U.S. DEPARTMENT OF COMMERCE
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PB-267 622

Studies of Freight Train Engineer Performance

Transportation Systems Center, Cambridge, Mass

Prepared for

Federal Railroad Administration, Washington, D C Office of Research and Development

Dec 76

REPORT NO. FRA-OR&D-76-306

STUDIES OF FREIGHT TRAIN ENGINEER PERFORMANCE

E.D. Sussman
D. Ofsevit

U.S. Department of Transportation
Transportation Systems Center
Kendall Square
Cambridge MA 02142

DECEMBER 1976

FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
Office of Research and Development
Washington DC 20590

Technical Report Documentation Page

1. Report No.
FRA-OR&D-76-306

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
STUDIES OF FREIGHT TRAIN ENGINEER PERFORMANCE

5. Report Date
December 1976

6. Performing Organization Code
TSC-642

7. Author(s)
E.D. Sussman and D. Ofsevit

8. Performing Organization Report No.
DOT-TSC-FRA-76-31

9. Performing Organization Name and Address
U.S. Department of Transportation
Transportation Systems Center
Kendall Square
Cambridge MA 02142

10. Work Unit No. (TRAIS)
RRT28/R7393

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Federal Railroad Administration
Office of Research and Development
Washington DC 20590

13. Type of Report and Period Covered
Final Report
January 1973-June 1974

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

As a part of the International Government-Industry Program on Track Train Dynamics, the performance of engineers in freight train handling was studied by recording and analyzing train operations and engineer responses under field conditions. Data collection took place during regular revenue freight operations over five representative railroads containing varied terrain and operating conditions. Data collection was accomplished by using a digital data aquisition system specifically designed for this study. Levels of engineer performance were evaluated through the use of an objective rating form specifically designed for this study. Scores on this form were correlated with digitally recorded data.

Engineers were found to consistently respond to changes in locomotive drawbar force as indicated on the cab loadmeter. Higher-rated engineers tended to make fewer and more accurate responses than lower-rated engineers. No systematic pattern of response to cab accelerations was found, nor was a systematic change in smoothness of performance revealed over the length of a trip. Fequency of the use of various controls was found to depend more on railroad terrain and procedures then on individual engineer skills.

17. Key Words
Freight Train Operations
Engineer -- Digital Recording
Control Response
Sensitivity
Data Acquisition

18. Distribution Statement
DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)
UNCLASSIFIED

20. Security Classif. (of this page)
UNCLASSIFIED

21. No. of Pages
75

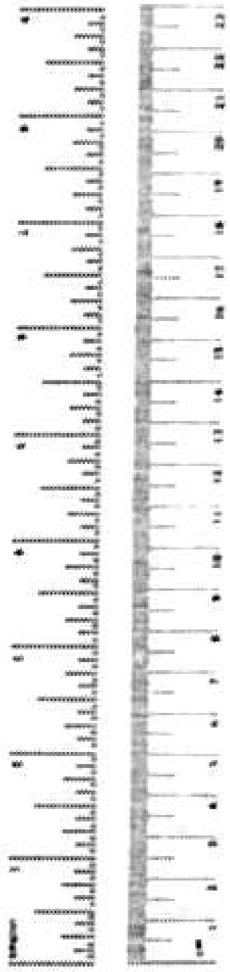
22. Price
PC-A04
MF-A01

Form DOT F 1700.7 (8-72)   Reproduction of completed page authorized

METRIC CONVERSION FACTORS

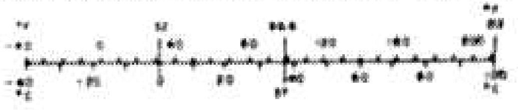
Approximate Conversions to Metric Measures

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



Approximate Conversions from Metric Measures

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



PREFACE

The work described in this report was performed as part of Transportation Systems Center's (TSC's) project in train handling, under agreement with the Federal Railway Administration and in cooperation with the International Government-Industry Track Train Dynamics program, Task Four.

The following personnel assisted in the progress of this work by providing technical and practical assistance, access to railroad properties, and aid in conducting experiments:

Association of American Railroads Technical Center:
E.F. Lind
Burlington Northern: J. Cannon
General Motors Corporation Electro-Motive Division:
N.L. MacDonald, A.M. Trest, L. Cannaday,
T. Jackson
Illinois Central Gulf Railroad: F. Lee
St. Louis - San Francisco Railway ("Frisco"): R. Tyler,
R. Newman
Southern Railway: E. Fernandez
Southern Pacific Transportation Company: D.D. Grissom,
R.D. Pigg, E. Thomas
Union Pacific: T. Stuart
Transportation Systems Center: M. Form, D. Gosselin

In addition, road foremen and other supervisory personnel from the participating railroads evaluated engineer performances on the form described in this report.

The following railroads provided additional help by allowing TSC to install test equipment on their locomotives, which were then assigned to test runs:

Southern Railway
Illinois Central Gulf
St. Louis-San Francisco ("Frisco")
Southern Pacific

The Southern Pacific also allowed its locomotives to be used in tests on the Union Pacific and Burlington Northern. General Motors Electro-Motive Division provided its test car, including technical personnel, for the extended tests described in this report. During tests on the Southern Pacific and Union Pacific, those railroads provided extra cars for tests and accomodations.

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1. INTRODUCTION

1.1 COOPERATIVE TRACK TRAIN DYNAMICS PROGRAM

One of the major continuing efforts in TSC's studies of Human Factors in Railroad Operations has been an investigation of the role and function of the railroad engineer in controlling adverse train dynamic action. This report describes a portion of those investigations performed as part of the International Government-Industry Research Program on Track Train Dynamics.

In 1972, the Association of American Railroads (AAR), the Railway Progress Institute (RPI), and the Federal Railroad Administration (FRA) initiated a research program which encompassed studies of the dynamic interaction of a train consist with track as a function of operating practices, terrain, and climatic conditions. The research program was divided into thirteen task areas. TSC's human factors efforts were performed under Task 4, "Investigation of Engineer Sensitivity and Locomotive Response Characteristics" of the research program. The purpose of this task was to evaluate, as objectively as possible, responses of typical locomotive engineers, in important train-handling situations, to various types of informational inputs.

1.2 GOALS

The original goals of the study were to determine the types and amplitudes of various events or occurrence, such as accelerations, which the engineer senses during the operation of the train, and, based on these determinations, to evaluate and define specific operating policies and train handling instructions. Discussions at the meetings of TTDRP indicated that the outcome of this sort of determination would be incomplete and the resulting recommendations might well be at best trivial. It was determined that the problem was not what is the amplitude or level of an event (such as an acceleration) to which the engineer is sensitive. Instead, to what types of events and at what levels of events does he or she respond, what types of patterns of response or ranges of response can we expect from the engineer population as a whole, and what differences exist between the response patterns of ordinary and superior engineers?

In order to answer these questions, it was necessary to determine not only what the stimuli impinging on the engineer were, but also what the interrelationships between the stimuli and the engineer's response patterns (control changes) and the changes in train operation or train motion were.

A number of goals are implicit in the study. One is the identification of simple objective techniques for estimating the engineer's skill. The road foreman can readily estimate an engineer's performance or skill level; he bases this determination on personal experience and bias, on the idiosyncratic procedures of the practical railroad, and even on procedures and customs particular to his or her district or region. However, for purposes of rating the proficiency of engineers, evaluating the progress of trainees, determing the need for retraining engineers, or selecting individuals for more demainding types of service, simple, quantifiable measures of performance which are clearly related to train operation are required.

Developing meaningful symbolic representations or models of engineer performance is another goal. These models could be of great value in two areas. The first involves the use of train dynamics models to develop optimum handling strategies. The current train dynamics models usually assume that the engineer will follow the recommendations or outputs of the model with great fidelity. However, in the "real world", engineers make errors in the timing, precision and direction of control use, and sometimes even omit entire control routines. It is possible that an optimum strategy provided by a train dynamics model for a "perfect" engineer would result in a relatively worse performance than the use of a strategy designed to accommodate the less-than-perfect performance of a real engineer. Models of engineer performance can provide information on the range of responses (both correct and incorrect) that engineers can be expected to make, in a form that can be used in planning and executing research in locomotive cab simulators. The second area where symbolic representations of critical aspects of engineer performance can be used is in the development of systems for monitoring critical aspects of engineer performance. These systems can provide for warning of, or automatic correction of, out-of-range or dangerous operation. Current monitoring is restricted to determining engineer alertness and in a few cases to deterining "over-speed." With the availability of symbolic models of engineer performance, which establish safe operating ranges for throttle use, brake application, train speed, and draft and buff forces, it will be technically feasible to develop on-board microcomputer systems which monitor and evaluate performance and provide warning or restrictions on erratic or otherwise unsafe performance.

As noted above, the engineer sensitivity effort was intended to provide the input data to support the use with locomotive cab simulators and for incorporation in automatic engineer monitoring systems. The data gathered has proved suitable for such efforts. An initial model of engineer performance under three conditions (starting on a level grade, stopping on a level grade, and maintaining speed during changes of grade) is currently being prepared, under Contract No. DOT-TSC-1037 (entitled "Development of a Train-Handling Control Model for Freight Train Locomotive Engineer Performance").

A final goal for gathering data on the engineer's response to his environment was to provide an improved understanding of the relationship between engineer performance and the configuration of the locomotive cab. To this end, the data gathered has been supplied for use in Contract DOT-TSC-913 (entitled "Locomotive Cab Design Development"), to determine the frequency and patterns of control usage in order in order to optimize placements of the controls and the cab design required under the terms of the contract.

1.3 STUDY PLAN

In order to accomplish the goals noted above it was determined that it would be necessary to perform field tests where ratings of the engineer performance in operating the train, the inputs made to the locomotive by the engineer and the information inputs available to the engineer from the train and other sources could be recorded and subsequently analyzed. Due to the exingencies of railroad operation it was further determined that these recordings would have to be made during normal revenue service in freight operations with minimum interference to operations. Execution of these studies required gaining the cooperation of the subject railroads, gaining use of the required locomotives, gaining use of and equipping a test car, developing a suitable recording system developing a technique for making an accurate and relatively unbiased "paper and pencil" evaluation of the engineer's performance, and analyzing the data acquired on the tests. The conduct of these activities is described in the following section.

2. METHODOLOGY

2.1 SUBJECTS

Data were recorded from 47 subjects. All subjects were male experienced freight locomotive engineers. Each of the engineers used as a subject in the tests was an employee of one of the following five railroads: The Illinois Central Gulf (ICG), The St. Louis-San Francisco Railroad (SL-SF), The Southern Pacific Transportation Company (SPTC), The Union Pacific Railroad (UP), and The Burlington Northern Railroad (BN).

2.2 OBJECTIVE RATING FORM

A form for objectively rating the subject engineer's performance was developed by Mr. Dale Grissom of the Southern Pacific Training Center and Mr. Norman MacDonald of the Electro-Motive Devision of the General Motors Corporation (EMD/GMC). On this form, the engineer's performance was rated in the following categories: timeliness, adherence to rules, observance of procedures, and maximum acceleration and drawbar force that occurred during the particular test. The form is provided in Appendix A of this Report.

The rating form was provided to the direct supervisor of the subject engineer (usually a road foreman) before the test and its use was explanined to him. The direct supervisor was used as the rater, in order to have an accurate estimation of the engineer's performance during the test. The use of a uniform rating instuurument, with highly objective content, and a rater who was familiar with the operations of the particular railroad and the test segment provided a measure which was relatively objective and yet corrected for the idiosyncrasies of the particular railroad and geographic area.

2.3 TEST ROUTE

The tests were performed over a route planned and prepared by Mr. Ed Lind (at the time of th tests, Research Director for the Track Train Dynamics Program) and Mr. Dale Grissom, (SPTC). The test route was designed to provide measures of performance on the following types of terrain: flat, undulating, steeply graded with few curves, and steeply graded with many curves (mountainous). Suitable track segments were identified and tests performed over the five railroads mentioned above (ICG, SL-SF, SPTC, UP, and BN). Figure 1 illustrates the route followed during the tests.

One suitable test track segment was chosen on each of the railroads except the Southern Pacific where two segments were chosen. Most segments were about two divisions in length, allowing for tests of two crews in each direction during each run.* At least two tests were run in each direction on each track segment, providing repeated performance measures on each of the track segments for different engineers.

2.4 LOCOMOTIVE SELECTION

In order to reduce the likelihood of subject performance differences due to variation in locomotive configuration, all tests except those on the SL-SF were performed using a consist of EMD/GMC SD-45-2 freight locomotives, (on the SL-SF only EMD GP-38 locomotives were available). The SD-45 locomotive was chosen as it represents a commonly used, modern, large, freight locomotive. The SD-45 is equipped with three-axle trucks, a "short" front hood, an AAR-type control stand, and extended range dynamic brakes. The SD-45 has a power output of approximately 3,600 HP and a weight of approximately 400,000 lbs. During the tests, the number of locomotives in the lead consist was adjusted according to the terrain and the train make-up, and helper units were attached as needed at or near the rear of the train.

2.5 RECORDING TECHNIQUES

To acquire the necessary data to analyze the interrelationships between engineer performance and train handling, a recording system had to be prepared and installed in a suitable test car. Investigation of the available recording systems revealed none were suitable

---

*The division on American railroads vary in length from about 2 to 10 hours in travel time, allowing replacement of the crew within a single 12-hour shift.

FIGURE 1. TEST ROUTE MAP

for the effort and new techniques were required.

Many railroads, as well as railroad equipment manufacturers and other related organizations, have recorded large volumes of data on locomotive performance, track train dynamics, and track measurements. The usual method is analog recording of the desired parameters on magnetic tape or oscillograph paper. While proven reliable, this method has drawbacks which prevented its application to the study of engineer performance. Continuous recording of a single engineer's performance for a single trip of up to approximately ten hours duration yields a glut of difficult-to-analyze and for-the-most-part-unwanted material. The recording speed of the magnetic tape or chart paper is governed by the need to analyze the most rapidly changing (highest frequency) signal, necessitating the use of great volumes of tape or paper. If even one high-frequency signal is to be recorded, physical limits of paper recording techniques and analog magnetic recording techniques preclude the recording of more than 14 channels uless complex and cumbersome multiplexing schemes are used, requiring even higher tape speeds than are dictated by the highest frequency signals.

These limitations were verified by initial field tests performed on the Southern Railroad, performed on revenue service freight operations between Atlanta, Georgia and Birmingham, Alabama in March 1973. This served to refine the development of the sensors required for the Task 4 effort. The recordings were made using an advanced analog tap recording system (Sangamo Model 3500).

The digital data recording and analysis system designed for the study (described in greater detail in Appendix B) eliminated many of the serious drawbacks of analog methods. The system controlled by a PDP-11/20 minicomputer, included input signal conditioners, none-track digital magnetic tape, teleterminals, and supplementary computer peripherals. The advantages and drawbacks of the system used can be summarized as follows:

Advantages	Disadvantages
Variable data rates	Higher initial cost
Large number of input lines	Higher electrical power requirements
Efficient data storage and retrieval	More stringent environmental control requirements
Data in convenient form for analysis	Need for minicomputer applications specialist
Selective recording of "events of interest"	

The system developed was capable of sampling up to 29 analog and 16 digital (two-valued) input lines at rates varying from 1 to 100 samples per second, depending on the nature of each line. As it scanned the data, the system sensed "events of interest" occuring in certain data lines and automatically stored the data associated with such events on magnetic tape. For the engineer sensitivity tests, the "events of interest" were the following:

(a) Automatic brake application - five psi or greater reduction in brake pipe pressure.
(b) Independent brake application - five psi or greater increase in locomotive brake cylinder pressure.
(c) Any change in throttle position.
(d) Use of dynamic brake.
(e) Drawbar force (in draft or buff) in excess of 200,000 lbs.

In order to understand the interrelations between engineer performance and train operations it is necessary to know the precursors as well as the results of events such as those listed. In order to accomplish this, the computer was programmed to maintain the most recent 18 seconds of data from all input lines in its core memory. When an event occurred, the program would cause the computer to store the 15 seconds of data occuring before the event on magnetic tape.* It would then continue to store incoming data on tape as well, until at least one full minute of continuous action had been stored. Another event during such a writing period would extend it to 45 seconds beyond the new event. The data tape created by this technique would contain "windows" of data, each containing an event along with its precursors and results.

The window technique is advantageous because it actively prefilters the data. As discussed earlier in this section, uneventful or uninteresting recordings are a great problem in the measurement of human performance in real world systems. For the vast majority of the time in railroad operations (certainly in any well-regulated reailroad operation) nothing at all happens, and nothing should be happening. Such "no-event" periods contain little or no information. The engineer's contribution occurs during a limited number of critical periods during the operation. The window technique eliminates the "no-event" periods, thus compressing the data on the tape.

The digital recording system was first tested in June, 1973, on a round trip test between Los Angeles, Calif., and El Paso, Texas. At that time the nine-track digital tape recorder was not available and it was necessary to record the data on a large number of small reels of DECtape (4-inch digital tapes). Despite this inconvenience the validity of the method was established.

2.6 PROCEDURE

The digital data recording system was installed on the EMD/GMC ET-800 test car at the EMD factory in La Grange, Illinois in early January of 1974. The installation is illustrated in Figure B-4. The ET-800 test car on the SL-SF in a consist is shown in Figure B-5. Subsequent to installation, data recording took place on the railroads mentioned above in the following sequence:

---

*The "oldest" 3 seconds' data were always in the process of being "overwritten" with incoming data and could not be reliably recorded.

ICG
SL-SF
SP
UP
BN

At the start of each test session, the participating road foreman was briefed and given instructions on the use of the rating form. The road foreman then instructed the engineer explaining that the test car was attached to the train to study locomotive performance and train dynamics (the most common use of the test car) and that the engineer should operate the train in a "normal" manner. Of course it was clearly understood that with the road foreman (the engineer's direct superior) present, the engineer would attempt to achieve exemplary performance. Even so, it was expected that there would be sufficient differences between the performance of the subject engineers to provide useful data.

After the necessary preparation the trip commenced. During the tests the recording system operated automatically, as described above. However, a manual data entry and start override system was also included. This system was used to enter time and milepost information which was required to relate the recorded data to the track chart information. The system was also used to ensure the operation of the recorder when slack "run-ins" occured, although the changes in brake pressure or throttle position accompanying such run-ins often started the system automatically. At the end of each test, a printout of the maximum drawbar forces and longitudinal accelerations experienced during the test was obtained from the recording system and the information entered into the engineer's score sheet. The total performance scores for the engineer were then completed by the test crew, the score, rating form, and data tape "logged in."

3. ANALYSIS AND RESULTS

3.1 PLOTS OF "RAW" DATA

Subsequent to completion of each test, portions of the data were displayed in "raw" analog form for purposes of ready examination. Figure 2 is an example of the unprocessed data. This plot was made by converting the digital data contained on one of the test tapes into its original analog form and displaying the analog signals on an oscillograph. The chart covers about three hours and depicts x, y, z accelerations, drawbar force, coupler angle, displacement of the coupler, throttle postion, traction motor current, throttle position, brake cylinder pressure, brake pipe pressure, reservoir pressures, use of dynamic brake, speed, and use of sanders. This type of format is useful in analyzing various patterns of train handling.

One point of interest in this graph is the portions of the traces which resemble tall thin plateaus. These represent intentional data gaps which were inserted when no event of interest (event programmed to trigger the permanent storage of data) occurred. During the period represented by these plateaus, the magnetic tape recorder did not operate. The lengths of these gaps are determined by a real time clock which is part of the computer system and is recorded on the tape, though not present on this chart.

Figure 3 represents a graphic display of data occurring during a break-in-two. The time scale is expanded so that the total time of the event is about 5 minutes; note the marking near the upper left corner which shows the distance on the chart representing 40 seconds. At the beginning (the left edge) of the event, the train (approximately 10,000 tons with 14,400 horsepower) was standing still (SPEED = 0) on level tangent track. As the engineer used the throttle the loadmeter reading increased (note the LOAD direction on the LOADMETER graph) and the drawbar force increased proportionally. The direct cause of the break-in-two is obvious; drawbar force reached 280,000 lb. The graph indicates that the engineer advanced the throttle too quickly, from notch 2 to notch 7 in less than a minute, which is too high a throttle setting for the train's

FIGURE 2. "RAW" DATA EXAMPLE

FIGURE 2. CONTINUED

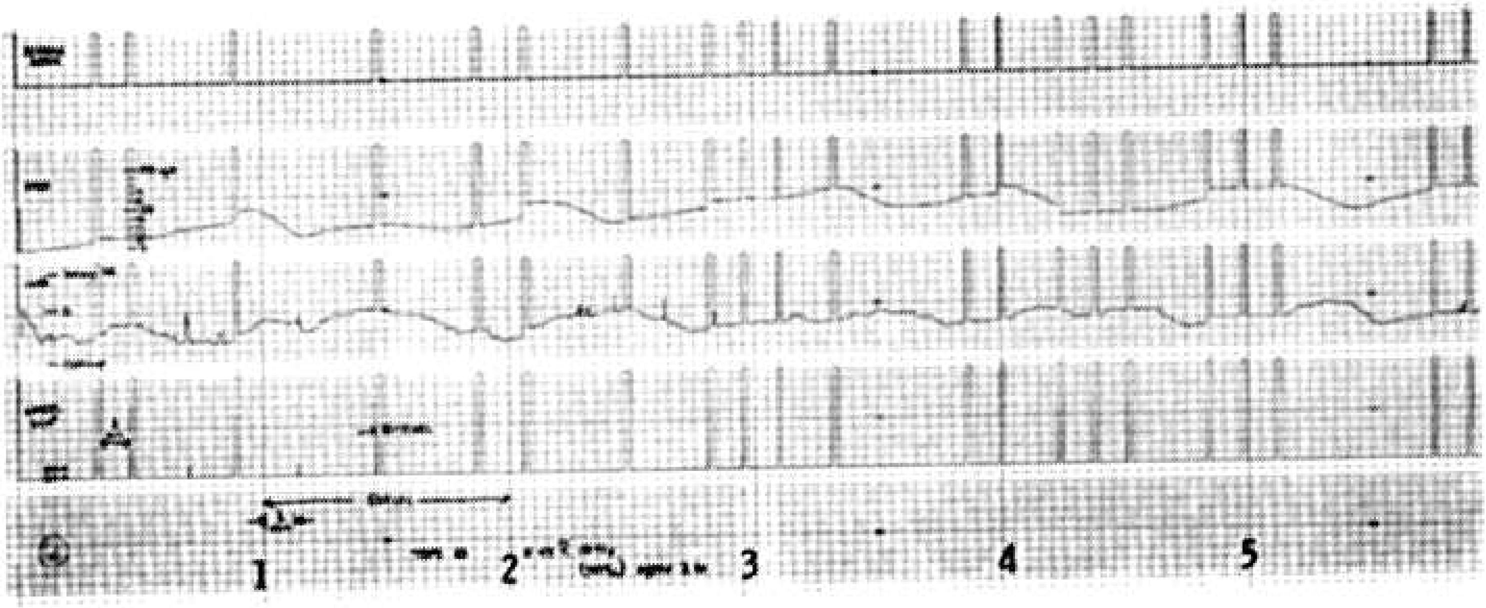


FIGURE 2. CONCLUDED

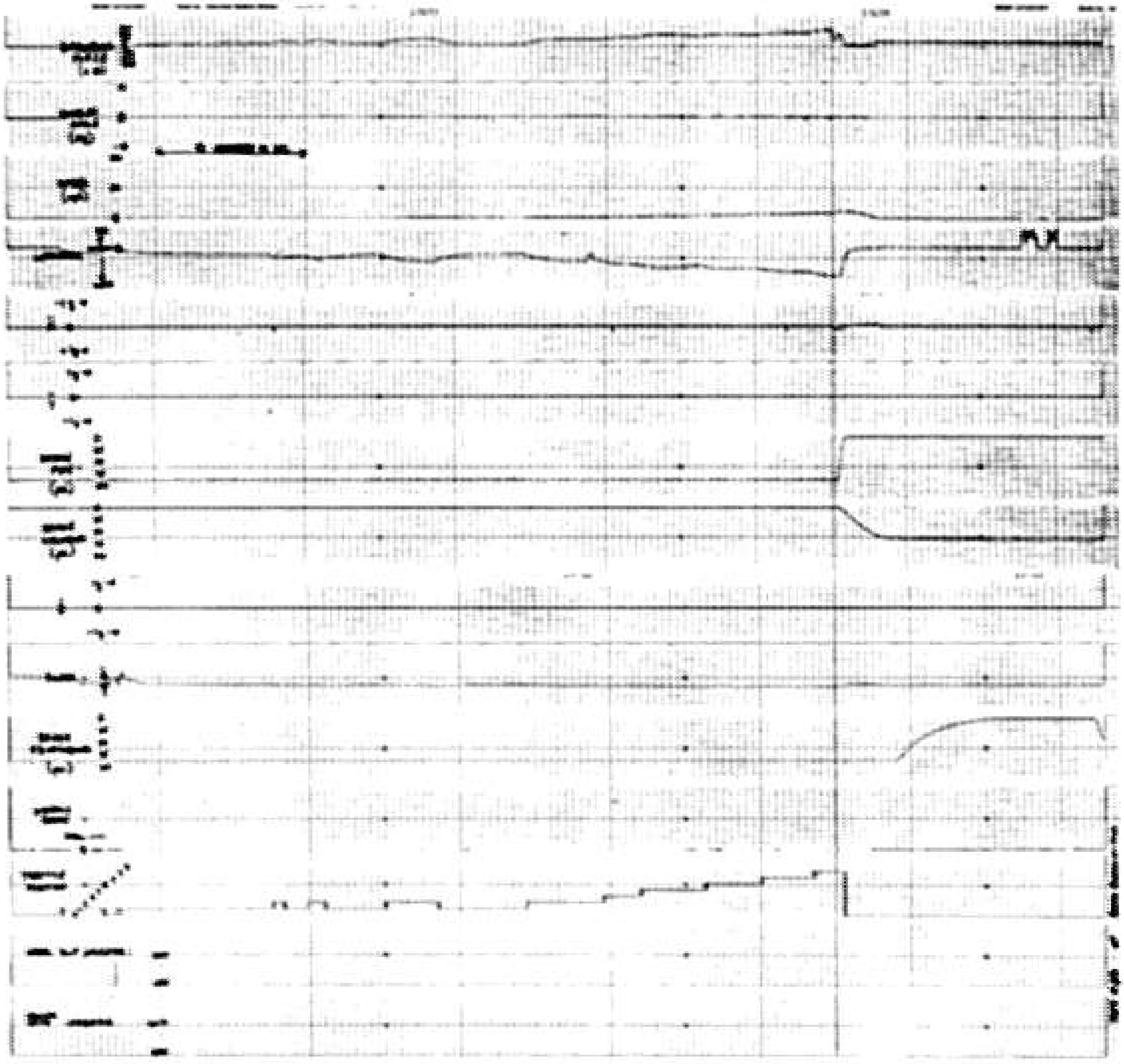


FIGURE 3. DATA EXAMPLE DURING BREAK-IN-TWO

speed, 8 mph. After the break-in-two occurred, there was a delay of several seconds before the ruptured brake line was detected (BRAKE PIPE pressure falling to zero) at the head end of the train. During this delay the throttle was still applied, and when the train separated, the drawbar force was reduced and the train accelerated; note the speed reaching 12 mph and the acceleration (x) is positive. Due to the parting of the air hoses the brake pipe pressure eventually fell and an emergency stop occurred; all brakes were applied, power was cut off, and the train stopped quickly. Note that the stop occurred on a slight (0.1 percent) downgrade and with approximately 70,000 lb. of draft force (tension) between the locomotives and the test car.

3.2 STATISTICAL ANALYSIS OF PERFORMANCE OF ADEQUATE AND SUPERIOR ENGINEER

3.2.1 Rationale

This study required identification of quantifiable indices of engineer performance. A simply hypothesis which might underly the development of such an index is: The greater the magnitude of the stimulus input to the engineer (such as a chnage in the loadmeter reading representing a change in drawbar force), the more likely the engineer is to make a response (change a control setting). A program was designed to enable the computer to examine and analyze the data required to test this hypothesis. The program enable the computer to sense every force change above a given threshold (in steps of 4000 lbs./sec.), classify the changes according to their magnitude, determine whether or not they were accompanied by a response, and determine the time between the event and the control change.

3.2.2 Results

Figure 4 depicts data recorded on the BN and UP railroads.* The figure contains two sets of curves representing the relationship between the magnitude of change in the drawbar force of the

---

*Due to recording problems noted in Appendix D, only the data recorded on these two railroads were termed suitable for this particular analysis.

test consist and the frequency of control responses made by the engineers in four time periods following the change. The curves with the solid lines represent the performance of engineers scoring in the lower third of all scores on the objective rating form (termed "adequate engineers") and those scoring in the upper third (termed "superior engineers"). The curves labelled 1/2 represent the relationship between the magnitude of the force changes and the frequency of the engineer's manipulation of controls within a half second after every such force change. The curve labelled 1 represents the relationship between force change and control response for 1 second after each force change; similarly, the curves identified with 2's and 3's represent the relationships for 2- and 3-second periods. Of course the curves in each group are quite similar as the 3-second curve contains all of the data which forms the 2-second curve; the 2-second curve contains all the data from the 1-second curve and the 1-second curve contains all of the data from the 1/2-second curve.

Examination of the figure suggests that there is a difference between the shapes of the curves representing the lowest scoring third of the engineers and those representing the highest third. Figure 5 illustrates a further time dissection of the data. Again the numbers associated with each curve represent the time period relative to the onset of the force change. For instance, the pair in the lower left represent the relationship for the period from 1/2 through 1 second after a change in drawbar force. Examination of the curves in Figures 4 and 5 suggests that there is a linear relationship between magnitude of drawbar change and frequency of response, and that this relationship differs for engineers scoring in the lower and upper thirds.

In order to test this hypothesis, equations were computed for each of the curves in Figures 4 and 5. The best fit was found to be linear; higher-order terms added no significant predictive

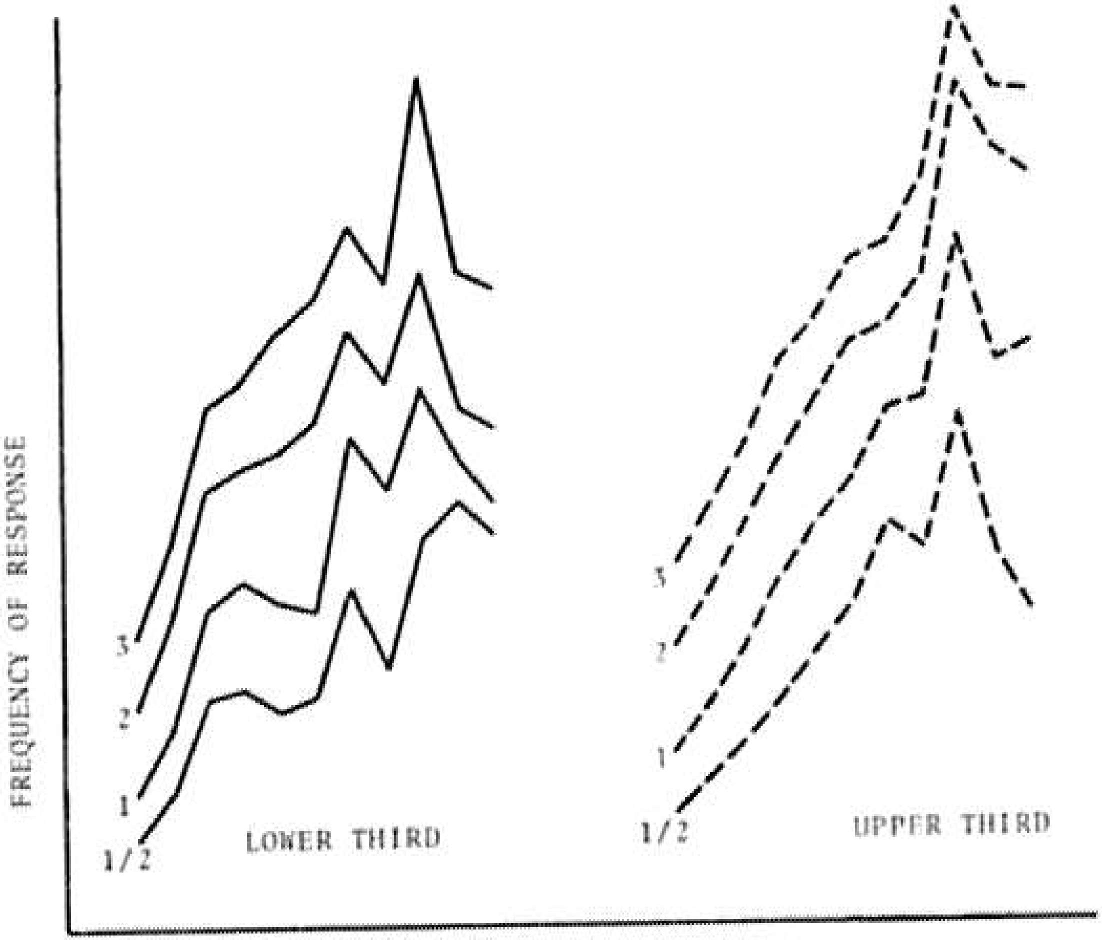


FIGURE 4. RESPONSES TO CHANGE OF DRAWBAR FORCE:
0 TO 1/2, 1, 2, 3 SEC.

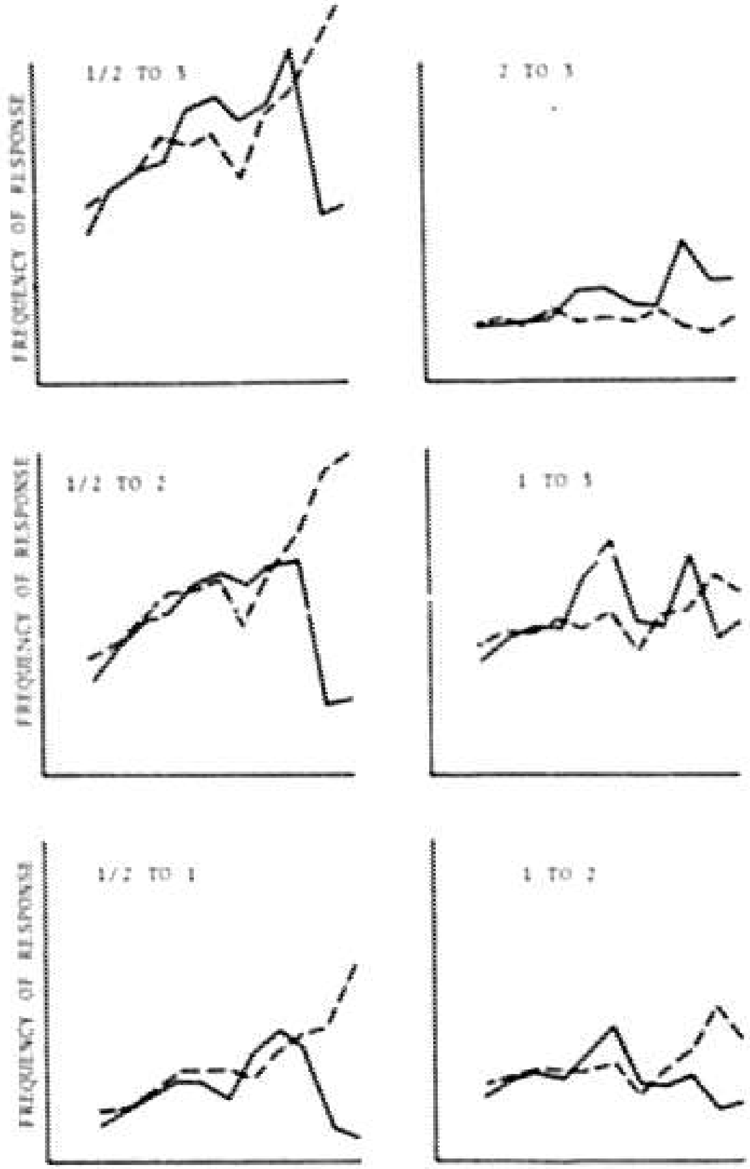


FIGURE 5. RESPONSES TO CHANGE OF DRAWBAR FORCE: 1/2 TO 1, 2, 3; 1 TO 2, 3; 2 TO 3 SEC.

ability.* These curves and their linear fits are depicted in Figures 6 and 7; in addition, the coefficient of linear correlation (Pearson product moment coefficient of correlation) is shown to the right of each linear representative.** As each curve is composed of tens of thousands of data points, it was possible to compute these curves and statistics with great confidence. In Figure 6 the linear correlations are quite high; the lowest is 0.78 and the highest 0.97. As the square of the coefficient represents the percentage of the variance accounted for by the best fit linear regression equation, it appears that, in general, the relationship between the magnitude of the force change and the frequency of the engineer's response is both monotonic and linear.

The linear regression equations fitted to the curves in Figure 5, shown in Figure 7, are more revealing. The linear plots on the left side of the figure represent the relationship between response frequency and force change magnitude for periods begun 1/2 second after a force magnitude change through 1, 2, and 3 seconds after the change. The figure on the lower left is particularly interesting; it represents the force change response relationship during the period when the engineer is making his early corrective responses. During this period (1/2 second through 1 second after a drawbar force change) the responses of the engineers scoring in the upper third on the objective rating scale showed an extremely high correlation between force change magnitude and frequency of third showed a negligible correlation (r = 0.13). Examination of the plot for the 1 to 2 second period (lower right) indicates that during this matter responses which correlated with the magnitude of the force change (r = 0.7) but the engineer in the lower 1/3

---

* Examination of the curves in Figure 4 recorded downturns at the extreme right hand end of each curve. Statistical analysis indicates that these downturns are artifactual.

** This is a simple mathematical expression of the relationship between two variables. The higher the absolute value of the coefficient (up to the limit of 1.0), the greater the relationship between the variables analyzed. The square of the coefficient indicates the amount of variance in the data which the linear relationship between the two variables can account for.

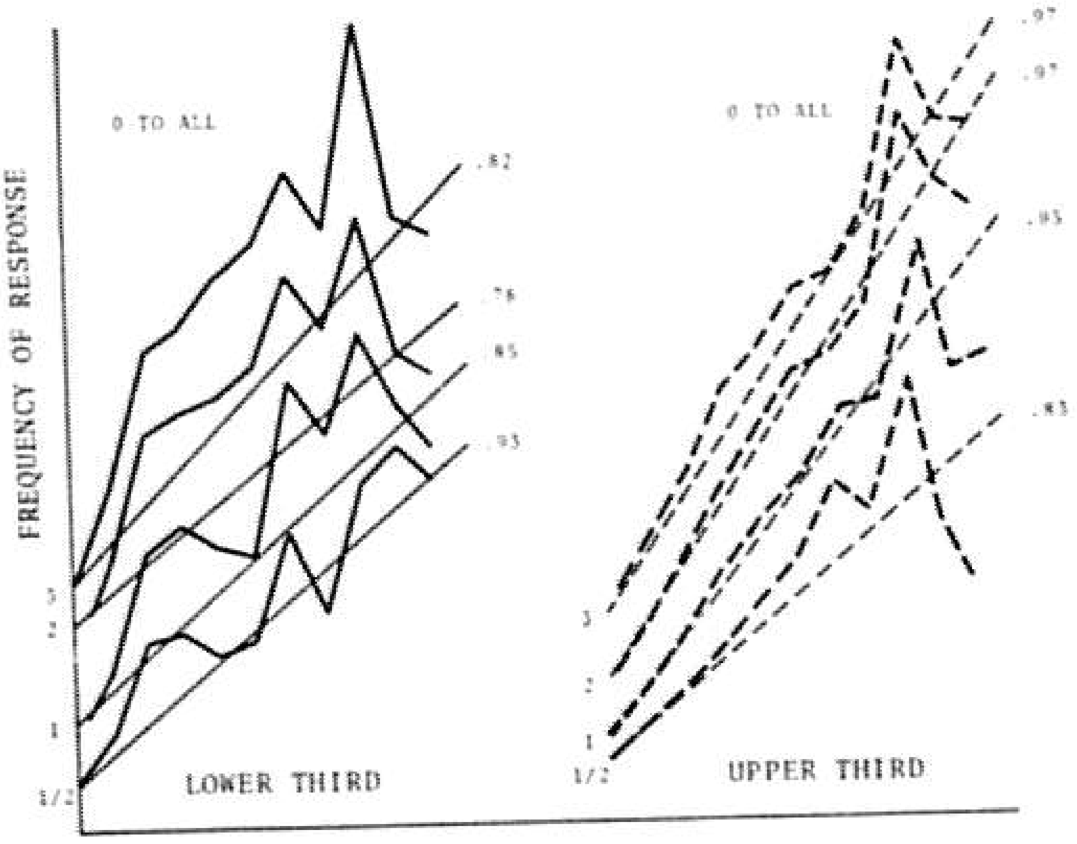


FIGURE 6. LINEAR CORRELATIONS FOR FIGURE 4.

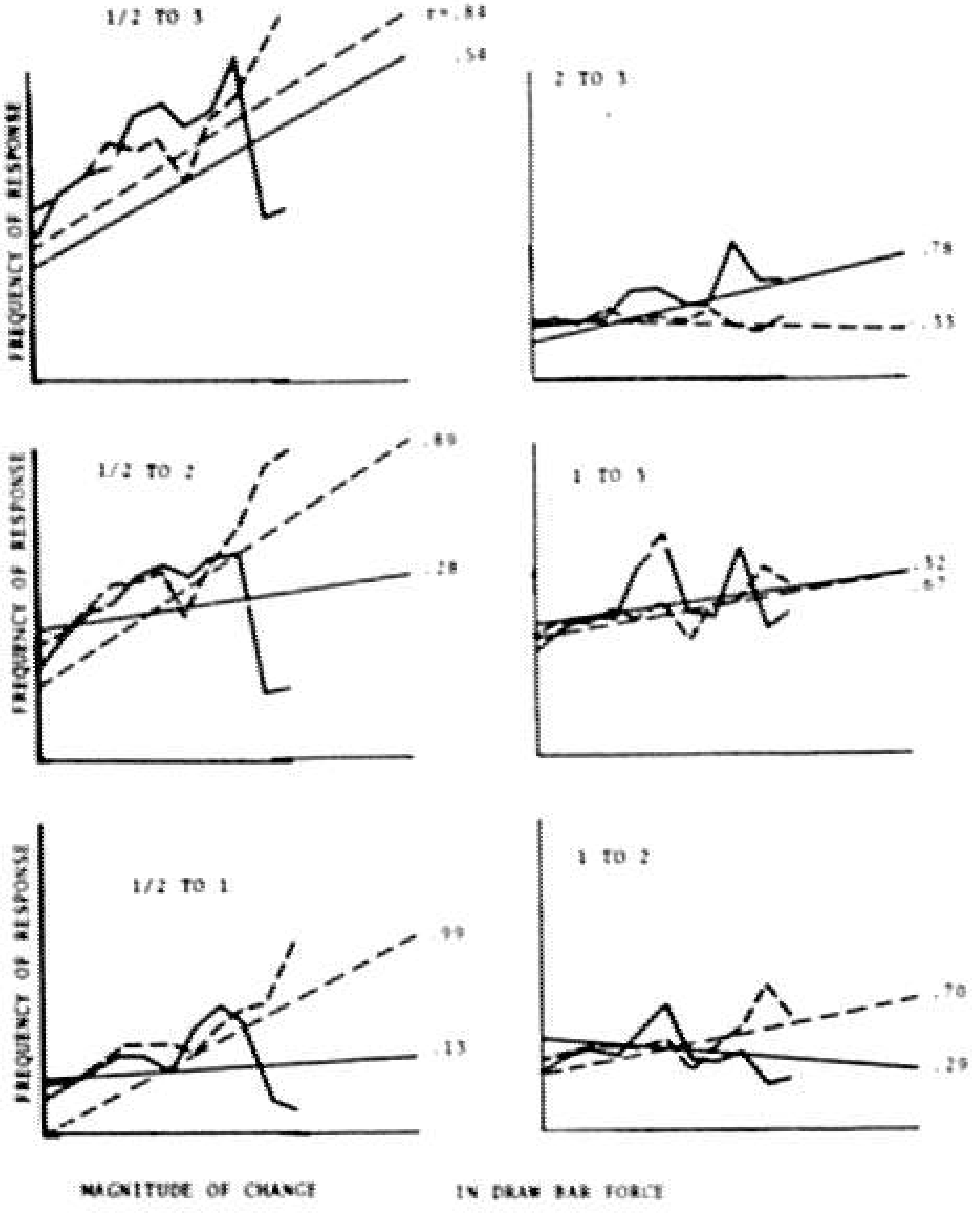


FIGURE 7. LINEAR CORRELATIONS FOR FIGURE 5.

made responses which at best slightly negatively correlated (r = -0.29). The nagative correlation indicates that if there is any relationship between force change and response frequency, it is the opposite of that hypothesized. That is, the larger a change in drawbar force, the less likely a response. Examination of the plots of the latest period analyzed, between 2 and 3 seconds after the change, suggests that any patterned responses made by the engineers in the upper 1/3 are completed and responses made during this late period are at best negatively related to force changes, but engineers in the lower 1/3 now indicate a highly positive correlation (r = 0.78). The sequence of the events could be conceptualized as follows. All engineers make almost immediate control adjustments after changes in drawbar force. Superior engineers continue their adjustments of controls up to two seconds after the change in force after which no real response pattern is noted. Adequate engineers also make immediate adjustments within the first half second after a change but then wait up to two seconds to see the results of the change and then make a second set of adjustments in the two to three second period. This difference in response timing may reflect a number of factors about superior engineers, including an elevated sensitivity to train performance changes, elevated self-assurance, the ability to continuously process changes in train performance, or any combination of these.

The relation between drawbar force change and changes in control settings by the engineer was chosen because it is one which is basic to train operations; however, the establishment of this relationship does not in itself identify the source of the engineer's information. One reasonable hypothesis is that a basic source of information on drawbar force changes is the loadmeter, and indeed examination of simultaneous recording of draft forces and loadmeter current show that in general they are directly proportional to each other.

Computation of the linear correlations for the relationship between loadmeter change and frequency of engineer response yields high correlations.* For instance, the linear correlation between current change rate and response frequency for the superior engineers for the first three seconds after the response is 0.98; the correlation for engineers scoring in the lower third is 0.87 for the same period. Correlation for the first two seconds for the engineers in the lower third is 0.86 and for the engineers in the upper third, it is 0.86. Figure 8 represents the plots for the linear regression equations for the 0 - 1/2, 1, 2, and 3 second periods for both groups of engineers. Similar results are available for the other time periods for each group of engineers. From examination of the relationship between loadmeter current and drawbar force and loadmeter current change and frequency of control change, it is possible to conclude that the engineer indeed uses the loadmeter in determining if and when a control change is to be made.

It may be also hypothesized that the engineer uses changes in cab acceleration as a source of information. Actually, two subhypotheses can be postulated: That the engineer detects or senses changes in train motion and makes immediate corrections and/or that the engineer senses changes in train motion and uses these changes to plan strategies for future actions.

The first subhypothesis may be tested by correlating magnitude of cab acceleration with changes in control settings. Figure 9 represents the relationship between x-accelerations (accelerations and decelerations along the direction of travel of the train). It is obvious from the graph that the engineers were no more likely to respond to moderate accelerations in the 0.1g to 0.2g range, than they were to respond to larger ones in the 0.4g to 0.5g range. This data provides no support to the first subhypothesis that the

---

*While these correlations have been corrected for possible inflation, their precision is questionable due to limited sample size. The sample size was limited by the resolution of the data collection system to steps of approximately 13.5 amperes. As the loadmeter reading changes very slowly, it was possible to analyze on only four points; changes of zero/amps/sec, 13.5 amps/sec, 27 amps/sec, and 40.5 amp/sec. Changes of 54.0 amps/sec or more corresponded to power transitions, artifactual events, or electrical noise.

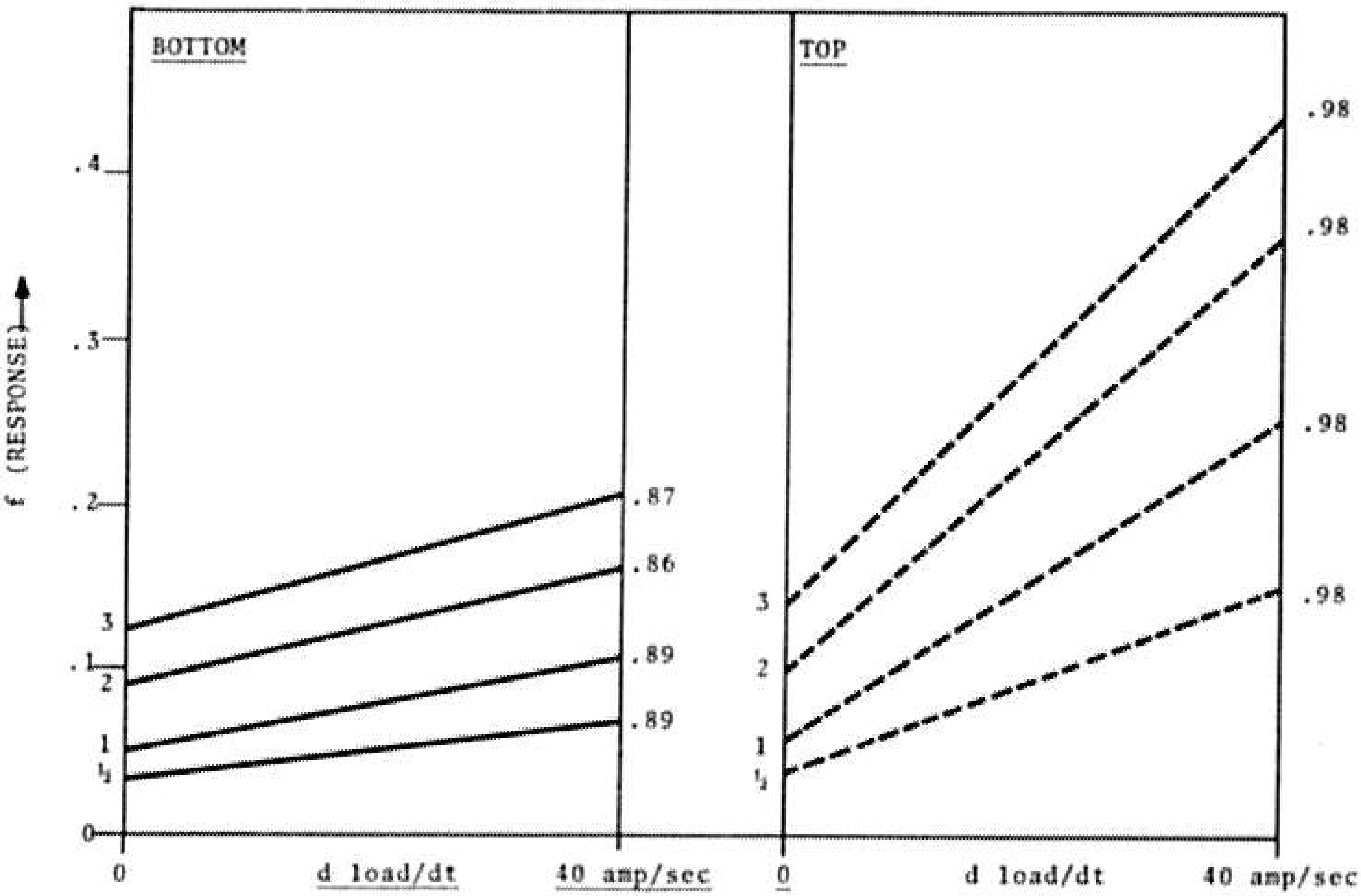


FIGURE 8. RESPONSES TO CHANGE IN LOADMETER READING

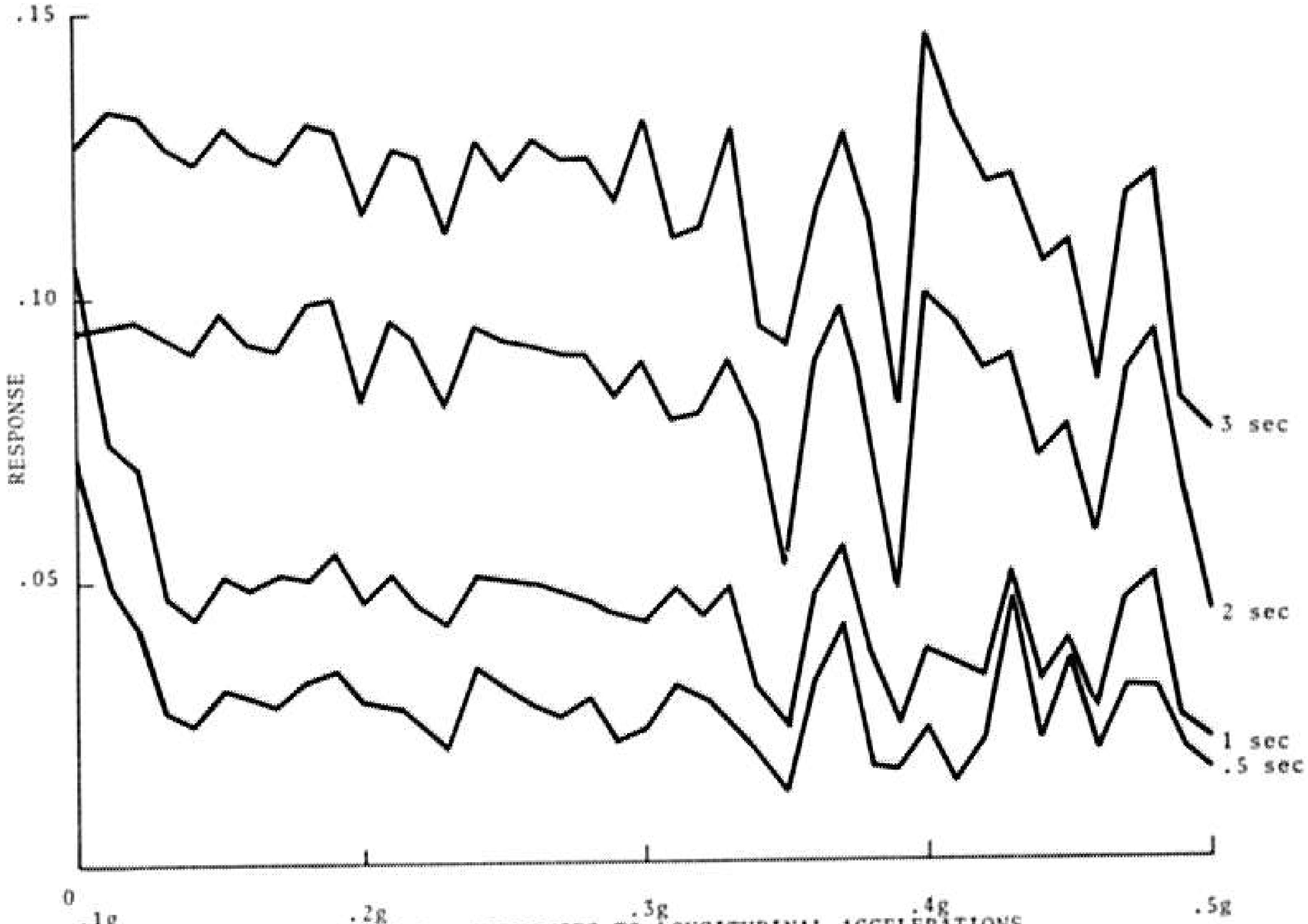


FIGURE 9. RESPONSES TO LONGITUDINAL ACCELERATIONS

engineer makes immediate control corrections based on x-acceleration. Figure 10 is a plot of the relationship between y-acceleration (lateral acceleration) and control change over the first 3 seconds after the acceleration; again there is no obvious relationship. The data collected do not support the subhypothesis that the x or y accelerations in an immediate fashion.

The second subhypothesis, as often stated by railroad personnel, that the engineer bases future strategies on perceived acceleration, and at best be only partially tested. If the engineer "learns the train: it should be expected that his operation become smoother over the length of a trip, and this would be reflected in a decrease in cab acceleration with time over the trip. This decrease in acceleration may not persist over the entire trip as fatigue may reduce the engineer's train handling precision. To test this, the data during the trip was divided into 10ths and the average x acceleration in the cab for each 10th of the trip was computed for all recorded trips on all railroads. Figure 11, which depicts the data, reveals no pattern which would indicate any learning effect. An analysis of variance revealed no systematic relationship between acceleration and trip segment.

This should not be taken to prove that the engineers do not use acceleration as an information input. Systematic variation may have been masked due to terrain, or it may be that the engineer learns the route rather than the train and associates accelerations with particular strategies at particular points in his route. As this learining takes place over extended periods, it was not possible to use the data collected here to test this hypothesis.

3.3 CONTROL USE BY ENGINEERS

In order to suggest improvements in train operating procedures and work station design, it is important to understand not only how the operator uses the information provided (as discussed above) but what use he makes of the controls. Figure 12 depicts the frequency of control use for the four major cab controls: throttle, dynamic brake, automatic air brake and independent air brake. The figure include data representing four types of terrain: rolling or

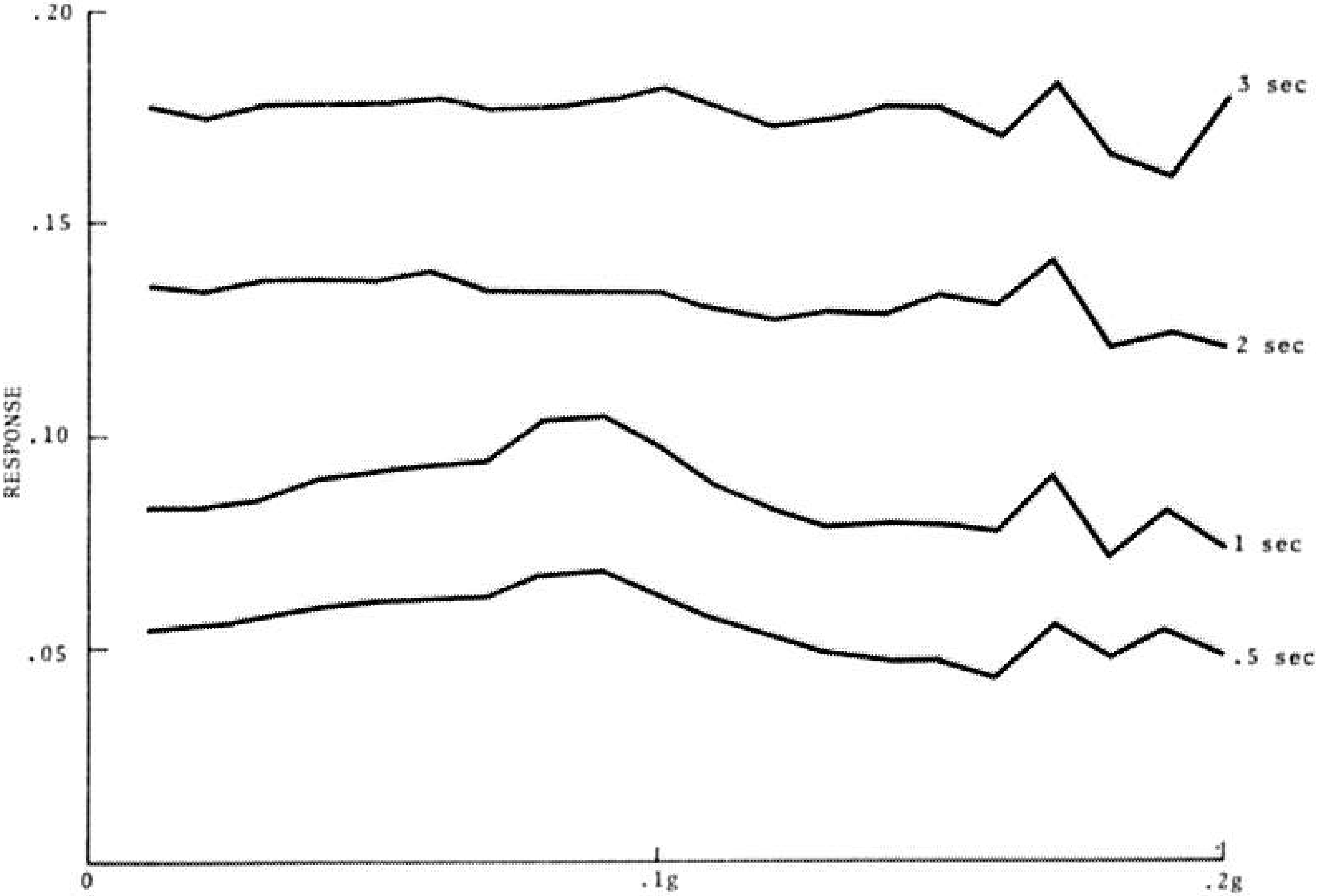
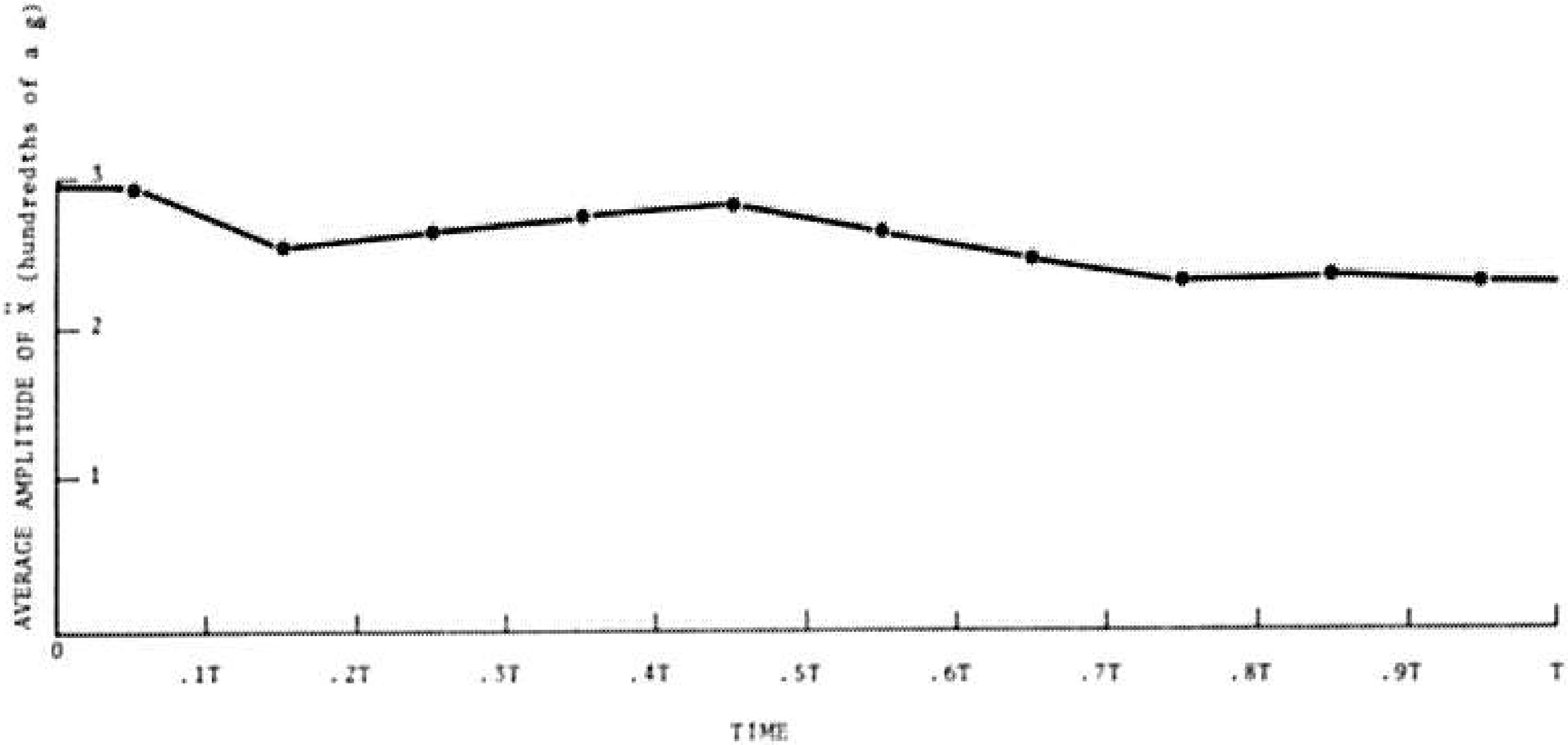


FIGURE 10. RESPONSES TO LATEPAL ACCELERATIONS



Runs 12-30; 42-50

FIGURE 11. AVERAGE LONGITUDINAL ACCELERATION OVER DURATION OF TRIP

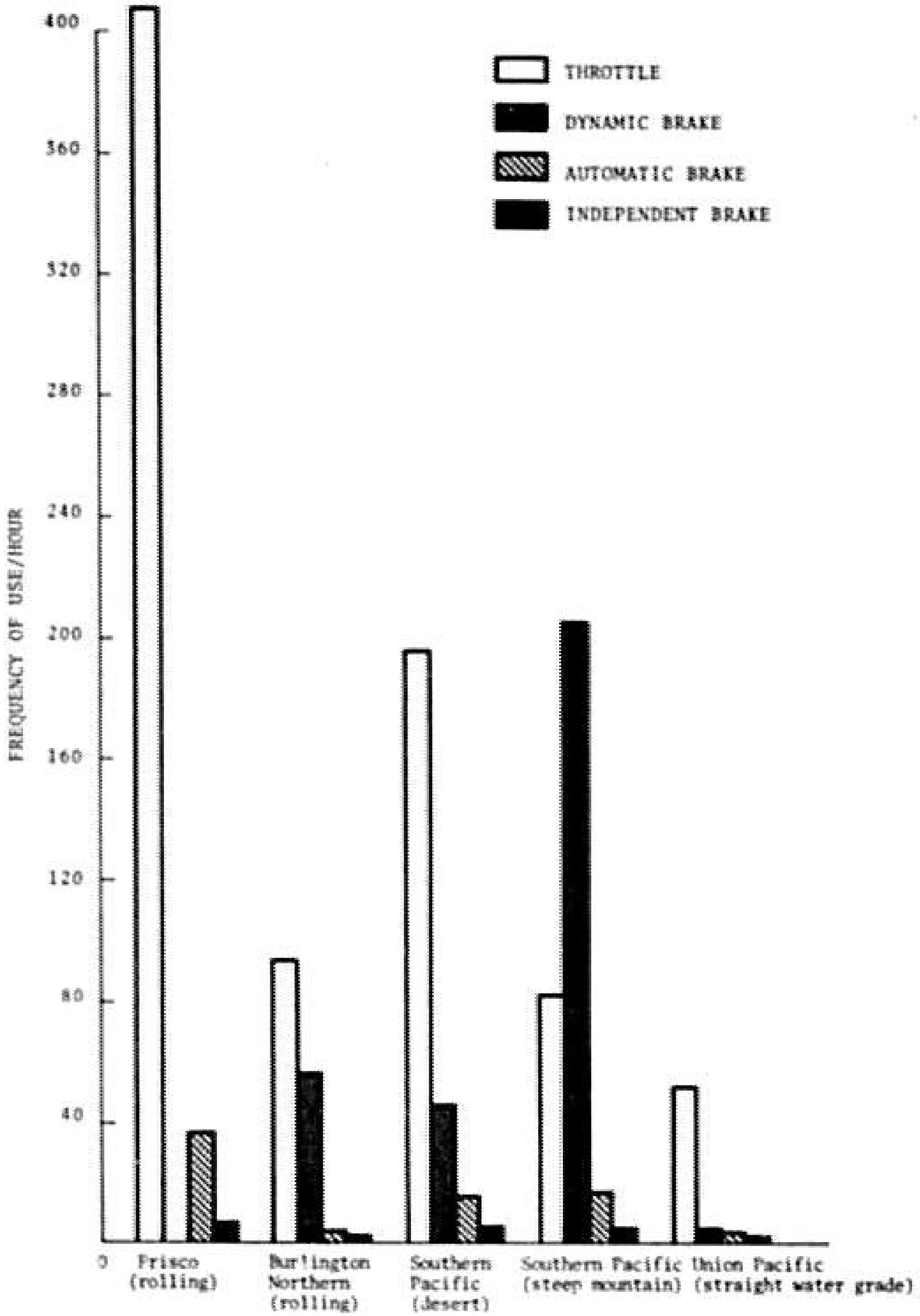


FIGURE 12. AVERAGE RATE OF CONTROL USE BY RAILROAD

undulating, flat desert with long grades, steep mountainous track with tight curves, and "water grade" with few curves. This data was collected on the five railroads listed previously. The desert recordings were made on the Southern Pacific division between Tuscon, Arizona, and El Paso, Texas; the steep mountain data were made on Southern Pacific's Tehachapi mountain division between Colton and Bakersfield, California; the "water grade" recordings were made on the Union Pacific Nebraska division between North Platte and Omaha; and recordings on rolling territory were made on two railroads: the Burlington Northern between Lincoln, Nebraska and Galesburg, Illinois, and the St. Louis-San Francisco between St. Louis and Springfield, Missouri. The control use frequencies are depicted in mean changes per hour. In all cases except the mountainous terrain, the throttle in the power position is used more than any of the other major controls. In mountainous terrain the dynamic brake was most frequently used.

As had been anticipated, different operating procedures strongly influence control use. This is refelected in the differences in control use patterns recorded in operations on rolling terrain in the St. Louis-San Francisco and on the Burlington Northern Railroads. On the former relatively little use is made of the dynamic brake but frequent air applications occur; on the latter there is a much greater relaince on the dynamic brake. The most frequent control use occurs in the rolling terrain on the St. Louis-San Francisco Railroad as expected. In fact, frequency of use of the throttle alone exceeded use of all four controls on the other terrain/railroad combinations.

4. SUMMARY

Analysis of the data recorded reveals that on non-mountainous terrain there is in general a linear correlation between the magnitude of the change in drawbar force and the frequency that the engineer responds to such a change. There is data to support the hypothesis that one difference between highly rated engineers and engineers with lower ratings is the temporal pattern of their control response; the better engineers makes one set of resposes and very quickly, while the poorer engineers provide two distinct response stages; a very early stage followed by a second corrective stage. Data presented herein supports the hypothesis that the engineer relies quite heavily on his loadmeter in train handling. However, the hypothesis that he relies directly on information derived from moderate or substantial cab acceleration was not supported, nor was the hypothesis supported that the engineer learns his train and significantly reduces cab accelerations and shocks as the train progresses.

Data were developed on the control use frequency for various operations, suggesting that operating procedures in some cases have as much influence on control use as terrain.

It should be noted that while this report contains the results of the analysis of the data recorded over the course of the study, the raw data remain available for further study and analysis. For instance, the entire data set is currently being used in an attempt to develop a symbolic representation or model of the locomotive engineer's performance. This effort seeks to provide mathematical representations of the critical train handling performances of freight engineers. The data on control frequency have also been used in a DOT contractual effort to develop an improved locomotive cab.

It is anticipated that other significant uses will be suggested for the data collected in this study and, therefore, the data will be retained and access provided to it for organizations participating in the cooperative Track Train Dynamics program, other Government agencies, and other qualified organizations.

APPENDIX A

ENGINEER OBJECTIVE RATING FORM

PERFORMANCE OF TASK 4 TEST TRAIN

DATE ________ ____ RAILROAD ____________ FROM ________ TO ________

NAME OF ENGINEER ______________________ CARS ________ TONS ______

PERFECT SCORE: 100

TIME PERFORMANCE: PERFECT SCORE 15 AVERAGE TIME FOR THIS RUN ____

1. TIME START TO STOP: TIME START ____ TIME STOP ____ ELAPSED MIN ____
2. TIME YARD LIMIT TO LIMIT START ____ TIME STOP ____ ELAPSED MIN ____
3. TIME 1 ____ TIME 2 ____ SUBTRACT POINTS FOR INTENTIONAL TERMINAL DELAY
4. TIME LOST FOR SLOW ORDERS ______ ______ TOTAL - ______
5. TIME LOST DUE TO MECHANICAL DIFF. ______ TOTAL - ______
6. TONS PER HORSEPOWER ______ TIME ADJUSTMENT TOTAL - ______
7. TIME LOST DUE TO WEATHER (RD FMN OPINION) TOTAL - ______
8. TIME LOST DUE TO TIME OF DAY TOTAL - ______
9. TIME LOST DUE TO MEETS TOTAL - ______
10. TIME LOST DUE TO TRAIN MAKEUP AND TYPE OF CARS TOTAL - ______
11. TOTAL TOTAL - ______
12. 2 - 11 TOTAL - ______

SCORE

RULE OBSERVANCE: PERFECT SCORE 55

1. POINTS SUBTRACTED FOR EACH INFRACTION ___ ___ ___ TOTAL - ______
2. OBSERVANCE OF SPEED LIMITS ___ ___ ___ ___ TOTAL - ______
3. TOTAL ______

SCORE ______

TRAIN HANDLING: PERFECT SCORE 30

1. MAXIMUM G SHOCK ON RUN ____ AVERAGE MAXIMUM FROM ALL RUNS ______
2. NUMBER OF SHOCKS OF ____ G's ___ AVERAGE ______
____ G's ___ ______
____ G's ___ ______

SCORE

ABUSE OF MECHANICAL EQUIPMENT: PERFECT SCORE 20
SUBTRACT 10 POINTS FOR EACH INFRACTION

1. EXCESSIVE DRAWBAR PULL ______ TOTAL - ______
2. EXCESSIVE BUFF THROUGH CROSSOVERS, ETC. ___ ___ TOTAL - ______
3. USE OF AIR INSTEAD OF DYNAMICS ___ ___ ___ TOTAL - ______
4. USE OF ENGINE BRAKES OVER 5 MPH ______ TOTAL - ______
5. EXCESSIVE USE OF INDEPENDENT WHILE STOPPING ___ TOTAL - ______
6. NOT WAITING 10 SECONDS INTO DYNAMIC ___ ___ TOTAL - ______
7. EXCESSIVE USE OF MANUAL SANDING ___ ___ ___ TOTAL - ______
8. TOTAL

SCORE

TOTAL SCORE

TABLE A-1. LOCOMOTIVE ENGINEER RULE OBSERVANCE

LOCOMOTIVE ENGINEER RULE OBSERVANCE

Name of Locomotive Engineer

Date Train # Engine Consist

Train Consist Loads - Empties - Tons From To

Legend: x-no o=yes *=if required

On judgment items put o in either above std., std., or below std.
Add comments where necessary

Terminal Preparation

1. Bulletin Book Observance
2. Timetable and Standard Watch
3. *Walk-around inspection
4. *Cab control check
5. *Locomotive supply check
6. Safety check - prior to coupling
7. Safe coupling speed
8. Brake test performance
9. Communication for departure clearance

Comments

1. ________
2. ________
3. ________
4. ________
5. ________
6. ________
7. ________
8. ________
9. ________

	Above Std.	Std.	Below Std.
10. Performance in operating light engine	____	____	____
11. Knowledge of brake test - conventional	____	____	____
12. Summary - terminal preparation	____	____	____

Comments & Supporting Information

TABLE A-1. CONTINUED

En Route	Comments
1. Familiarity with train orders	1. ______
2. Observation of train (Rule 1014)	2. ______
3. Signal communication by name	3. ______
4. Signal indication and observance	4. ______
5. Use of whistle (14L-1016)	5. ______
6. Whistle signal for approaching tunnels and warning trackmen	6. ______
7. Handling of headlight (Rule 17A-17C)	7. ______
8. Use of radio (Rule 37,37A-37D)	8. ______
9. Approaching meeting or waiting point	9. ______
10. Observance of speed	10. ______
11. Reporting defects - track, bridge signals	11. ______
12. Avoids applying brakes while passing over bridges and trestles	12. ______
13. Handling of air brakes with dynamic brakes inoperative when train consist exceeds 135 cars	13. ______
14. Knowledge and handling of brake valve during train separation	14. ______
15. Knowledge and application of yard speed	15. ______
16. Knowledge and application of slow speed	16. ______

	Above Std.	Std.	Below Std.
17. Knowledge and handling changing operating ends, coupling hose	____	____	____
18. Knowledge and handling of picking up, setting out locomoties.	____	____	____
19. Knowledge and handling air brakes when picking up, setting out	____	____	____
20. Summary - En Route	____	____	____

Comments & Supporting Information

TABLE A-1. CONCLUDED

Starting	Comments
1. Bell sounded	1. ________
2. Whistle sounded	2. ________
3. Headlight burning	3. ________
4. Concentration on starting	4. ________

Comments & Supporting Information

Stopping	Comments
1. Knowledge and compliance with rule 1311 when setting out cars, picking up cars	1. ________
2. Acknowledges by radio and stops train when notified of hot journal or other train defect	2. ________
3. Avoids leaving engine cab (Rule 1028)	3. ________
4. Secures locomotive at tie up point	4. ________

	Above Std.	Std.	Below Std.
5. Summary - Stopping	____	____	____

Comments & Supporting Information

APPENDIX B

DESIGN OF DATA COLLECTION SYSTEM

B.1 INTRODUCTION

The data for this project were collected and recorded by a PDP-11/20 minicomputer. The computer served as an "intelligent tape recorder" and had several advantages over ordinary analog tape recording:

a) Multiplexing - Many digital and analog input lines could be scanned at varying gains and data rates.

b) Time compression - Data recording was done on 9-track digital magnetic tape. Such tapes could later be read at a much higher speed than that at which they were recorded, with no loss of data.

c) Selective recording - The computer program could scan the input data and determine whether an "event of interest" had taken place. In the absence of such an event, recording did not take place; this saved tape and made later data reading mor efficient.

d) Memory as buffer - The computer memory could contain several seconds of data at any time. When an "event of interest" occurred, the computer could record not only the event and what follows it but also what preceded it.

The limitations of the computer were primarily space and power requirements. The former was not critical because a test car is used, but the latter would have been had the GM-EMD test car not been available. A minicomputer installated with a Teletype and other peripheral units can require two to three kilowatts of dependable 115 VAC power. This may require an auxiliary generator set. Further, the power consumed is converted to heat energy which necessitates a cooling system requiring additional power.

B.2 DATA COLLECTION SYSTEM

B.2.1 Computer

The Digital Equipment Corporation (DEC) PDP-11/20 minicomputer has been used by TSC for a variety of mobile applications. For this project the system consisted of the following components:

a) PDP-11/20 central processor with 12,288 words of 16-bit core memory,

b) Programmable real-time clock,

c) ASR33 Teletype,

d) High-speed paper tape reader/punch,

e) Alphanumeric display,

f) Analog-to-digital converter,

g) Digital interface,

h) DECtape controller and tape drivers,

i) Peripheral Instruments Corp. 9-track digital magnetic tape drive with controller.

The real-time clock provides accurate time interval information so that the program can provide the proper data rate for each input channel. Once it is set by the program, the clock keeps time with a crystal-controlled oscillator and generates "interrupts" at regular intervals. The use of these interrupts is explained in the programming section below.

The Teletype, alphanumeric display, and highspeed paper tape reader/punch are the user's means for programming and controlling the computer. The Teletype's principal use is to save, in printed form, progam listings and data which is not written on magnetic tape. The alphanumeric display is faster and quieter than the Teletype and is used for creating the editing programs. It also serves as the principal means for issuing commands to the operating system. The high-speed paper tape reader/punch has been the most convenient means for saving and reading programs, both in symbolic and binary (machine code) forms; TSC now has a more powerful operating system which uses DECtape as the program storage medium.

The analog-to-digital (A/D) converter and the digital interface are the means by which the computer accepts input data. The A/D converter can select any one of up to 32 analog inputs with a range of -10 volts to +10 volts and convert that voltage to a digital word with 10 bits to represent amplitude plus one bit for the sign. This provides 1024 levels for amplitude, so that the difference between digital levels is approximately 10 millivolts. In addition, the A/D converter has an amplifier that allows the program to select gains of 1, 2, 4, or 8 depending on the expected signal range for each channel.

The digital interface assumes that its inputs will be one of only two possible values, 0 and +3 volts. Many locomotive trainline signals take values of 0 or +74 volts and must be scaled down to be connected to the digital interface. One interface, with 16 input lines corresponding to one 16-bit PDP-11 word, is sufficient for this project.

DECtape is a special digital magnetic tape used on DEC computers. Its tape comes on small (four-inch diameter) reels which are easy to handle but whose limited capacity (less than 150,000 words) makes the tapes most suitable for storage of programs or small amounts of data; the contents of 50 or more DECtapes will fit onto one 9-track tape.

The 9-track digital magnetic tape (also called industry-compatible or IBM-compatible tape) is at present the best available storage medium for a large volume of data which occur sequentially in time. The principal drawback of any magnetic tape system is that it is not a random-access storage medium; that is, a particular piece of data may not be readily available at a given instant but may be at the other end of a reel of tape. In a disk memory, any data word can be retrieved in less than a second; on tape, a data word may require several minutes of tape action to be found. For our purposes this is not a serious drawback, as we intend to read the tapes in order and are willing to accept the order of data as it was recorded. A single 2400 foot reel of tape can hold approximately 10,000,000 data words; we shall see below that this is equivalent to several hours of continuous recording for this project. The tape drive does not require a highly protected operating environment; this makes it more suitable for mobile data recording. Finally, 9-track magnetic tape (800 bits per inch data density) is used on most current computer systems with tape facilities, making it possible to share data with others or to do data analysis on a different or more powerful machine than that which did the recording.

B.2.2 The Program

The following is a description of the specific program developed for this project.

The PDP-11/20 computer contained 12,288 16-bit words of core memory for stage of programs and data. Each word is further divided into two 8-bit bytes, each of which has a unique address. There were, therefore,24,576 addressible locations in memory, or in octal notation, 60000_8.* The allocation of core memory for the data collection program is shown schematically in Figure B-1.

The operating system was a program which was always in memory beginning at location 50000_8. It enabled the user to control progrms more easily through the Teletype or alphanumric display as a control unit. Among other tasks, the operating program could:

a) save, on paper tape or DECtape, binary (machine-code) versions of programs,

b) load such programs into memory from their storage media,

c) clear all memory not used by the operating system,

d) dump (display on the Teletype or alphanumeric display) the contents of selected memory locations,

e) start execution of a program which has been loaded into memory.

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*A subscript 8 will denote octal, or base-8, numbers in this discussion. Decimal, or base-10, numbers will be unsubscripted.

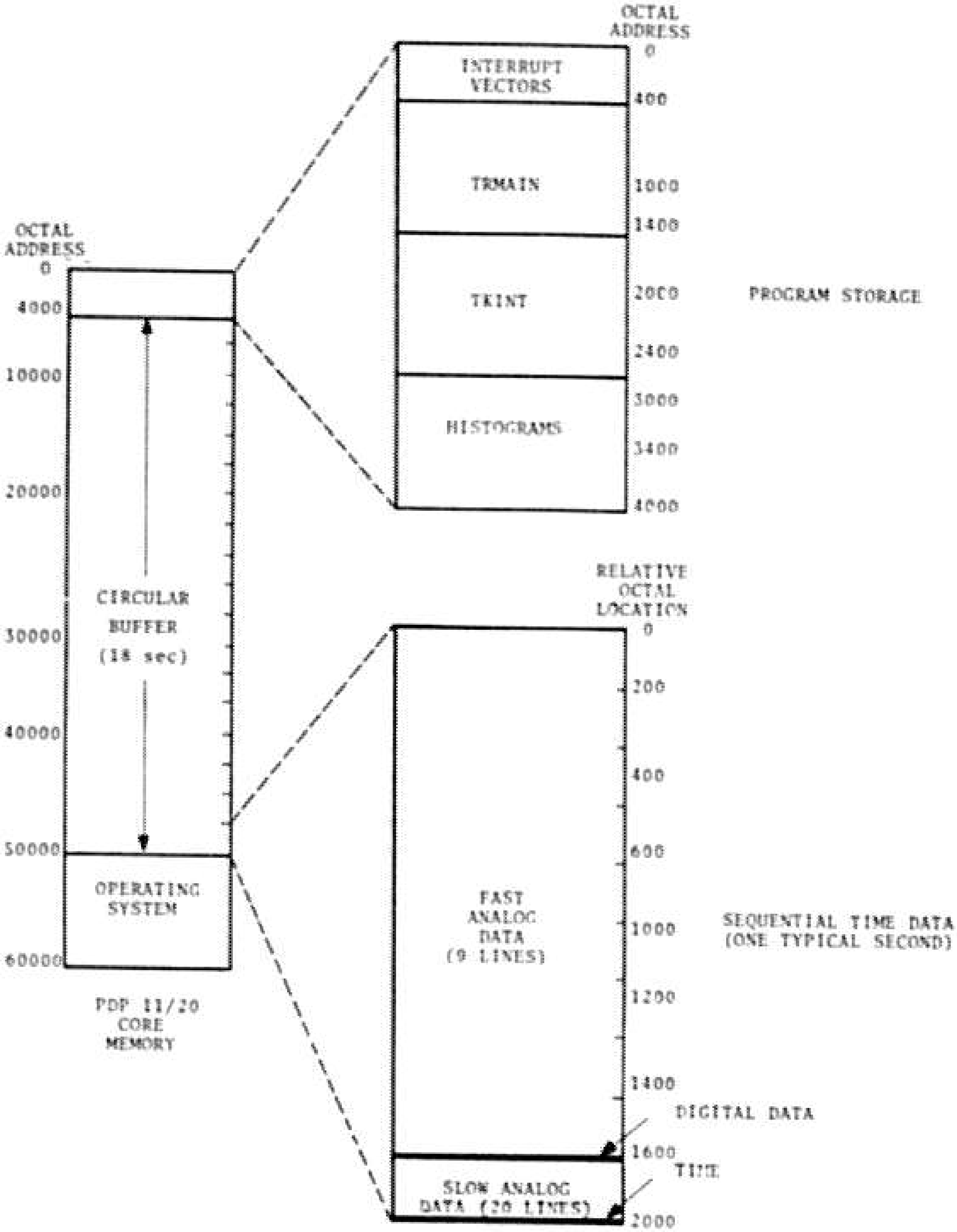

FIGURE B-1. MEMORY ALLOCATION FOR DATA COLLECTION

The memory available to the user under the operating system was that below address 50000_8. As Figure B-1 shows, the amount of memory occupied by the actual data collection program was quite small, less than 10 percent of the total memory. Most of the memory was used as a large data buffer which contained all of the data which the program had gathered in the most recent 18 seconds when the program was running. Figure B-1 shows that each second's data occupied 2000_8 locations, or 1024 bytes or 512 words. The figure further shows an expanded view of one second and the four types of data stored within it:

1) Fast analog data - 100 samples/sec, each stored in one byte, up to 9 such data lines, total storage 900 (1604_8) bytes.
2) Digital data - 16 digital lines (one world) sampled 10 times per sec, or 20 (24_8) bytes.
3) Slow analog data - 5 samples/sec, one byte/sample, up to 20 such lines, total storage 100 (144_8) bytes.
4) Time - the program keeps count of the number of seconds elapsed since the program was started. The current count is stored in the last 2 words (4 bytes) of the data area for each second.

The program viewed this storage area as a circular buffer. It stored consecutive seconds of data beginning from locations 4000_8 up to (not including 50000_8, and then began over at location 4000_8. (See Table B-1).* Thus the program always had the most recent 18 seconds of data available in memory. An analogy to the operation of this curcular buffer may be made by comparing to the type of slide projector that has a rotary tray. One can imagine placing slides into a consecutive slots in the tray as it turns. When it is full, the next slot to pass will contain the first slide - the "oldest" data. This slide is discarded and the newest one inserted in its place; thus the tray always contains a "history" of the most recent slides.

TABLE B-1 SEQUENCE OF DATA IN CIRCULAR BUFFER

TIME		BEGINNING DATA ADDRESS (OCTAL)
1		4000
2		6000
3		10000
.		.
.		.
.		.
17		44000
18		46000
19		4000
20		6000
.		.
.		.
.		.
35		44000
36		46000
37		4000
38	6000	6000
.		.
.		.
.		.

---

* Note that in octal notation: $4000_8 + 2000_8 = 6000_8$, $6000_8 + 2000_8 = 10000_8$, $46000_8 + 2000_8 = 50000_8$, etc.

The concept of a circular buffer arises from our desire to avoid writing data onto tape when no events of interest have occurred. The main program TRMAIN had three principal functions:

a) Initialization - clearing all data areas and starting the clock.
b) Testing for events of interest.
c) Writing tape if desired.

The program identified an event of interest as any one of the following:

1) The operator pushing the "*" button on the numerical keyboard.
2) Dynamic braking in use.
3) Air brake application; specifically, a brake pipe pressure reduction or an increase in independent brake cylinder pressure.
4) Drawbar force (draft or buff) over 200,000 lb.
5) A change in state of any train lines (control lines for the multiple units) connected to the digital interface, including throttle position, wheel slip, manual sand, etc.

The program spent most of its time testing for these events or conditions in the most recent part of the circular buffer. Detection of an event caused the program to begin transferring data to magnetic tape, beginning with the oldest data presently in the circular buffer. Therefore, when an event occurred, the first recorded data began approximately 15 seconds before the event. Tape writing continued for at least one full minute, so that a "window" of data was recorded, as shown in Figure B-2. If the tape-writing section of the program was already operating and another event of interest occurred, the period of tape-writting was extended for a full minute beyond the most recent event. This technique saved all events of interest on tape along with at least 15 seconds of action preceding the event and 45 seconds following. This insured that, when the tapes were later read and processed, the precursor and successor data to each event would be available for analysis.

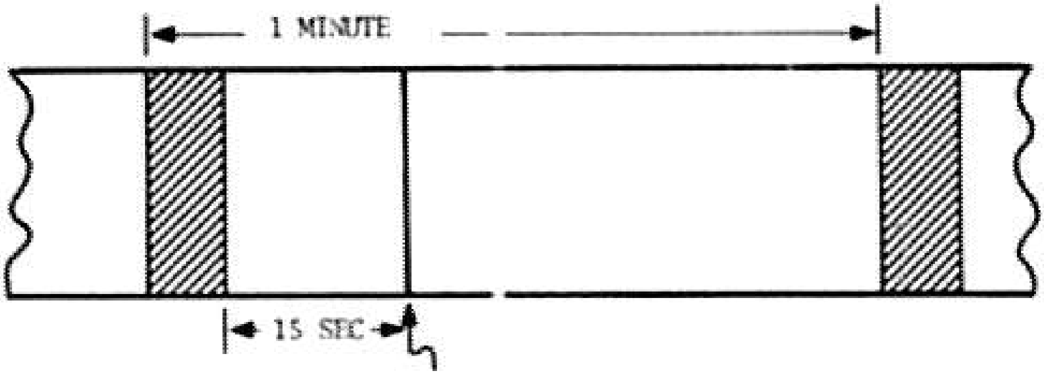

FIGURE B-2. DATA WINDOW RECORDED ON TAPE

The program wrote 3-second intervals of data onto tape as single tape records of 1536 words. To write such a record took less than a half-second, including time to start and stop the tape drive. Even during tape-writing, the drive was mainly occupied in a waiting mode which required 3 seconds to pass before another write operation can occur. The majority of the program time was occupied with sampling for more "events of interest". Experience on this effort indicates that when the tapes are read back, without the need to wait between records, there is a gain in data rate of about ten to one; this time compression is a major advantage of digital tape recording.

The other program shown in Figure B-1 is TKINT, the clock service routine, which collected the data and stored it in the circular buffer. It operated as follows: Once TRMAIN performed initialization, the rest of the run was occupied by testing for events and writing data on tape. One hundred times per second, the real-time clock generated an interrupt, a signal to the computer's central processor. This interrupt suspended execution's of TRMAIN. The computer then examined location 104_8 and began executing instructions at the address contained there.* In this case location 104_8 pointed to the beginning of TKNIT. TKINT's operation ended with a special instruction which restores control to TRMAIN, which then proceeded from the point at which it was suspended.

TKINT contained several counters in order to determine the various data reates desired. The relatively high frequency analog data lines which take 100 samples/second were scanned every time TKINT was executed. The low frequency lines which took 5 samples/second were scanned every 20th time, and the digital lines (10 words/sec) every 10th time. Every hundredth time through TKINT (once per second) the clock was incremented and stored. Note the analog data were stored one sample per byte. Since the A/D converter

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* Thus location 104_8 is a pointer--the "interrupt vector" for the real-time clock. Similar interrupt vectors for other peripheral devices are located in the low-address area of core memory, as shown in Figure B-1.

provided 10 bits plus sign for a given voltage and a byte can hold only 7 bits plus sign, TKNIT dropped the 3 least significant bits (equivalent to approximately one decimal place) before moving an analog sample to the circular buffer. This increased and "coarseness" of the A/D converter to about 80 milli-volts per level. The use had to select the analog channel gains with care to avoid having too few significant levels corresponding to the expected range of each signal.

During test runs, it was desirable to have some of this information available immediately upon completion of the run without waiting for the tape to be processed. TKINT also performed this task. Once per second it found the maximum values of longitudinal acceleration, draft force, and buff force during the previous second and saved these values in the histogram area shown in Figure B-1. At the end of the run the user could run the "dump" section of the operating system to print out the histogram in order to display the frequency of occurrence of force amplitudes. This information was incorporated into the objective engineer evaluation for each run.

B.3 TYPES OF DATA AND INSTRUMENTATION

Two principal types of data were observed in this train-handling project;

a) Analog data - parameters which can be represented by signals which can assume all possible values within a specific range for each data line;

b) Digital data - parameters which can assume a limited number (in some cases as little as two) of discrete values.

These types are discussed separately, as they present different problems in observation and signal conditioning which is required for the computer or other data collection device to accept the data in proper form. In addition, there is a class of data which falls outside the analog or digital description and which is not recorded by the computer; this is discussed separately.

B.3.1 Analog Data

These data include the basic signals available in the locomotive, for example, speed, loadmeter, and air brake pressures. In general, they require transducers, which convert physical properties to electrical signals, and signal conditioners, which transmit the signals to the computer, remove noise, and scale the signals so that the computer can accept them. The following detailed list includes all analog data which TSC has recorded on at least one data run.

a) Acceleration.

The accelerations of the locomotive cab are proportional to the forces on the locomotive. A block bolted to the floor of the car near the engineer's control stand serves as the mount for three orthogonal linear accelerometers. The axes of these accelerometers are aligned as follows: x, or longitudinal, along the direction of travel of the locomotive; y, or lateral, to measure side-to-side motions; and z, or vertical, to measure up-and-down motions. The amplitude of each normally stays below 0.2g with a few spikes of up to 1g. The output of an accelerometer is a voltage proportional to the acceleration. The ratio is usually adjustable; TSC has used calibrations of between 4V and 8V per g, corresponding to between 1.25g and 2.5g maximum at the analog-to-digital converter, which accepts a 10V maximum signal.

b) Air brake pressures.

The pressures in the brake pipe, brake cylinder, and brake equalizing lines indicate the engineer's use of the various air brake controls. Such pressures normally range between 0 and 100 psi. The pressure transducers used by TSC have a nominal response of 1V/100 psi, so their expected output is between 0V and 1V.

c) Loadmeter.

This meter displays the current flowing through the No. 2 traction motor of the lead locomotive in the power consist, showing either the current drawn by the motor under load or the current produced for dissipation under dynamic braking. From this the engineer can estimate the force which the power consist is placing upon the train, although he must use his judgement and experience to correct for grades, number and type of locomotives, defective units within the consist, and helper locomotives in the train. The typical loadmeter is an off-center meter calibrated 800-0-1500 amps for dynamic brake and power. (See Figure B-3). The actual quantity measured is the voltage across a large copper shunt in series with the traction motor. Since the motor, shunt, and meter can be several hundred volts above ground, the interface must be isolated from common system ground. The isolation circuit is divided into two parts which are separated by an optical isolator. The first part is powered by an isolated floating supply good for 2KV breakdown. This part contains a high-gain differential-input operational amplifier to amplify the meter voltage and bias the reading from zero to allow for the two-way character of the meter. The operational amplifier drives the input section of the optical isolator which contains a light-emitting diode, the light from which causes current to flow in a photo-transistor which is the output section of the isolator. The photo-transistor drives the second stage of the circuit, another operational amplifier powered by a second power supply referenced to common ground. The entire circuit, with power supplies, attaches directly to the loadmeter in the control stand. Nominal output of this circuit is -1V for 700 amps dynamic brake, -4V for zero current and -10V for 1500 amps power. This isolation method is satisfactory for experimental and data collection purposes but is not presently practical in regular railroad service because the optical isolator incorporates a new type of circuit element whose performance can degrade rapidly in a predictable manner; typically it must be replaced every few days or weeks.

d) Drawbar force and motion.

The most direct interaction between the power consist and the train is related to the forces on and motions of the coupler drawbars between the two parts of the train. The greatest drawbar forces usually occur at those couplers, and large motions of

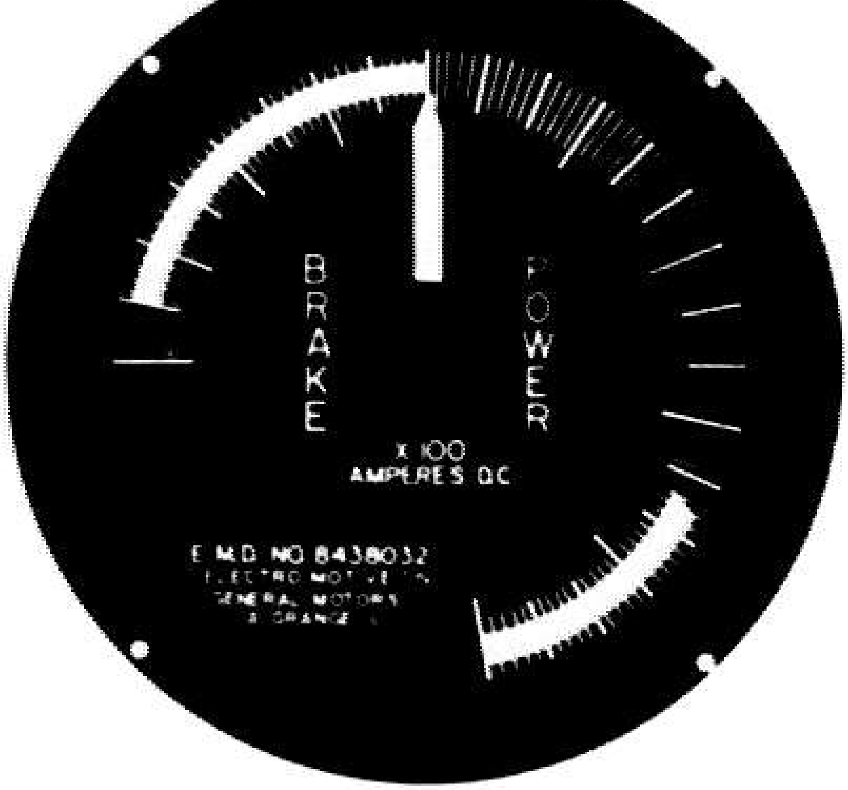

FIGURE B-3. LOADMETER

the drawbar may indicate undesirable interactions between the power and the train. Measurement of drawbar force requires an instrumented drawbar, using either hydraulic mechanical means as an older dynamometer cars or electrical strain gages as on modern test cars. The latter was available to TSC on the General Motors Electro-Motive Division test car, ET-800, complete with signal conditioning to give an output of 100,000 lb/V, thus a maximum range of ± 1,000,000 lb. This is more than sufficient for the expected force maxima of f ± 280,000 lb., the specified limit of the standard draft gear. Measurement of coupler motion requires less sophisticated instrumentation, both for slack action (longitudinal motion of the draft gear with respect to the car) and coupler angle (lateral motion of the draft gear). This is done by using "string pullers", spring loaded multiturn potentiometers built so that the rotation of the potentiometer and therefore its ouptut, is proportional to the extension of the string from the potentiometer. The outputs can be easily calibrated to 1 in/V for slack and 1°/V for coupler angle; the expected maxima are 5 in and 5°, respectively.

e) Physiological responses.

When the cooperation of the engineer was obtained either on government-owned railroads or when a road foreman operated the locomotive, the following parameters could be measured: EEG (Brain wave), shoulder and biceps EMG (muscle activity), and heart rate. Physiological amplifiers with 2.5V nominal full-scale output are located in the lead unit to send the signals.

f) Dynamic brake.

When the dynamic brake is used, the power handle on the control stand connects to a rheostat which controls the amount of braking. Train line No. 24 carries a signal proportional to the control handle setting, with zero volts representing no braking and 74V full braking. This signal is available on the patch panel which parallels the train line in the test cars which have been used. A simplified version of the loadmeter isolator, described in c) above, reduces the signal to a range of 0V to 1.5V and isolates it from common system ground.

g) Speed.

The speedometers available in locomotives and test cars provide voltage output proportional to speed. The standard Vapor Industries recorder has an output of 16 mph/V, while the speedometer in the General Motors car was adjusted to 100 mph/V. Either can be used directly; the expected speed range was 0-70 mph.

h) Main generator.

The instantaneous power drawn from the main generator is the product of the current and voltage. The current can be estimated by multiplying the load (see c) above) by the number of traction motors, correcting for defective motors and mixed power consists. The voltage, which has an expected range of 0-1000 V, is available in the high-voltage cabinet of the locomotive. This can be brought to the data collection point on a high-voltage cable and passed through a signal conditioning amplifier to be reduced to a proper range of 0-1V.

i) Total load.

As part of Track Train Dynamics Task 4, General Motors has developed a device which sums the currents in all traction motors and displays the result on a meter calibrated in pounds of drawbar pull. For correlation to other parameters, the voltage from the meter display was sent to the test car and scaled to a usable range of 50,000 lb/V.

Many of the analog signals - acceleration, physiological, brake pressures, load - require filtering to remove high frequency noise which is produced principally by the high voltages and mechanical vibrations of the locomotive. In TSC's data collection system, the filters are mounted on the same rack panel as the input connections to the analog-to-digital converter so that when an analog line is connected a filter may be selected or bypassed. Ten filters are available on the panel, each with four-pole Butterworth response set for a 30 Hz breakpoint.

Several of the insturments which are installed in the locomotive cab require 110 VAC power, which is not available from the locomotive power systems. These instruments include the x, y and z accelerometers, loadmeter isolator, physiological amplifiers, and air brake pressure transducers. The most satisfactory means for supplying this power is via an extension from the test car power supply. Care must be taken to either use heavy enough power cord so that voltage losses are not so large that the performance of the instrumentation is affected, or to use a "Variac" to correct the voltage drop.

B.3.2 Digital Data

Digital data, in general, contain information on the state of the electrical locomotive controls and indicators. Since digital data exist as electrical signals on the train lines, they do not require transducers. The nominal voltages on the train lines are zero and 74V, so a simplified optical-isolator circuit is used to reduce the voltage and keep the computer and train electrical systems independent. Since the optical isolator must assume one of only two states, the circuit can be designed to overcome the time-related degradation of the isolator. The train lines observed by the computer are listed in Table B-2. These lines are stored in the computer as bits (binary digits) in a computer word as shown.

Also connected to this digital interface is a 16-button touch-tone type keyboard. Personnel on the test car can use it to enter time of day, milepost, or special event codes into the computer, or to cause the computer to record the present dat regardless of other preprogrammed decision criteria.* The 16 buttons can be coded into 4 binary bits and stored in the same computer word as the train line information.

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* See Section B.2.2 of this Appendix.

TABLE B-2 DIGITAL TRAIN LINES

TRAIN LINE NAME	TRAIN LINE NUMBER	PURPOSE	PDP-11 BIT
A	15		0
B	12		1
C	7	THROTTLE POSITION	2
D	3		3
REV	8	REVERSER POSITION	4
GF	6	GENERATOR FIELD ON	5
BRAKE	17	DYNAMIC BRAKE ON	6
WS	10	WHEEL SLIP INDICATOR	7
SA	23	MANUAL SAND ON	8
BG	21		9
ALARM	2	ALARM	10

B.3.3 Other Data

Stop-action motion pictures have been taken on several runs to aid TSC personnel in understanding the engineer's task. At a frame rate of between 1 to 1/2 frame per sec, a single roll of super-8 film can record one to two hours. Problems encountered in this filming include poor lighting within the cab, positioning the camera to observe all actions of the engineer, and damage to the camera due to vibration.

A detailed log of actions taken by test personnel has proved valuable in selecting sections of taped data for analysis and in noting special events for detailed consideration. Track profiles and train schedules provided by the participating railroads aid in the location of events and may be used to correlate engineer actions to grades, curve, etc.

On the data runs of January-February, 1974, in the General Motors test car, each engineer's performance was evaluated by his road foreman on a rating form (Appendix A) devised for these runs. This form had two purposes:

a) Identification of "excellent", "good", or "adequate" engineer performance for correlation to quantitatively measured performance, and

b) Evaluation of the form itself as a first attempt to produce a standardized engineer performance rating form.

B.4 TEST CAR AND INSTALLATION OF INSTRUMENTATION

Figure B-4 shows the head end of a typical train on the test runs of January-February 1974. The test car was coupled into the train immediately behind the last locomotive in the power consist. This allowed the instrumented drawbar, which was at the head end of the test car, to be at the point where maximum power is applied to the train consit. The cables which connected the test car to the instrumentation in the cab of the lead locomotive can not be seen in this picture; they ran along the outer edge of the locomotive catwalks, past the bases of the handrail supports.

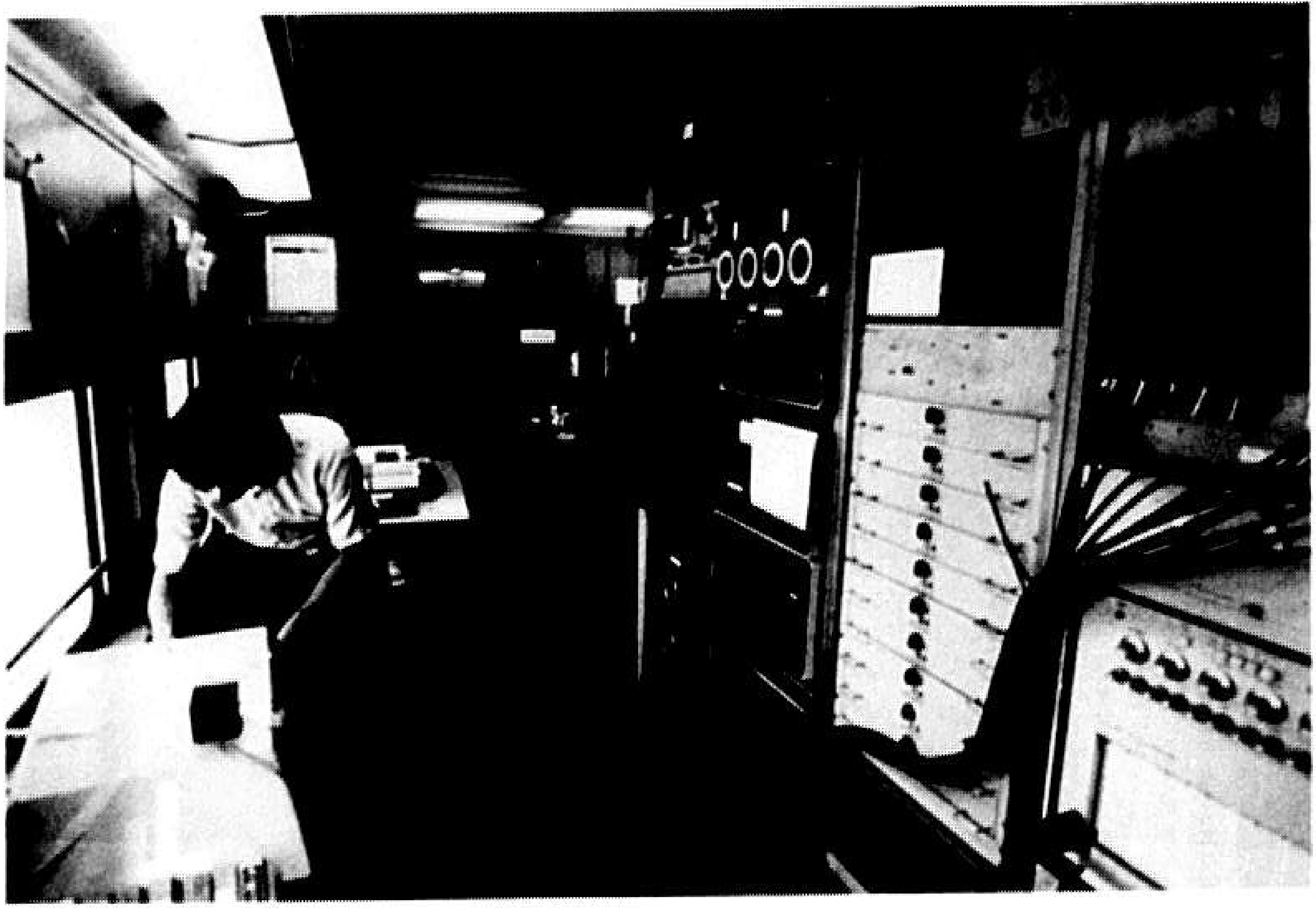

FIGURE B-4. DIGITAL DATA RECORDING SYSTEM INSTALLATION

Figure B-5 shows part of the interior of the General Motors Electro-Motive Division test car, ET-800. The picture was taken from the front of the test car's instrumentation area, looking toward the rear. As shown, the TSC instrumentation and computer occupied parts of the rearmost four (out of nine) electronics racks available in the test car. The test car also provided ample work space as shown, along with dining and sleeping accommodations. A 60-kilowatt onboard generator provided heat and electricity, with ample reserve to operate all instruments.

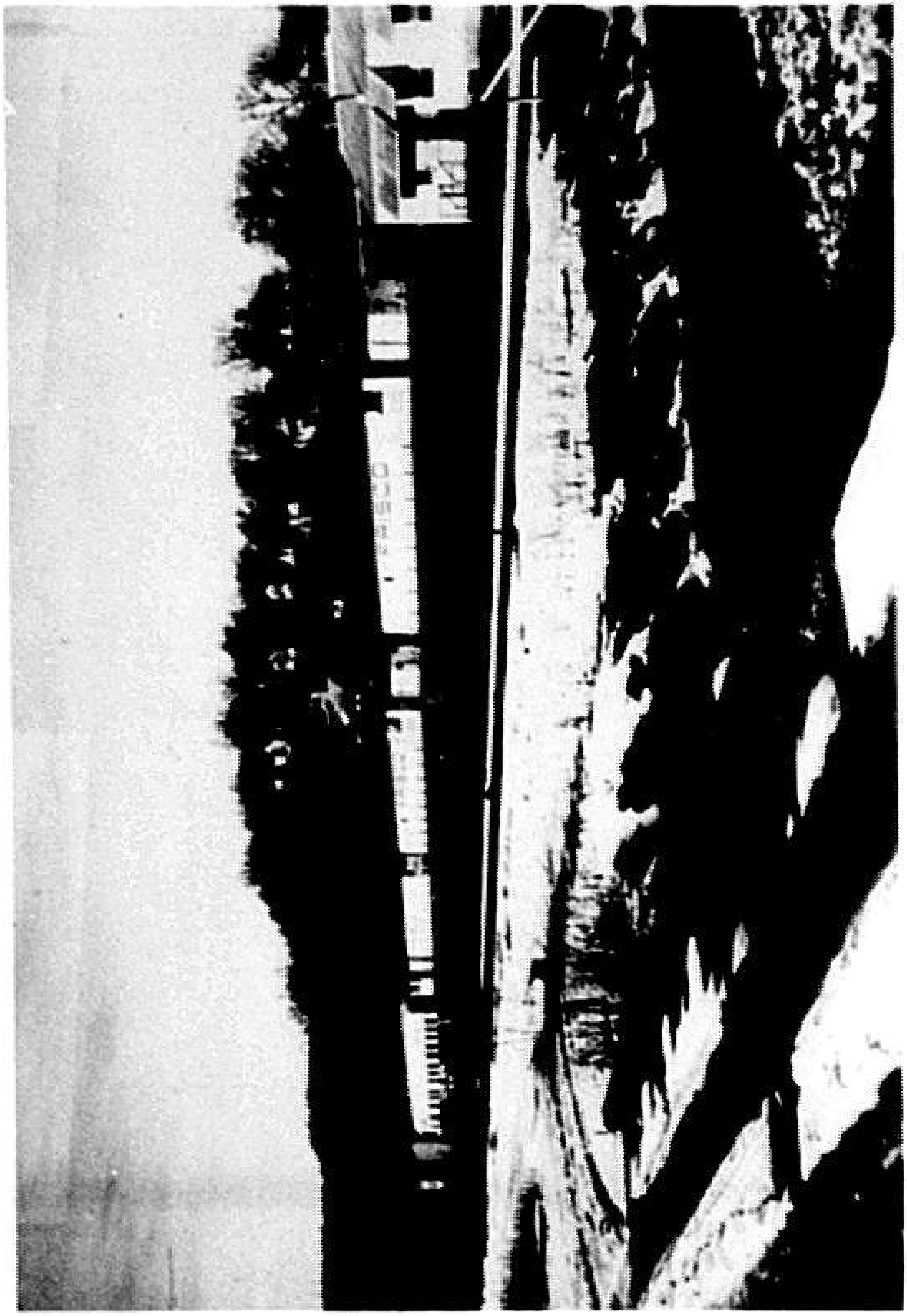

FIGURE B-5. TEST CAR IN CONSIST

APPENDIX C

DATA COLLECTION PROGRAM LISTINGS

```
; GENERAL INTERFACE DR11-A
        DGSR=177520     ;STATUS
        DGBR=177522     ;BUFFER
        DGIT=177524     ;INPUT TRANSMITTER
; REAL-TIME CLOCK KW11-P
    CKCSR=172540    ;CONTROL/STATUS
        CKBUF=172542    ;COUNT SET
        CKCTR=172544    ;COUNTER
; MAGTAPE CONTROLLER
        MTS=172520      ;STATUS
        MTC=172522      ;COMMAND
        MTBRC=172524    ;BYTE RECORD COUNTER
        MTCMA=172526    ;CURRENT MEMORY ADDRESS
        MTD=172530      ;DATA BUFFER
        MTRD=172532     ;READ LINES
; PROCESSOR REGISTERS AND MNEMONICS
        SR=177570       ;SWITCH REGISTER
        CC=177776       ;CONDITION CODES
        NOP=240
        R0=%0
        R1=%1
        R2=%2
        R3=%3
        R4=%4
        R5=%5
        R6=%6
        R7=%7
        SP=%6
        PC=%7
        .=400
BEGIN:  MOV #1500,104             ;CLOCK INTERRUPT VECTOR
        MOV #300,106
        MOV #RESTRT,0
        MOV #RESTRT,24            ;0-HALT AND POWER-FAIL RESTART
        MOV #57300,SP
        CLR @TICK
        CLR @TIC10
        CLR @LCLOCK
        CLR @HCLOCK
        CLR @TENTHS
        CLR @FIFTHS
        MOV MAX,R0
        CLR (R0)
        CLR 2(R0)
        CLR 4(R0)
        CLR THROTL
        CLR DROWOP
        MOV #4000,@BASE
        CLR SECS
        MOV #2600,R0
CLROUT: CLR (R0)+
        CMP #50000,R0
        BNE CLROUT
RESTRT: MOV #144,@#CKBUF          ;1 INTERRUPT/100 CLOCK COUNTS
        MOV #113,@#CKCSR          ;100 INTERRUPTS/SEC,GO
WAIT1:  TST @HCLOCK
        BNE GO1
        CMP @LCLOCK,#22
        BLE WAIT1                 ;WAIT UNTIL BUFFER IS FULL 1ST TIME
GO1:    MOV #144,@#CKBUF           ;RESTART CLOCK IF NECESSARY
        MOV #113,@#CKCSR
```

```
        BIT #200,@#DGSR              ;TEST REQUEST A
        BEQ N3                       ;IF LOW, GO TO OTHER TESTS
        MOV #100,@#DGBR         ;IF HIGH,RESET REQUEST A
        BR SET                  ; AND WRITE TAPE
N3:     MOV @BASE,R1            ;R1 CONTAINS BASE
        SUB #2000,R1            ; OF LAST COMPLETE SEC
        CMP R1,#2000
        BNE DBTH
        ADD #44000,R1
DBTH:   MOV #26,R0              ;CHECK 10 THROTTLE & DB / SEC
DBTH1:  TST -(R0)               ;R0 IS 24,22,...,0
        TST R0                  ;R0=0 IS END OF LIST
        BEQ BRAKES
        MOV R1,R2               ;BASE
        ADD #1630,R2            ; DIGITAL-LINES AREA
        SUB R0,R2               ;R2 IS 1604,1606,...,1626
        MOV (R2),R3
        BIT #100,R3            ;TEST FOR DYNAMIC BRAKE
        BNE SET
        BIC #170000,R3          ;GET ALL TRAIN LINES
        CMP R3,THROTL           ;COMPARE TO LAST
        BEQ DBTH1               ;SAME, CHECK NEXT
        MOV R3,THROTL           ;DIFFERENT,TRAIN LINE CHANGED,
        BR SET                  ; WRITE TAPE
BRAKES: MOV #6,R0               ;CHECK 5 BRAKES/SEC
BRAKE1: DEC R0                  ;R0 IS 5,4,3,2,1,0
        BEQ DRAWBR              ;DONE CHECKING BRAKES
        MOV R1,R2               ;BASE
        ADD #1635,R2
        SUB R0,R2               ;R2 IS 1630,1631,...,1634
        MOVB (R2),R3            ;R3 CONTAINS MOST RECENT BP
        SUB #6000,R2
        CMP R2,#4000
        BGE BP
        ADD #44000,R2           ;R2 POINTS TO BP 3 SEC AGO
BP:     MOVB (R2),R4
        SUB R4,R3               ;R3=CHANGE IN BP
        NEG R3                  ;GM'S XDUCERS GIVE NEG VOLTAGE
        CMPB R3,#-5
        BGE BC
        BR SET                  ;DELTA BP < -5 PSI, WRITE TAPE
BC:     ADD #6005,R2
        CMP R2,#50000
        BLT BC1
        SUB #44000,R2
BC1:    MOVB (R2),R3            ;R3 CONTAINS MOST RECENT BC
        SUB #6000,R2
        CMP R2,#4000
        BGE BC2
        ADD #44000,R2
BC2:    MOVB (R2),R4
        SUB R4,R3               ;R3 CONTAINS CHANGE IN BC
        NEG R3                  ;GM'S XDUCERS GIVE NEG VOLTAGE
        CMPB R3,#5
        BGT SET                 ;DELTA BC > 5 PSI,WRITE TAPE
        BR BRAKE1               ;CHECK MORE BRAKE VALUES
DRAWBR: MOV #145,R0             ;CHECK 100 DRAWBARS/SEC
DRAWB1: DEC R0                  ;R0=144,...,1 (OCTAL)
        BEQ TAPES
        MOV R1,R2               ;BASE
        ADD #620,R2
        SUB R0,R2               ;R2=BASE+454,...,617
        MOVB (R2),R3            ;R3=MOST RECENT DRAWBAR
        BPL DRAWB2
        NEG R3                  ;TAKE ABSOLUTE VALUE
DRAWB2: CMP R3,#51.             ;COMPARE TO 200K LB
```

```
        BLT DRAWB1
             ;WRITE TAPE IF GREATER
SET:   TST SECS               ;TEST IF ALREADY WRITING
        BNE SET3              ;YES,BRANCH
        MOV @BASE,R2
        ADD #4000,R2          ;GET NEXT-OLDEST SEC IN BUFFER
        CMP R2,#50000         ;(LEAVE 1 SEC FOR INTERRUPT
        BLT SET1              ; ROUTINE TO CATCH UP)
        SUB #44000,R2
SET1:   CLR R0                ;R0 COUNTS 0,2,4,6,10
SET9:   MOV BASES(R0),R1      ;R1 IS 12000,20000,...,42000
        CMP R2,R1
        BLT SET2              ;START WRITING AT NEXT HIGHER BASE
        TST (R0)+
        CMP R0,#12
        BLT SET9
        MOV #4000,R1          ;R2>42000 => NHB IS 4000
SET2:   MOV R1,TAPEAT
SET3:   MOV #74,SECS         ;SET OR RESET FOR 120 SEC
TAPES:  TST SECS
        BEQ GO2               ;LOOP IF NO WRITING DESIRED
        MOV TAPEAT,R0         ;ADJUST R0(=TAPEAT) TO BE
        CMP R0,@BASE          ; ALWAYS LOGICALLY GREATER THAN
        BGT NOCIR             ; BASE IN CIRCULAR MEMORY
        ADD #44000,R0
NOCIR:  SUB @BASE,R0
        CMP R0,#6000
        BGT GO2               ;BRANCH IF BASE IS  MORE THAN
                              ; 3 SEC BEHIND TAPEAT
        SUB #3,SECS           ;OTHERWISE, WRITE 3 SEC
        MOV TAPEAT,TAPTMP     ;SAVE WRITING BASE
        ADD #6000,TAPEAT      ;SET NEXT WRITING BASE
        CMP TAPEAT,#50000
        BNE TAPES2
        MOV #4000,TAPEAT
TAPES2: MOV #-6000,@#MTBRC   ;WRITE 3 SEC
        MOV TAPTMP,@#MTCMA
        MOV #60005,@#MTC
TAPES3: TST @#MTC
        BEQ TAPES3
        BMI ERROR
        BR GO2
ERROR:  MOV #-1,@#MTBRC
        MOV #60013,@#MTC
ERR1:   TSTB @#MTC
        BEQ ERR1
        MOV #-6000,@#MTBRC
        MOV TAPTMP,@#MTCMA
        MOV #60015,@#MTC
        BR TAPES3
GO2:    JMP GO1
TAPTMP: .WORD 0
BASES:  .WORD 12000,20000,26000,34000,42000
SECS:   .WORD 0
TAPEAT: .WORD 0
THROTL: .WORD 0
DBONOF: .WORD 0
TENTHS: .WORD 2422
FIFTHS: .WORD 2424
TICK:   .WORD 2426
TC10:   .WORD 2430
BASE:   .WORD 2432
LCLOCK: .WORD 2434
HCLOCK: .WORD 2436
MAX:    .WORD 2440
        .END 50000
```

```
 ; PERIPHERAL REGISTER ASSIGNMENTS
; A/D CONVERTER AD01-D
        ADCSR=176770    ;CONTROL/STATUS
        ADDBR=176772    ;DATA BUFFER (READ ONLY)
; GENERAL INTERFACE DR11-A
        DGSR=177520     ;STATUS
        DGBR=177522     ;BUFFER
        DGIT=177524     ;INPUT TRANSMITTER
; PROCESSOR REGISTERS AND MNEMONICS
        SR=177570       ;SWITCH REGISTER
        CC=177776       ;CONDITION CODES
        NOP=240
        R0=%0
        R1=%1
        R2=%2
        R3=%3
        R4=%4
        R5=%5
        R6=%6
        R7=%7
        SP=%6
        PC=%7
        .=1500
TKINT:  INC TICK
        INC TC10
        MOV R0,-(SP)        ;SAVE R0,R1,R2
        MOV R1,-(SP)
        MOV R2,-(SP)
        MOV #20,R0          ;9 FAST LINES
FAST:   MOV FCONTR(R0),R1
        BEQ FAST2           ;LOOP IF LINE INACTIVE
        MOV R1,@#ADCSR      ;SAMPLE THIS LINE
        MOV BASE,R2         ;BEGINNING OF THIS SEC
        ADD FPOINT(R0),R2 ; THIS LINE
        ADD TICK,R2         ; THIS SAMPLE
FAST1:  TSTB @#ADCSR        ;WAIT FOR A/D READY
        BEQ FAST1
        MOV @#ADDBR,R1      ;DATA INTO R1
        ASR R1
        ASR R1
        ASR R1              ;R1 (BYTE) = DATA (SIGN+7MSB)
        MOVB R1,(R2)
FAST2:  TST -(R0)           ;R0=R0-2
        TST R0
        BPL FAST            ;LOOP IF MORE FAST LINES
        MOV BASE,R2         ;BEGINNING OF THIS SEC
        DEC R2            ;POINT BEFORE ACCELEROMETER DATA
        ADD TICK,R2         ;POINT TO LATEST DATA
        MOVB (R2),R1        ;R1=LATEST DATA
        BPL FAST10
        NEG R1             ;TAKE ABSOLUTE VALUE
FAST10: CMP R1,XMAX        ;COMPARE TO LARGEST THIS SEC
        BLE FAST11         ;NO,SKIP
        MOV R1,XMAX        ;YES,SAVE
FAST11: ADD #454,R2        ;POINT TO LATEST DRAWBAR DATA
        MOVB (R2),R1       ;R1=LATEST DATA
        BMI FAST12         ;R1 NEG => BUFF FORCE
        SUB #38.,R1
        BLT EVENT          ;EXIT IF DATA<38 (150K LB)
        CMP R1,DRMAX       ;SAVE IF LARGEST THIS SEC
        BLE EVENT
```

```
         MOV R1,DRMAX
         BR EVENT
FAST12:  NEG R1                ;DO BUFF AS ABOVE ONCE INVERTED
         SUB #38.,R1
         BLT EVENT
         CMP R1,BFMAX
         BLE EVENT
         MOV R1,BFMAX
EVENT:   CMP TC10,#12           ;TEST TENTH OF SEC
         BNE EXIT1              ;NO,EXIT
         INC TENTHS             ;COUNT TENTHS OF SEC
         MOV #1,@#DGBR          ;LOOK AT EVENT REGISTER
         MOV TENTHS,R2          ;THIS TENTH
         ASL R2                 ; X2 (WORD ADDRESS)
         ADD BASE,R2             ;BEGINNING OF SEC
         ADD #1602,R2           ; WORD PRECEDING TENTHS AREA
SLOW10:  TST @#DGSR
         BEQ SLOW10             ;WAIT FOR EVENT REGISTER
         MOV @#DGIT,(R2)+
         BIT #1,TENTHS          ;ODD OR EVEN TENTH
         BNE EXIT10             ;ODD,EXIT
         INC FIFTHS             ;EVEN,COUNT FIFTHS
         MOV #46,R0             ;20 SLOW LINES
SLOW:    MOV SCONTR(R0),R1
         BEQ SLOW2              ;LOOP IF LINE INACTIVE
         MOV R1,@#ADCSR         ;SAMPLE THIS LINE
         MOV BASE,R2            ;BEGINNING OF THIS SEC
         ADD SPOINT(R0),R2      ; THIS LINE
         ADD FIFTHS,R2          ; THIS FIFTH
SLOW1:   TSTB @#ADCSR           ;WAIT FOR A/D READY
         BEQ SLOW1
         MOV @#ADDBR,R1         ;DATA INTO R1
         ASR R1
         ASR R1
         ASR R1
         MOVB R1,(R2)           ;R1(BYTE) - DATA(SIGN+7MSB)
SLOW2:   TST -(R0)              ;R0=R0-2
         TST R0
         BPL SLOW               ;LOOP IF MORE SLOW LINES
         CMP #5,FIFTHS            ;TEST END OF 1 SEC
         BNE EXIT10             ; NO,EXIT
         INC LCLOCK             ;YES,STORE TIME,DOUBLE PRECISION
         ADC HCLOCK
         MOV BASE,R2
         ADD #1774,R2
         MOV LCLOCK,(R2)+
         MOV HCLOCK,(R2)+       ;AFTER WHICH R2=NEXT BASE
         CMP R2,#50000
         BNE N2
         MOV #4000,R2
N2:      MOV R2,BASE
         CLR TENTHS             ;RESET TIMERS
         CLR FIFTHS
         CLR TICK
         MOV XMAX,R2          ;X-ACCELEROMETER MAX OFFSET
         ASL R2               ;WORD ADDRESS
         INC 3400(R2)         ;COUNT FREQUENCY THIS MAX
         CLR XMAX             ;PREPARE FOR NEXT SEC
         MOV DRMAX,R2         ;SIMILARLY FOR DRAG
         ASL R2
         INC 2600(R2)
         CLR DRMAX
         MOV BFMAX,R2         ;SIMILARLY FOR BUFF
         ASL R2
         INC 3100(R2)
         CLR BFMAX
```

```
EXIT10: CLR TC10
EXIT1:  MOV (SP)+,R2        ;RESTORE R2,R1,R0
        MOV (SP)+,R1
        MOV (SP)+,R0
        RTI                 ;RETURN FROM INTERRUPT
FCONTR: .WORD 0,0,0,0,0,0,0,0,0      ;9 FAST A/D LINE CONTROLS
SCONTR: .WORD 0,0,0,0,0,0,0,0,0,0  ;20 SLOW LINES
        .WORD 0,0,0,0,0,0,0,0,0,0
FPOINT: .WORD -1,143,307,453,617,763,1127,1273,1437
SPOINT: .WORD 1627,1634,1641,1646,1653,1660,1665,1672
        .WORD 1677,1704,1711,1716,1723,1730,1735,1742
        .WORD 1747,1754,1761,1766
; ALL FPOINT AND SPOINT POINT TO BYTE PRECEDING DESIRED AREA
; BECAUSE TICK AND FIFTHS BEGIN AT 1, NOT 0
TENTHS: .WORD 0
FIFTHS: .WORD 0
TICK:   .WORD 0                ;COUNT TO 100 (1 SEC)
TC10:   .WORD 0               ;COUNT TO 10 (1/10 SEC)
BASE:   .WORD 4000
LCLOCK: .WORD 0
HCLOCK: .WORD 0
XMAX:   .WORD 0
DRMAX:  .WORD 0
BFMAX:  .WORD 0
        .END 50000
*
```

APPENDIX D

LIMITATIONS IN COLLECTED DATA

During the test runs described in Section II. A. of this report, a total of 50 data runs were made, where a "run" is defined as the train action for a single crew over a division; there can therefore be several runs in a single day's train action. The runs are numbered to 1 to 50 on the tapes numbered 1 to 39 and divided among the various railroads according to the following table:

RUNS	TAPES	RAILROAD (ROUTE)
1-6	1-3	Illinois Central Gulf
7-16	4-8	St. Louis - San Francisco
17-30	9-15	Southern Pacific (El Paso-Tuscon)
32-37	17-28	Southern Pacific (Colton-Baskerfield)
38-41	29-33	Union Pacific
42-50	34-39	Burlington Northern

Runs 38-50 were recorded completely according to the description of the computer system in Section B.2. A programming error caused the following limitation in the data recorded for runs 1-37: out of each 18 consecutive seconds in a given time window described in Section B.2.2, only 3 consecutive seconds were recorded. This 3-second "sub-window" was then repeated 6 times until new data filled its corresponding area in the circular-buffer memory. The available data, then, consist of 3-second windows occurring every 18 seconds as long as the program specified that recording take place; the interventing 15-second intervals were not recorded. These data are useful for taking averages of measured parameters and for testing short-interval (one second or less) control responses. For longer intervals and complete train handling actions, complete data (as in Runs 38-50) should be used.

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