total savings has not changed because the minimum procurement justification volume of casings has decreased, but the savings to cost ratio has improved the one-year payback option. Now, if it happens that certain Army facilities handle enough casings to justify TDM procurement on the basis of the first analysis (i.e., N = 697 for a one-year payback), then the resultant discounted savings from an improved false rejection rate could be $59,180 and the discounted costs would be $44,670. The savings to cost ratio is now 1.32 and can improve with increasing inspection volume. It now becomes very important to track casings both through the retread process and through their subsequent service life to establish an accurate TDM false rejection ratio and thereby make the economic analysis better reflect field utilization.

This has been an example of a cost-benefit analysis of a simple implementation of TDM casing inspection of two tire types based on a composite field data profile. It demonstrates that ultrasonic TDM casing inspection can yield net savings for the Army rejecting unretreadable casings before retreading is attempted. It also demonstrates that the cost-justification point for TDM implementation can be rather low. When the data from Ober-Ramstadt are collected, it could conceivably become lower.

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The report work is part of a larger Army program to evaluate the benefit from using ultrasonic tire inspection, Tire Degradation Monitor (TDM), in the Army Tire Retread System.

The objectives of this work were to:

a) develop a closed loop test plan to direct the Army ultrasonic tire inspection evaluation of the TDM,
b) perform a field test of the plan at RRAD,
c) analyze resultant RRAD inspection data, to determine tire suitability

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) for retreading and TDM ultrasonic measurement correlation, and

d) develope the mathematical model for a cost analysis to be performed with the data obtained in the closed loop evaluation (scheduled for the Army Depot Activity, Ober-Ramstadt).

This final report presents (a) the results of a field evaluation of the test plan (the plan was completed earlier in the program and submitted under separate cover), and (b) a model for an economic analysis to be performed with the data obtained in a subsequent closed loop evaluation (scheduled for June 79 in Ober-Ramstadt).

In summary, we show that a viable evaluation plan was developed, field tested and is ready for use in the planned evaluation. The RRAD ultrasonic tire inspection data analysis verifies pervious data (Yuma Proving Grounds (YPG)*) and indicates the potential for cost savings. The framework for the cost savings analysis provided herein delineates the suggested analysis rationale and indicates the data required to provide a viable economic analysis.

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* Mathieson, T. A., "Using Ultrasonics to Establish Maintenance Expenditure Limits for Tires", November, 1974.