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TECHNICAL REPORT

NO. 12570

FAILURE ANALYSIS STUDIES OF T-142 TRACK PADS

JUN 1981

by JACOB PATT & PETER G. SAKALAS

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U.S. ARMY TANK-AUTOMOTIVE COMMAND
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20030908011

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 12570	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Failure Analysis of T-142 Track Pads		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Jacob Patt Peter G. Sakalas		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Tank-Automotive Command ATTN: DRSTA-RCKT Warren, MI 48090		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Tank-Automotive Command ATTN: DRSTA-RCKT Warren, MI 48090		12. REPORT DATE 15 Jun 81
		13. NUMBER OF PAGES 63
14. MONITORING AGENCY NAME & ADDRESS(If different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Pad Failure
Track
Elastomers
T-142

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of this work was to ascertain the various modes of failure of T-142 track pads and the steps needed to alleviate this high failure rate. A heavy emphasis was placed on failure analysis. These procedures have proven invaluable in analyzing the causes and modes of track pad failures. Future use of these procedures will enhance our knowledge of why track pads fail, how they fail, and the steps needed to formulate a compound which will better withstand these failure modes.

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1. INTRODUCTION:

The ultimate objective of all the ongoing track pad programs is to obtain the information necessary to enable TACOM to specify the best possible elastomer for combat vehicle track pads.

To this end, a number of various inter-related programs are presently being conducted. Some of the features of these programs are:

a. Finite Element Analysis of the T142 pads.

b. Failure analysis of vehicle tested pads.

c. Property/Structure Analysis of present design.

d. Vehicle testing of various modified compounds.

e. Preliminary testing of new concepts in elastomer formulation.

f. Use of reinforcing fillers.

The work described in this report encompasses the use of modified compounds, the use of reinforcing fillers, and failure analysis of vehicle test pads. Through these efforts, we were able to establish that the analytical procedures which, until now, had not been used for track elastomer analysis, were (shown to be) capable of producing meaningful results. Future use of these procedures will enhance our knowledge of why the pads fail, how they fail, and the steps needed to formulate a compound which will better withstand these failure modes.

2. OBJECTIVES:

The objectives of this work were to ascertain the modes of failure of the T-142 track pads and to develop Laboratory methods and techniques to analyse these modes. With this information we will be able to compound our pads with a visco-elastic material possessing properties which would be able to overcome these failure modes.

3. BACKGROUND:

The T-142 track is of double pin, rubber bushed, end and center connected, dual sprocketed design incorporating replaceable rubber pads. It is a 28 inch (710 mm) wide track designed for vehicles of the 55 ton weight class and was introduced as a production item on the M60 series tank in 1975. The operational life of the metal components of this track is approximately, 5,000 miles, or more, while the average life of the rubber pad is seldom more than 2,000 miles under the best of circumstances and is usually less than 500 miles under the severest conditions.

Any significant increase in pad life would be beneficial in a number of ways:

a. Track reliability would be increased.

b. Maintenance and vehicle down time would be reduced.

c. A tremendous cost savings in maintenance and the purchase of replacement pads would be realized.

d. Logistics would be enhanced.

4. APPROACH:

In order to develop a more durable track pad, it is imperative to know not only which compounds or variations give a longer service life, but also the various modes of pad failure. With this information, new compounds can be formulated in order to combat these failure modes. Therefore, not only were various compound modifications tested at YPG, but also samples from each test set were analysed prior to vehicle testing and at various intervals during the vehicle tests. These samples were tested with the standard ASTM rubber tests such as modulus, tensile, elongation and tear strength. In addition, they were tested by methods previously not used on track pad rubber such as Thermogravimetric Analysis (TGA), Scanning Electron Micoscopy (SEM), Energy Dispersive Analysis of X-ray (EDAX), Electron Spectroxcopy for Chemical Analysis (ESCA), Thermo-Mechanical Analysis (TMA), and Differential Calorimetric Analysis (DCA). These procedures are capable of analysing failures on a microscopic level in order to determine the ultimate cause of failure.

5. CONCLUSIONS:

a. The surface analyses techniques can be used as effective analytical tools in determining causes of failures in track pads. These tools can also be used to determine the quality of the rubber processing prior to any vehicle testing.

b. Improper processing or curing of the rubber used for track pads causes heterogeneities in the rubber which acts as sites for initiation of failures.

c. Thermal, mechanical, and chemical degradation of the rubber is caused by service conditions.

d. When using fibers to reinforce the pad rubber, the fibers must first be surface treated in order to promote adhesion between the fiber and rubber stock.

e. Results from all standard laboratory tests of pads examined prior to field testing have indicated that, so far, we have not been able to definitely establish a correlation between laboratory tests and actual field performance with the possible exceptions of tear resistance and toluene swelling tests.

f. More trials should be conducted comparing these two tests with vehicle performance in order to determine whether a correlation does in fact exist.

6. RECOMMENDATIONS

a. Continue the use of ESCA, SEM, EDAX, and TGA in conjunction with all Proving Ground testing.

b. Conduct further trials with the compound used in set number 1 and further improve this compound.

c. Conduct vehicle tests using standard production stocks which have been adequately mixed and followed. Compare the results obtained from these trials against the results obtained from normal regular production mixed stocks.

d. If futher trials are to be conducted with fiber filled rubber, insure that:

(1) The fibers have been surface treated so that an adequate bond between the rubber and fibers can be obtained.

(2) Mix the fibers with the rubber in such a manner that a completely homonogenous mixture can be obtain.

e. Continue with these and other on-going programs in order to obtain data needed to establish property/structure relationships.

f. Expand the Toluene Swelling (cross link density) and Tear Resistance experiments in order to determine whether variations in these properties will have an effect on field performance.

7. TEST PROCEDURES METHODOLOGY:

Nine sets of track pads were sent to YPG for testing. The classification of these nine sets is as follows:

Set 1 - T-142 pad from supplier number 1 with modification M.

Set 2 - T-142 pad standard production from track supplier number 1.

Set 3 - T-142 pad standard production from track supplier number 2.

Set 4 - T-142 pad standard production from track supplier number 3.

Set 5 - T-142 pad from supplier number 1 with modification K.

Set 6 - T-142 pad from supplier number 3 with modification K.

Set 7 - T-142 pad from supplier number 1 with modification T.

Set 8 - T-142 pad from supplier number 1 with modification A.

Set 9 - New design pad from supplier number 3 with modification G.

The testing of these sets was divided into two areas:

a. YPG TESTING.

The YPG testing was comprised of three phases with each phase starting with a new set of pads:

Phase I - 2,000 miles on smooth pavement with an M103 combat vehicle.

Phase II - 1,000 miles on gravel (secondary) roads with an M48A5 combat vehicle.

Phase III - 500 miles on hill cross-country with an M48A5 combat vehicle.

b. LABORATORY TEST PROCEDURES.

Prior to testing, and at regular intervals during each test phase, all pads were weighed in order to determine the amount of rubber lost for that test interval. At each weighing, three pads from each set were removed and sent to various laboratories for analysis. These analyses were compared to the data obtained when analysing an untested pad, and an attempt was made to correlate laboratory test results with performance on the YPG test vehicles.

The schedule of weighing and analysing the pads was as follows:

PHASE	MILEAGE INTERVALS FOR PAD WEIGHT AND ANALYSES
I	0
	500
	1,000
	1,500
	2,000
II	0
	500
	1,000
III	0
	250
	500*

*Final weight and analysis was at 366 miles rather than 500 miles due to failure of all pads at 366 miles.

Upon completion of the testing, the results were compiled, compared, recorded, and graphed. Percentages of rubber lost by each set were calculated and a comparative rating of each set was then established. The percent weight loss for the pads was calculated by the following formula:

$$\text{Percent weight loss} = \frac{A}{B} \times 100$$

A = average total weigh loss.

B = average original weight of the rubber portion of the pads. "B" was obtained by taking the original total weight of the pad and subtracting the metal part of the assembly.

The rating was calculated by the following formula using the regular production T-142 pad from supplier number 1 as a base (Set number 2):

$$\text{Rating} = \frac{C}{D}$$

C = percent weight loss of base.

D = percent weight loss of set being rated.

The percent weight loss was used rather than the actual grams lost because each set did not weigh the same at the beginning of the tests. Using percent weight loss rather than grams lost would not skew the rating in favor of a compound which lost less during the test but weighed less prior to testing.

After the YPG results were compiled, graphed, and compared, the laboratory results were also graphed and compared in order to determine whether any trends could be detected or whether a correlation could be found between the peformance at YPG and the results of various laboratory tests.

APPENDIX A

YUMA RESULTS

A-1 SUMMARY OF YUMA RESULTS

a. All pads completed 2,000 miles paved road testing with a significant difference between pads in percent of rubber lost.

b. All pads completed 1,000 miles gravel road testing with a significant difference between pads in percent of rubber lost.

c. All pads failed 500 miles hilly cross-country testing at 366 miles with significant differences between pads in percent of rubber lost.

d. Compound number two (rated 100 as a baseline) was the best of the three vendor regular production compounds with a significant advantage over compound number four which was another vendor's regular production compound and was rated 67 on gravel and 81 on cross-country, and a good advantage over compound number three which was the third vendor's regular production compound and was rated 81 on gravel and 90 on cross-country.

e. The best compound was number one (a T-142 pad with a new, proprietary compound) with a rating of 116 on paved roads, 115 on gravel, and 107 on hill cross-country.

f. The track pad with the new configuration and modified compound rated 110 on paved roads, 104 on cross-country, and 101 on gravel roads.

A-2 DISCUSSION:

a. The Yuma results show that there is a decided difference in the standard track pads supplied by the present three track contractors. All three compounds had qualified and had been certified by the contractors as having passed qualification requirements. Their performance on the test vehicle, however, indicates a significant variation in field capabilities. This variation is significant enough that it cannot be attributed to experimental error or testing variables.

b. Of all the experimental compounds tested only one was able to consistently surpass the performance of the compounds we are presently using. This experimental compound was manufactured by the supplier with the best overall rating for the standard track pads.

c. All the other experimental compounds, were worse than the standard compounds. These experimental compounds, however, appeared to have been mixed using procedures which were inadequate for the production of durable track pads.

A-3 GRAPH & TABLES

1. Table #1 gives the comparative rating of all the sets for the three phases of the test.

2. Graphs #1-8 show each set individually graphed as to performance on the 2,000 mile paved road test. These graphs show the loss in grams from the pads and the percent loss at each weighing interval.

3. Graphs #9-16 show each set individually graphed as to performance on the 1,000 mile gravel road test. The weights and percents graphed represent the same type of information as those graphed on 1-8.

4. Graphs #17-25 show each set individually graphed as to performance on the 500 mile hilly cross-country test. These graphs show the same type of grams and percent information as the previous two categories.

5. Graphs #26-28 show the comparisons of each set of pads for the three phases. These graphs give a direct comparison of the percent of rubber lost by each set during each phase.

TABLE #1

	RATING		
SET NUMBERS	PAVED ROAD	GRAVEL ROAD	CROSS-COUNTRY
1	116	115	107
2	100	100	100
3	109	81	90
4	111	67	81
5	97	81	95
6	95	74	82
7	79	-	89
8	-	90	90
9	110	101	104

YUMA PAVED

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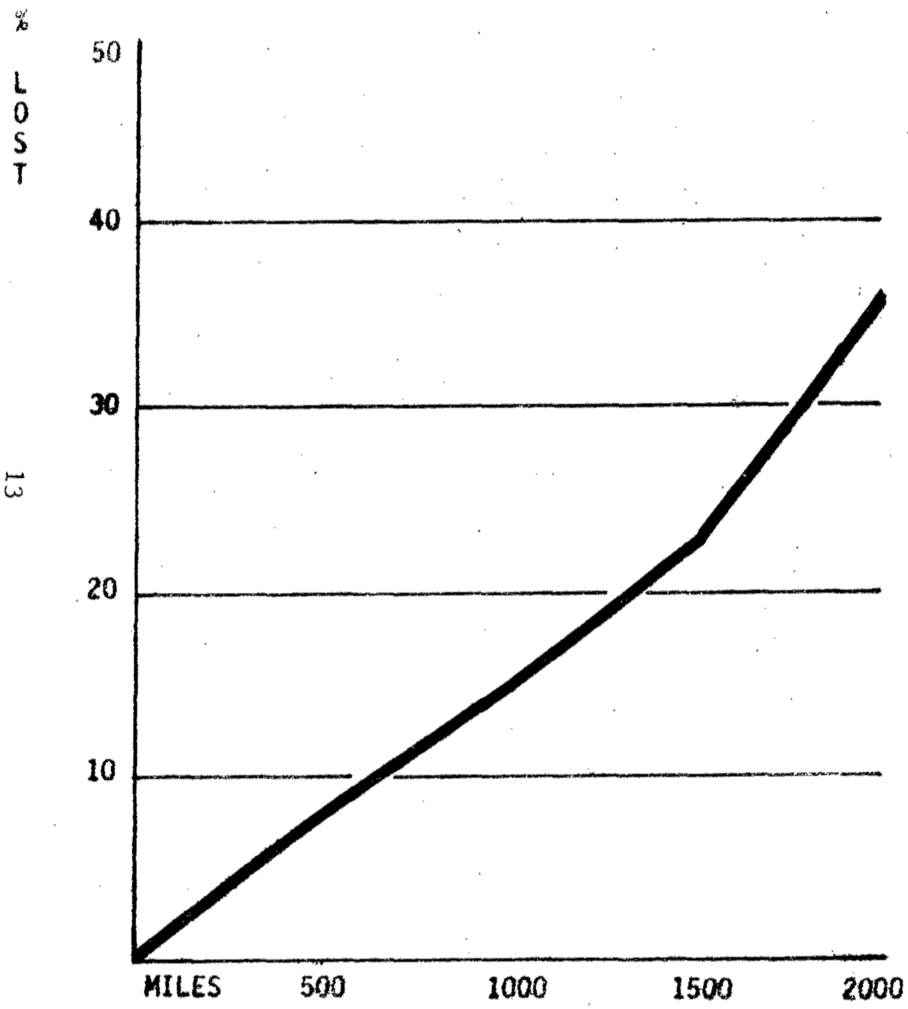

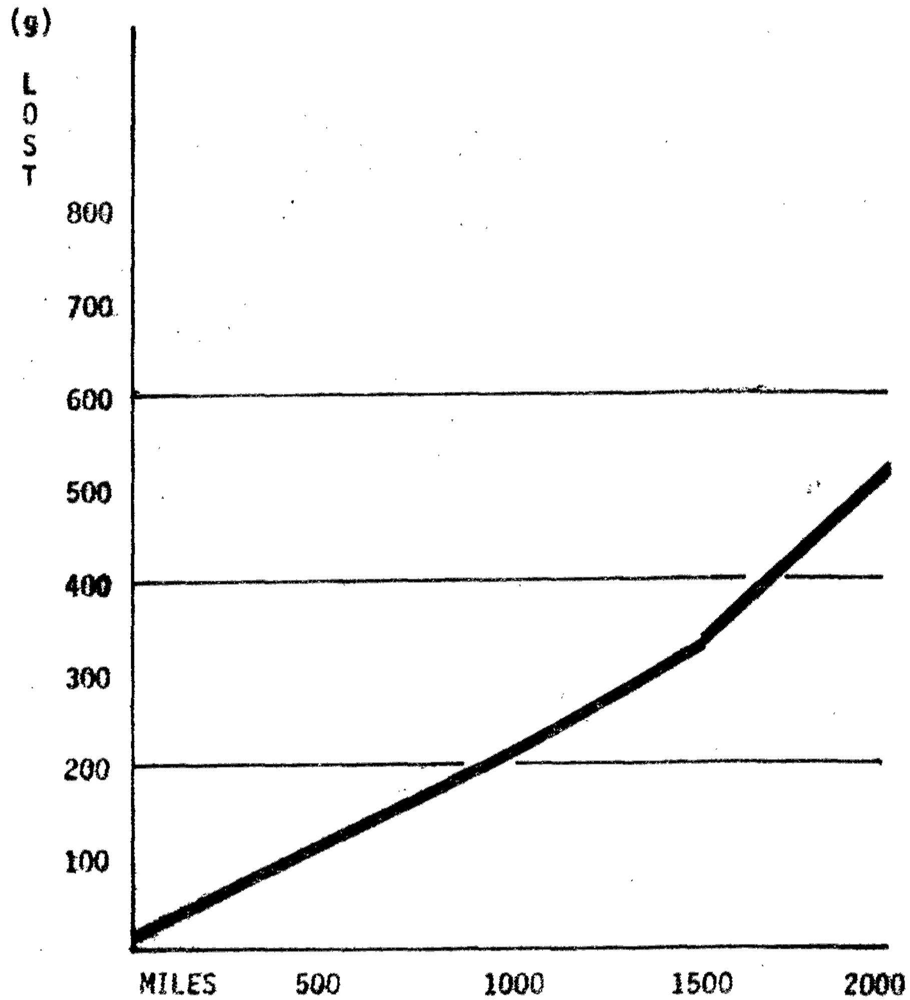

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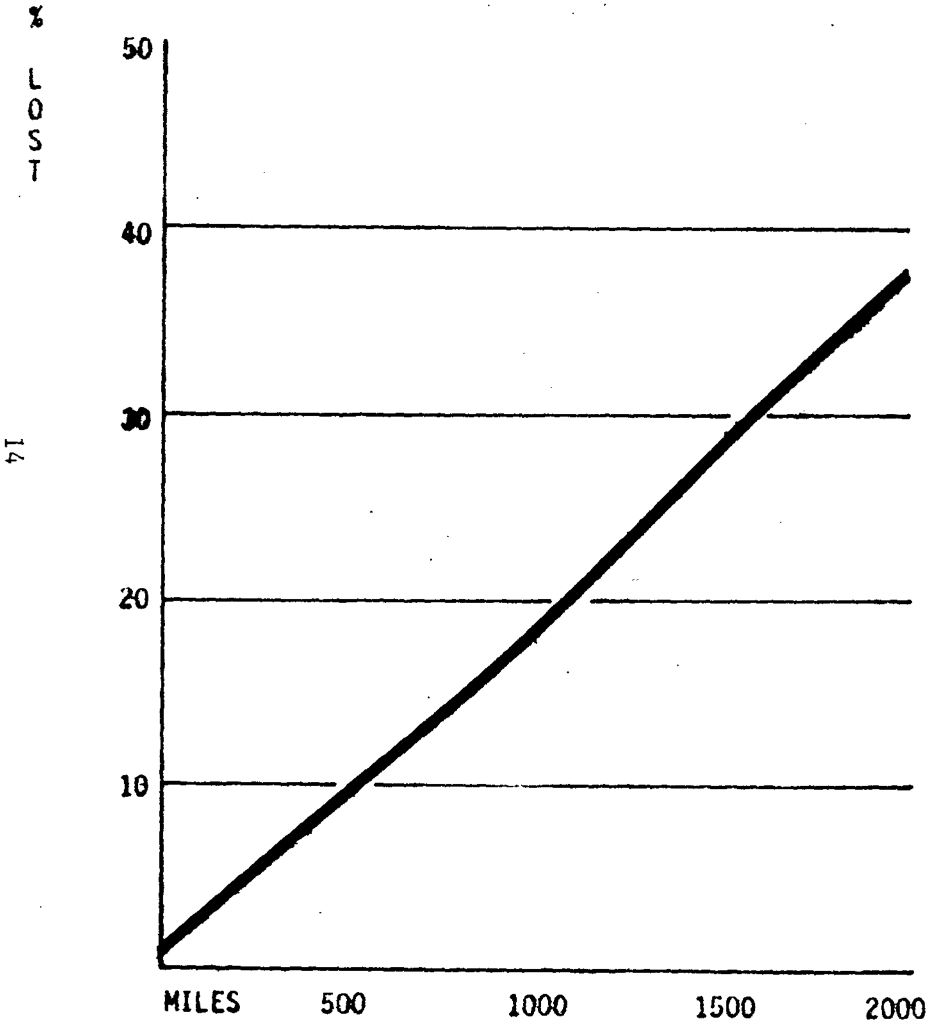

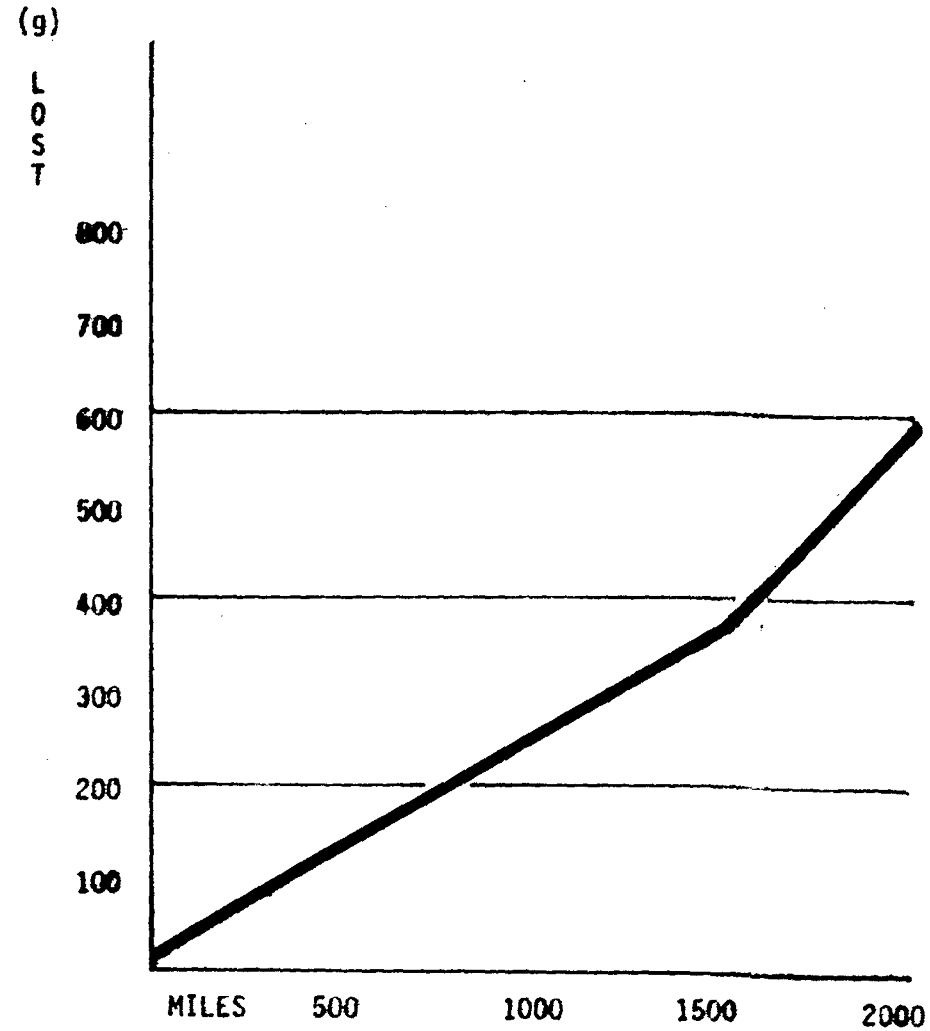

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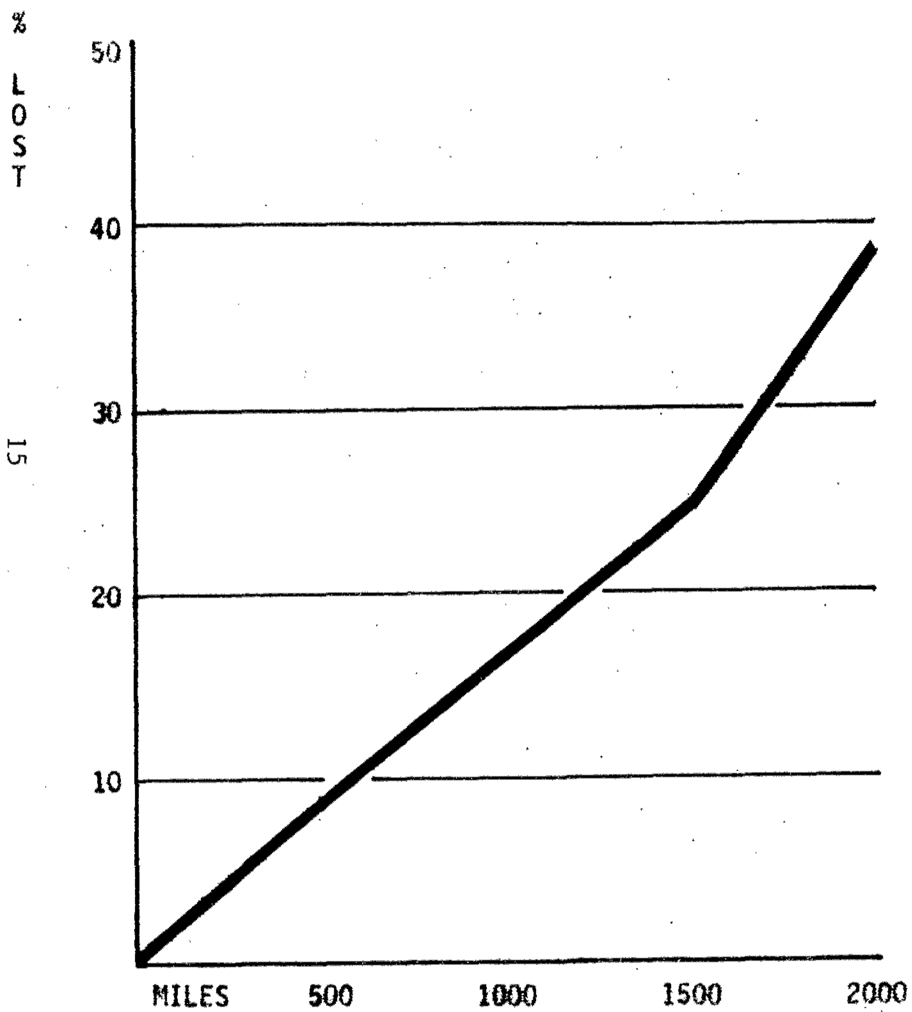

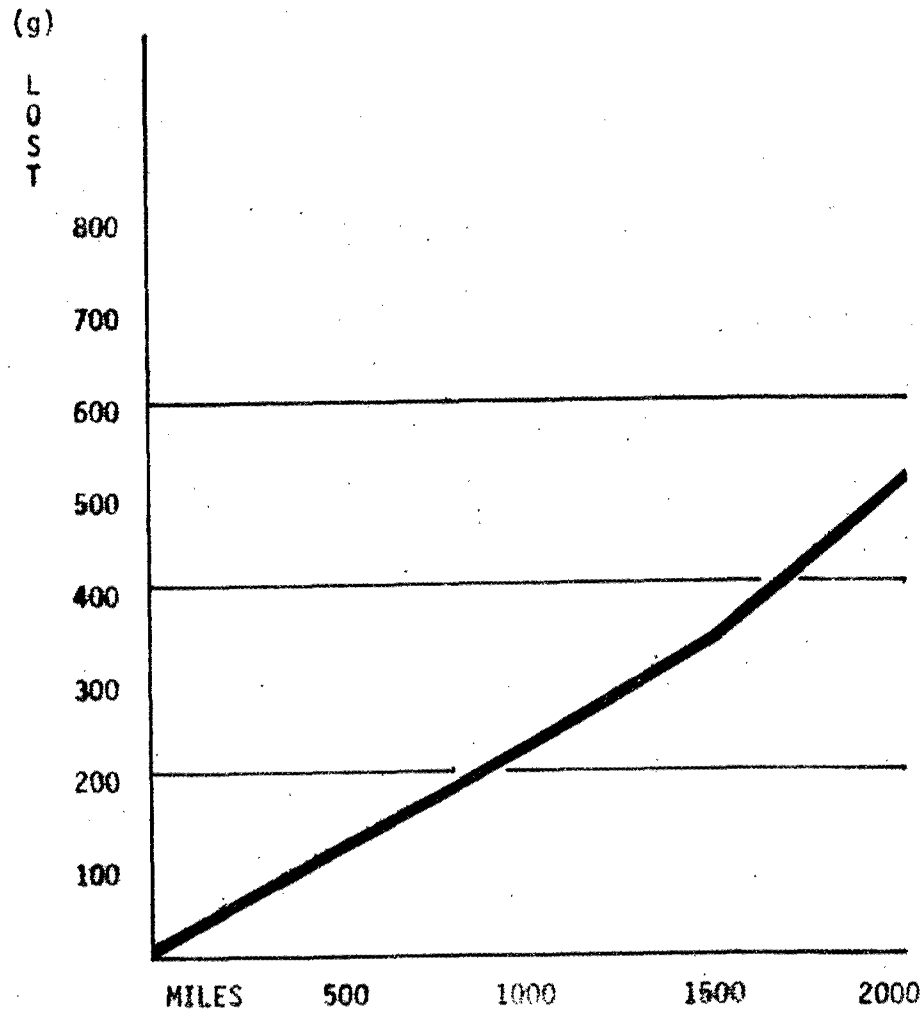

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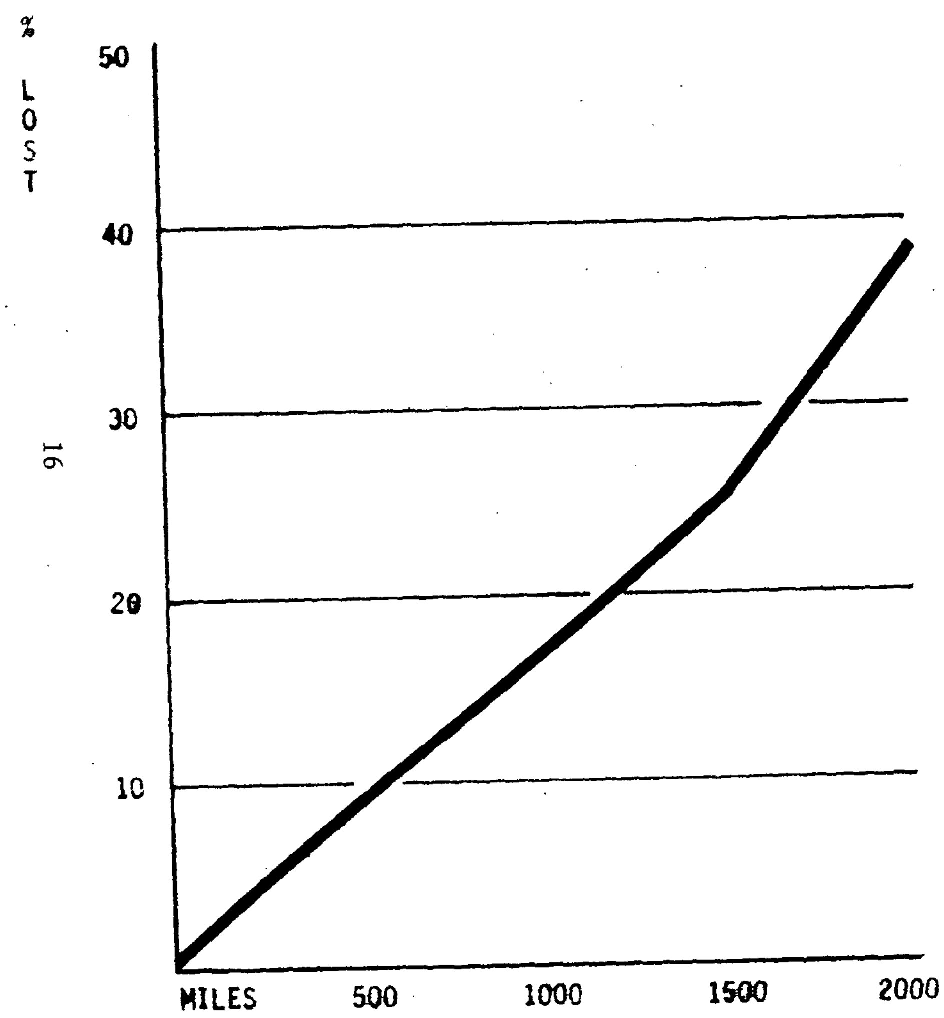

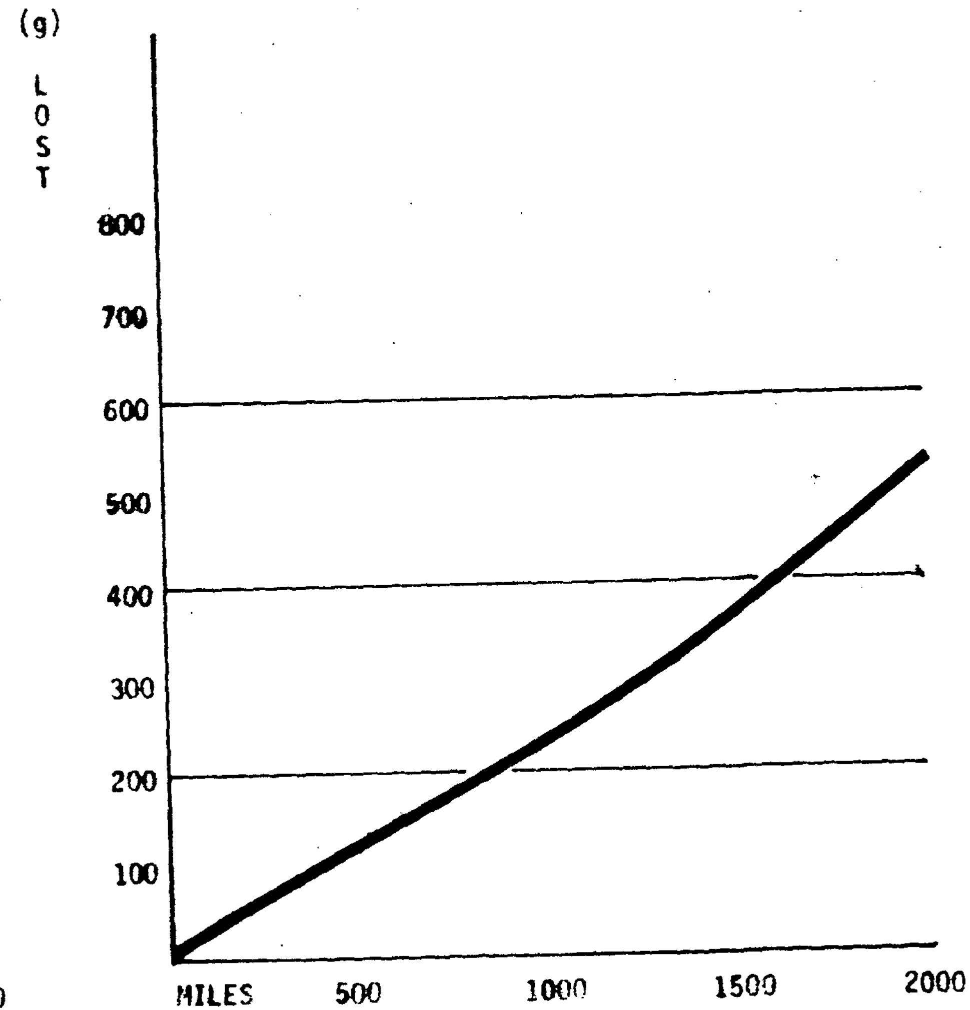

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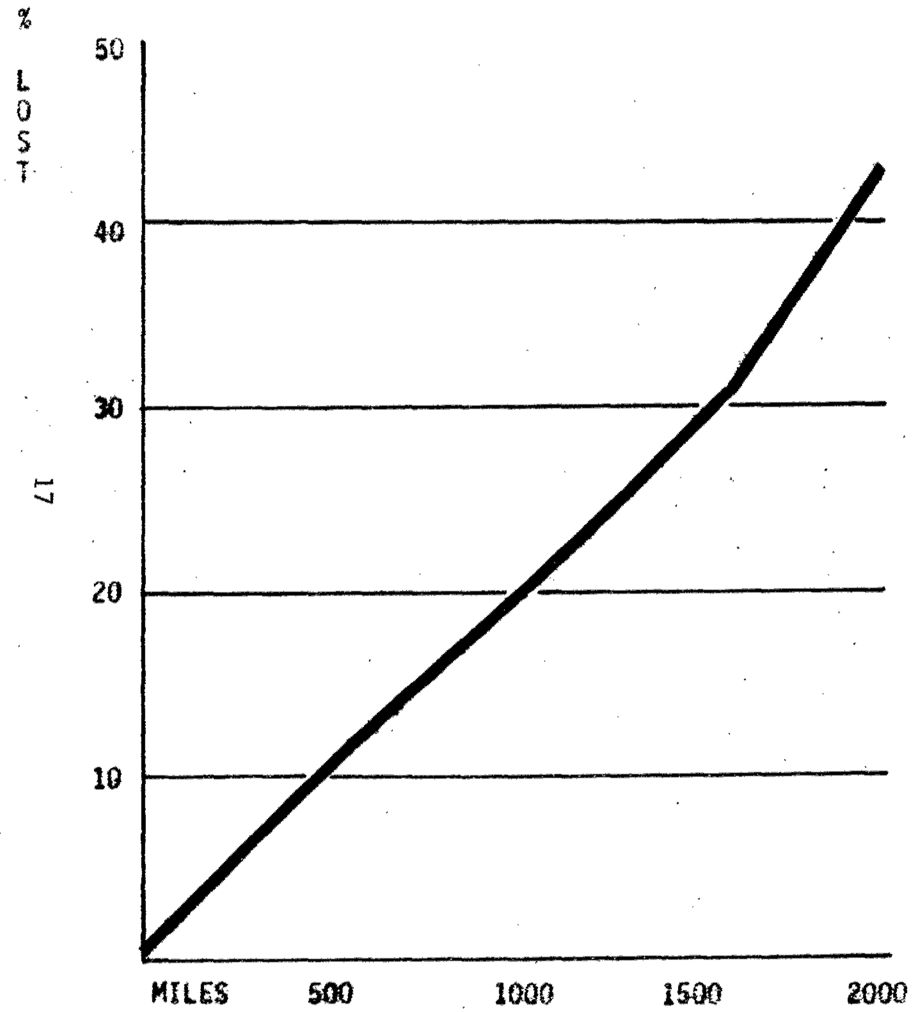

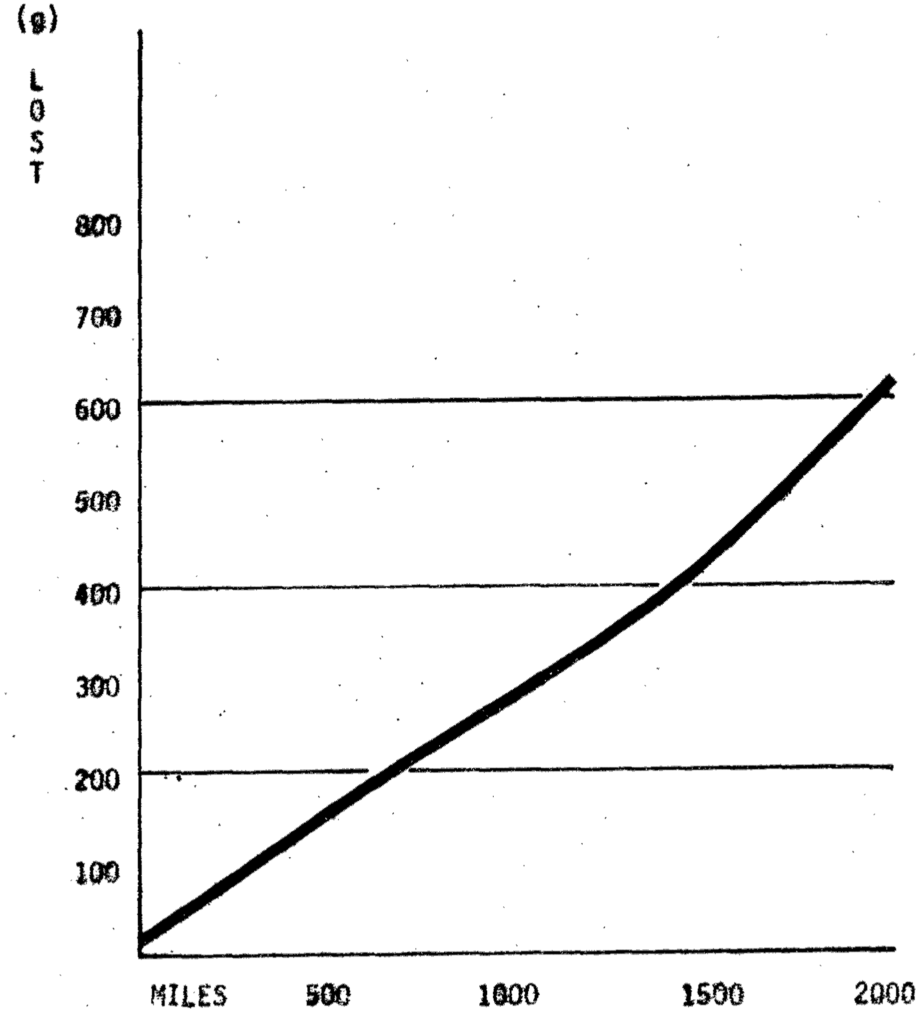

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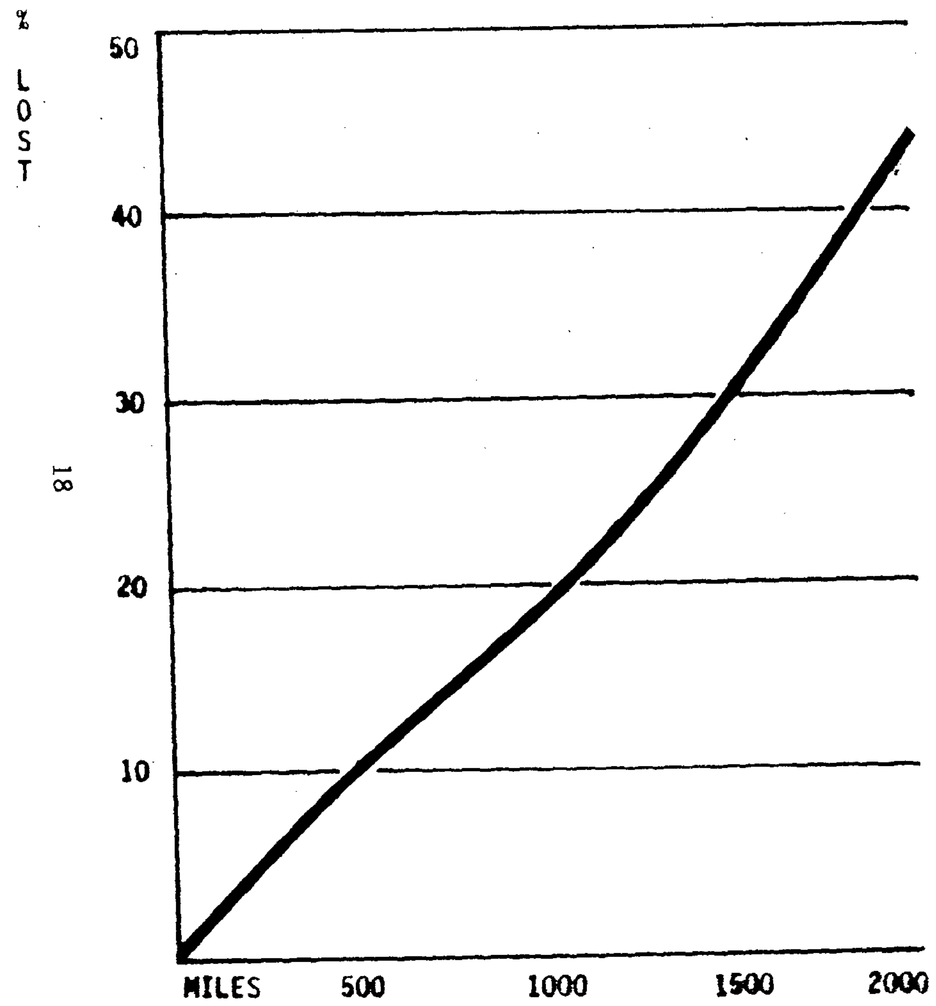

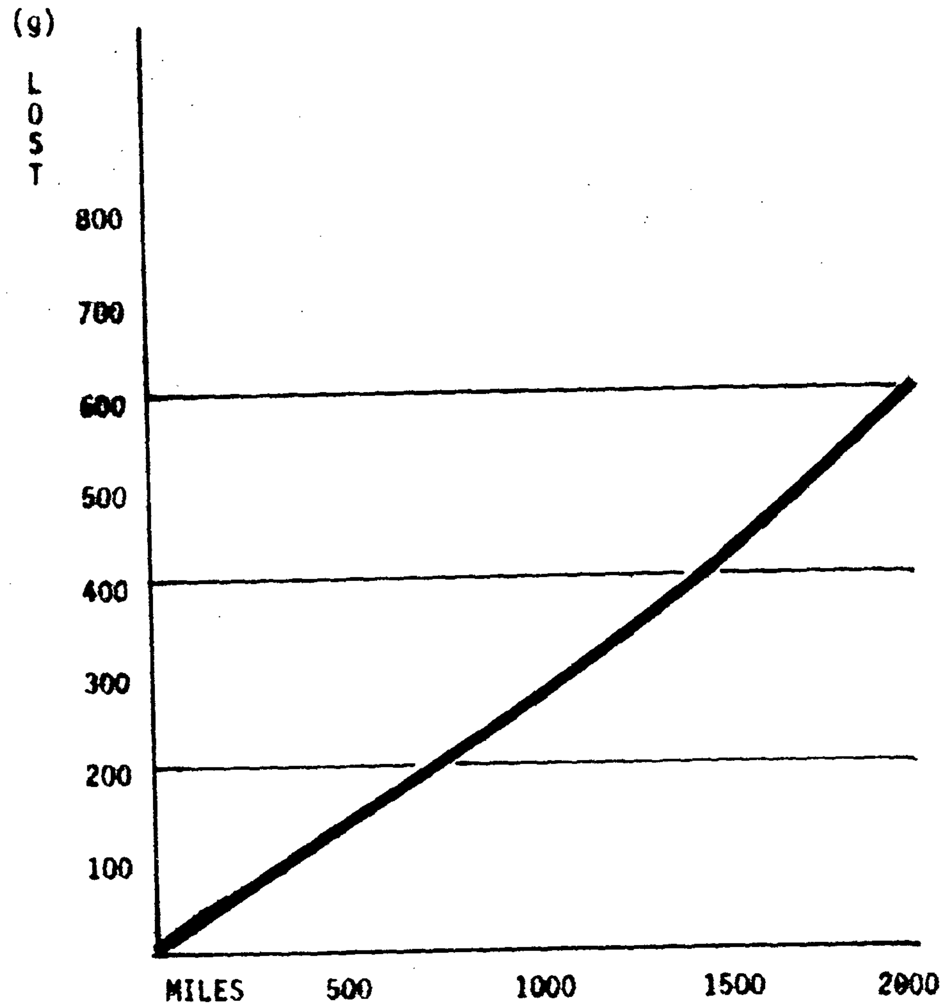

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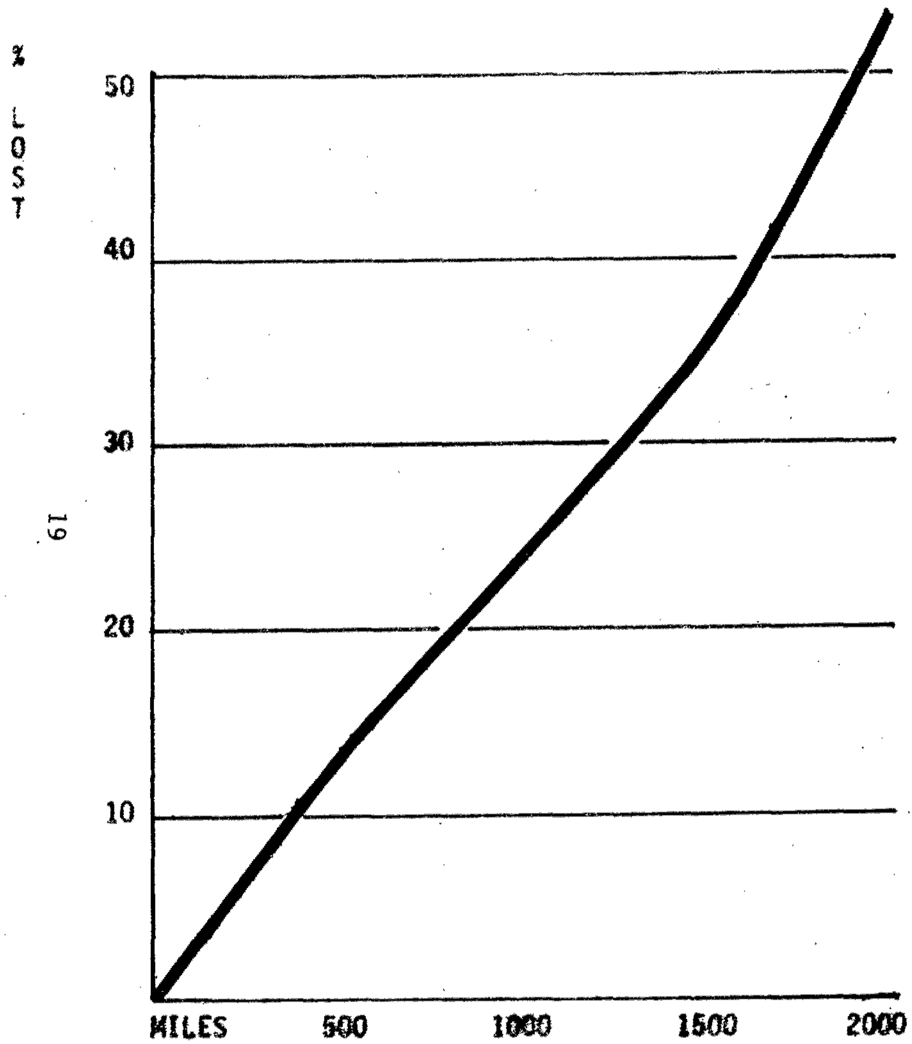

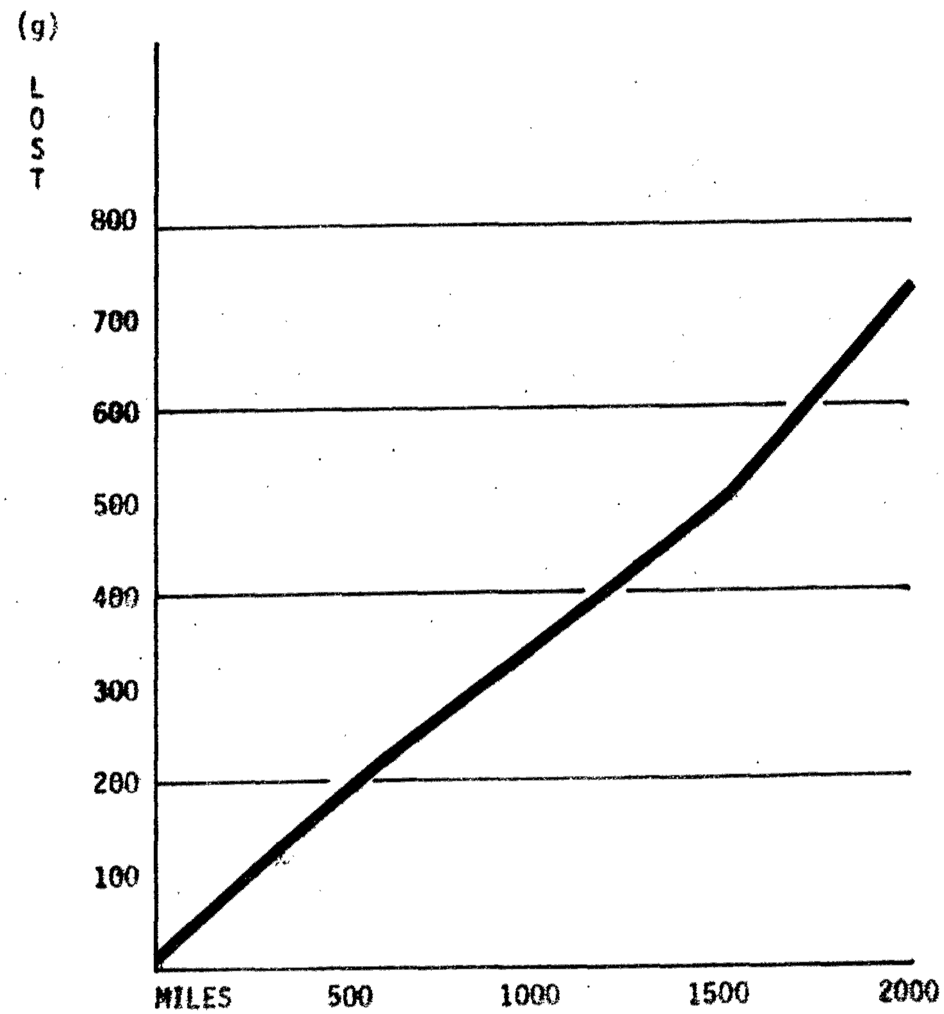

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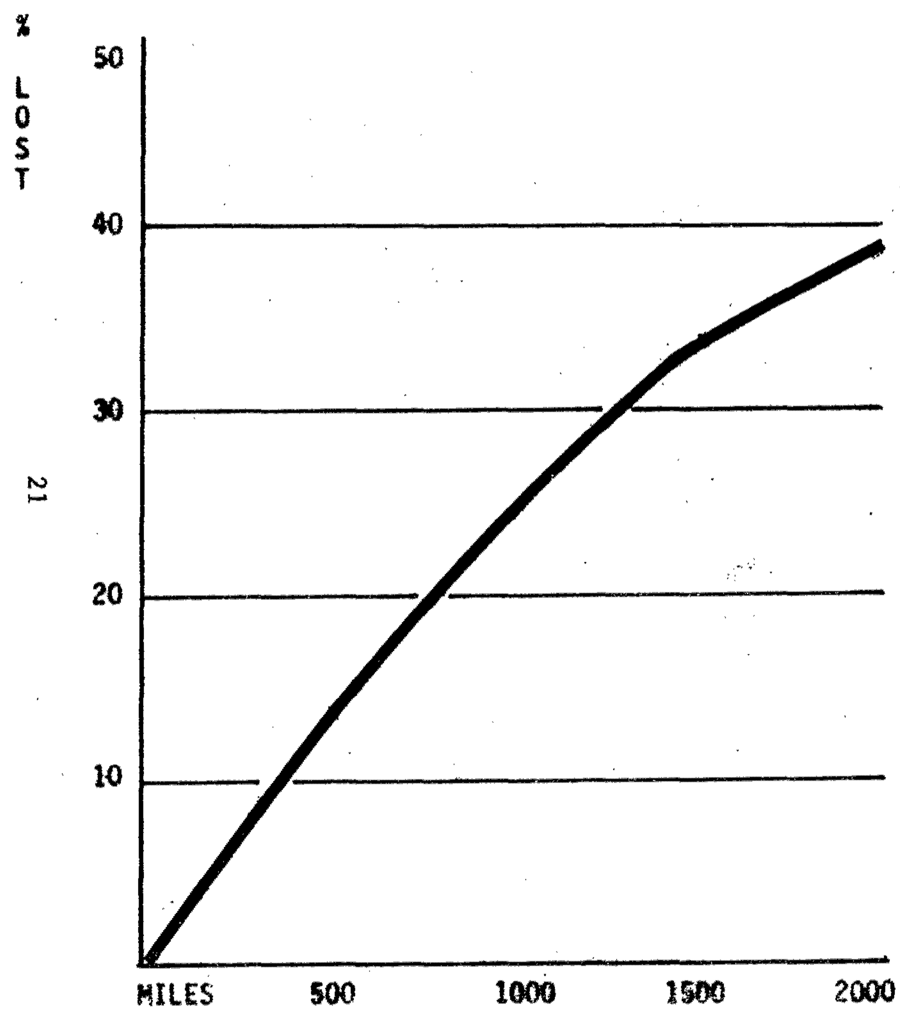

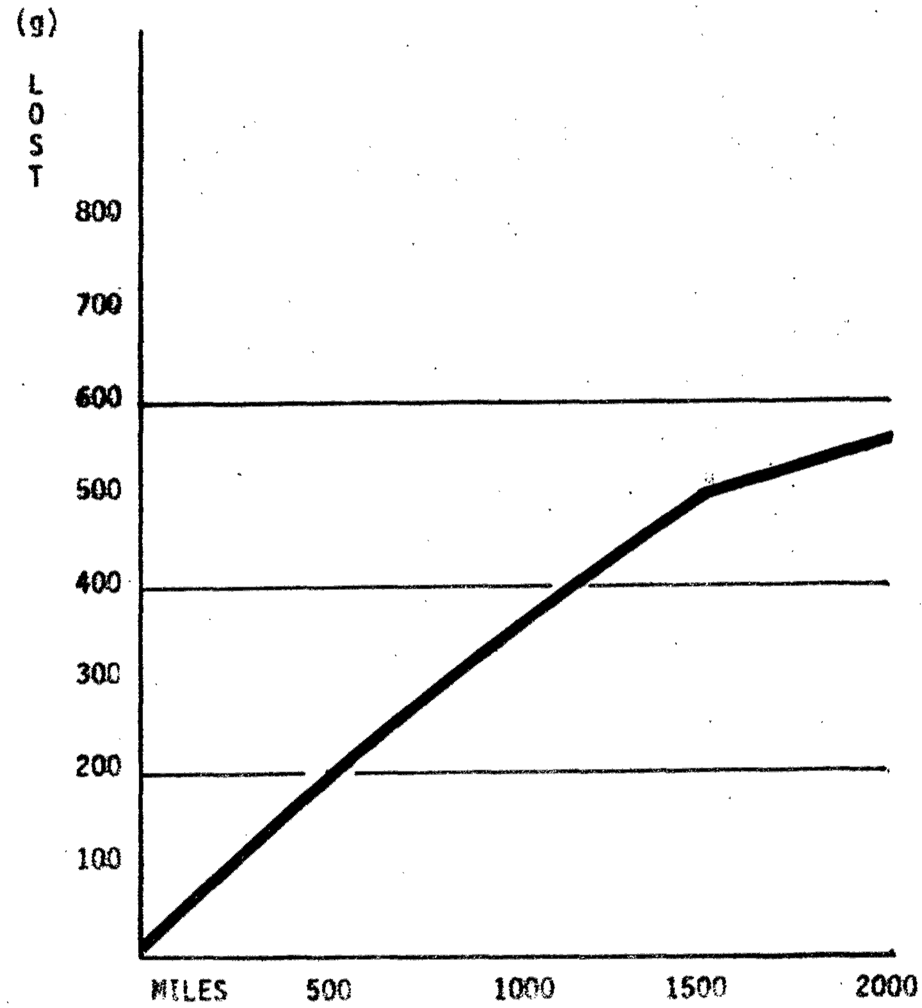

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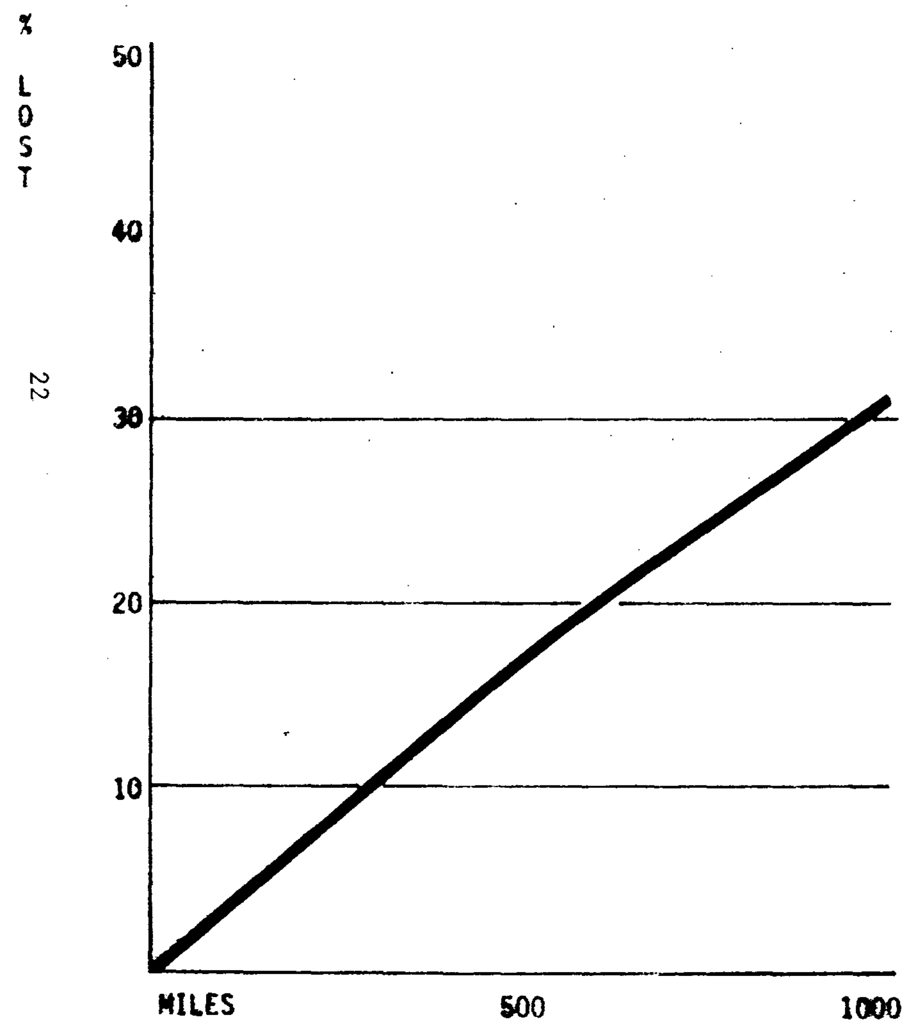

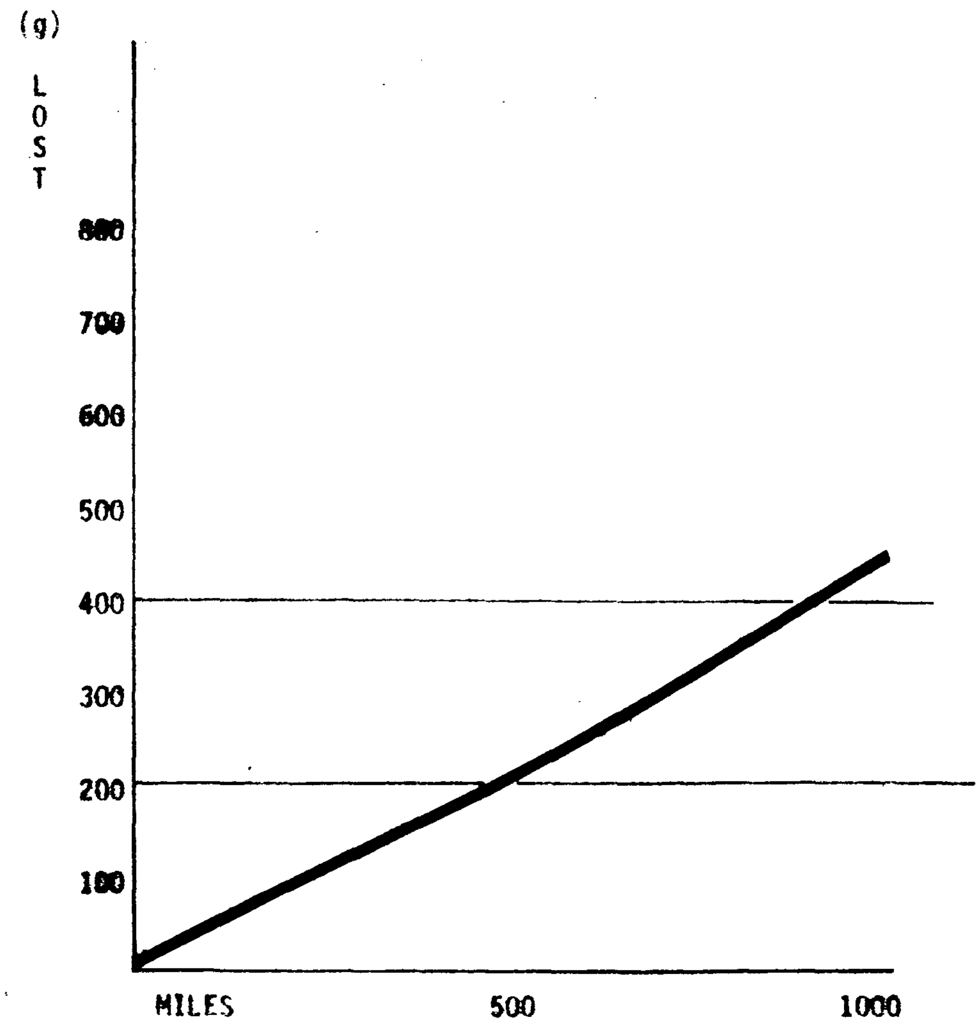

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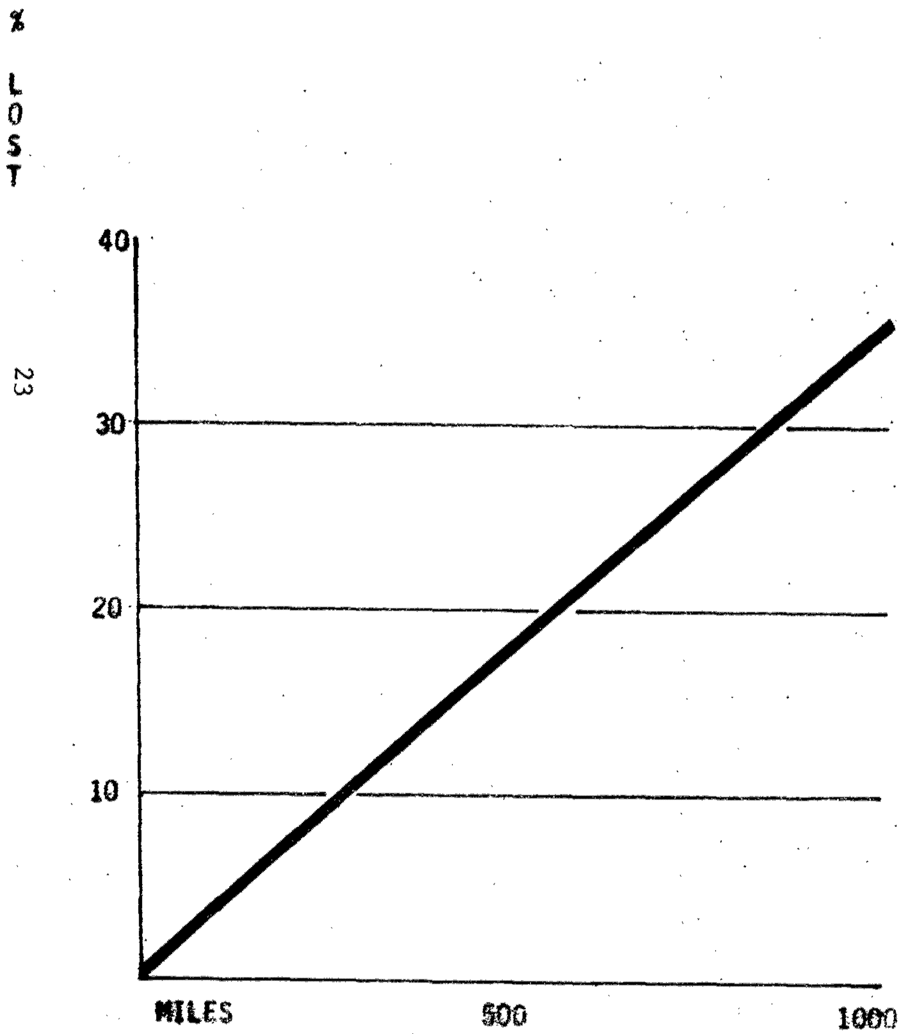

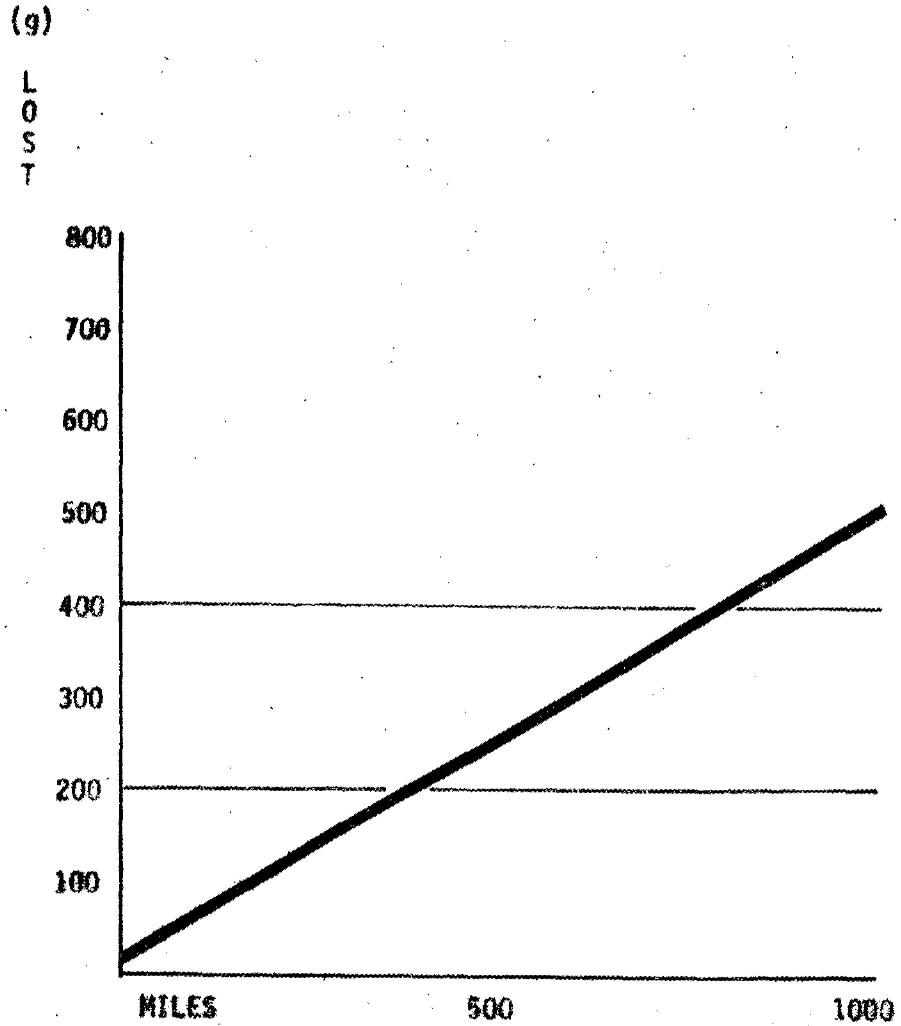

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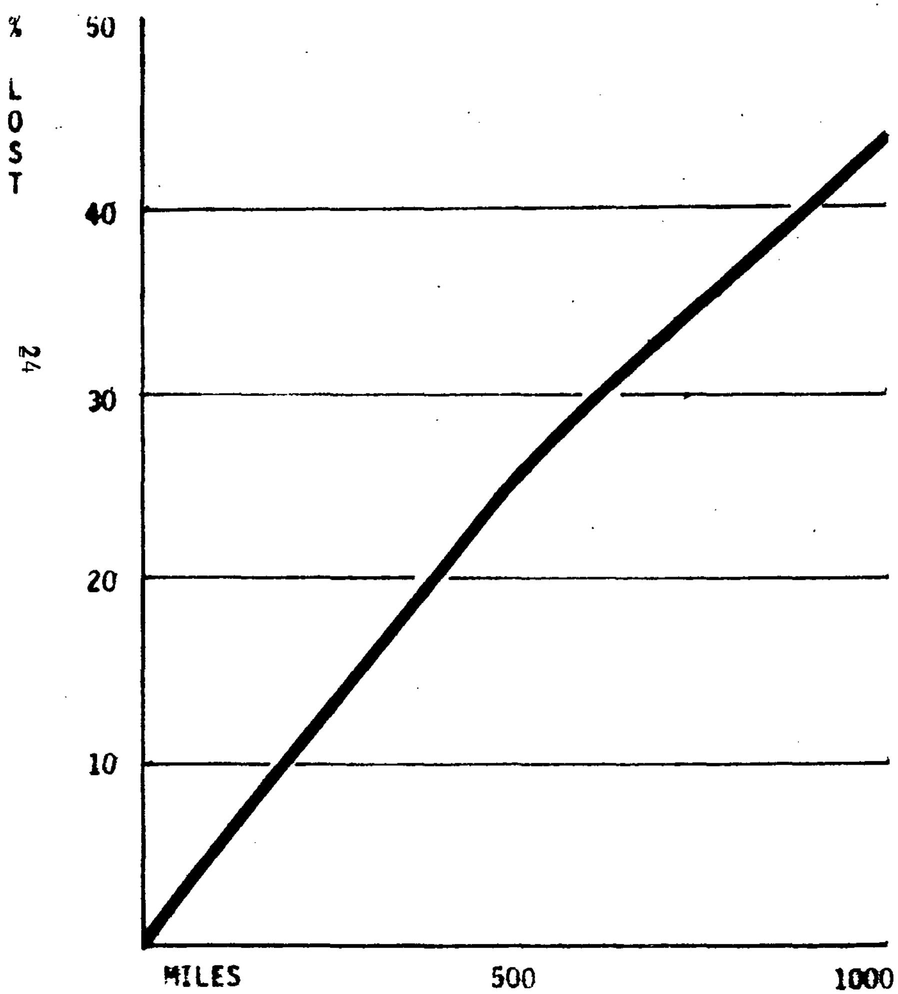

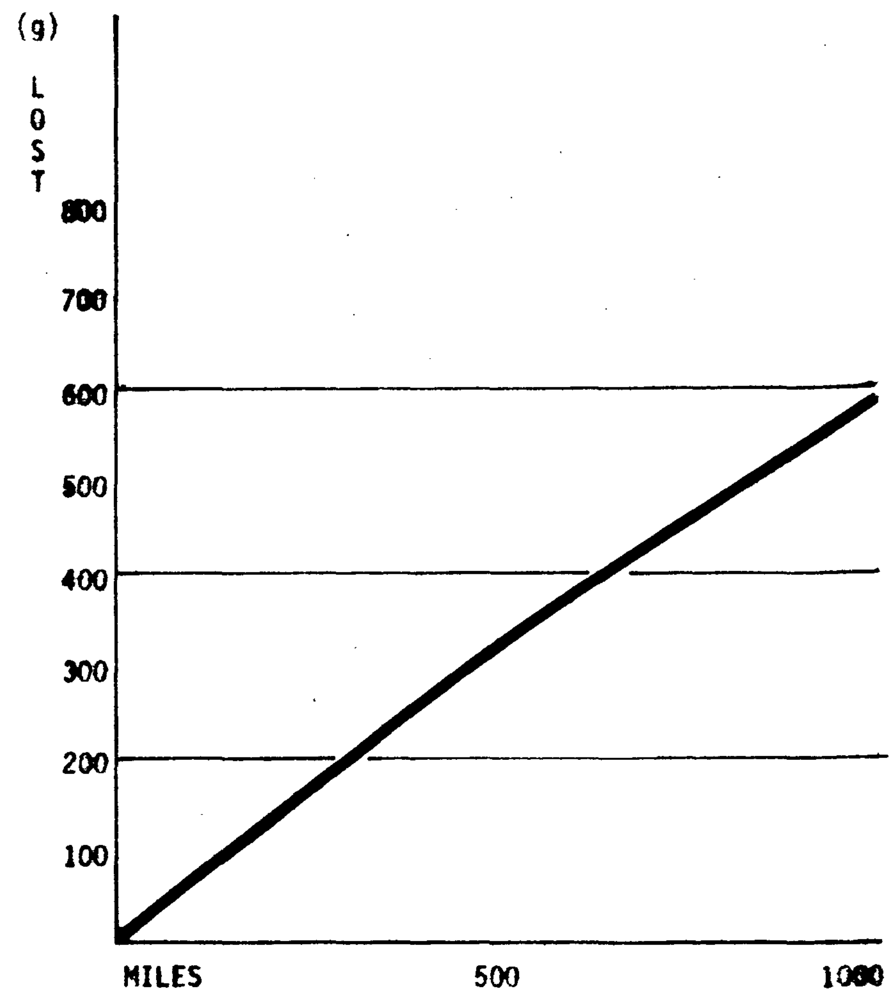

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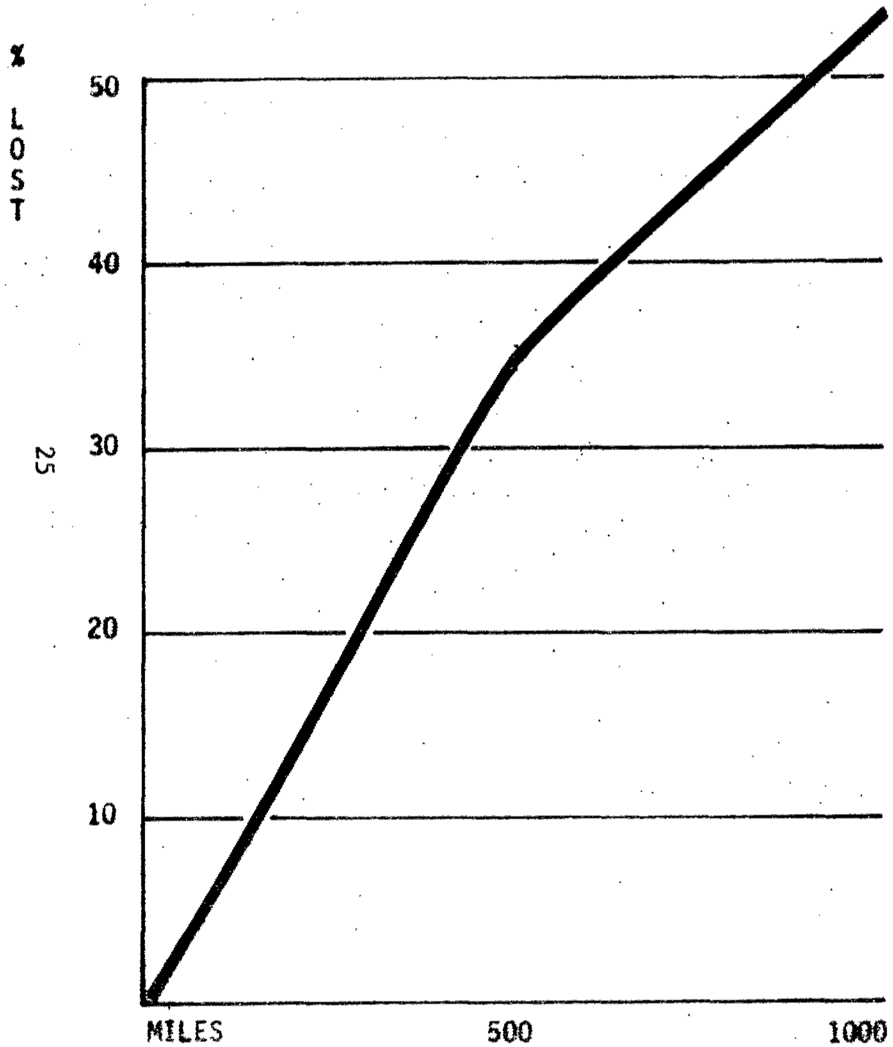

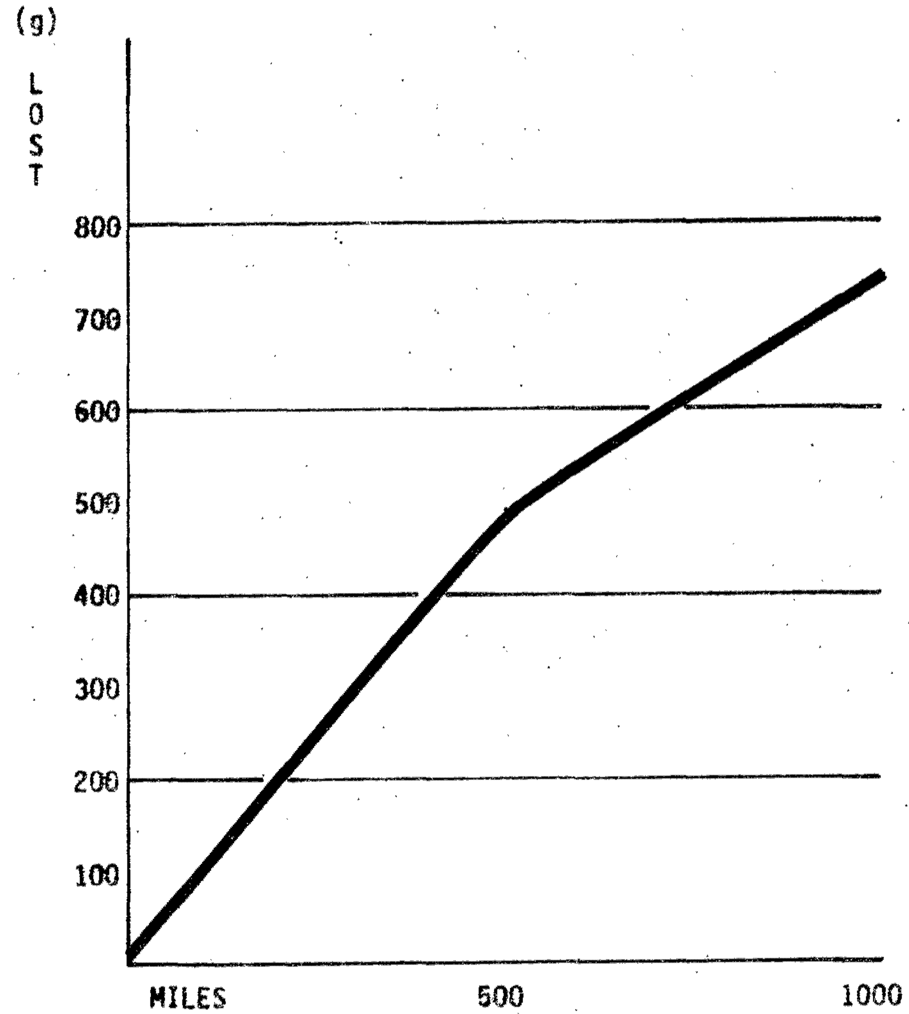

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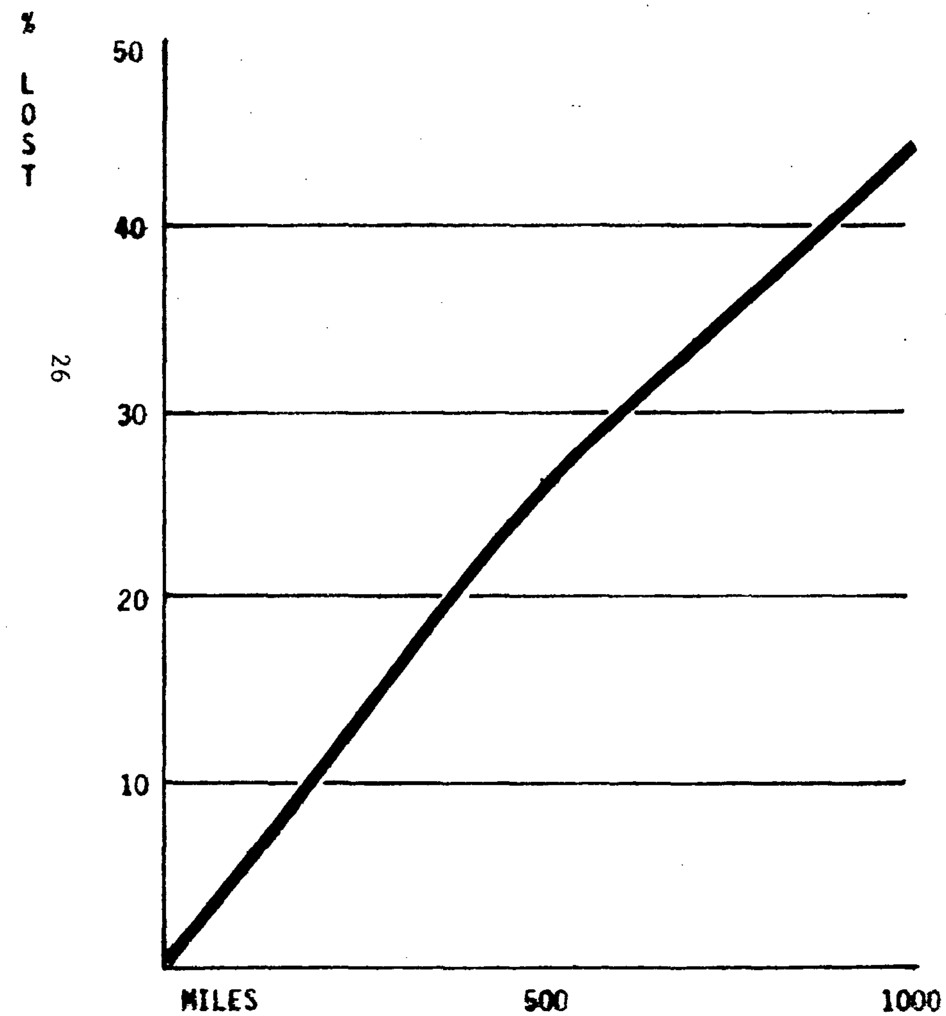

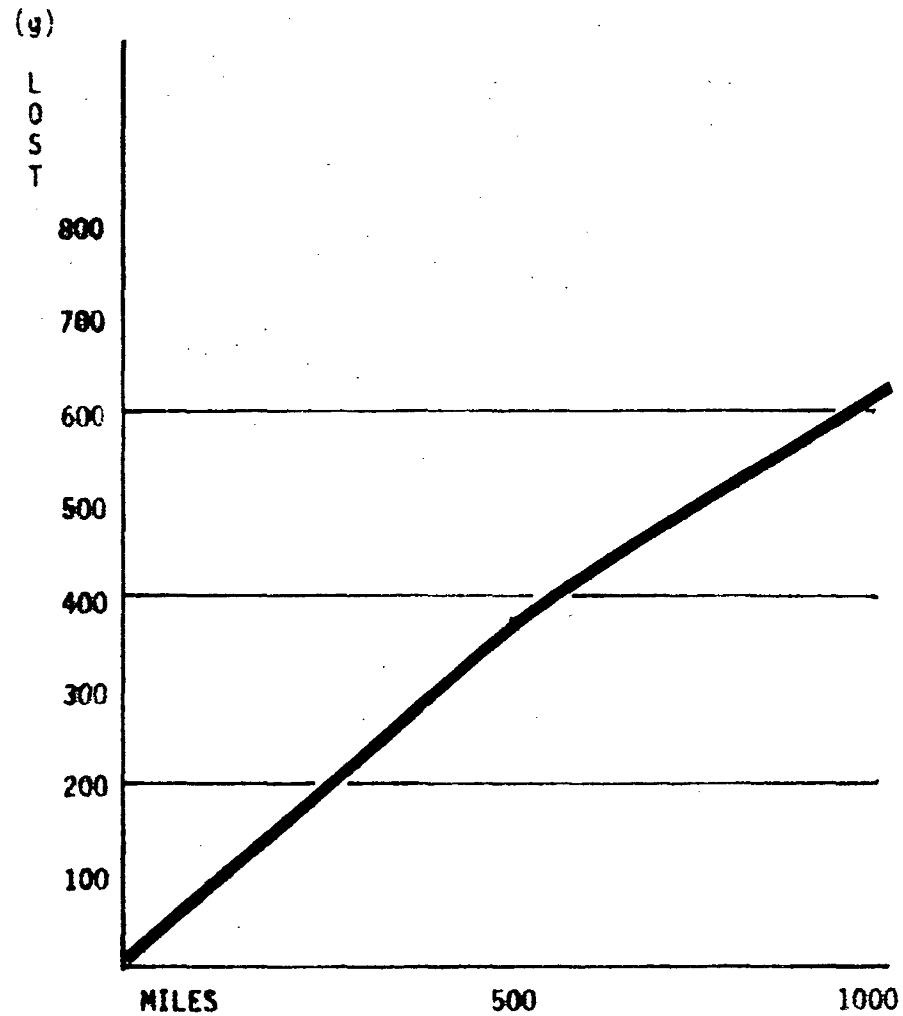

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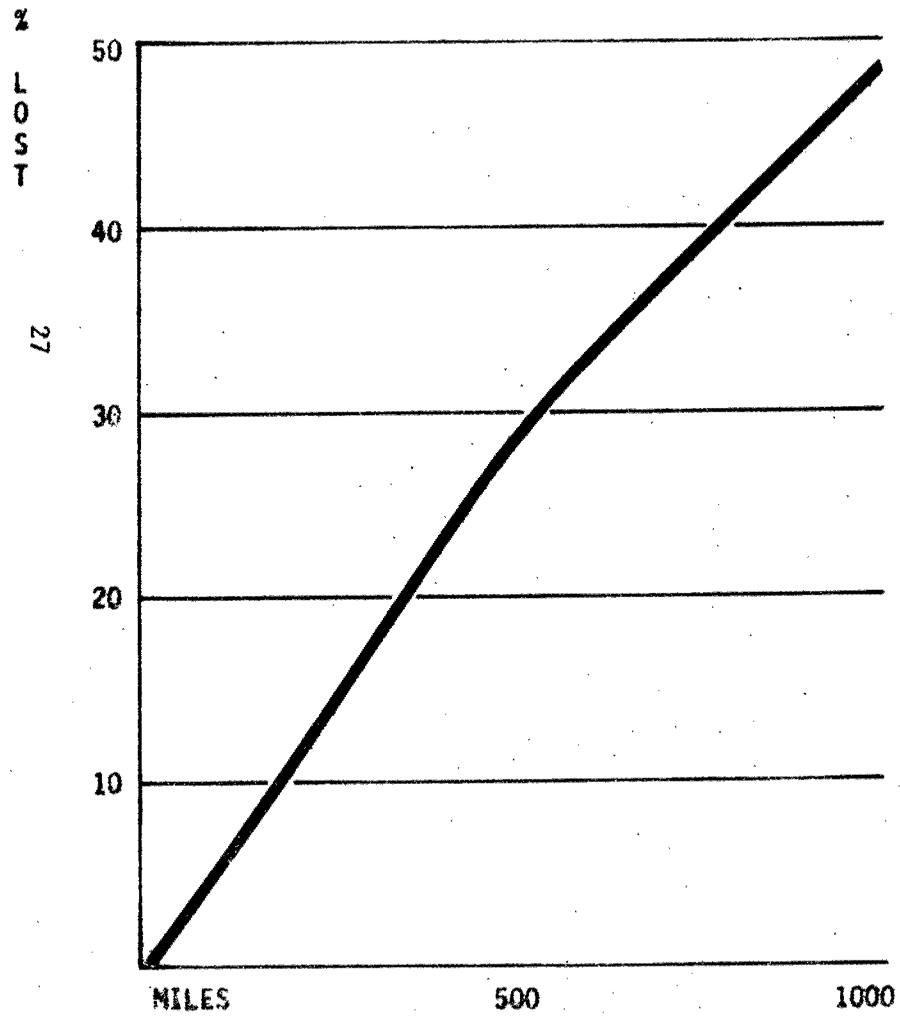

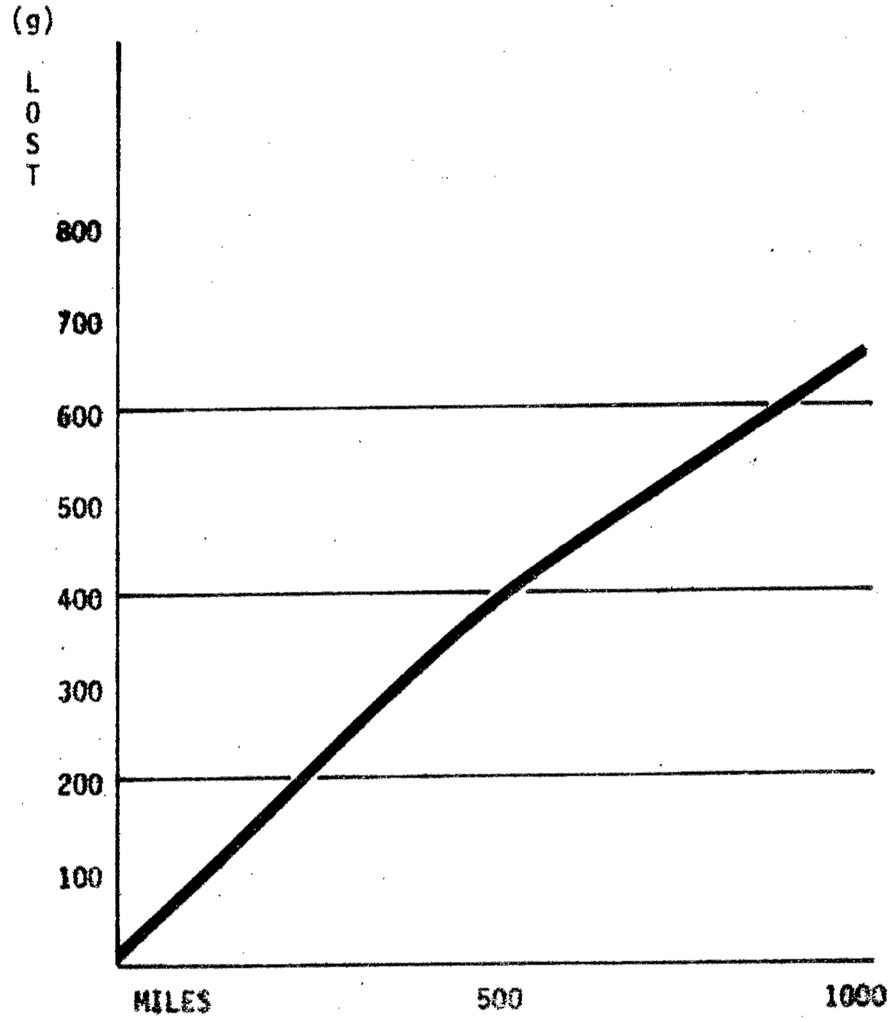

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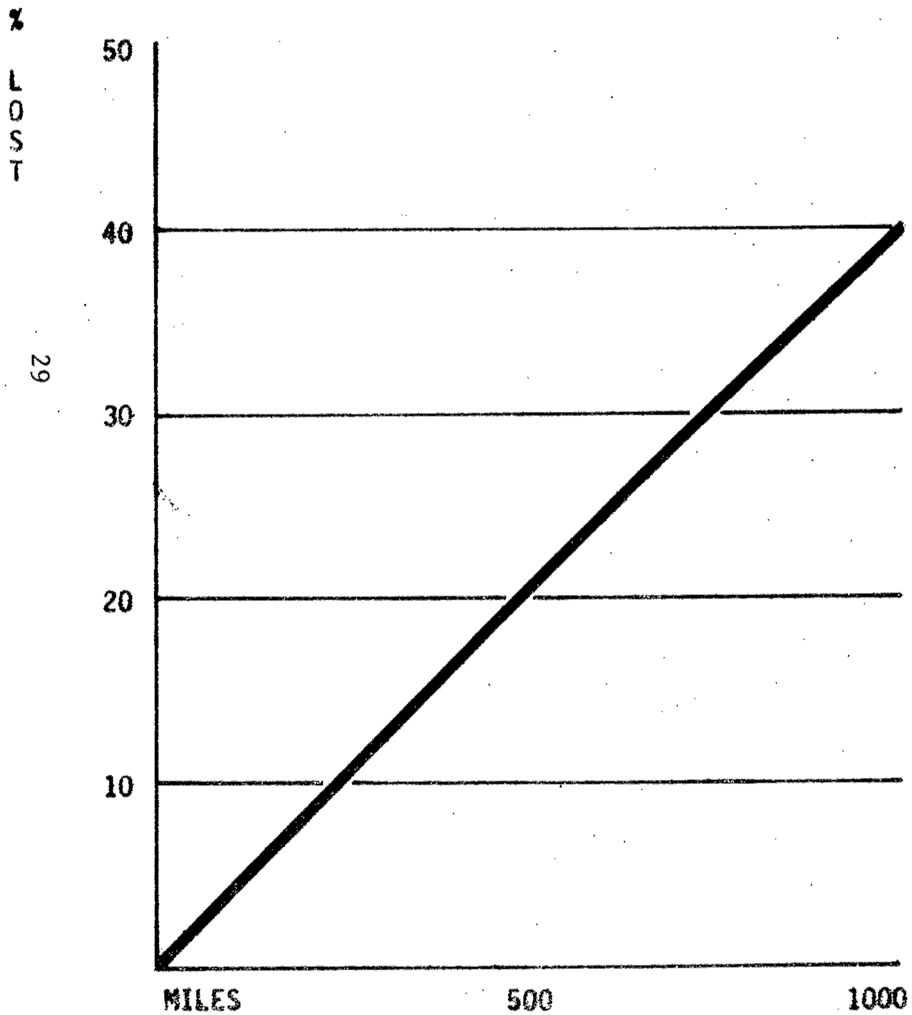

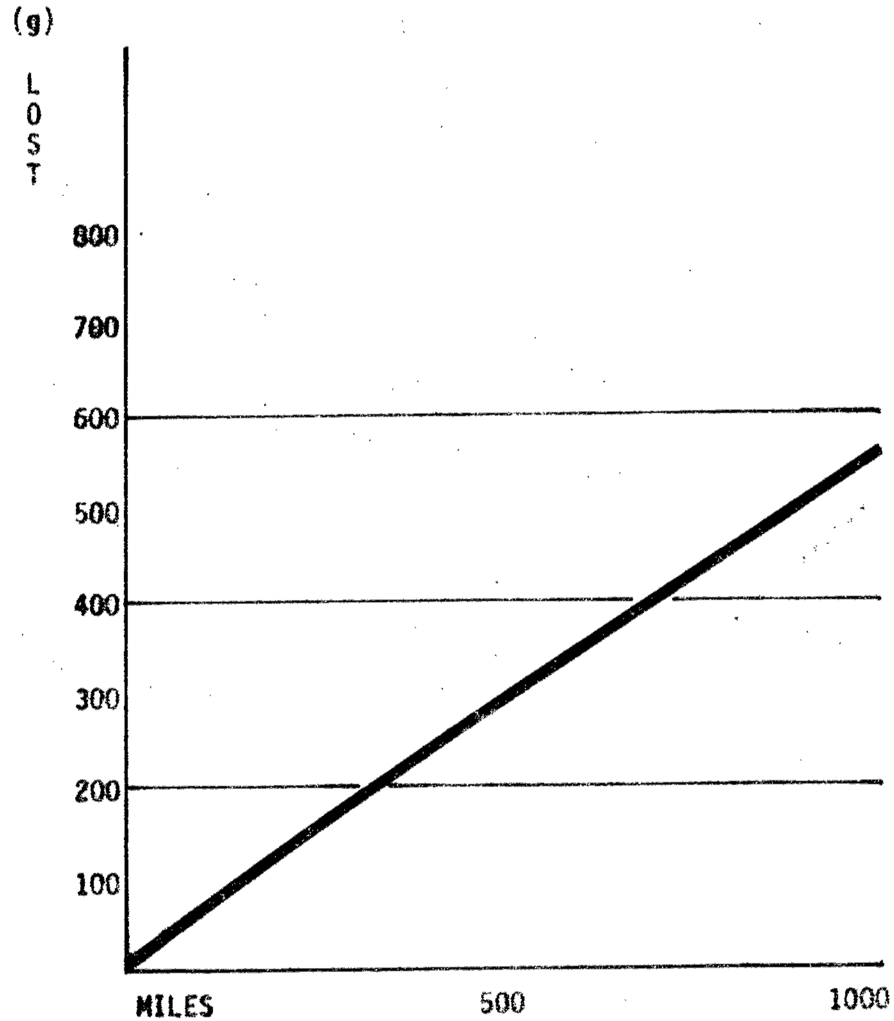

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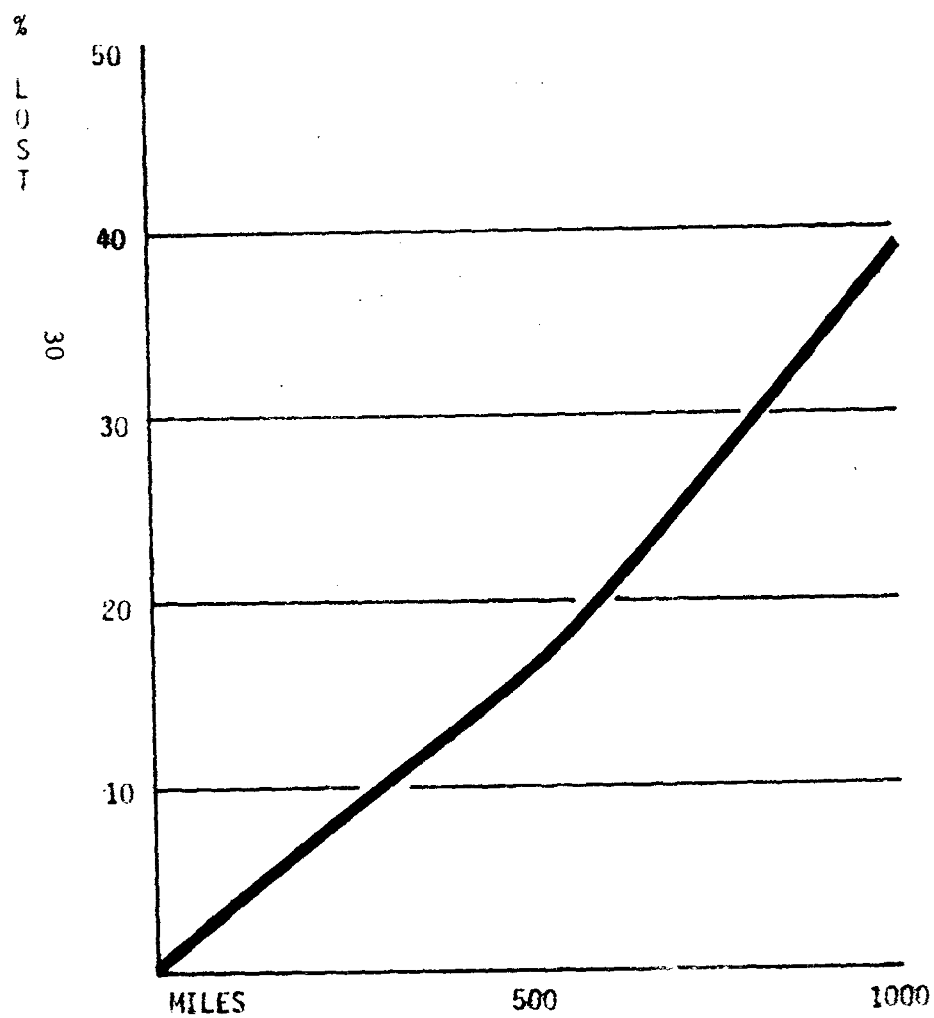

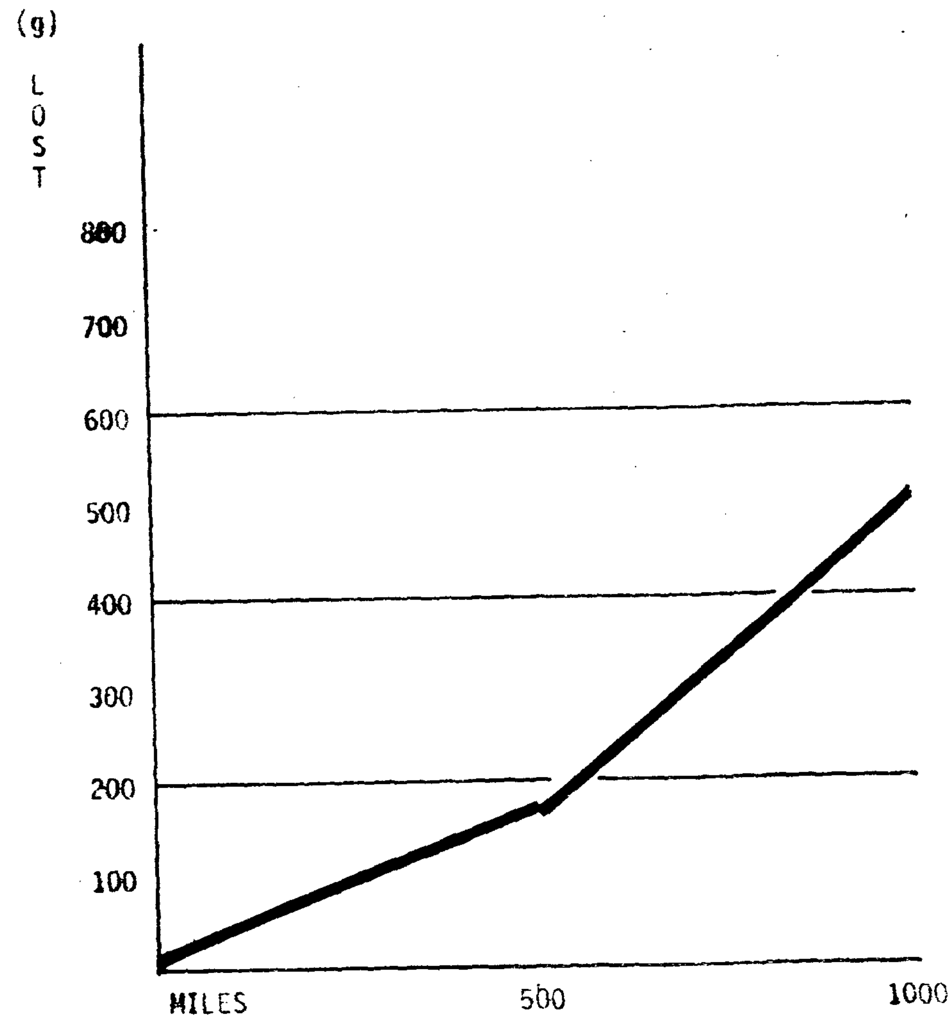

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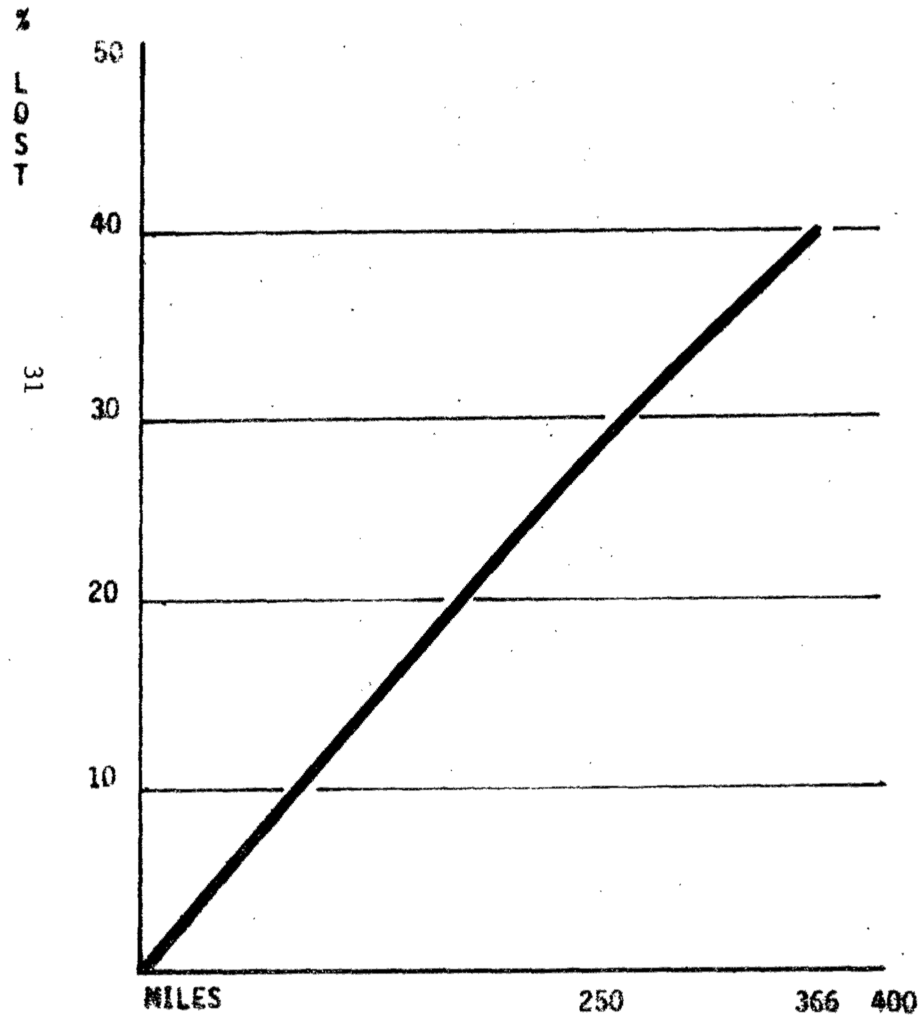

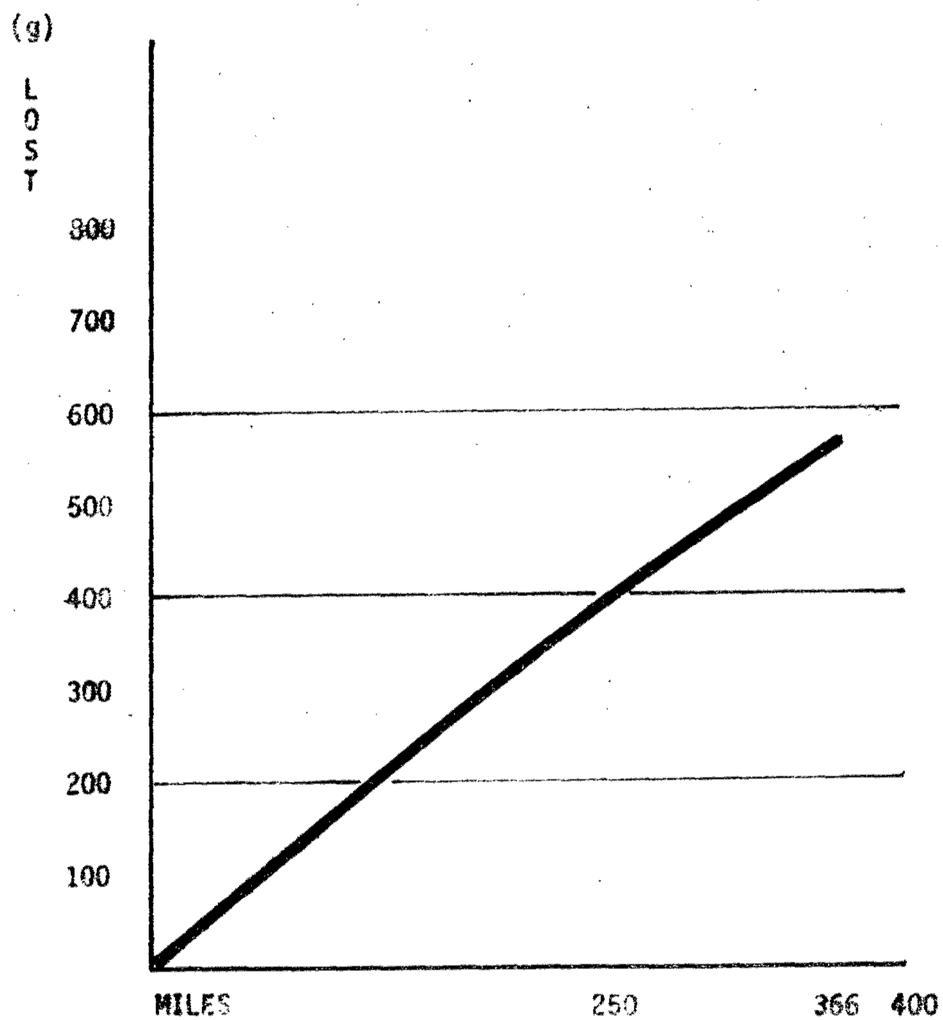

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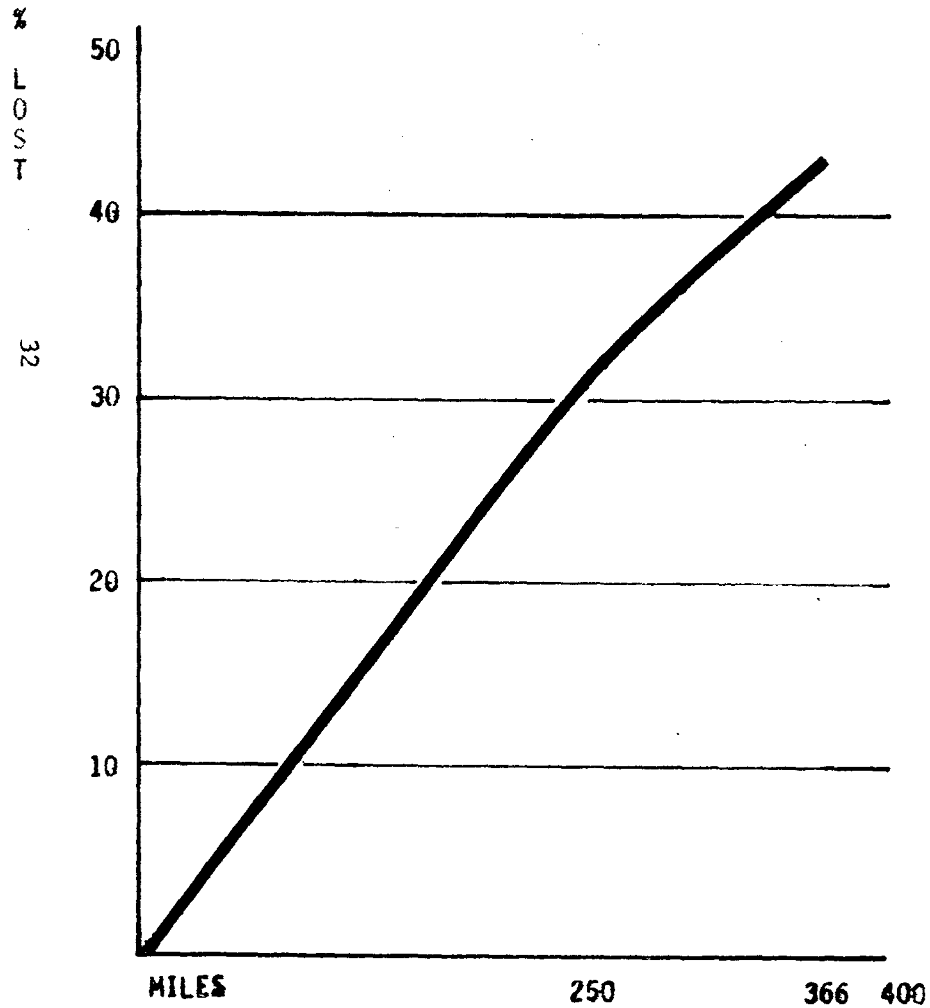

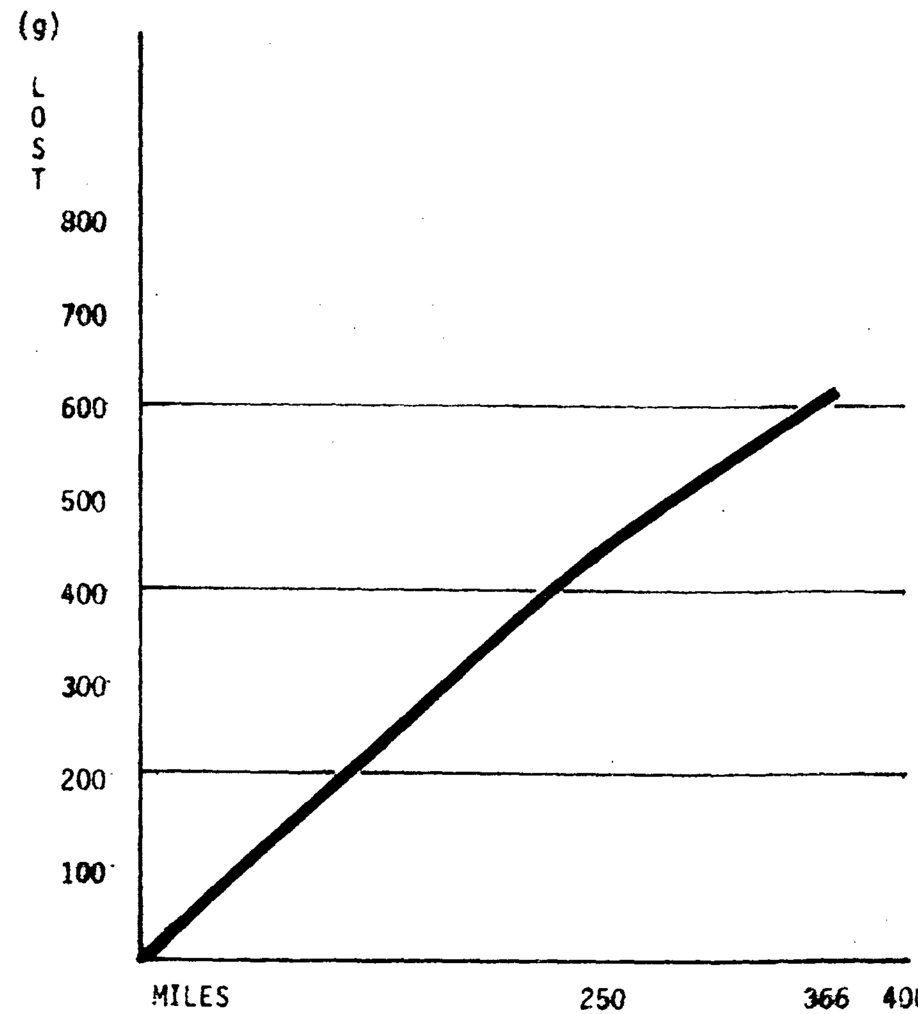

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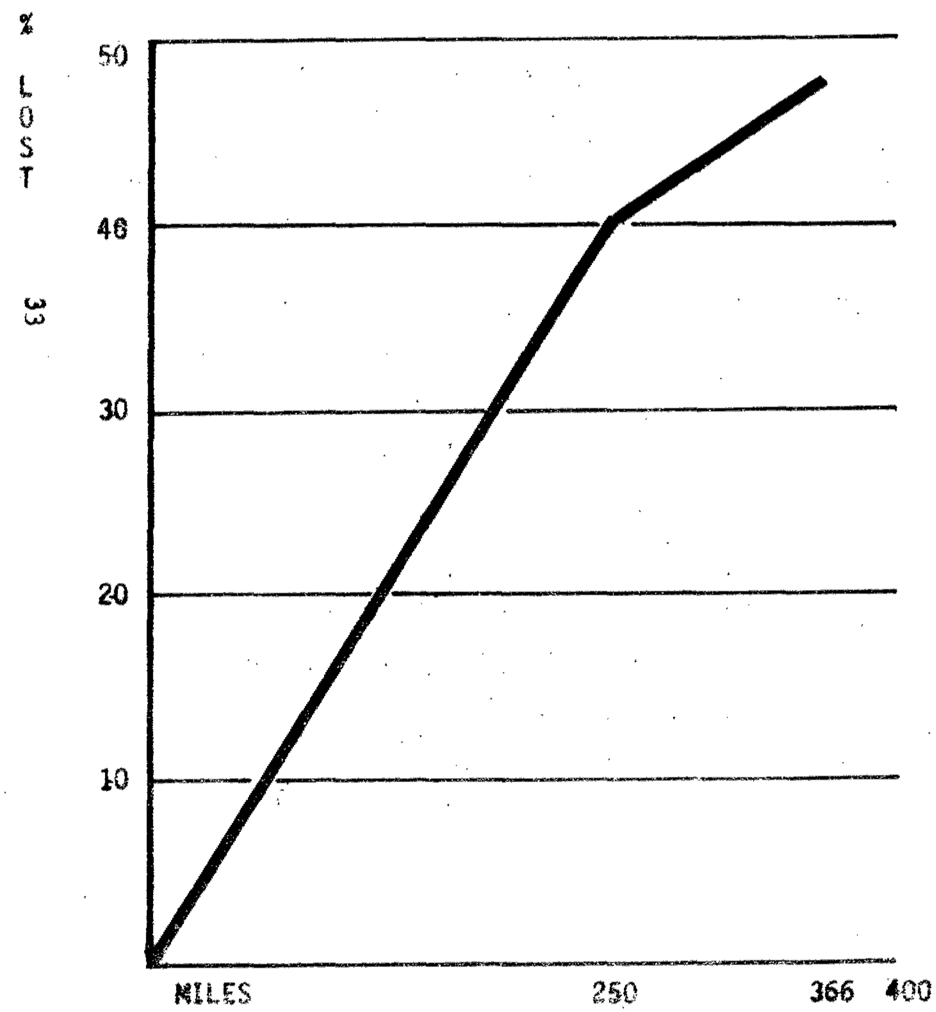

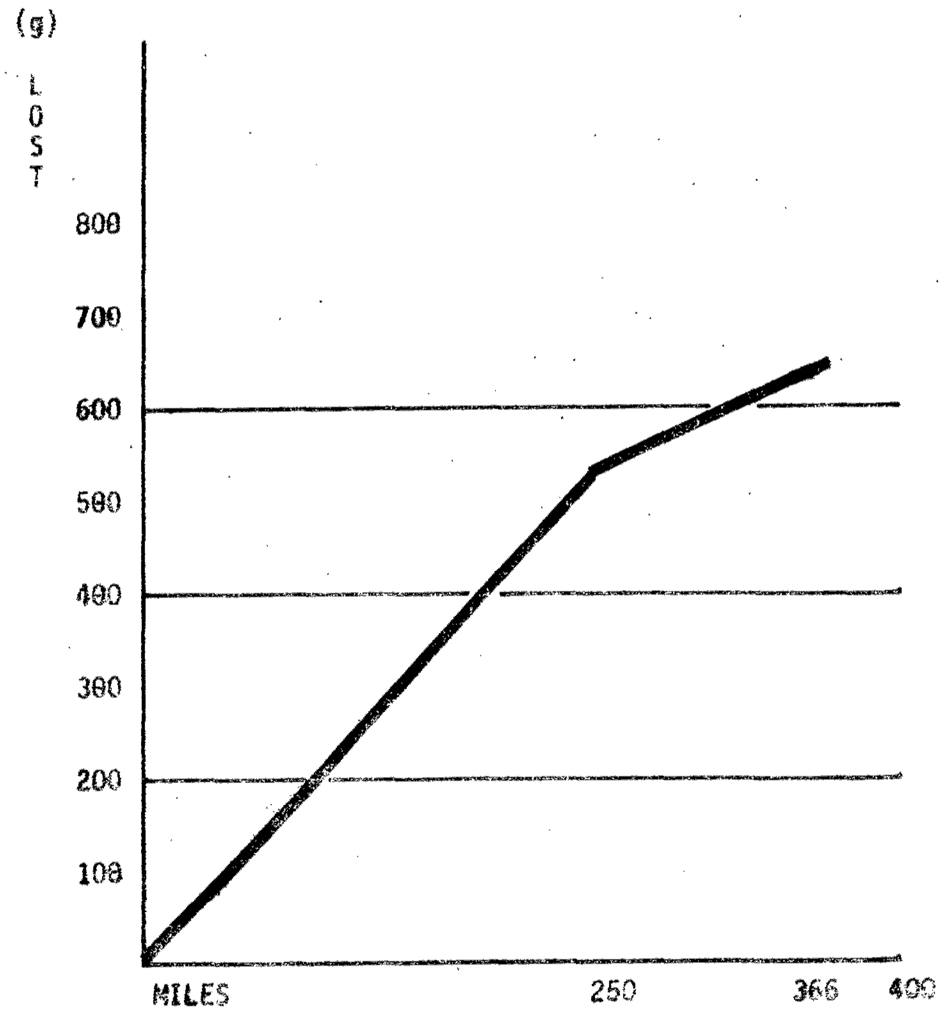

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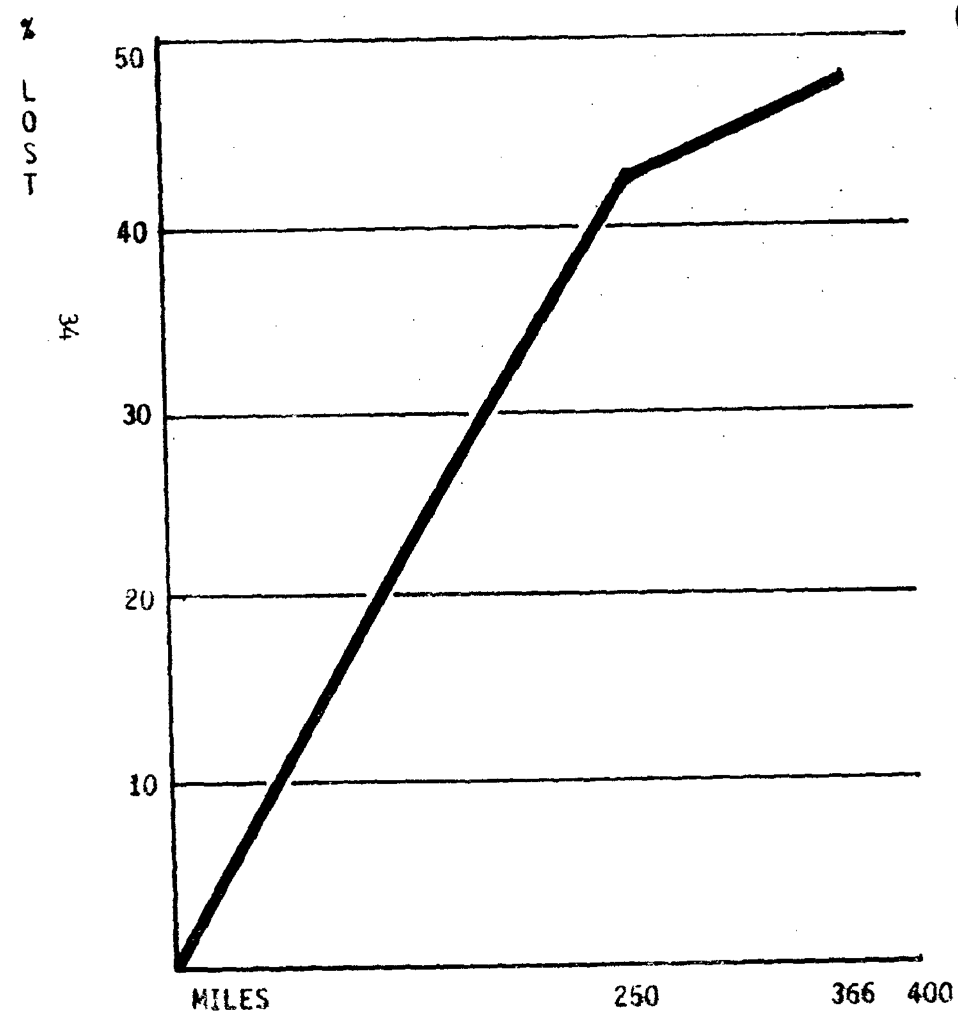

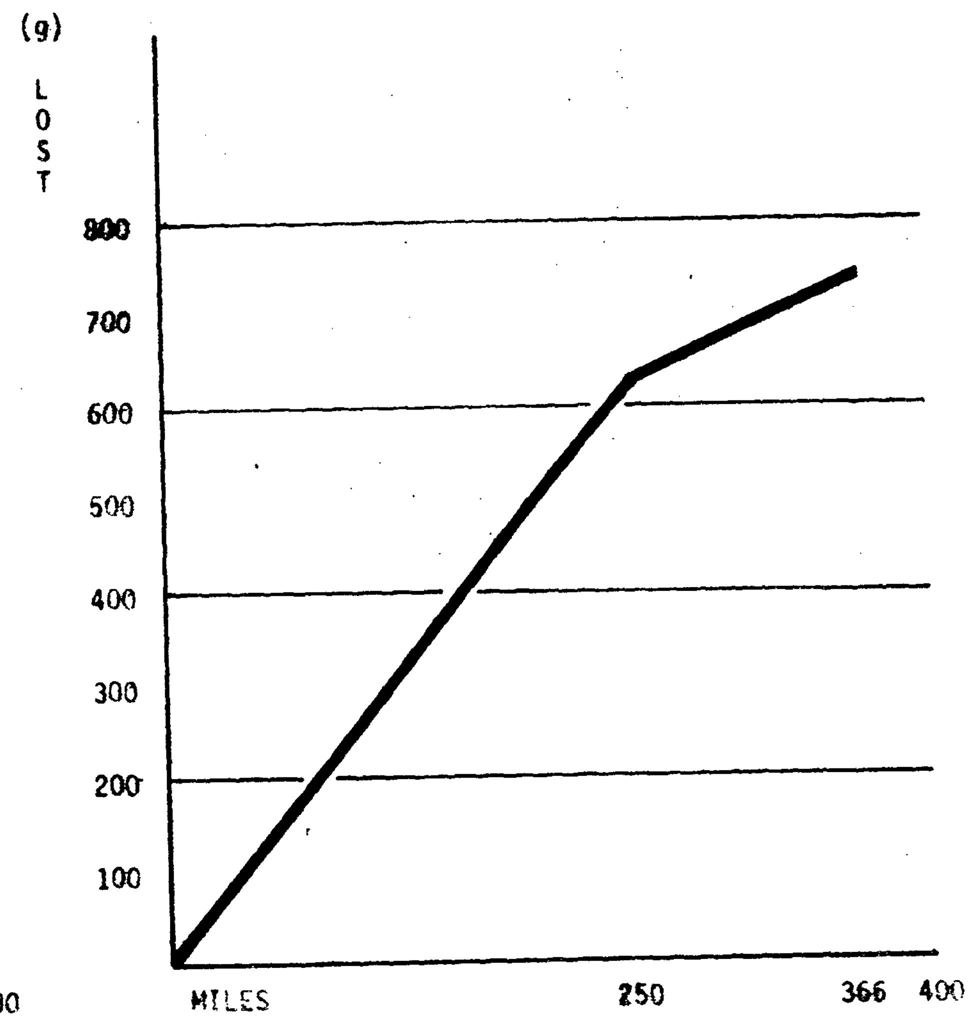

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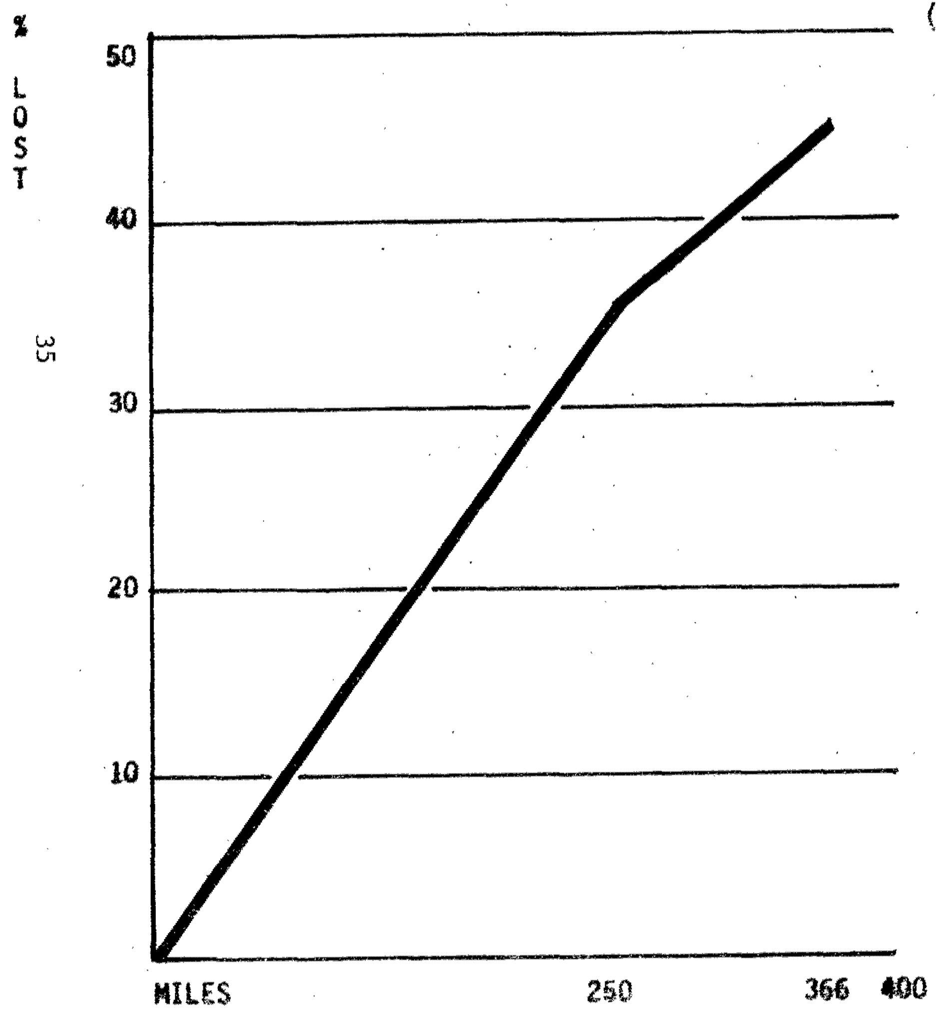

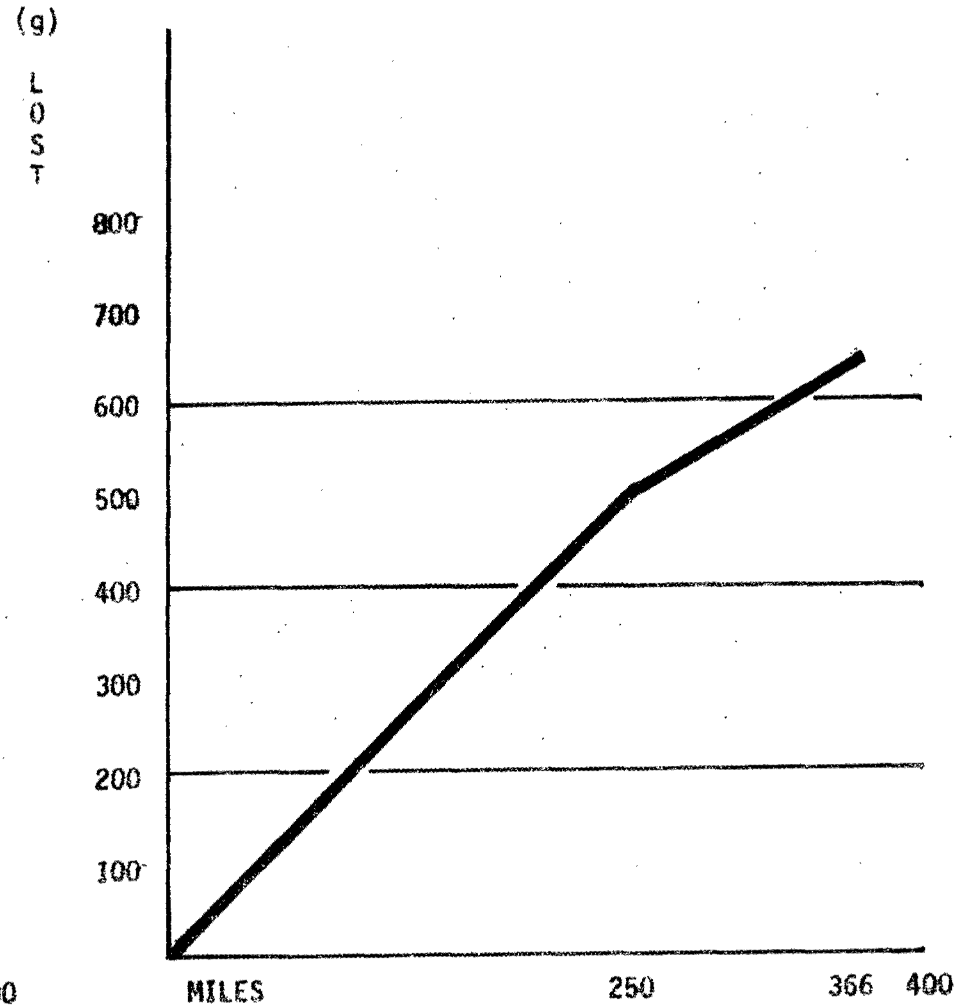

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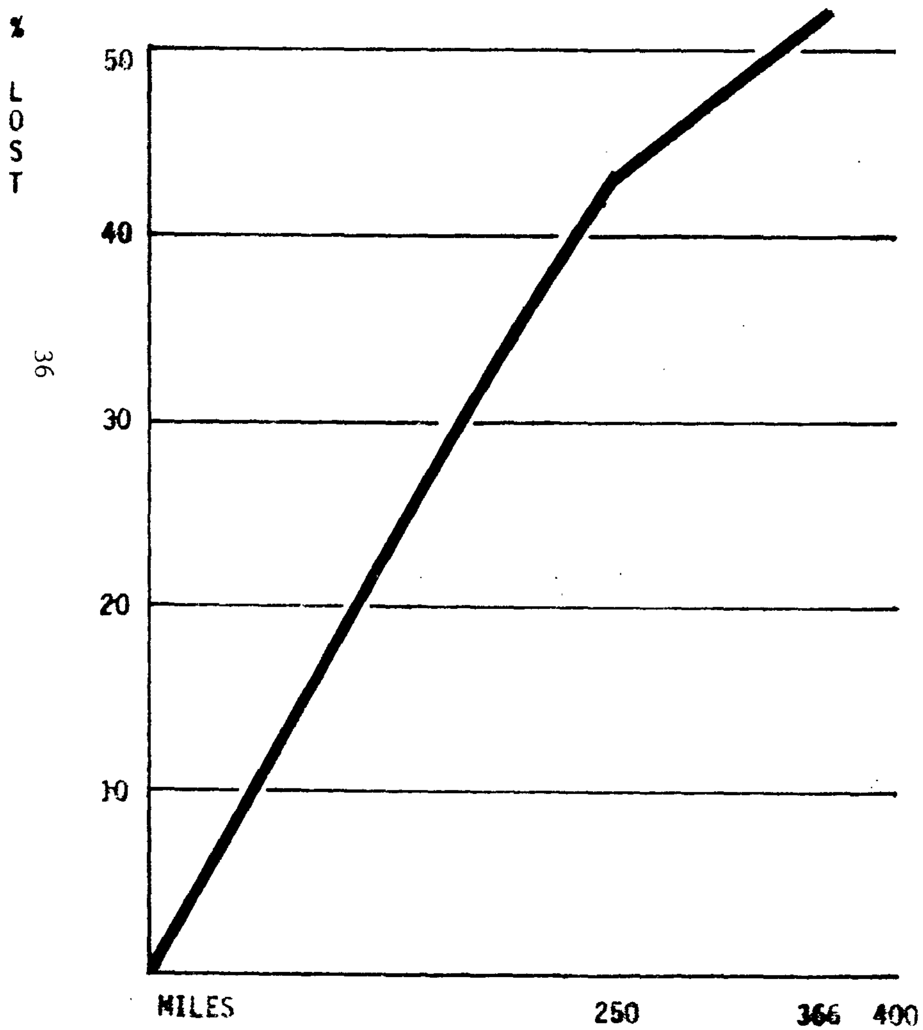

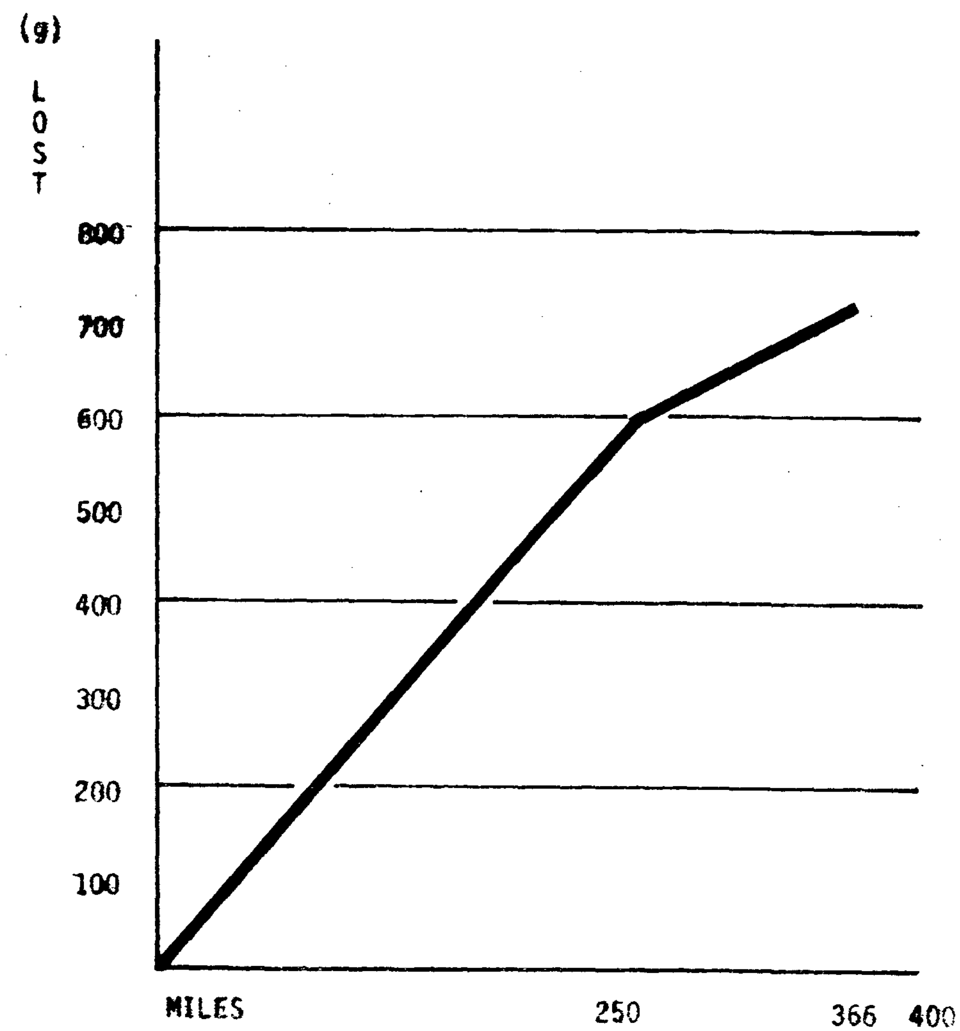

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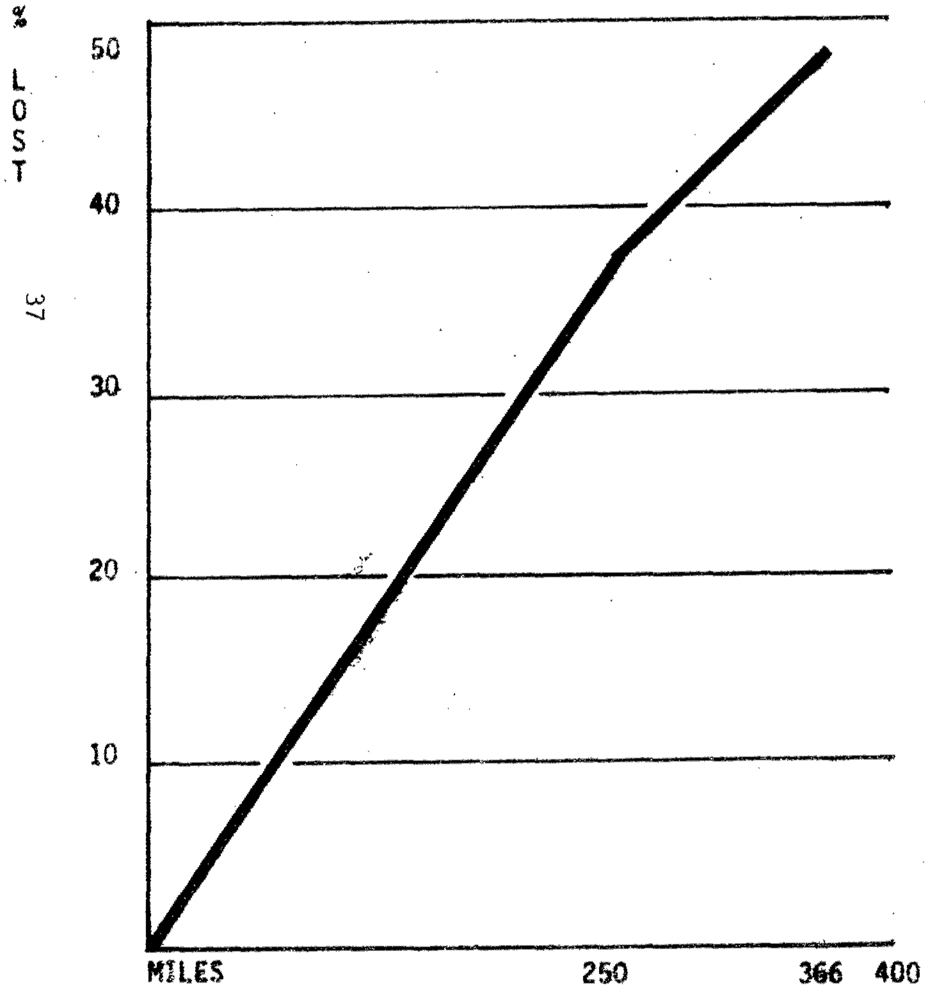

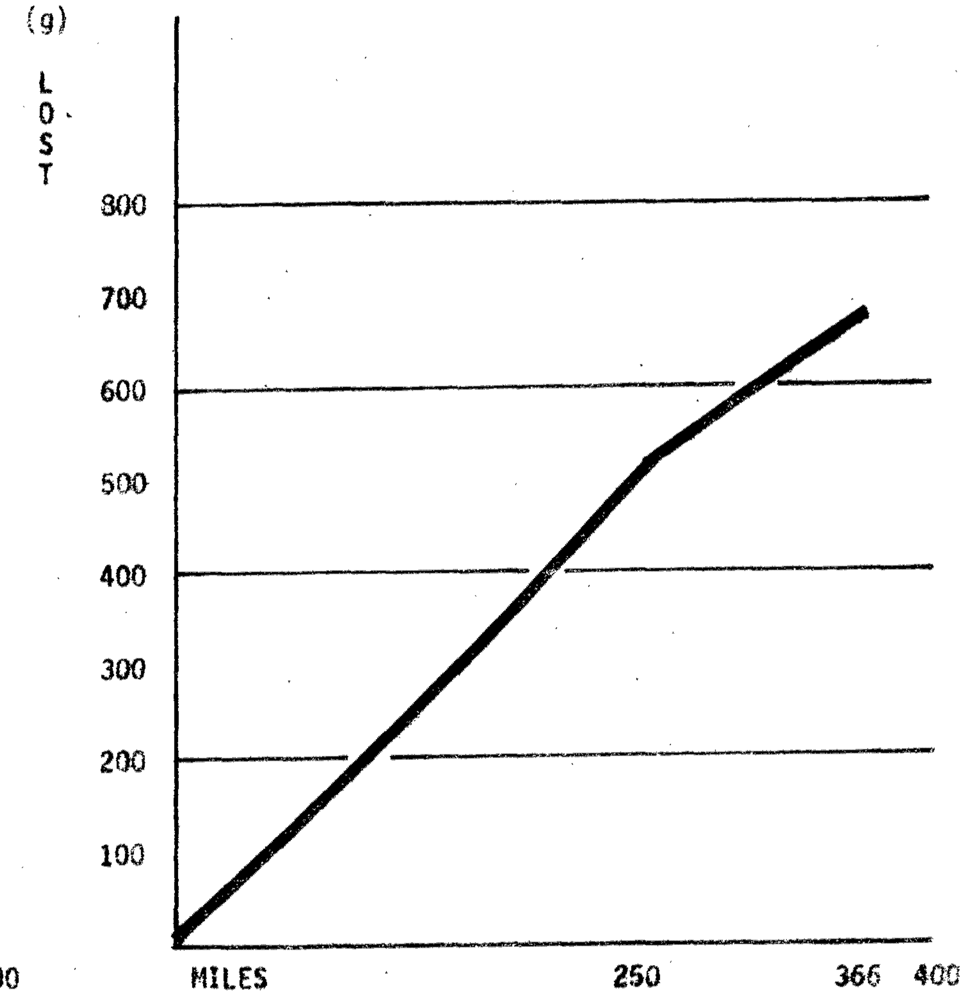

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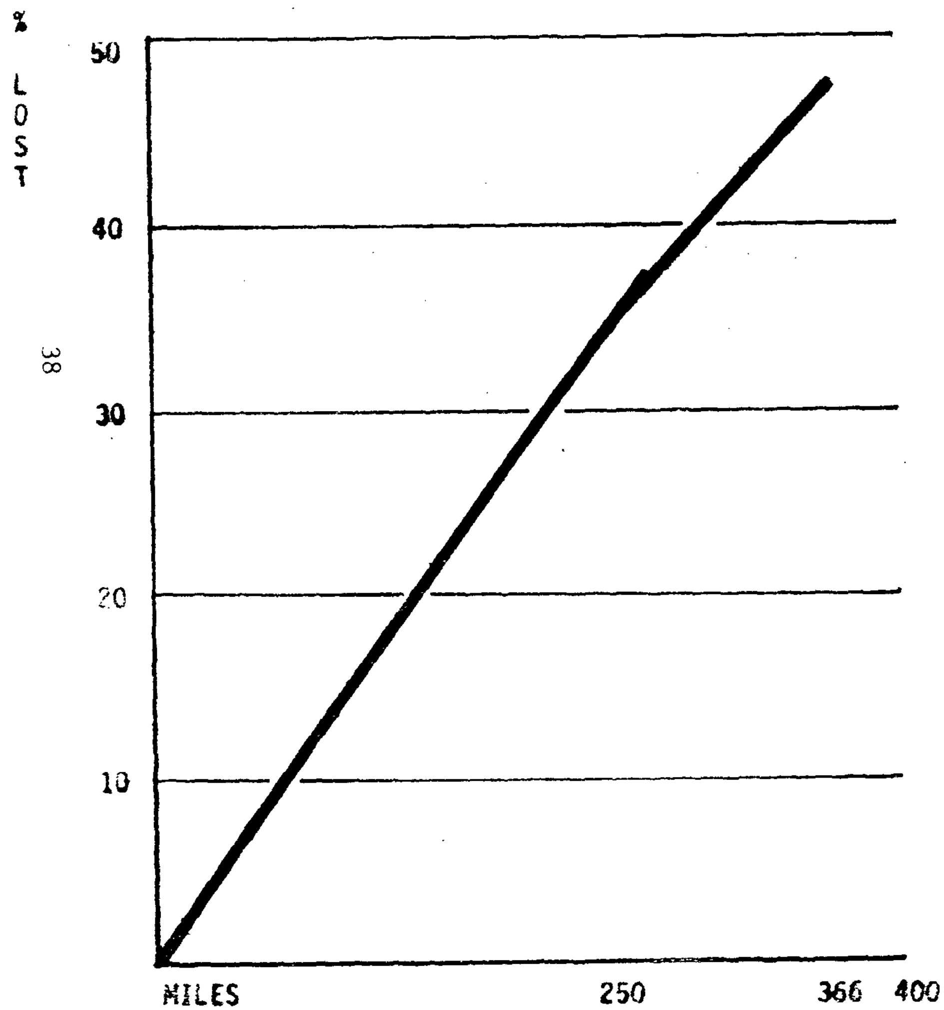

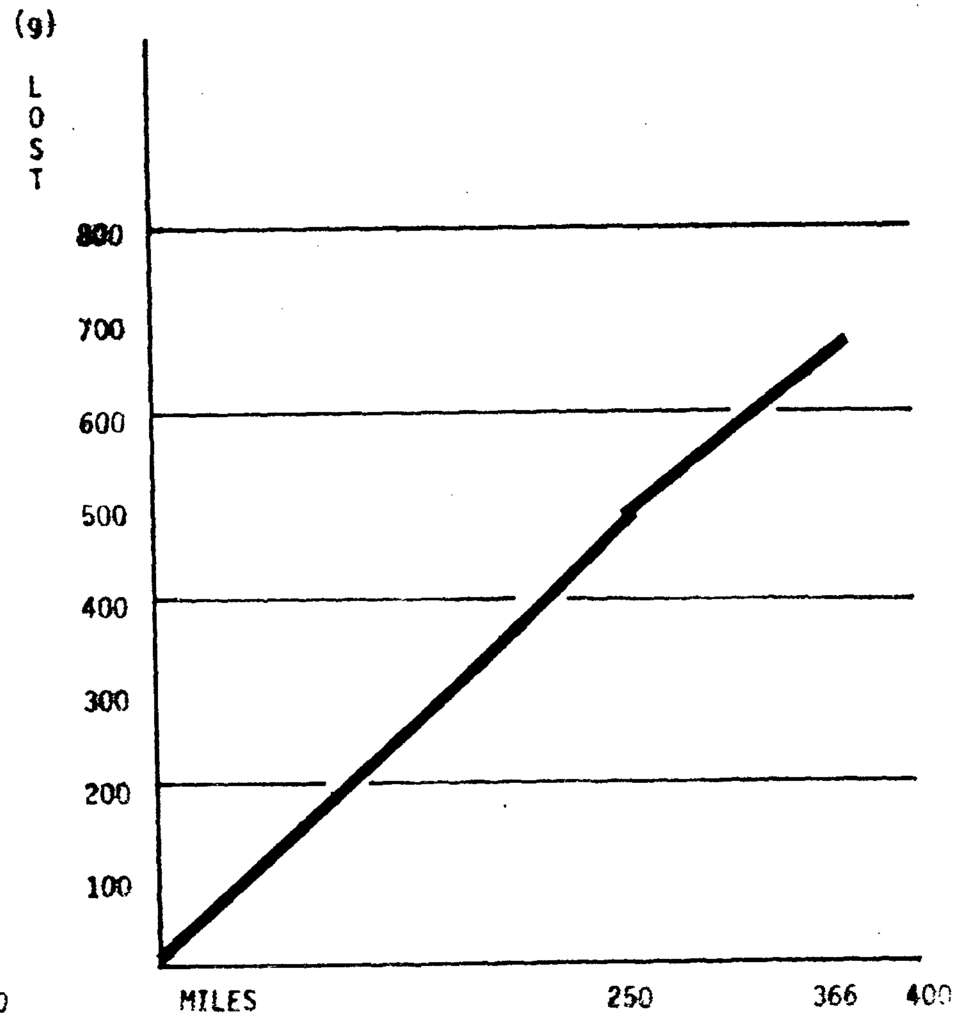

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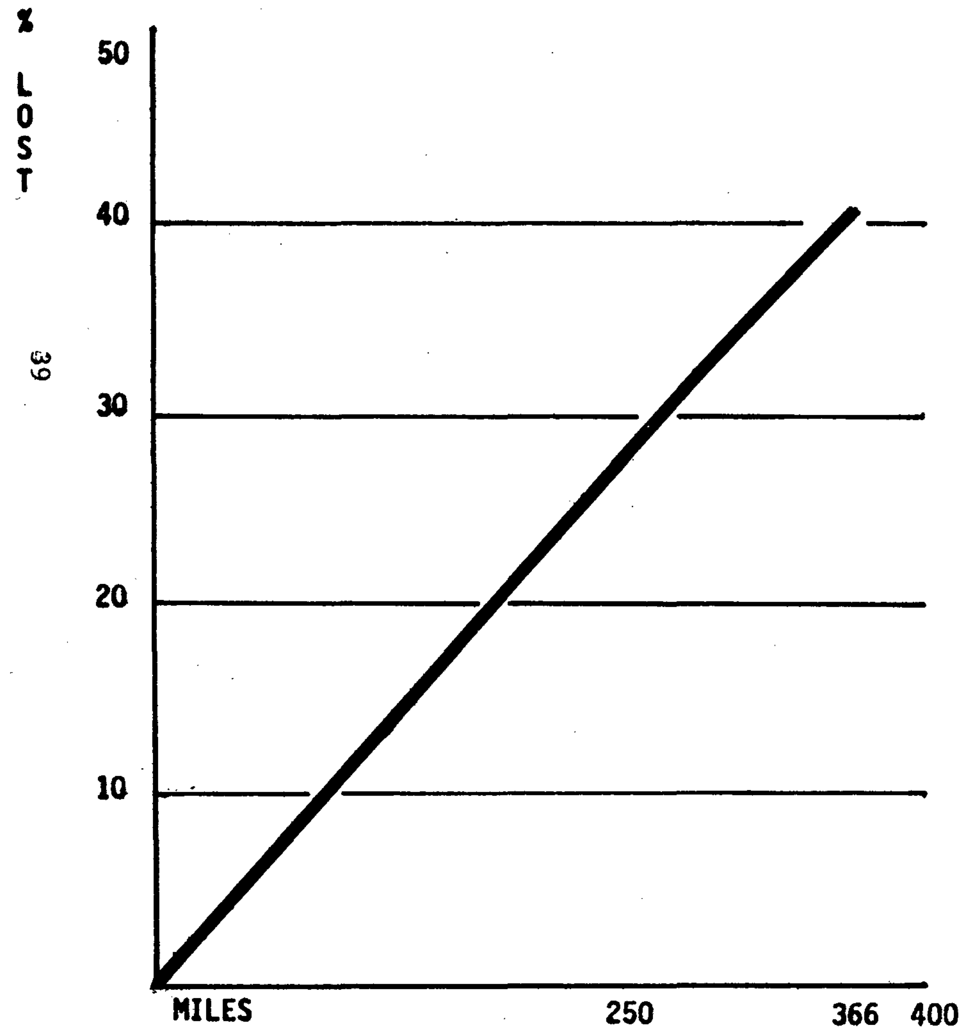
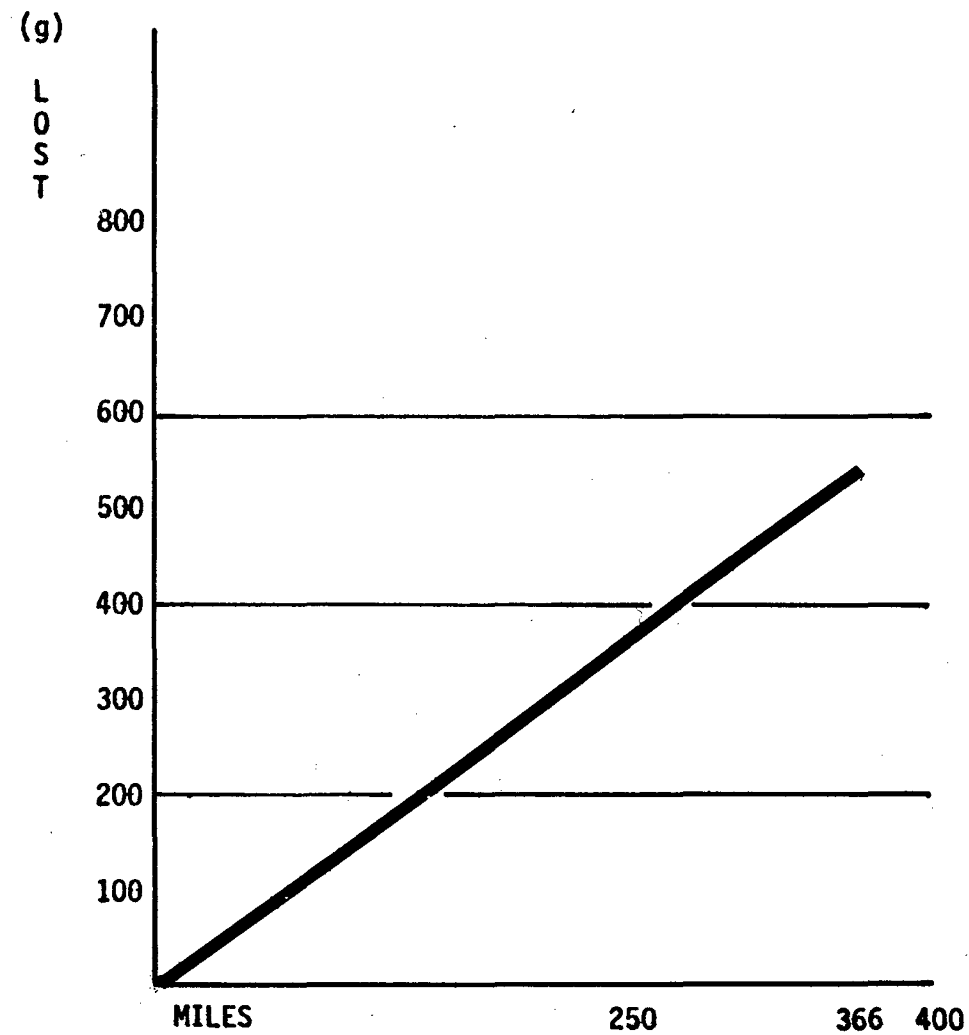
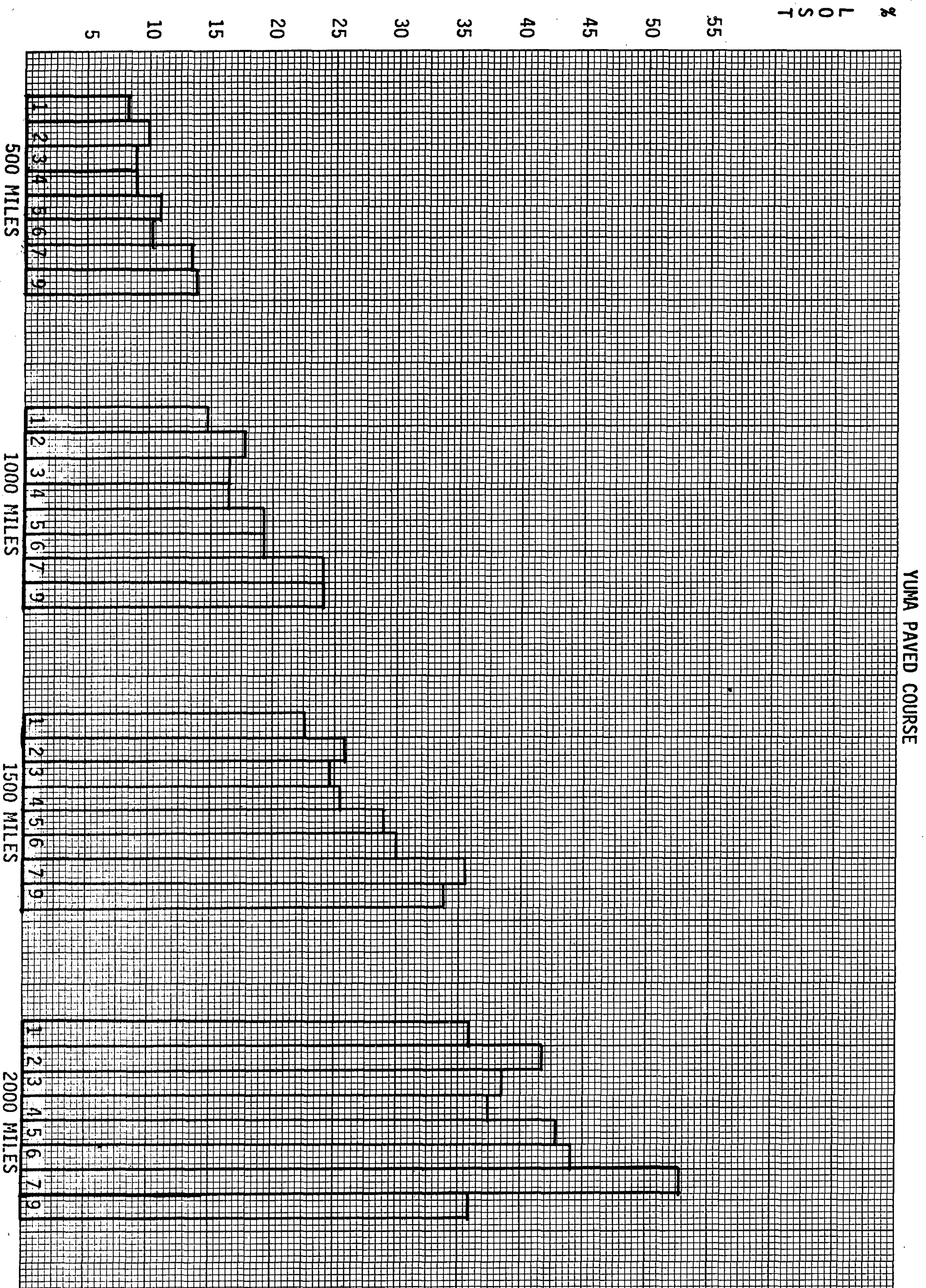
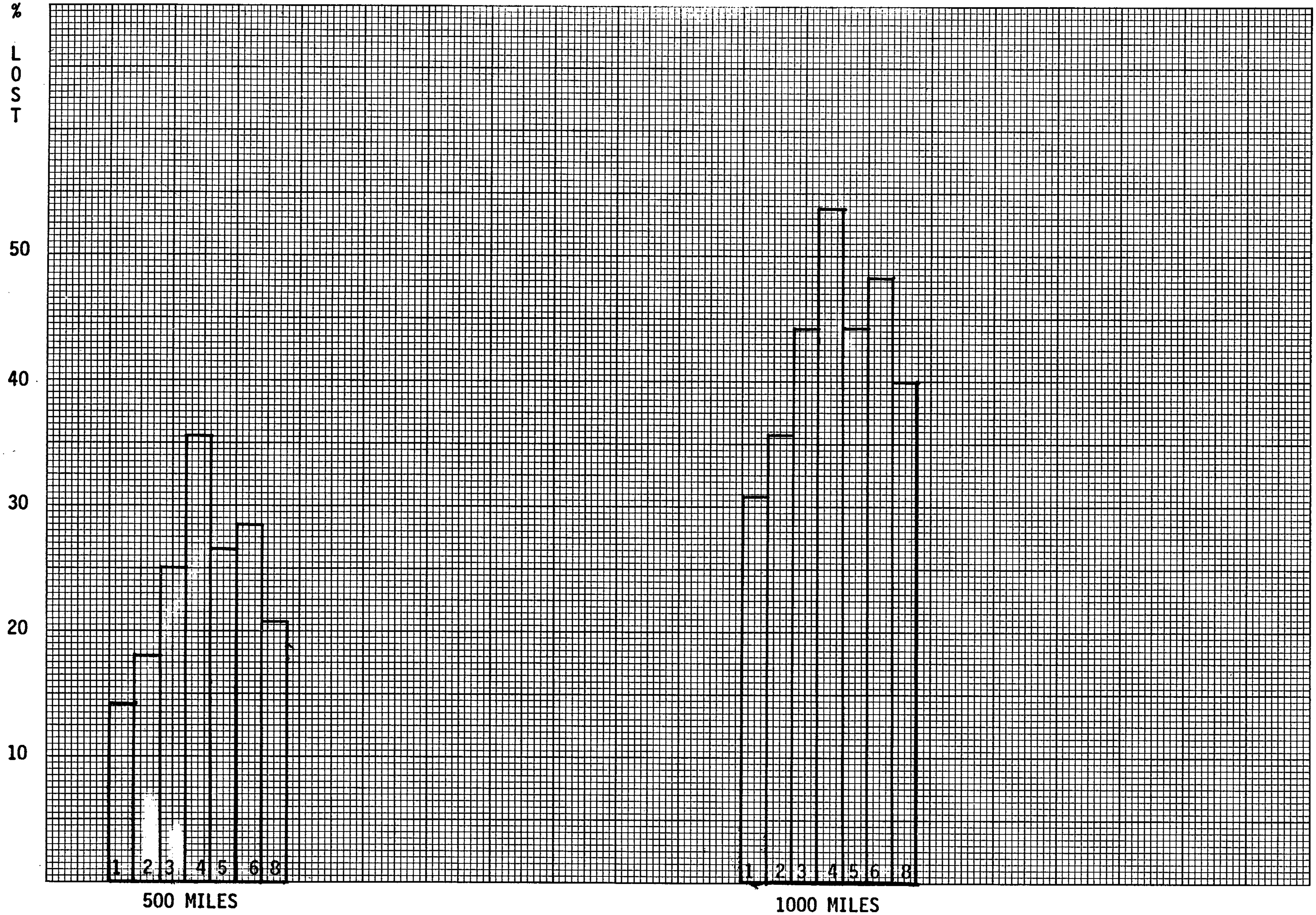
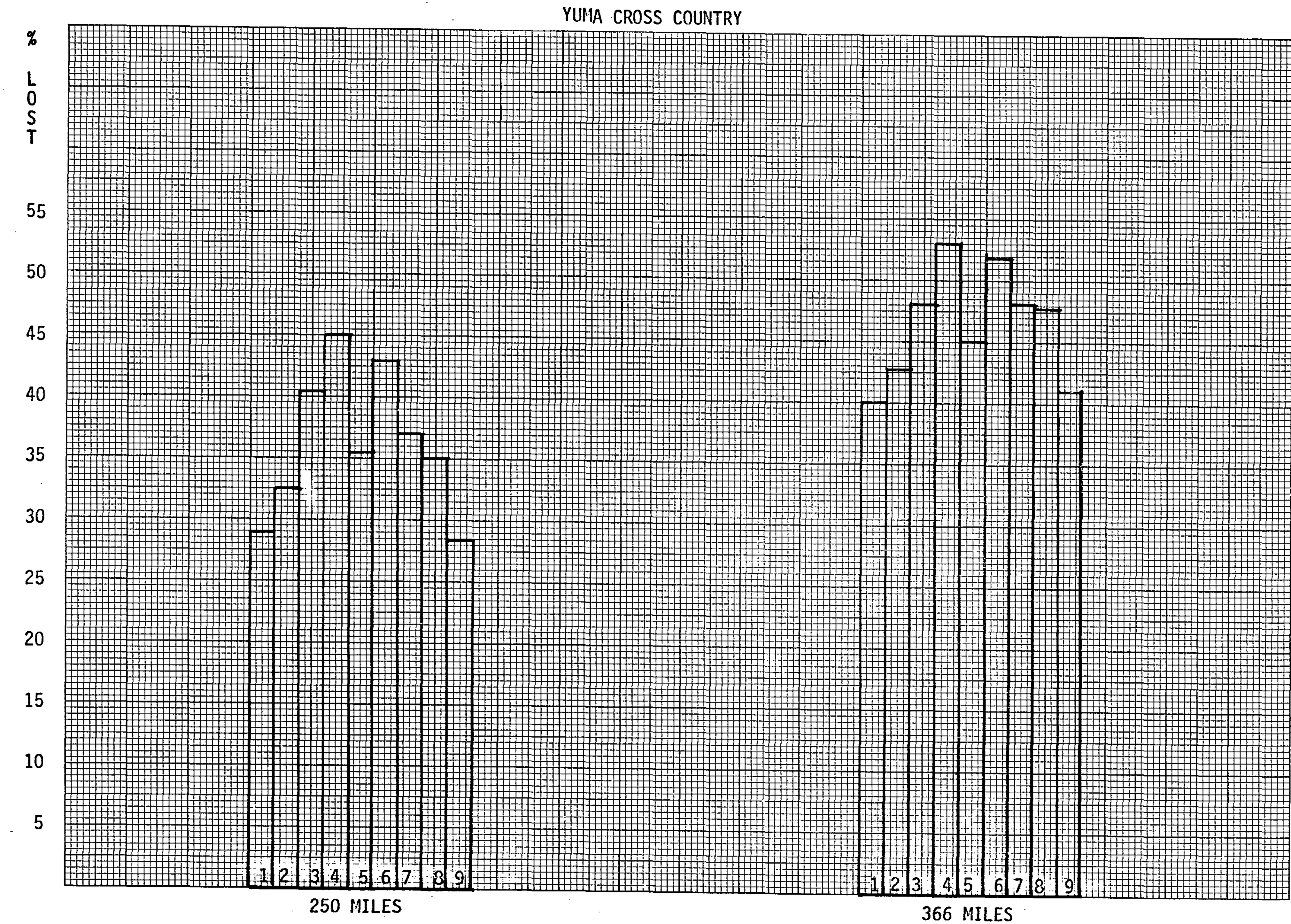





YUMA PAVED COURSE
% LOST
5
10
15
20
25
30
35
40
45
50
55
500 MILES
1000 MILES
1500 MILES
2000 MILES
1 2 3 4 5 6 7 9

YUMA GRAVEL TEST




YUMA CROSS COUNTRY
% LOST
55
50
45
40
35
30
25
20
15
10
5
1 2 3 4 5 6 7 8 9
250 MILES
1 2 3 4 5 6 7 8 9
366 MILES

APPENDIX B

LABORATORY RESULTS

B-1 LABORATORY TESTS CONDUCTED

HARDNESS

TENSILE

ELONGATION

MODULUS

TEAR RESISTANCE

OVEN AGED TEAR RESISTANCE

SPECIFIC GRAVITY

TOULENE SWELLING

THERMOGRAVIMETRIC ANALYSIS (TGA)

DIFFERENTIAL THERMAL ANALYSIS (DTA)

SCANNING ELECTRON MICROSCOPE (SEM)

ENERGY DISPERSIVE ANALYSIS OF X-RAY (EDAX)

THERMAL MECHANICAL ANALYSIS (TMA)

GLASS TRANSITION TEMPERATURE

ELECTRON SPECTROSCOPY FOR CHEMICAL ANALYSIS (ESCA)

B-2 DEFINITIONS

a. Thermogravimetric Analysis (TGA)

Thermogravimetric Analysis is a thermo-analytical technique in which the changes in weight of a material are followed as a function of temperature (dynamic TGA), or as a function of time at a specified temperature (isothermal TGA). The studies listed in this report were conducted with a Perkin-Elmer TGS-2 in couple with a System 4 microprocessor.

b. Thermomechanical Analysis (TMA)

Thermomechanical Analysis is a technique which records the temperature at which the eslatomer will become brittle (T_g or glass transtion temperature) and the temperature at which the elastomer will become viscous (T_{vf}). The changes in these critical temperatures after field testing are indicators of the molecular changes which are occuring.

c. Electron Spectroscopy For Chemical Analysis (ESCA)

Electron Spectroscopy for chemical analysis is an analytical technique which uses a DuPont 650 x-ray photoelectron spectrometer to investigate the chemical nature of the pad surface. This technique can detect molecular changes in the pad by comparing results obtained from untested and vehicle tested pads.

d. Scanning Electron Microscopy (SEM)

This technique bombards the specimen with high energy electrons, secondary electrons, and x-rays. Through the use of a collector of secondary electrons, the local surface morphology can be shown. When coupled with and EDAX (Energy Dispersive Analysis of X-ray), an analysis of the chemical composition of the bombarded region can be obtained.

B-3 SUMMARY OF LABORATORY RESULTS

a. Results from all standard laboratory tests of pads examined prior to field testing have indicated that, so far, we have not been able to definitely establish a correlation between most laboratory tests and actual field performance.

b. There are two tests, however, which may have a correlation to field performance. These tests are tear resistance and preservice cross link density. More trials should be conducted comparing these tests with vehicle performance in order to determine whether a correlation does in fact exist.

c. Analysis of failed pads indicates that:

(1) The elastomer used to make the pads was not uniform and homogenous, indicating inadequately mixed stock with incipient failure sites.

(2) The pads under service conditions are subjected to mechanical, thermal and chemical degradation which further weaken the elastomer.

B-4 DISCUSSION LABORATORY TESTING

a. Pad Rubber: Modulus, tensile, elongation, and hardness results are all graphed in the "Laboratory Results Graphs" portion of this report. These graphs show no correlation between these properties and field test performance. Toluene swelling (cross link density) tear resistance and hot tear resistance results are also graphed. These results indicate that a correlation may exist between these properties and field performance. Lower cross link density materials (higher toluene swelling) and materials with a higher tear resistance appear to perform better on vehicle testing. Only one data point is represented by these graphs, and further studies should be conducted before a definite conclusion can be drawn.

b. Failure Analysis:

(1) Electron Spectroscopy for Chemical Analysis (ESCA) - A post service failure ESCA run showed an increase in the ratio of oxygen to carbon. This reflects the oxidative degradation that is occurring, especially at the surface.

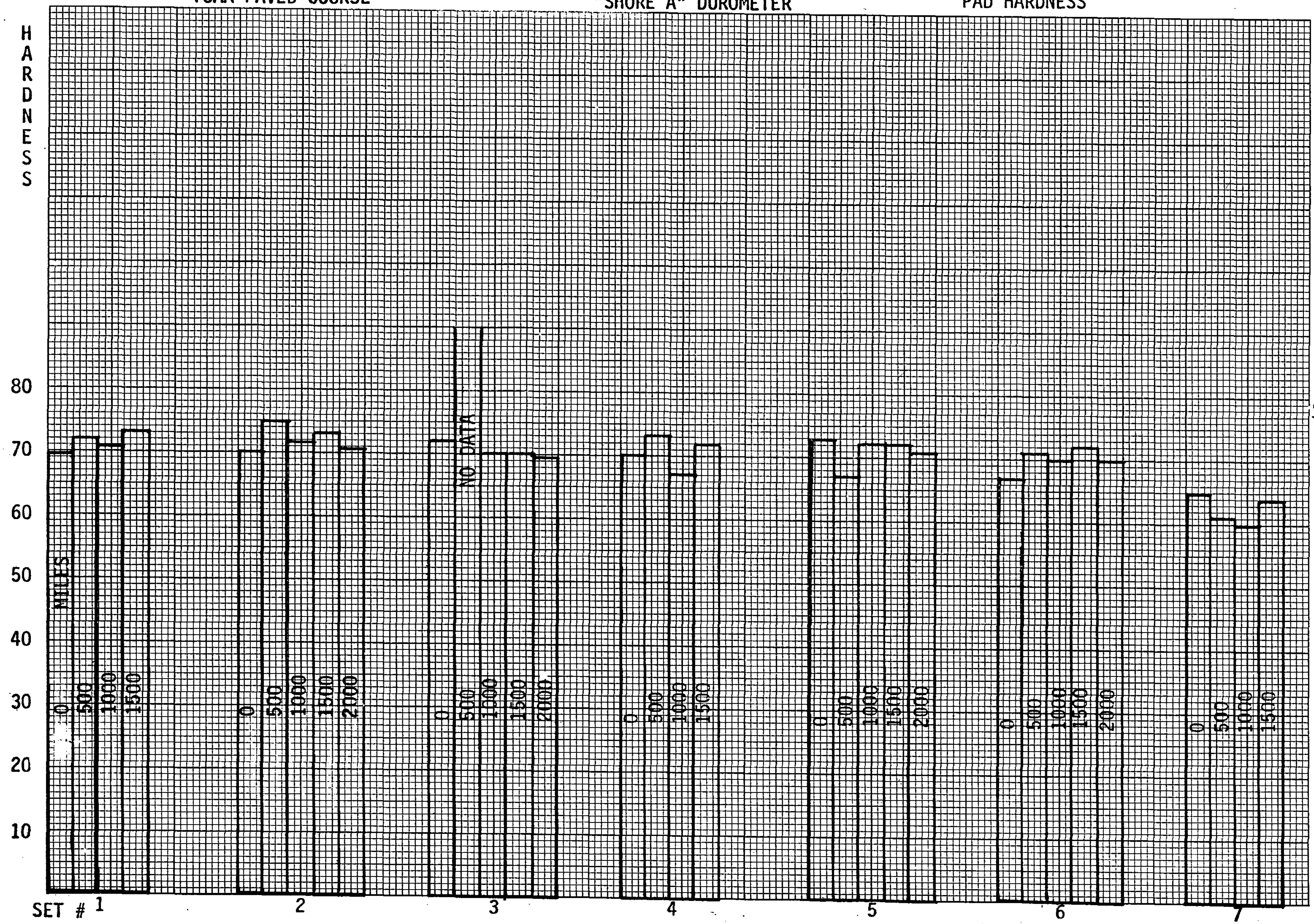
(2) Thermogravimetric Analysis (TGA) - Service failures show weight loss at lower temperatures reflecting a thermo-oxidative degradation of the material causing an increase in percent volatile content. The degradation would decrease the materials resistance to cutting, chunking and wearing.

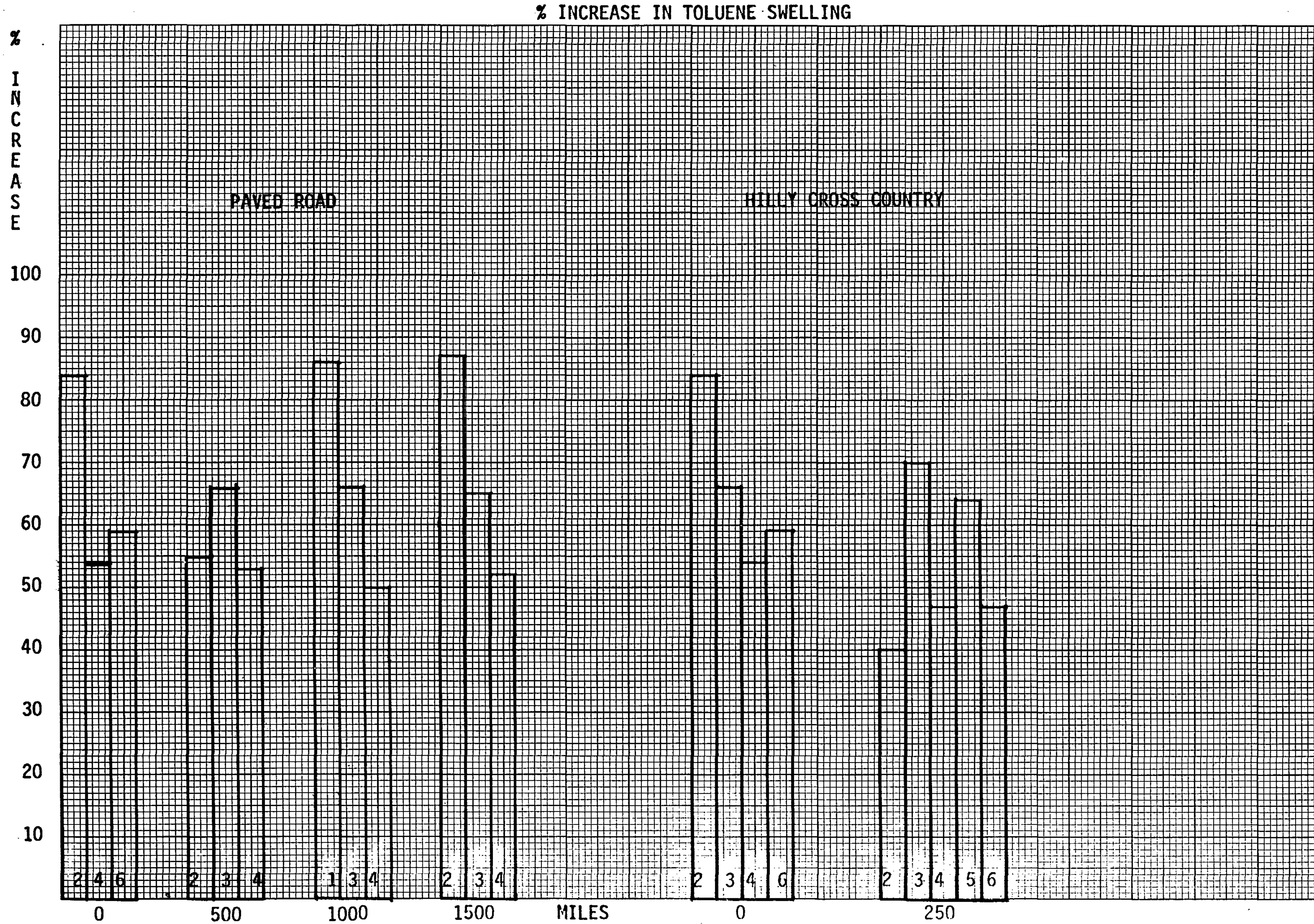
(3) Thermo-Mechanical Analysis (TMA) - Pads which failed in service show a marked increase in the glass transition temperature (T_{gf}) and a decrease in the temperature where viscous flow starts (T_{vf}). This can be attributed to the mechanical and thermal action in service breaking the macromolecules into radicals and a change in molecular weight distribution.

(4) Scanning Electron Microscope (SEM) - Agglomerations of ZnO particles, aliphatic rich layers, and areas of high concentration of sulfur were found in the failed regions. The high concentration of ZnO and sulfur suggest that the blending of the rubber with compounding ingredients is inadequate causing weak areas in the elastomer where cracks can initiate and propagate. The aliphatic rich layers indicate incomplete polymerization of the styrene and butdiene suggesting poor quality of the original polymers used coupled with poor mixing.

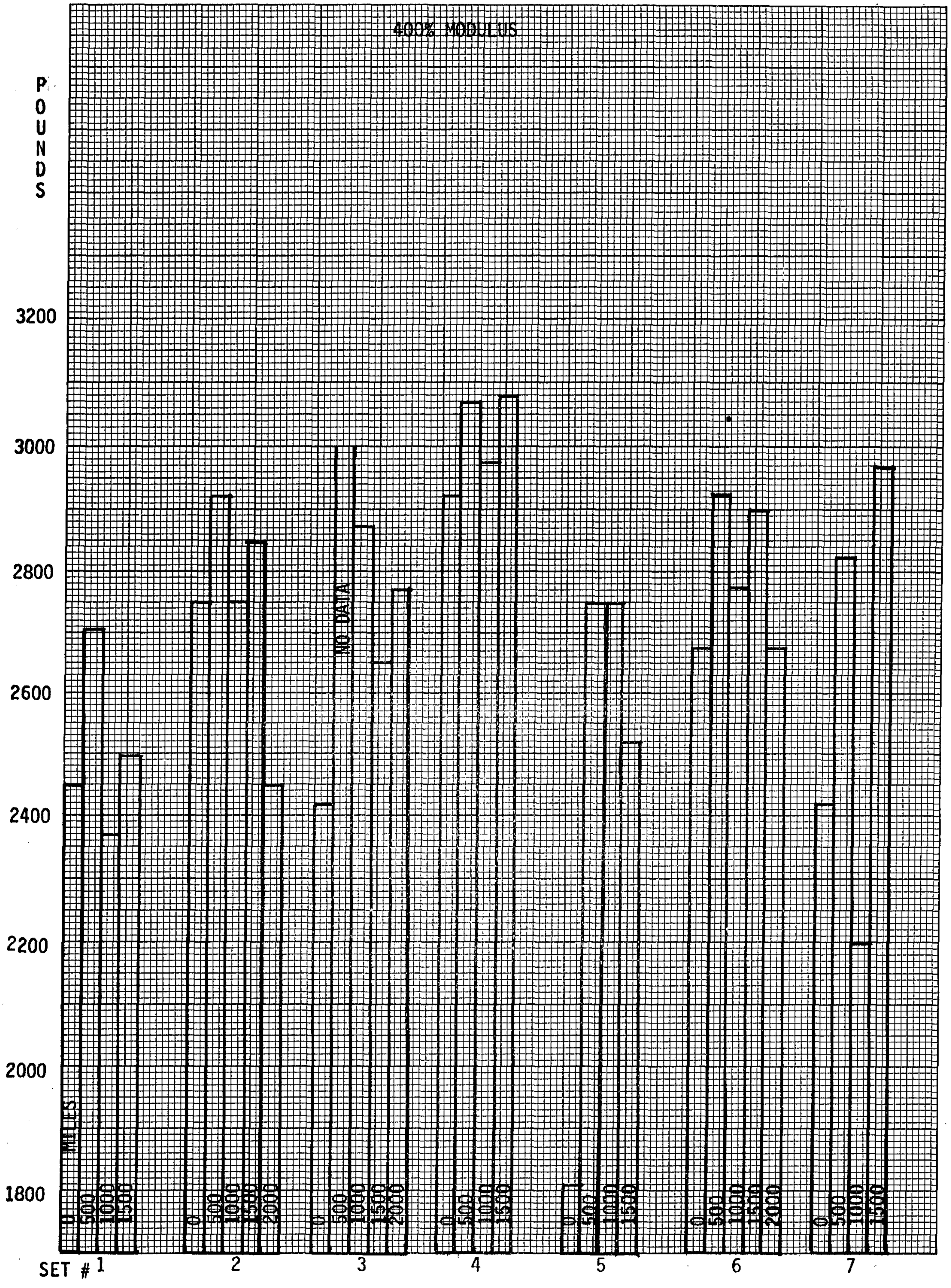
(5) Energy Dispersive Analysis of X-ray (EDAX) - This test confirmed the agglomeration of ZnO particles and an extraordinary amount of sulfur at the initiation points of the failure.

YUMA PAVED COURSE "SHORE A" DUROMETER PAD HARDNESS

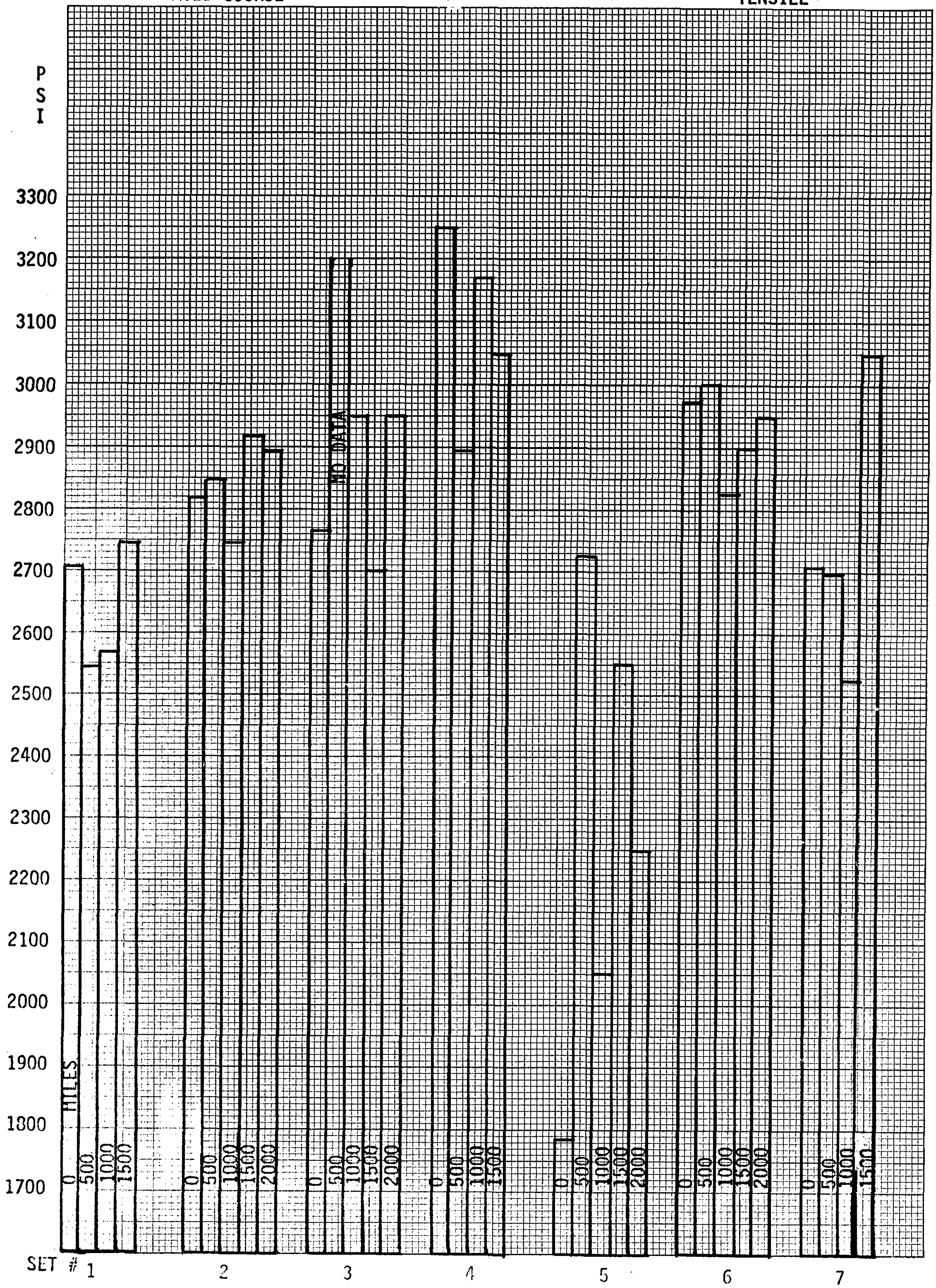



% INCREASE IN TOLUENE SWELLING
% INCREASE
PAVED ROAD
HILLY CROSS COUNTRY
100
90
80
70
60
50
40
30
20
10
2 4 6
2 3 4
1 3 4
2 3 4
2 3 4 6
2 3 4 5 6
0
500
1000
1500
MILES
0
250

YUMA PAVED COURSE

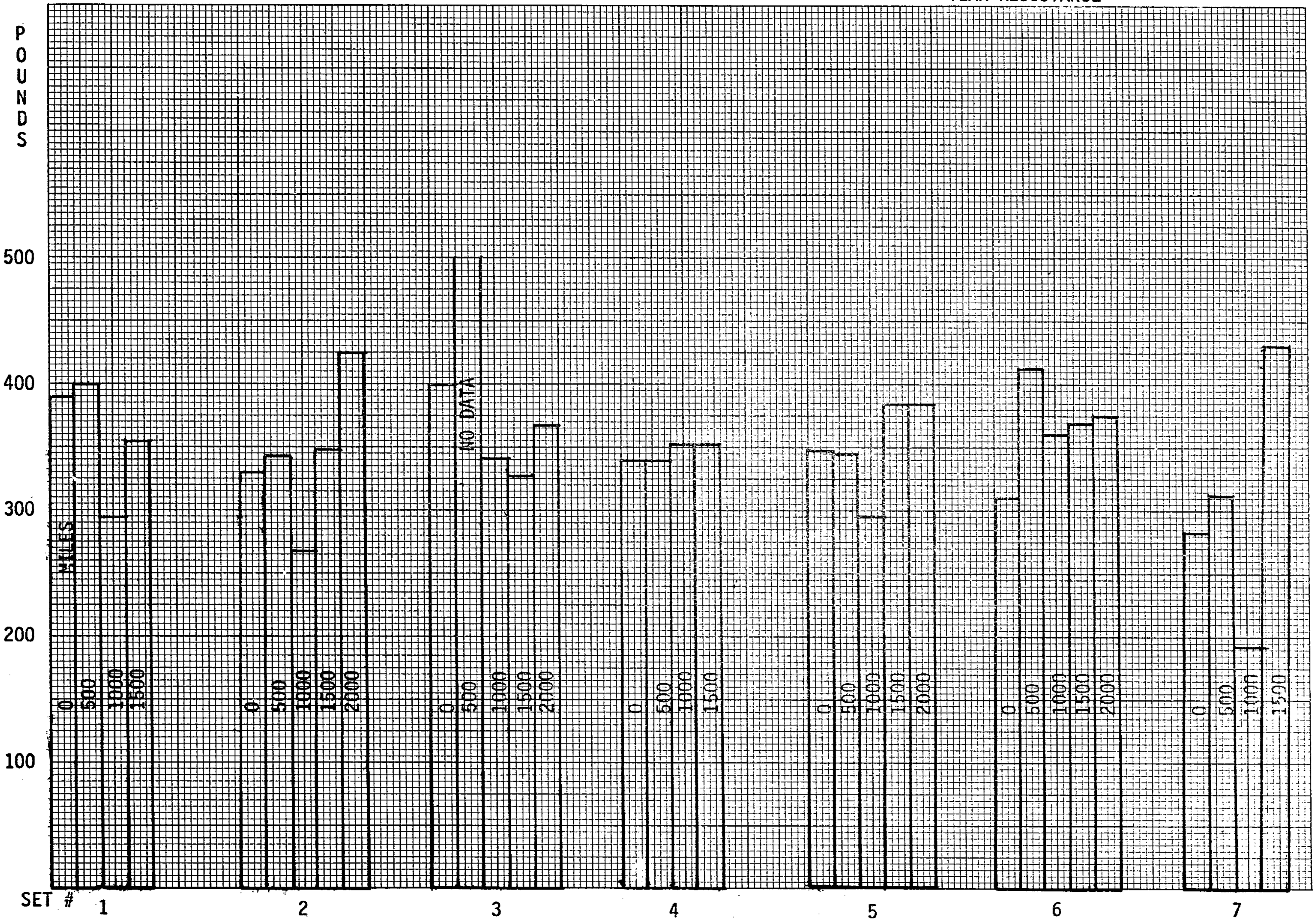


YUMA PAVED COURSE TENSILE

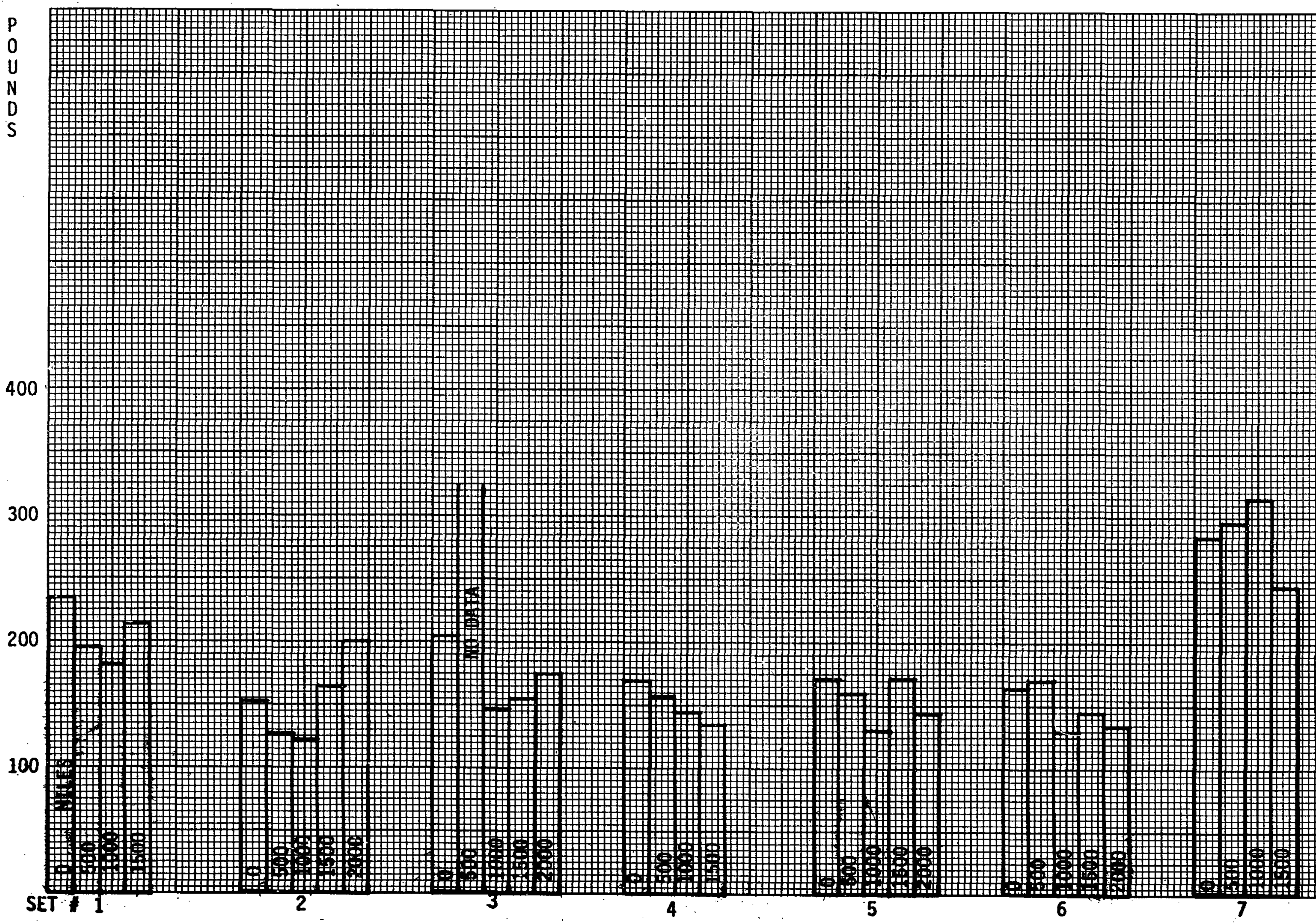


YUMA PAVED COURSE

TEAR RESISTANCE

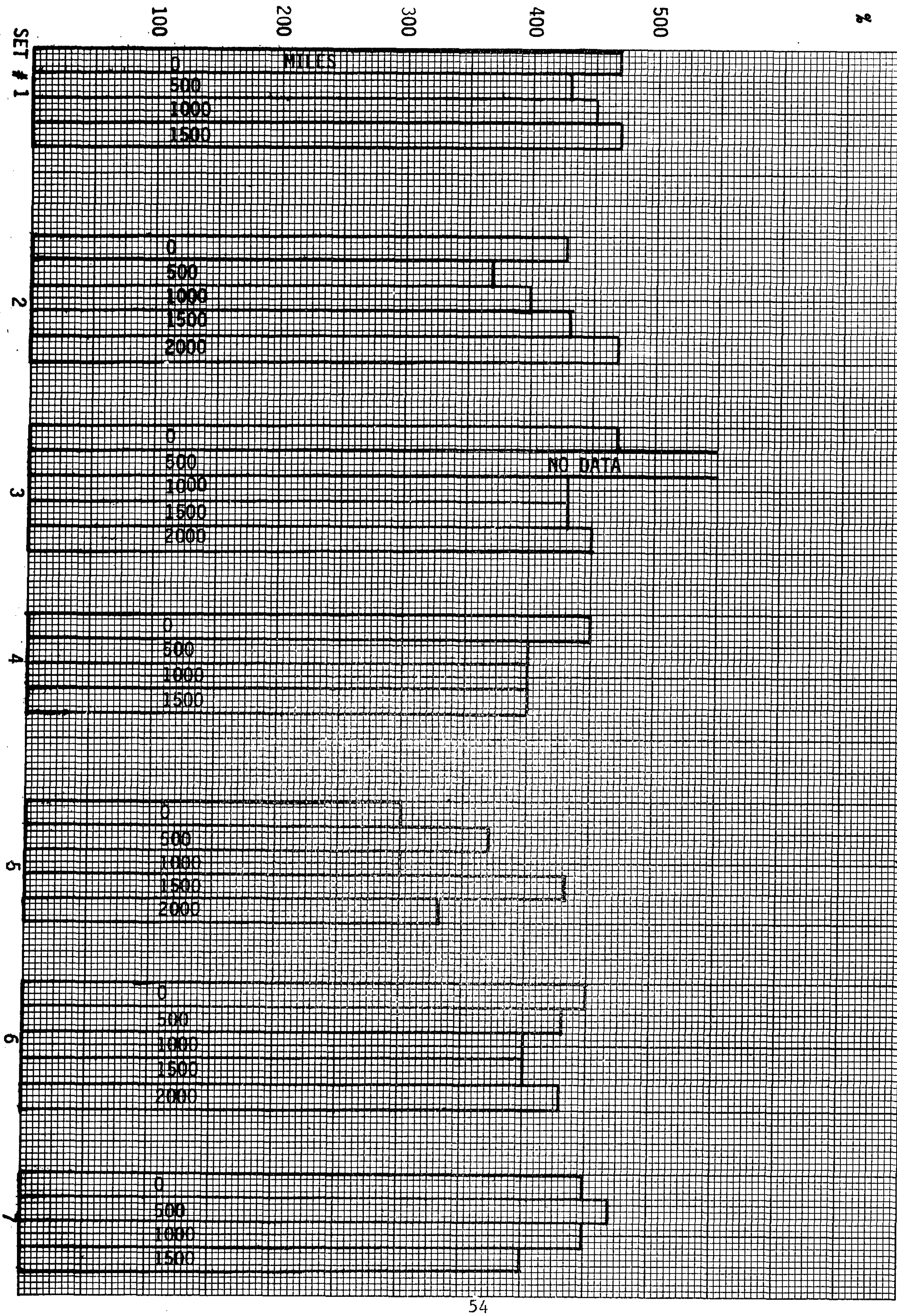


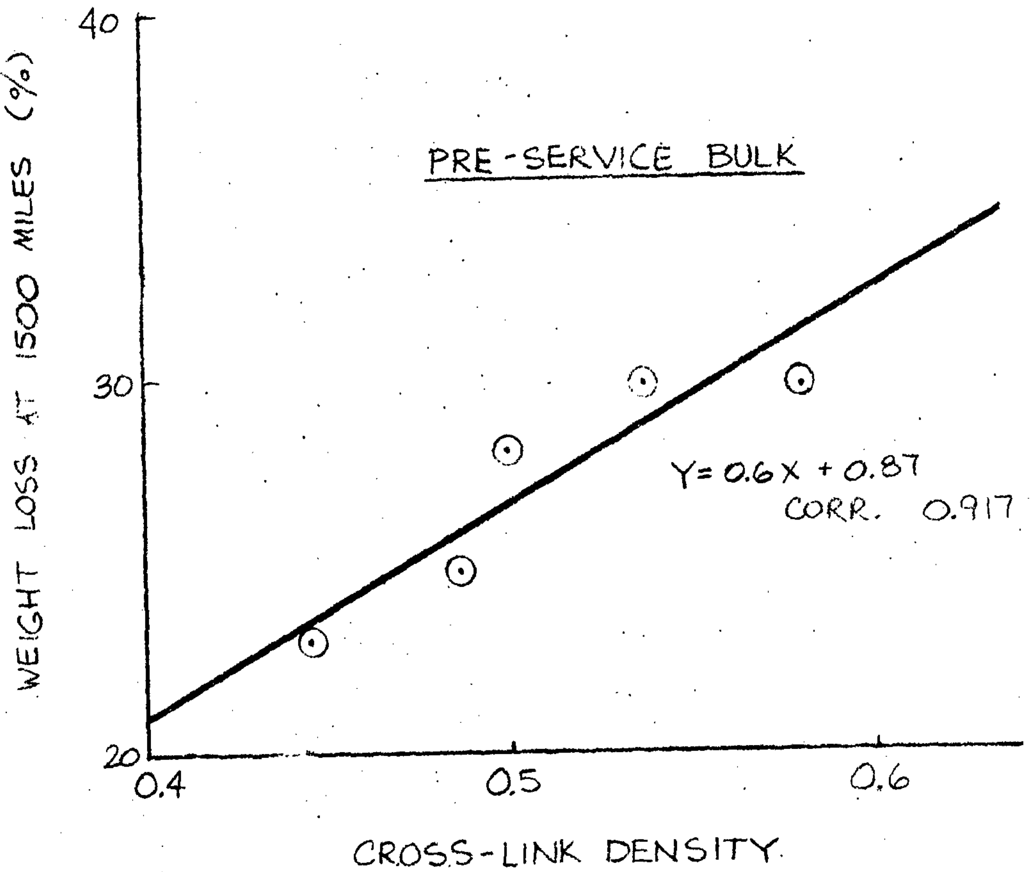
PAVED HOT TEAR



YUMA PAVED COURSE

ELONGATION





40
30
20
WEIGHT LOSS AT 1500 MILES (%)
PRE-SERVICE BULK
Y= 0.6X + 0.87
CORR. 0.917
0.4
0.5
0.6
CROSS-LINK DENSITY

REFERENCES

1. US Army Yuma Proving Ground, "Letter Report of Feasibility Test of T-142 Track Pads, TECOM Project No. 1-VC-087-142-016," 28 August 1980.

2. TARADCOM Technical Report No. 12498, "Formation and Failure of Elastomer Networks Via Thermal, Mechanical and Surface Characterization," prepared for the Department of the Army, Contract No. DAAK30-78-0098, December 1979 by Virginia Polytechnic Institute and State University.

3. Supplemental letters to Final Report, 31 Mar 1980, 7 October 1980, and 30 July 1981, by Virginia Polytechnic Institute and State University.

APPENDIX C

TESTING LOCATIONS

C-1. Yuma Proving Grounds - Yuma, Arizona. Vehicle testing of pads on three types of terrain:

a. Smooth Pavement.

b. Gravel Roads.

c. Hilly Cross-Country.

C-2. Lawrence Livermore Laboratory - Livermore, California. Laboratory testing of new and vehicle tested track pads.

C-3. Virginia Polytechnic Institute and State University - Blacksburg, Virginia. Laboratory testing of new and vehicle tested track pads.

C-4. TACOM - Warren, Michigan. Laboratory testing of new and vehicle tested track pads.

APPENDIX

APPENDIX

DOD USE ONLY

COMPOUND	CONTRACTOR & DESCRIPTION
1	Firestone - Experimental (Proprietary) Formula
2	Firestone - Standard Production Formula
3	Standard Products Company - Standard Production Formula
4	Goodyear - Standard Production Formula
5	Firestone - Standard Production Formula with Kelvar Fibers added.
6	Goodyear - Standard Production Formula with Kelvar Fibers added.
7	Firestone - Natural Rubber replacing SBR
8	Firestone - Tri Blend - Natural Rubber; SBR; cis-isoprene
9	Goodyear - T-97 Modified Pad (Prototype XT152) with new compound.

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