United States
Environmental Protection
Agency

Motor Vehicle Emission Lab
2565 Plymouth Rd.
Ann Arbor, Michigan 48105

EPA-460/3-81-009
April 1981

Air

EPA

Light-Duty Vehicle Driveability Procedure Investigation

EPA-460/3-81-009

LIGHT-DUTY VEHICLE DRIVEABILITY PROCEDURE INVESTIGATION

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Contract No. 68-03-2875

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Prepared for:
ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF AIR, NOISE AND RADIATION
OFFICE OF MOBILE SOURCE AIR POLLUTION CONTROL
EMISSION CONTROL TECHNOLOGY DIVISION
CHARACTERIZATION AND APPLICATIONS BRANCH
ANN ARBOR, MICHIGAN 48105

APRIL, 1981

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INTRODUCTION

The automotive and petroleum industries have long recognized that vehicle driveability is an important consideration in product design and manufacturing. Over the years companies in both industries have independently and cooperatively gathered research data to use in setting product specifications that insure desired driveability performance in customer service.

One of the predominate cooperative organizations is the Coordinating Research Council (CRC). Since 1970 CRC has conducted several research programs (1,2,3,4)* to evaluate driveability variations among vehicles and to evaluate the influence of gasoline volatility upon vehicle driveability. In most of these tests trained raters subjectively evaluated vehicle driveability as they drove cars through a specified test cycle. Test repeatability was often poor partially because many of the ratings were subjective.

The Environmental Protection Agency's (EPA) interest in driveability stems from evidence that adjustments of some vehicle engine settings to values other than those recommended by the manufacturer can improve driveability during cold start and warmup driving but often exhaust emissions and/or fuel economy suffer as a result (5). Because of this, EPA may eventually consider issuing driveability guidelines or standards. Such regulations must be based on quantitative test methods but current industry test procedures are primarily subjective. Consequently EPA awarded contract 68-03-2875 to Amoco Oil Co. to determine whether an objective procedure could be developed for assessing vehicle cold start and warmup driveability.

SUMMARY

A research program was conducted by the Amoco Oil Co. under contract with the Environmental Protection Agency to develop instruments and computer programs for objectively measuring vehicle cold start and warmup driveability. After a series of screening tests on 15 candidate cars, a 1979 Chrysler was selected for the extensive driveability testing required to accomplish the research objective. The car was equipped with several instruments which the investigators judged capable of detecting and measuring the severity of driveability problems. Nearly 200 driveability tests were conducted with this car on chassis dynamometers using various driving cycles and ambient test temperatures. Throughout each test the instrument output signals and the trained raters' evaluations of performance were computer recorded at the rate of five times per second. From the data gathered, a series of computer programs were developed to identify and measure the severity of several driveability problems. Most of the computer programs were designed specifically for the one car used in the test work -- they generally are not to be considered universally applicable to other vehicles.

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* Numbers in parentheses indicate references listed at the end of the report.

CONCLUSIONS

Computer methods were developed for measuring the severity of five driveability problems. They were:

- stumble (sudden loss of power followed by a resumption of power)
- hesitation (lack of response to opening the throttle)
- engine stalls (any time the engine quits running with the ignition key in the "on" position)
- engine idle roughness
- hard starting (excessive cranking time during startup)

In CRC testing, hard starting and engine stalls are rated objectively and computer methods were developed which nearly duplicate these results. The other driveability problems are subjectively evaluated and attempts were made to develop computer correlations that accurately match the raters' observations. In some cases this was successful but in other cases additional developmental work is needed. It appears feasible that, with further effort, the computer methods described in this report can be improved.

No attempt was made to develop methods of measuring backfire (an explosion in the induction or exhaust system), extension (an abnormally slow or sluggish acceleration), or surge (cyclic pulses of power). Previous driveability testing by Amoco and CRC indicated that these are relatively minor problems. For the car tested in this program, backfire was a major problem, but surge and extension rarely occurred. With proper instrumentation methods can probably be developed to measure any of these problems.

In general, the instruments used and the computer programs developed during this investigation provide a means to measure driveability of the only car tested. The specific correlations developed for calculating demerits probably cannot be directly applied to other cars, but the general analytical procedures and the basic measurement methods should be valid.

RECOMMENDATIONS

In developing the computer procedures described in this report, only one car was tested, all work was done on chassis dynamometers and driveability evaluations were obtained from only two trained raters. To develop a universal objective driveability system, many more cars need to be included in the data base, the methods should be verified by on-the-road driveability tests, and subjective opinions of driveability performance should be gathered from additional trained raters.

In the long term we suspect test repeatability on chassis dynamometers can be further improved by using mechanical/electrical "automatic drivers" in place of human drivers to manipulate the throttle. Auto drivers are more consistent than humans in throttle opening rates and throttle positions.

We recommend that driveability testing not be attempted using the Federal Test Procedure cycle nor any other cycle in which a driver is forced to drive the car according to a predetermined vehicle speed-versus-time schedule. These types of cycles purposely allow the throttle to be manipulated to overcome and thereby mask driveability problems. Furthermore, we found the FTP cycle does not require rapid enough accelerations to highlight driveability problems of the car we tested and we therefore suspect that differences between cars cannot be found by using this cycle.

Our last recommendation is that if further development work is conducted on the problem of objective driveability measurement, the engine/vehicle operating parameters studied should not be limited to the few used in the system finally developed for this project (primarily engine speed, throttle position, and starter engagement). Driveability of other cars may correlate better with other operating parameters.

EXPERIMENTAL

Literature Search

A literature search was conducted early in the program to identify potential instruments and methods for objectively measuring vehicle driveability. Based on this search and Amoco's previous driveability measurement experience, ten engine/vehicle operating parameters were identified as candidates. They were:

- vehicle speed
- vehicle acceleration
- engine speed
- engine intake manifold vacuum
- engine vibration
- engine rotational movement relative to the car frame
- throttle position
- drawbar pull
- driveshaft torque
- starter voltage

Car Screening and Selection

Screening tests were conducted on several cars to select one which displayed a variety of driveability problems. For this work the CRC cold start and driveaway test procedures were used. They are described in detail in Appendix A. Basically a rater drives the car through a specified cycle and evaluates the severity (slight, moderate or heavy) of any driveability problems which occur. These ratings are then translated into numerical demerit values for analyses. For reference the most serious driveability problem, engine stall while driving, is assigned 32 demerits per occurrance.

The screening tests were conducted in an all-weather, large-roll (7 ft. diameter), chassis dynamometer at 20°F (-7°C). Two trained raters each evaluated performance of all candidate cars three times: twice using a low volatility fuel and once using a high volatility fuel. Pertinent inspections on these fuels were:

	Fuels for Car Screening	
	Low Volatility	High Volatility
Distillation, °F (°C)		
10% Evap.	140 (60)	105 (41)
50% Evap.	250 (121)	185 (85)
90% Evap.	355 (179)	295 (146)
Reid Vapor Pressure, lbs. (Kpa)	7.1 (48.9)	13.5 (93.1)

A description of the 15 cars screened, is shown in Table I and results of the screening tests are shown in Table II. Based on these results the Chrysler LeBaron (car ID 9CHY1) was selected for the remainder of the test work. This car was chosen for two reasons. First, it displayed a wide range of driveability problems and problem severities with the low volatility fuel. Second, the driveability of this car was highly sensitive to changes in fuel volatility as shown by the difference in total demerits for the two fuels.

Instrumentation Installed on Car

After selecting the test car, it was equipped with instruments to measure the ten engine/vehicle operating parameters mentioned previously. Description of each instrument is given in Appendix B. After a few preliminary tests, four operating parameters were eliminated from further consideration. These parameters and the reasons for discarding them were:

- vehicle acceleration -- the available instrument could not accurately measure accelerations at vehicle speeds below 10 mph and many problems occurred at low speeds.
- engine vibration -- high frequency instrument signals tended to mask driveability problems
- engine rotational movement -- same as engine vibration, and
- draw-bar pull -- because car movement was necessary to produce a signal, it became highly dependent upon the method used to secure the car to the dynamometer

Data Collection System

A large number of cold start and warmup driveability tests were conducted on chassis dynamometers using the instrument-equipped test car. Throughout each test the analog instrument signals were monitored continuously and

TABLE I

CANDIDATE TEST CARS

Make and Model (1)	Engine Displ., L.	Carburetor Venturis	Car ID
AMC Concord	2.0	2	9AM1
Buick Century	3.8	2	9BU1
Buick Century (2)	3.8	4	9BU2
Buick LeSabre	4.9	2	9BU4
Chevrolet Chevette	1.6	2	9CV1
Chevrolet Impala	5.0	2	9CV4
Chevrolet Malibu	3.3	2	9CV2
Chevrolet Malibu	4.4	2	9CV3
Chrysler LeBaron	5.2	2	9CHY1
Ford Fairmont	3.3	1	9FO3
Ford LTD	5.0	2 (3)	9FO4
Mecury Marquis (4)	5.8	2 (3)	9MER1
Oldsmobile Cutlass	4.3	2	9OL1
Plymouth Horizon	1.7	2	9PLY1
Pontiac Sunbird	2.5	2	9PO1

---

(1) All were 1979 models equipped with automatic transmission.

(2) Turbocharged.

(3) Variable Venturi carburetor.

(4) Equipped with three-way catalyst system and closed-loop A/F ratio control.

TABLE II

CAR SCREENING TEST RESULTS

Car ID	Fuel*	Average Demerits									
		Hard Starting	Stalls Idle	Stalls Driving	Hesitation	Stumble	Surge	Extension	Backfire	Idle Rough.	Total
9AM1	L	9.8	4.0	136.0	120.0	42.0	1.0	0.0	8.5	1.8	323.1
	H	1.5	0.0	64.0	21.0	6.0	2.0	0.0	0.0	1.5	96.0
9BU1	L	1.4	0.0	32.0	37.5	42.0	19.0	0.0	0.0	0.8	132.7
	H	1.0	0.0	0.0	30.0	9.0	16.0	0.0	0.0	2.0	58.0
9BU2	L	1.2	8.0	56.0	96.0	36.0	8.0	0.0	0.0	3.0	208.2
	H	0.8	0.0	0.0	9.0	18.0	6.0	0.0	0.0	1.5	35.3
9BU4	L	2.2	10.0	144.0	54.0	76.5	5.0	0.0	1.5	2.8	296.0
	H	0.5	0.0	0.0	6.0	3.0	0.0	0.0	0.0	0.0	9.5
9CV1	L	14.4	4.0	352.0	96.0	72.0	9.0	0.0	0.0	2.8	550.2
	H	1.0	0.0	48.0	27.0	15.0	0.0	0.0	0.0	0.0	91.0
9CV4	L	5.8	22.0	104.0	43.5	64.5	2.0	6.0	13.5	1.8	263.1
	H	0.5	0.0	0.0	9.0	3.0	0.0	0.0	0.0	0.0	12.5
9CV2	L	2.4	12.0	32.0	60.0	66.0	12.0	0.0	21.0	7.2	212.6
	H	10.5	12.0	16.0	3.0	12.0	8.0	0.0	0.0	6.0	67.5
9CV3	L	4.4	14.0	120.0	43.5	75.0	7.0	0.0	21.0	5.0	289.9
	H	1.8	4.0	0.0	9.0	9.0	0.0	0.0	0.0	1.0	24.8
9CHY1	L	4.5	8.0	248.0	103.5	159.0	18.0	9.0	3.0	1.5	554.5
	H	0.5	0.0	0.0	36.0	6.0	2.0	0.0	6.0	2.5	53.0
9FO3	L	2.2	8.0	104.0	42.0	61.5	2.0	0.0	16.5	5.5	241.7
	H	1.0	0.0	16.0	9.0	3.0	0.0	0.0	0.0	4.5	33.5
9FO4	L	3.8	12.0	0.0	9.0	0.0	0.0	0.0	0.0	2.5	27.3
	H	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
9MER1	L	0.0	0.0	280.0	27.0	46.5	5.0	0.0	0.0	0.2	358.7
	H	0.0	0.0	0.0	9.0	0.0	4.0	0.0	0.0	1.5	14.5
9OL1	L	3.3	7.0	176.0	29.4	33.8	0.0	0.0	0.0	1.0	250.5
	H	1.0	0.0	0.0	1.2	6.0	0.0	0.0	0.0	0.0	8.2
9PLY1	L	5.3	16.0	10.6	22.0	14.0	2.6	1.3	0.0	1.7	73.5
	H	1.2	4.0	16.0	33.0	12.0	10.0	8.0	0.0	3.0	87.2
9PO1	L	1.5	2.0	48.0	52.5	16.5	3.0	0.0	0.0	0.0	123.5
	H	1.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.5	7.5

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* L - Low Volatility Fuel, H - High Volatility Fuel.

recorded on strip charts. The instrument signals were also converted to ditigal form and stored by computer on magnetic disk as the rate of five times per second. Throughout each test the trained rater entered his driveability ratings into the computer via a keyboard located in the car; the keyboard was also used to indicate which maneuver was being attempted. A photograph of the driver's keyboard is shown in Figure 1, and examples of computer printouts available for each driveability test are shown in Figures 2 and 3. Figure 2 shows the value of each engine/vehicle parameter and the status of all keyboard buttons every 0.2 seconds during a 10-second segment of Test Number 26. Figure 3 shows a tabulation of rater-observed demerits for Test 26. After an elapsed test time of 265.6 seconds, the driver opened the throttle to attempt the 2nd, 0-35 mph wide-open-throttle acceleration of the test. The engine stalled at 268.0 seconds (manifold vacuum was 0.0 in. Hg). At 269.0 seconds the rater depressed the "Stall" button on the keyboard and then engaged the engine starter at 271.4 seconds. The engine started at about 272.4 seconds. Figure 3 shows a tabulation of rater-observed demerits in Test 26.

Driveability Tests Conducted

Driveability tests conducted in this program have been segregated into six phases described by the chassis dynamometer used, the ambient test temperature, and the driving cycle used. They are:

Phase	Dynamometer	Ambient Temperature, °F (°C)	Driving Cycle
I	Large Roll	20 (-7)	CRC
II	Large Roll	70 (21)	CRC
III	Large Roll	20 (-7)	Motorist
IV	Small Roll	20 (-7)	CRC
V	Small Roll	20 (-7)	FTP
VI	Small Roll	70 (21)	FTP

The CRC and motorist driving cycles are described in Appendix A; the FTP cycle is the cycle currently specified by EPA to use for measuring light-duty vehicle exhaust emissions and fuel economy (6). The Phase I tests were conducted because the investigators felt this combination of dynamometer, test temperature, and cycle held good potential for objective driveability measurement. Test Phases II thru VI were conducted to determine whether driveability could be measured either by raters or instruments on other dynamometers, at different test temperatures or using various driving cycles.

In all test phases, each of two trained raters evaluated car performance several times on three test fuels. Two of the fuels were the same throughout the entire program but the third fuel was inadvertently changed between Phases I and II. Pertinent inspections on all test fuels are:

Figure 1

Driver's Data Entry Keyboard

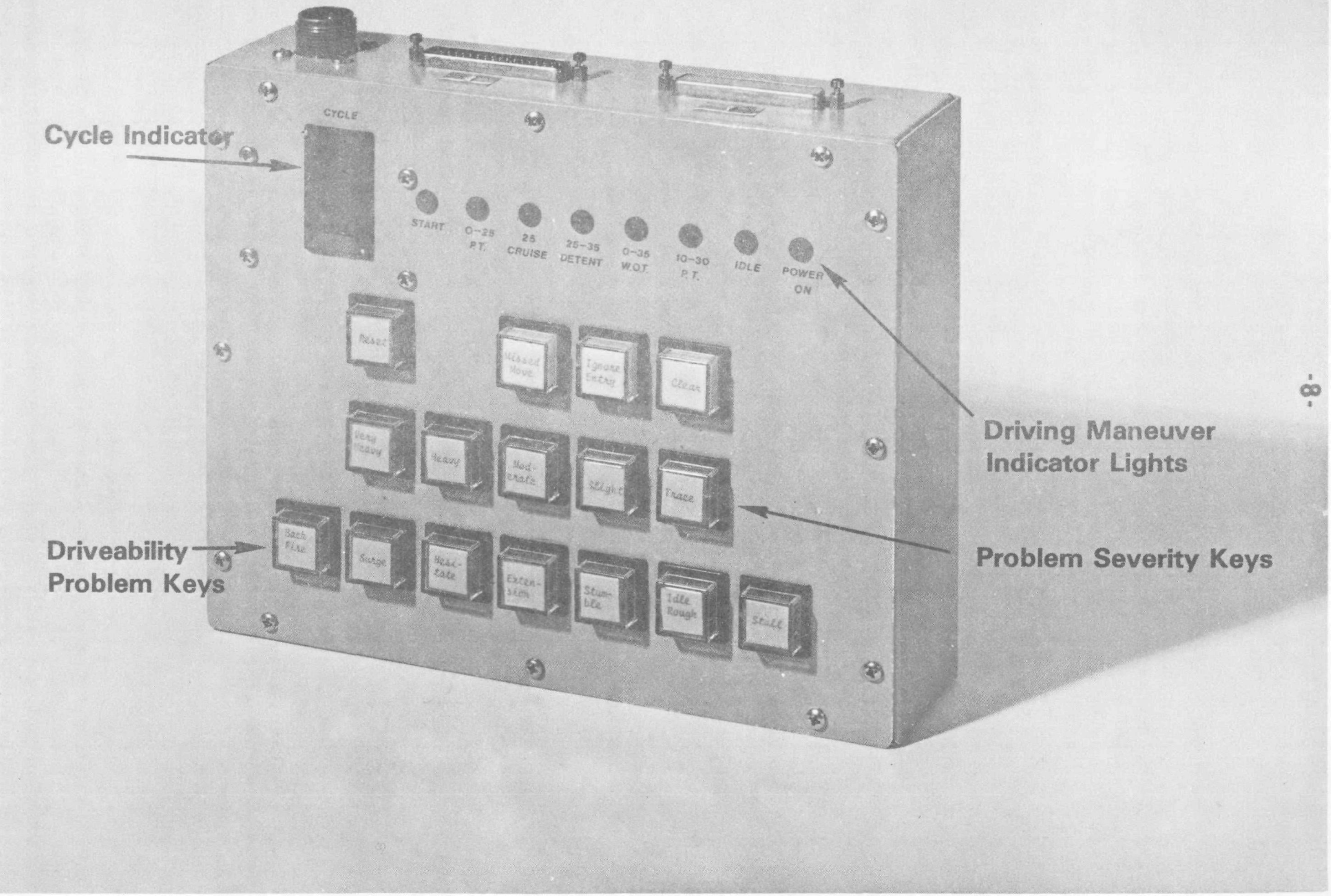
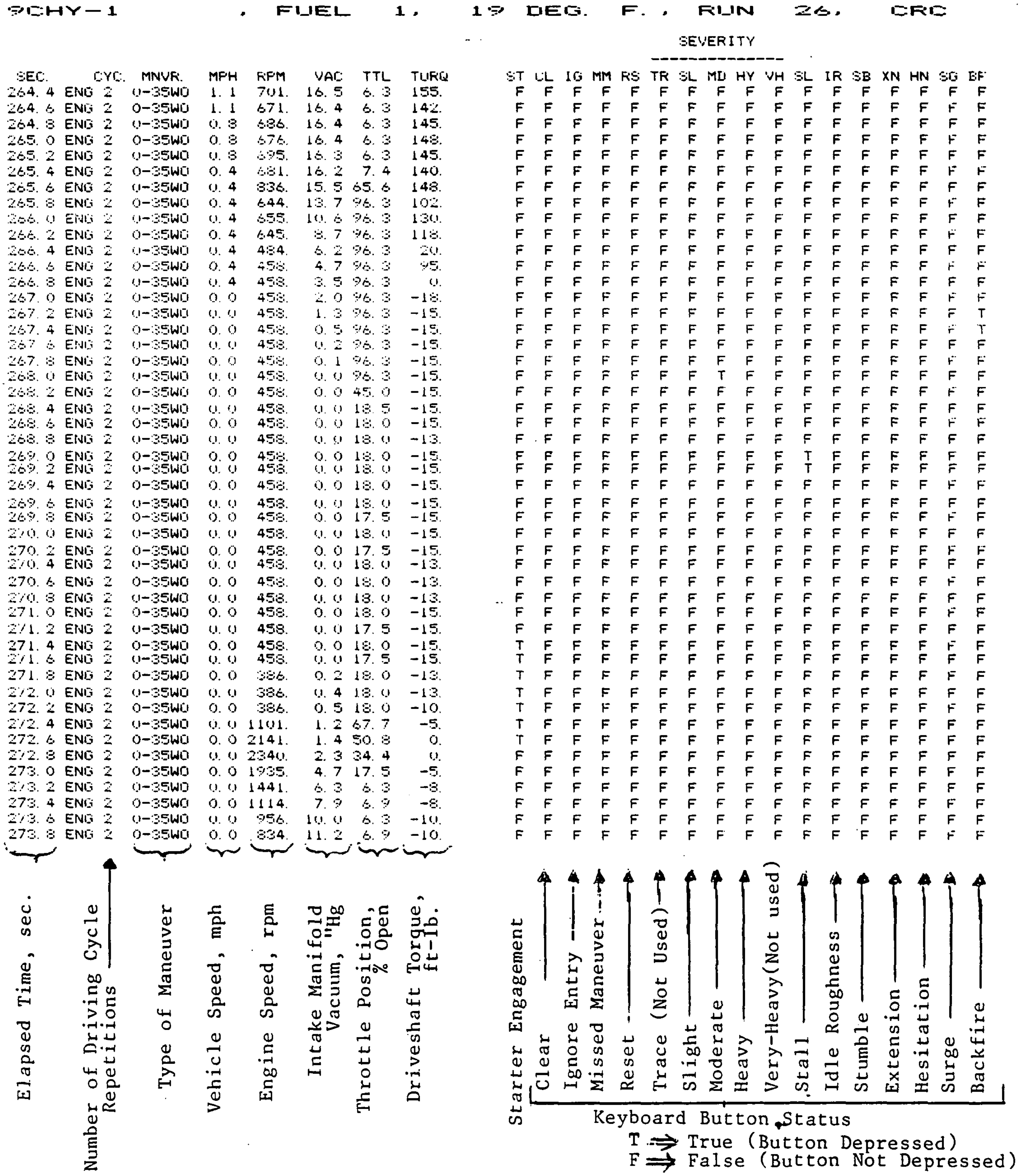


Figure 2

Raw Data Printout



```
9CHY-1          , FUEL   1,    19 DEG. F. , RUN   26,     CRC

                                                                            SEVERITY
                                                                         --------------
 SEC.   CYC.  MNVR.    MPH   RPM     VAC   TTL  TURQ      ST CL IG MM RS TR SL MD HY VH SL IR SB XN HN SG BF
264. 4 ENG 2  0-35WO  1. 1   701.  16. 5  6. 3   155.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
264. 6 ENG 2  0-35WO  1. 1   671.  16. 4  6. 3   142.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
264. 8 ENG 2  0-35WO  0. 8   686.  16. 4  6. 3   145.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
265. 0 ENG 2  0-35WO  0. 8   676.  16. 4  6. 3   148.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
265. 2 ENG 2  0-35WO  0. 8   695.  16. 3  6. 3   145.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
265. 4 ENG 2  0-35WO  0. 4   681.  16. 2  7. 4   140.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
265. 6 ENG 2  0-35WO  0. 4   836.  15. 5 65. 6   148.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
265. 8 ENG 2  0-35WO  0. 4   644.  13. 7 96. 3   102.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
266. 0 ENG 2  0-35WO  0. 4   655.  10. 6 96. 3   130.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
266. 2 ENG 2  0-35WO  0. 4   645.   8. 7 96. 3   118.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
266. 4 ENG 2  0-35WO  0. 4   484.   6. 2 96. 3    20.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
266. 6 ENG 2  0-35WO  0. 4   458.   4. 7 96. 3    95.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
266. 8 ENG 2  0-35WO  0. 4   458.   3. 5 96. 3     0.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
267. 0 ENG 2  0-35WO  0. 0   458.   2. 0 96. 3   -18.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
267. 2 ENG 2  0-35WO  0. 0   458.   1. 3 96. 3   -15.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  T
267. 4 ENG 2  0-35WO  0. 0   458.   0. 5 96. 3   -15.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  T
267  6 ENG 2  0-35WO  0. 0   458.   0. 2 96. 3   -15.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
267. 8 ENG 2  0-35WO  0. 0   458.   0. 1 96. 3   -15.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
268. 0 ENG 2  0-35WO  0. 0   458.   0. 0 96. 3   -15.     F  F  F  F  F  F  F  T  F  F  F  F  F  F  F  F  F
268. 2 ENG 2  0-35WO  0. 0   458.   0. 0 45. 0   -15.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
268. 4 ENG 2  0-35WO  0. 0   458.   0. 0 18. 5   -15.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
268. 6 ENG 2  0-35WO  0. 0   458.   0. 0 18. 0   -15.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
268. 8 ENG 2  0-35WO  0. 0   458.   0. 0 18. 0   -13.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
269. 0 ENG 2  0-35WO  0. 0   458.   0. 0 18. 0   -15.     F  F  F  F  F  F  F  F  F  F  T  F  F  F  F  F  F
269. 2 ENG 2  0-35WO  0. 0   458.   0. 0 18. 0   -15.     F  F  F  F  F  F  F  F  F  F  T  F  F  F  F  F  F
269. 4 ENG 2  0-35WO  0. 0   458.   0. 0 18. 0   -15.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
269. 6 ENG 2  0-35WO  0. 0   458.   0. 0 18. 0   -15.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
269. 8 ENG 2  0-35WO  0. 0   458.   0. 0 17. 5   -15.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
270. 0 ENG 2  0-35WO  0. 0   458.   0. 0 18. 0   -15.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
270. 2 ENG 2  0-35WO  0. 0   458.   0. 0 17. 5   -15.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
270. 4 ENG 2  0-35WO  0. 0   458.   0. 0 18. 0   -13.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
270. 6 ENG 2  0-35WO  0. 0   458.   0. 0 18. 0   -13.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
270. 8 ENG 2  0-35WO  0. 0   458.   0. 0 18. 0   -13.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
271. 0 ENG 2  0-35WO  0. 0   458.   0. 0 18. 0   -15.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
271. 2 ENG 2  0-35WO  0. 0   458.   0. 0 17. 5   -15.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
271. 4 ENG 2  0-35WO  0. 0   458.   0. 0 18. 0   -15.     T  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
271. 6 ENG 2  0-35WO  0. 0   458.   0. 0 17. 5   -15.     T  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
271. 8 ENG 2  0-35WO  0. 0   386.   0. 2 18. 0   -13.     T  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
272. 0 ENG 2  0-35WO  0. 0   386.   0. 4 18. 0   -13.     T  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
272. 2 ENG 2  0-35WO  0. 0   386.   0. 5 18. 0   -10.     T  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
272. 4 ENG 2  0-35WO  0. 0  1101.   1. 2 67. 7    -5.     T  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
272. 6 ENG 2  0-35WO  0. 0  2141.   1. 4 50. 8     0.     T  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
272. 8 ENG 2  0-35WO  0. 0  2340.   2. 3 34. 4     0.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
273. 0 ENG 2  0-35WO  0. 0  1935.   4. 7 17. 5    -5.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
273. 2 ENG 2  0-35WO  0. 0  1441.   6. 3  6. 3    -8.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
273. 4 ENG 2  0-35WO  0. 0  1114.   7. 9  6. 9    -8.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
273. 6 ENG 2  0-35WO  0. 0   956.  10. 0  6. 3   -10.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
273. 8 ENG 2  0-35WO  0. 0   834.  11. 2  6. 9   -10.     F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F  F
```

Figure 3

Trained Rater-Observed Demerit Summary

9CHY-1 , FUEL 1, 19 DEG. F., RUN 26, CRC

CYC-		ST.	STALLS			IDLE						
LE	MANEUVER	TIME	IDLE	ACCEL.	DECEL.	ROUGHNESS	STUMBLE	EXTENSION	HESITATION	SURGE	BACKFIRE	TOTAL
0	START	7.4	16.	0.	0.	0.	0.	0.	0.	0	0.	23.4
1	0-25PT	0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0
1	CRUISE	0.0	0.	0.	0.	0.	0.	0	0.	0.	0.	0.0
1	25-35D	0.0	0.	0.	0.	0.	6.	0.	0.	0	0.	6.0
1	0-35WO	0.0	0.	32.	0.	0.	6.	0.	0	0.	0.	38.0
1	10-25P	0.0	0.	32.	0.	0.	12.	0.	0.	0	0.	44.0
1	IDLE	0.0	0.	0.	0.	0.	0.	0.	0	0	0.	0.0
TOTAL		7.4	16.	64.	0.	0	24.	0	0.	0	0.	111.4
2	0-25PT	0.0	0.	0.	0.	0	6.	0.	0.	0	0.	6.0
2	CRUISE	0.0	0.	0.	0.	0.	0.	0.	0	0	0.	0.0
2	25-35D	0.0	0.	0.	0.	0.	72.	0	0.	16.	0.	88.0
2	0-35WO	0.0	0.	32.	0.	0.	12.	0	0	0	12.	56.0
2	10-25P	0.0	0.	64.	0.	0.	12.	0	0.	0	0.	76.0
2	IDLE	0.0	0.	0.	0.	2.	0.	0	0	0	0.	2.0
TOTAL		0.0	0.	96.	0.	2.	102.	0	0.	16.	12.	228.0
3	0-25PT	0.0	0.	32.	0.	0.	36.	0.	0.	0	0.	68.0
3	CRUISE	0.0	0.	0.	0.	0.	0.	0	0.	0.	0	0.0
3	25-35D	0.0	0.	0.	0.	0.	24.	0	0	8.	24	56.0
3	0-35WO	0.0	0.	64.	0.	0.	12.	0	0.	0	54.	130.0
3	10-25P	0.0	0.	0.	0.	0	12.	0.	0.	0	0.	12.0
3	IDLE	0.0	0.	0.	0.	0.	0.	0.	0.	0	0.	0.0
TOTAL		0.0	0.	96.	0.	0.	84.	0	0.	8	78.	266.0
4	0-45CD	0.0	0.	0.	0.	0.	12.	0.	0.	0.	0.	12.0
4	CRUISE	0.0	0.	0.	0.	0.	0.	0	0.	0	0.	0.0
4	25-35D	0.0	0.	0.	0.	0.	24.	0.	0.	0	18.	42.0
4	0-35WO	0.0	0.	32.	0.	0	0.	0.	0.	0	54.	86.0
4	10-25P	0.0	0.	0.	0.	0.	0.	0.	0.	0	0.	0.0
4	IDLE	0.0	0.	0.	0.	2.	0.	0	0.	0.	0.	2.0
TOTAL		0.0	0.	32.	0.	2.	36.	0.	0.	0.	72.	142.0
5	0-45CD	0.0	0.	0.	0.	0.	0.	0	0.	0.	0.	0.0
5	CRUISE	0.0	0.	0.	0.	0.	0.	0	0	0	0.	0.0
5	25-35D	0.0	0.	0.	0.	0.	12.	0.	0	16	0.	28.0
5	0-35WO	0.0	0.	0.	0.	0.	6.	0.	0.	0.	6.	12.0
5	10-25P	0.0	0.	0.	0.	0.	6.	0.	0.	0.	0.	6.0
5	IDLE	0.0	0.	0.	0.	0.	0.	0	0.	0.	0.	0.0
TOTAL		0.0	0.	0.	0.	0.	24.	0	0.	16.	6.	46.0
6	0-45CD	0.0	0.	0.	0.	0.	30.	0.	0	0	0.	30.0
6	CRUISE	0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0
6	25-35D	0.0	0.	0.	0.	0.	0.	0.	0.	0	0.	0.0
6	0-35WO	0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0
6	10-25P	0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.0
TOTAL		0.0	0.	0.	0.	0.	30.	0.	0.	0.	0.	30.0
RUN TOTAL		7.4	16.	288.	0.	4.	300.	0.	0.	40.	168.	323.4

	Driveability Test Fuels*			
Driveability, °F (°C)	1	2A	2B	3
10% Evap.	135 (57)	105 (41)	115 (46)	128 (53)
50% Evap.	240 (116)	185 (85)	220 (104)	220 (104)
90% Evap.	360 (182)	305 (152)	330 (166)	330 (166)
Reid Vapor Pressure lbs. (Kpa)	8.4 (57.9)	13.5 (93.1)	10.5 (72.4)	8.3 (57.2)

* Fuels 1, 2A and 3 were used for Phase I testing and Fuels 1, 2B and 3 were used for Phases II thru VI.

Fuels 1, 2A, and 2B are the same fuels as the low, high, and average volatility fuels, respectively, used in the 1980 CRC program on cold start and warmup driveability. Fuel 3 was similar to Indolene used for EPA certification testing.

RESULTS

Trained Rater Observations

Trained rater observed demerits tabulated by test number and driveability problem type are shown in Appendix C. Total demerits for each test are shown in Table III. A few general conclusions can be made based on the information for Fuels 1 and 3 (the third fuel was changed after Phase I). Perhaps most noticeable is the large standard deviations shown in the table. They range from about 10 percent of the mean value to over 100 percent of the mean. Based on past experience, these standard deviations are unusually high and we suspect some of the variability is due to vehicle performance inconsistencies in addition to changes in rater severity between runs. Comparing Phase I and Phase II results it appears that driveability of this car at 70°F (21°C) is generally not as poor as at 20°F (-7°C) and, therefore 20°F (-7°C) would be a better temperature to use for developing an objective driveability system. Comparing Phases I and III it is interesting to note that use of the motorist driving cycle appears to have markedly improved the standard deviations without large changes in mean demerits.

Phases I and IV are identical except that they were conducted on dynamometers of different design. Because the means and standard deviations are nearly the same in both phases, we conclude that either dynamometer could be used equally well for driveability testing. In Phases V and VI the FTP driving cycle was used and ambient test temperatures were 20 and 70°F respectively. Recall that the car used for this test work had the poorest driveability of all those screened and yet average driveability demerits when using the FTP cycle are very low. Therefore, this cycle should not be used for driveability measurement

TABLE III

RATER-OBSERVED DEMERITS BY TEST PHASE

	Fuel:	1		2A or 2B *		3	
Test Phase	Rater:	A	B	A	B	A	B
I		577.6	617.6	149.4	34.8	335.0	199.2
		489.4	572.4	177.0	18.0	188.8	237.2
Large Dyno		613.4	543.4	326.8	106.0	188.8	175.0
CRC Cycle		1374.4	577.8	32.0	13.0	183.6	70.0
20°F (-7°C)		90.0	398.0	25.2	24.0	293.2	72.2
		700.0	311.6	10.0	37.0	152.0	54.2
		823.4	439.4	42.0	31.0	75.6	30.0
		717.6	268.0	18.6	31.0	28.2	81.2
		275.6	303.6	25.0	10.0	40.0	74.0
		295.2	515.8	38.4	12.0	28.2	58.2
		444.0	446.4	18.0	12.0	113.0	-
		332.2	270.8	7.2	44.8	-	-
		230.2	-	13.0	28.0	-	-
		508.8	-	-	25.0	-	-
		167.6	-	-	-	-	-
	** Mean	509.3	438.7	67.9	30.5	147.9	105.1
	Std. Dev., % of Mean	63.2	29.1	139.1	82.8	70.1	67.6
II		650.2	381.4	6.0	37.0	18.0	44.0
		208.4	126.0	15.2	47.0	25.0	51.0
Large Dyno		152.0	122.0	6.0	41.0	6.0	56.0
CRC Cycle		88.6	71.0	0.0	59.0	15.0	85.0
70°F (21°C)		35.0	-	6.0	-	0.0	-
	Mean	226.8	175.1	6.6	46.0	12.8	59.0
	Std. Dev., % of Mean	108.2	79.8	81.8	20.9	77.3	30.5
III		349.4	400.0	37.0	49.0	111.8	89.4
		365.6	422.4	80.0	92.0	89.4	68.0
Large Dyno		495.2	401.0	79.4	52.0	126.0	125.0
Motorist Cycle		326.4	344.2	93.2	93.0	120.8	93.0
20°F (-7°C)		414.8	345.4	-	120.0	67.4	92.0
		191.4	-	-	-	-	117.0
		369.8	-	-	-	-	-
	** Mean	358.9	382.6	72.4	81.2	103.1	97.4
	Std. Dev., % of Mean	25.7	9.3	33.8	37.2	23.6	21.2

TABLE III
- Continued -

RATER-OBSERVED DEMERITS BY TEST PHASE

	Fuel:	1		2A or 2B *		3	
Test Phase	Rater:	A	B	A	B	A	B
IV		284.0	157.0	151.0	275.0	24.0	130.2
		670.4	562.6	258.4	136.0	60.2	139.0
Small Dyno		293.0	432.6	293.4	138.0	18.2	101.4
CRC Cycle		592.6	333.6	244.4	129.0	112.4	101.4
20°F (-7°C)		-	596.0	102.2	-	224.4	-
		-	-	88.6	-	-	-
	** Mean	460.1	416.4	189.7	169.5	87.8	118.0
	Std. Dev., % of Mean	43.6	43.0	45.9	41.5	96.9	16.5
V		43.6	196.2	12.2	0.0	36.0	9.0
		99.0	174.6	42.2	6.0	14.0	21.0
Small Dyno		127.8	204.4	36.4	10.0	16.0	7.0
FTP Cycle		44.2	31.8	15.2	18.0	30.0	-
20°F (-7°C)		-	-	-	-	6.0	-
	** Mean	78.7	151.7	26.5	8.5	20.4	12.3
	Std. Dev., % of Mean	53.1	53.3	56.6	88.2	60.2	59.2
VI		8.0	148.0	42.0	22.0	24.0	8.0
Small Dyno		0.0	42.0	1.2	53.0	12.0	23.0
FTP Cycle		-	42.0	32.0	-	-	-
70°F (21°C)							
	** Mean	4.0	77.3	25.1	37.5	18.0	15.5
	Std. Dev., % of Mean	142.5	79.2	84.9	58.4	47.2	68.4

---

* Fuel 2B was used for all tests except Phase I.

** Means and Standard Deviations calculated from all available observations.

because it likely will not yield measurable driveability differences between cars. There are two possible explanations for the low demerits. First, the driver is forced to manipulate the throttle so vehicle speed follows an established speed versus time chart. This tends to mask driveability problems. Second, the FTP cycle is not severe enough (acceleration rates are low) to disclose driveability problems.

The computer routines that were developed are based solely upon the data collected in the Phase I tests; they are then applied to Phases II thru IV data. Because the FTP cycle is not well suited to driveability testing, we have not attempted to computer analyze the data from Phases V or VI.

Data Editing by Computer

An enormous amount of data was collected from the instruments and raters and stored by computer. To correlate the raters' evaluations with the engine/vehicle operating parameters, it was necessary to devise ways of eliminating data collected when specific driveability problems could not or should not occur. For measuring hard-starting (excessive cranking) demerits, the computer only considers data collected during the start maneuver. Recall that one of the keyboard entries by the rater was type of maneuver being made. To find idle stalls the computer "looks" during the start maneuver and all the idle maneuvers during the test. Conversely, driving stalls could occur during any maneuver except start or idle. To identify stumble and hesitation, the computer searches only those pieces of the data collected while an acceleration was being attempted. This means that first the computer completely ignored the start, cruise, and idle maneuvers. Second, because the CRC driving cycle is a series of maneuvers made at constant or continually increasing throttle opening, the beginning, duration, and end of each maneuver is computer-defined by throttle movements and position. The computer was programmed to recognize that an acceleration begins when the throttle opens by 2 percent (of full-throttle opening) or more in 0.2 seconds and continues as long as the throttle is open more than 18 percent or until the throttle closes by 2 percent or more in 0.2 seconds. Third, the computer was also programmed to ignore data collected during a transmission shift. This was done because the investigator's previous experience indicated that some engine/vehicle operating parameters respond to transmission shift and stumble in much the same manner. Transmission shift is not considered a driveability problem. A transmission shift occurs when all the following conditions are met:

1. Vehicle speed is above 10 mph and increasing by 1 mph during a 1.0 second interval.

2. Engine speed declines by 50 or more rpm over the same time interval as in "1".

3. Intake manifold vacuum declines during a 1.0 second interval which begins 0.4 seconds later than the interval in "1".

For any time interval in which these three requirements are met simultaneously, all data are excluded between the times when engine speed is maximum and minimum (inclusive).

By using these editing rules, the amount of data to be searched for driveability problems was reduced to a manageable size.

Stumble Measurement by Computer

Stumble is a sudden loss of power followed some time later by a recovery of power. By inspecting strip chart recordings of the engine/vehicle operating parameters, engine speed and driveshaft torque were initially selected for objectively measuring stumble. However, later analyses showed that excluding torque from consideration improved the system's stumble measurement ability. A brief description of this and several other unsuccessful attempts to objectively measure driveability problems (including stumble) are described in Appendix D.

Figure 4 graphically shows engine speed as a function of time during an acceleration in which the rater noted one heavy stumble occurred. The fluctuations or dips in engine speed are used for stumble measurement. This is not a novel idea; engine speed was also used extensively for objectively measuring stumble in a 1973 CRC program on driveability instrumentation (7). Attempts were made to correlate various characteristics of these dips with the severity (demerits) assigned the stumble by the trained rater. The correlation finally selected is:

$$\text{Rater Observed Stumble Demerits} = b_0 + b_1(\Delta t) + b_2(\Delta a) + b_3(\Delta t)(\Delta a)$$

where: b_i's are constants to be determined by regression analysis,
t and a are the time duration and amplitude, respectively, of a dip (see Figure 4).

Two questions presented themselves, however:

1. Should Δt be limited only to the time interval between maximum and minimum values of engine speed?

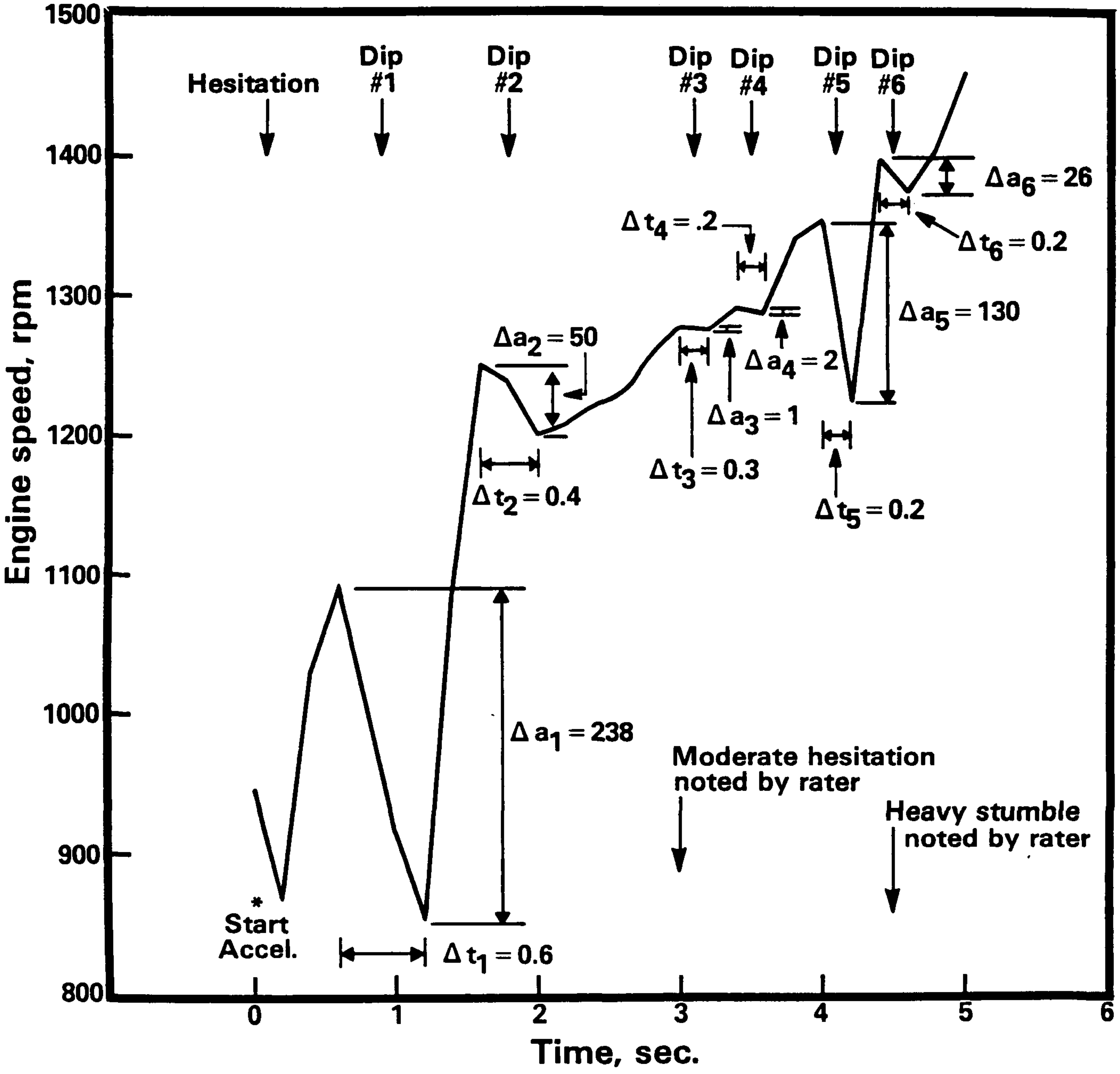
2. If the number of dips during an acceleration is greater than the number of stumble evaluations by the rater, which dip should be paired with the evaluation for the regression analysis (Figure 4 shows a case like this)?

To provide flexibility on the time interval question, part of the "shoulder" immediately prior to the dip is included in the Δt calculation. To do this, an RPM slope cut-off was established which effectively allows the dip to begin when the RPM slope drops below this value. The value of the slope cut-off (variable S) was not known and had to be determined.

Figure 4

Hesitation and Stumble(s) During an Acceleration

Phase I test #10, 4th 25-35 mph Detent



The problem of a rater identifying fewer stumbles than dips was handled with three rules. First, if the end of one dip and the beginning of the next dip were close to one another the dips were grouped together and the Δt and the Δa values of the individual dips were summed together. However, the amount of time to allow between dips without grouping them was unknown and had to be determined. This variable was named association interval "I". Second, through trial and error, it was discovered that many small dips not noticed by the raters could be eliminated from consideration by imposing some minimum requirements. Dips are ignored if the following three statements are <u>all</u> true:

1. $\Delta t < 0.4$ sec
2. $\Delta a < 68.5$ rpm
3. $(\Delta t)(\Delta a) < 207$

Third, of those dips remaining after applying these rules, it was necessary to find which ones to "pair" with the raters' evaluation of stumble (if any). To be paired with a dip, the drivers' keyboard entry of stumble could not preceed the beginning of a dip and both the keyboard entry and the dip had to occur within the same driving cycle maneuver. Of those dips which satisfy all these rules, the drivers' stumble evaluation was paired with the dip having the largest product of Δt and Δa and the remaining dips were paired with an assumed stumble demerit rating of zero.

A series of regressions were conducted to find the "best" values for the association interval (I), the slope cutoff (S), and the regression coefficients (b_i's) in the equation above. The Phase I driveability data were used for the regressions and included over 500 dips that potentially could be associated with rater observations of stumble. To run the regressions, values for S and I were manually entered into the computer. Next, the computer went through the data determining all the dip groupings and stumble pairings and last conducted a linear least squares regression to determine the stumble equation coefficients (b_i's). The best values for these variables are:

$S = 98$ rpm/sec
$I = 0.2$ sec

$$\text{Computer Calculated Stumble Demerits} = 9.107 - 1.76(\Delta t) + 0.0048(\Delta a) + 0.00377(\Delta t)(\Delta a)$$

This demerit equation and these values for "S" and "I" were next used to calculate stumble demerits for each driveability test conducted. Figure 5 is a comparisons of the trained rater-observed and computer-calculated stumble demerits for all engine speed dips in Phase I Test Number 73. Typically the computer and rater seldom agree exactly on the demerits to assign a given dip or stumble. This is partly because the rater is forced to put his evaluations into one of four categories having demerits of 0, 6, 12 or 24 (severities of none, slight, moderate and heavy, respectively). The computer on the other hand assigns demerits using a continuous function. Another part of the rater versus computer discrepancy is caused by inconsistent severity assignments by the rater whereas the computer, given a set of rules, is very consistent in assigning demerits.

Figure 5

Stumble Demerits in Test 73 (Phase I)

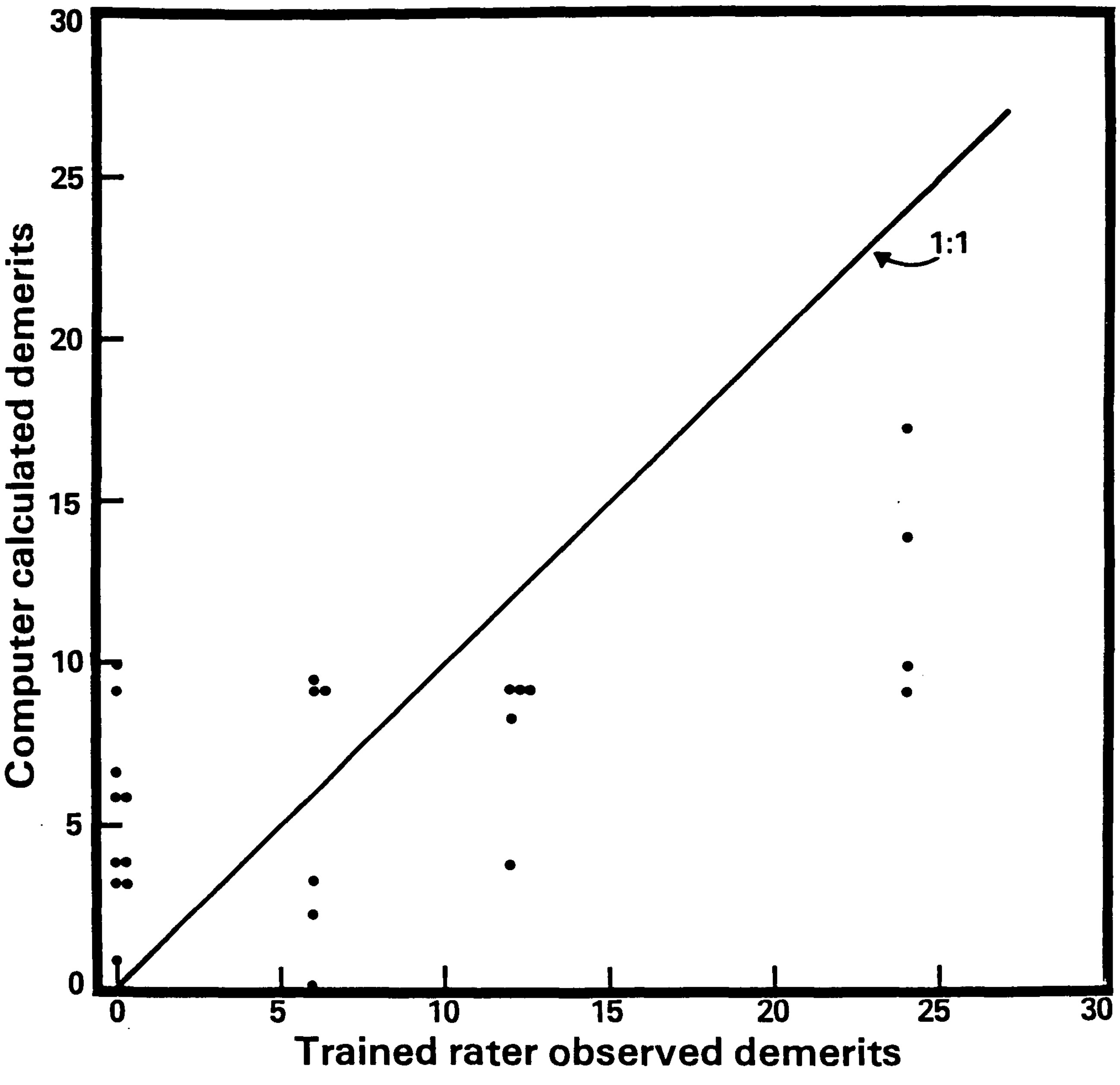


Figure 6 is a comparison of rater and computer stumble demerits for Phase I tests. Each data point represents total stumble demerits for one driveability test. In this case the two are in good general agreement but the computer tends to underpredict at high demerit levels and overpredict at lower levels. Another regression of computer-versus-rater demerits could have been conducted to improve the agreement between the computer and rater but this was not done because the result certainly would only apply to the car tested in this program and the general conclusions would remain unchanged.

Compared with the rater evaluations, the computer calculations yield a narrower range of average demerits between low and high volatility fuels. This does not mean the computer method is less able to measure performance difference between fuels. Because the standard deviations of the computer averages are lower than those of the trained rater averages (Table IV), the difference between fuels is measured with greater confidence by the computer than by the raters. These analyses show that the computer system developed can adequately measure stumble demerits <u>for this car</u>; whether this system can be used for other cars cannot be determined without further testing beyond the scope of this contract.

Hesitation Measurement by Computer

Hesitation is a momentary lack of response to opening the throttle. Again, after inspecting strip charg recordings, engine speed was selected as the best parameter to use for detecting and measuring hesitation. Following several futile attempts, described in Appendix D, a method was developed which correlates rater-observed hesitation with the rates of throttle opening, and engine speed increase during the initial 1.0 second of an acceleration, and with the vehicle speed immediately before the start of an acceleration. It was theorized that the raters' opinion of hesitation was primarily influenced by how rapidly the engine speed <u>initially</u> responded to the throttle movement and less influenced by the response later in the one-second interval. The relationship form is:

$$\text{Rater Observed Hesitation Demerits} = b_0 + b_1 \left(\frac{\text{WTTL}}{\text{MPH}_0 + 0.58}\right) + b_2 \text{ WRPM}$$

where: MPH_0 is vehicle speed 0.2 seconds prior to the acceleration start

$$\text{WRPM} = 0.5(\Delta\text{RPM}_1)+0.25(\Delta\text{RPM}_2)+0.13(\Delta\text{RPM}_3)+0.06(\Delta\text{RPM}_4)+0.06(\Delta\text{RPM}_5)$$

$$\text{WTTL} = 0.5(\Delta\text{TTL}_1)+0.25(\Delta\text{TTL}_2)+0.13(\Delta\text{TTL}_3)+0.06(\Delta\text{TTL}_4)+0.06(\Delta\text{TTL}_5)$$

ΔRPM_i is the engine speed (rpm) increase during the i^{th} 0.2-second time interval following the start of an acceleration

ΔTTL_i is the throttle opening (expressed as percent of wide-open) increase during the i^{th} 0.2-second time interval beginning 0.2 seconds before the start of an acceleration

This demerit calculation scheme places strong emphasis upon the first 0.2 seconds of an acceleration and progressively less emphasis upon following time intervals. The data used for this regression analysis is shown in Appendix E. It consists of the 27 accelerations during the Phase I

Figure 6

Stumble Demerits for Phase I Tests

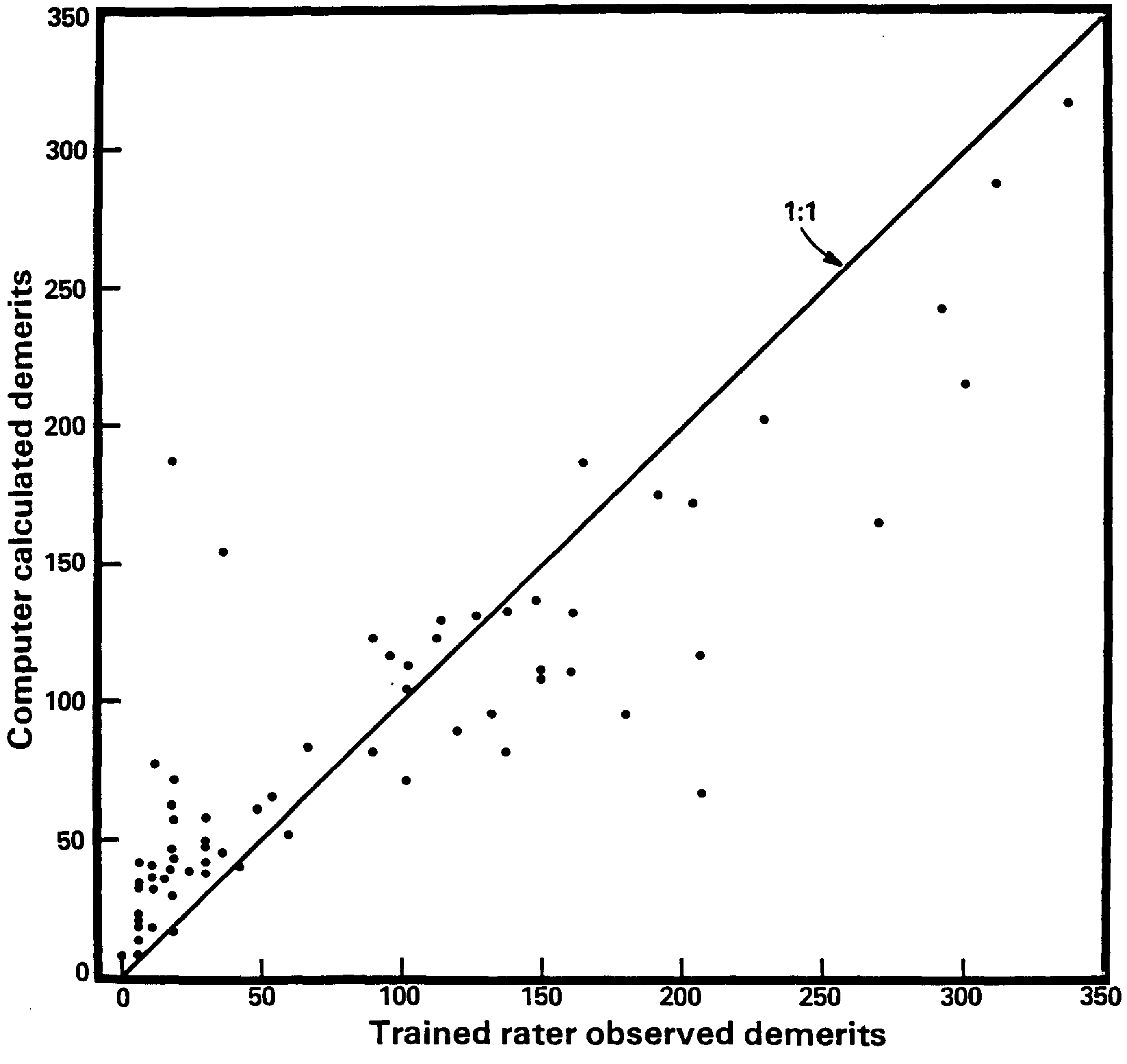


TABLE IV

STUMBLE DEMERITS BY TEST FUEL
(Test Phase I)

Fuel 1			Fuel 2A			Fuel 3		
Test Number	Stumble Demerits		Test Number	Stumble Demerits		Test Number	Stumble Demerits	
	Rater	Comp.		Rater	Comp.		Rater	Comp.
1	168	- *	4	18	71.2			
2	180	-	5	18	61.7	16	102	113.1
3	330	-	7	126	135.6	20	204	171.5
6	336	316.9	8	162	188.7	21	150	111.7
9	738	-	11	24	193.3	23	132	95.4
10	306	215.3	14	210	62.8	24	102	71.2
12	312	288.5	17	12	76.3	25	120	89.6
13	90	123.2	18	18	57.1	27	210	124.9
19	294	242.0	22	30	58.1	32	102	109.1
26	300	-	28	30	41.2	36	54	65.2
30	270	165.6	29	30	49.8	37	60	51.1
31	354	-	33	30	38.4	44	18	30.3
34	150	109.2	39	6	21.7	48	30	-
35	138	81.3	41	6	33.0	49	12	38.0
38	96	116.2	46	6	42.0	51	18	45.9
40	144	135.9	52	12	45.3	55	6	33.2
42	228	202.7	54	0	7.3	57	18	43.2
43	162	113.5	56	6	34.7	62	48	61.3
47	114	129.6	58	6	23.6	70	36	153.9
50	90	81.9	61	24	28.2	76	42	40.5
53	162	133.2	64	12	36.0	79	36	45.1
59	108	123.8	66	6	19.9			
65	180	98.5	69	18	16.9			
68	66	84.1	72	24	39.4			
73	192	175.2	74	6	14.9			
77	138	133.1	80	18	46.3			
			81	6	19.6			
**Mean	217.2	153.5		32.0	54.2		75.0	78.6
Std. Dev., % of Mean	63	44		158	87		83	54

---

* Dashes indicate that the test data could not be computer analyzed.

** Means and Standard Deviations are calculated from all available observations.

tests in which the trained raters said hesitation occurred and another 36 accelerations made when the car was fully warmed-up and no hesitations were recorded by the rater. The demerit calculation equation resulting from the linear-least squares regression on this data is:

$$\text{Hesitation Demerits} = 7.5 + .25\left(\frac{\text{WTTL}}{\text{MPH}_0 + 0.58}\right) - 0.033\ \text{WRPM}$$

To improve the agreement between rater-observed and computer-calculated hesitation demerits, a few empirical requirements were established which must be met before hesitation demerits are calculated for an acceleration. Demerits are calculated if:

1. the engine was still running 3.0 seconds after the start of the acceleration (intake manifold vacuum $>$0.0" Hg) or
2. WRPM is less than 140 or
3. a. $\frac{\text{WRPM}}{\text{WTTL}}$ is 7 or less and

   b. MPH_0 is 0.2 or less

In general, the equations and rules assign hesitation demerits to those accelerations when the engine speed increase was "abnormally slow". The correct engine speed increase is defined by the rate and final amount of throttle opening and by car speed at the start of the acceleration. For example, an acceleration with slow engine speed increase will be assigned fewer demerits if the throttle opening-rate is slow rather than fast.

Results of applying this method to the Phase I data are shown in Figure 7 and Table V. Each data point in the figure represents the total hesitation demerits for one driveability test. The figure shows that total hesitation demerits calculated for each test do not agree with the rater observed values. One obvious explanation for this is that other independent variables should be included in the prediction equation. Another possible reason for the discrepancy is that raters may have mis-named some hesitations as stumble and vice-versa -- often these driveability problems are difficult for a rater to distinguish.

In studying Table V, there is another fact which comes to light. Average computer-demerits are considerably higher than the rater-observed values but, the standard deviations (as percent of the mean) of the computer values are much less than for the rater values. Additionally, the computer method, like the rater, recognizes a difference in performance of low-volatility Fuel 1 and high-volatility Fuel 2A.

Figure 7

Hesitation Demerits for Phase I Tests

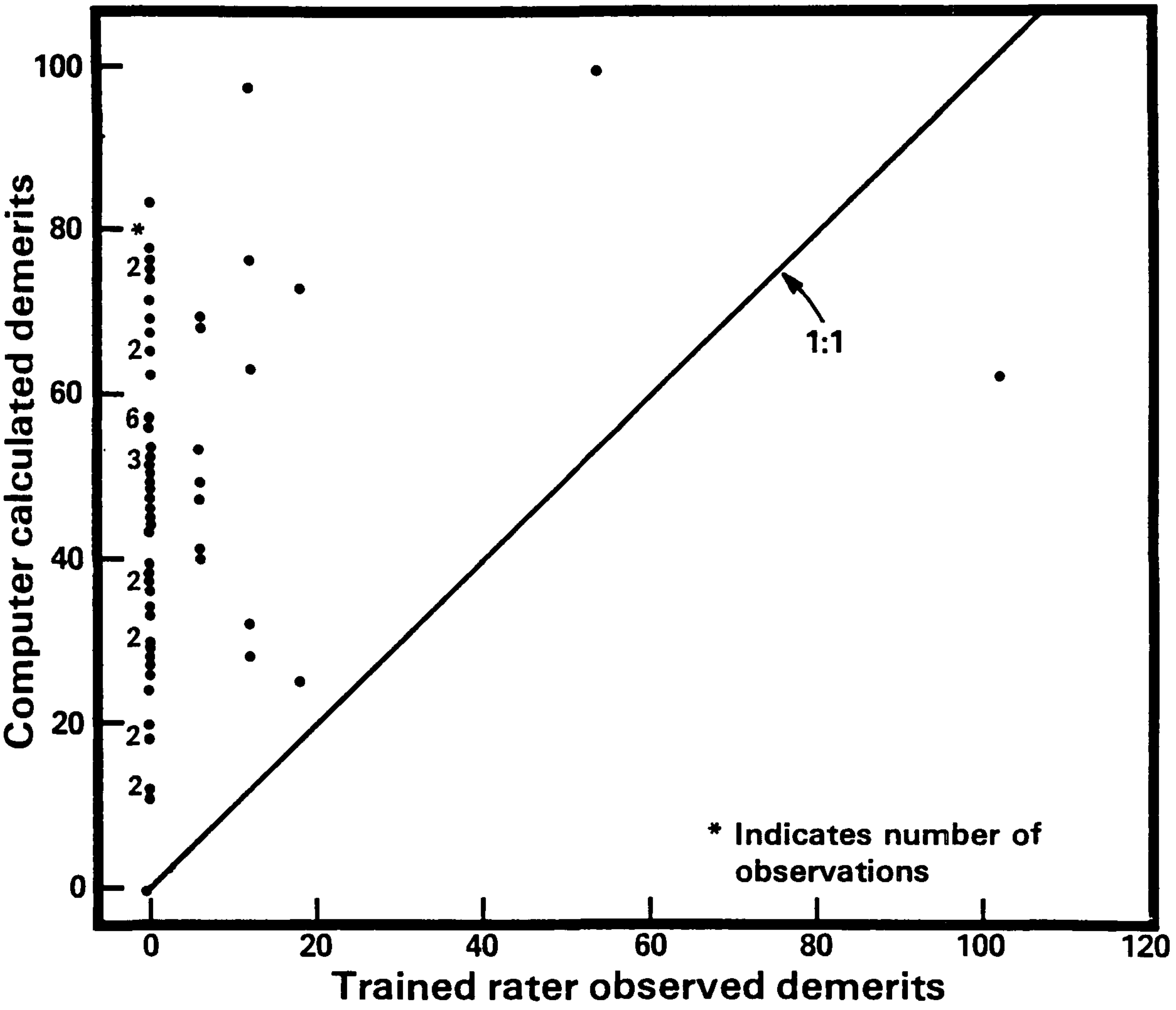


TABLE V

HESITATION DEMERITS BY TEST FUEL
(Test Phase I)

Fuel 1			Fuel 2A			Fuel 3		
	Hesitation Demerits			Hesitation Demerits			Hesitation Demerits	
Test Number	Rater	Comp	Test Number	Rater	Comp	Test Number	Rater	Comp
1	36	-*	4	0	30			
2	66	-	5	0	27	16	0	78
3	102	62	7	18	25	20	6	69
6	0	75	8	12	28	21	0	74
9	54	99	11	12	97	23	6	53
10	18	73	14	0	42	24	6	40
12	12	63	17	0	28	25	0	69
13	0	12	18	0	57	27	0	57
19	0	76	22	6	41	32	0	52
26	0	38	28	0	49	36	0	37
30	0	77	29	0	36	37	0	44
31	12	76	33	0	12	44	6	68
34	0	65	39	0	30	48	0	52
35	0	47	41	0	11	49	0	71
38	0	37	46	0	26	51	0	54
40	0	83	52	0	18	55	0	53
42	0	67	54	0	62	57	6	47
43	0	46	56	0	48	62	0	24
47	0	57	58	12	32	70	0	57
50	0	34	61	0	45	76	0	52
53	0	56	64	0	39	79	0	33
59	0	57	66	0	57			
65	0	76	69	0	29			
68	6	49	72	0	43			
73	0	50	74	0	0			
77	0	51	80	0	19			
			81	6	18			
**Mean	11.8	59.6		2.2	35.1		1.5	54.2
Std. Dev., % of Mean	215	31		223	55		178	26

---

* Dashes indicate that the test data could not be computer analyzed.

** Means and Standard Deviations are calculated from all available observations.

Because of the large discrepancy between rater and computer demerits, the hesitation method developed in this investigation is inadequate and additional effort needs to be expended on this problem, first using the data collected in this program and then with data from other cars.

Engine Stall Measurement by Computer

An engine stall is any time when the engine quits running with the ignition switch in the "on" position. Developing a method of detecting engine stalls was relatively simple. The computer searches the data to:

1. find when the starter was engaged,
2. determine the type of driving maneuver being attempted when the engine stalled,
3. read engine speed following each starter engagement.

After the initial startup, 8 demerits were assigned whenever the starter was engaged if it occurred during the start or idle maneuvers, and 32 demerits if an acceleration or cruise was being executed. Engine speed was used simply to ensure that the car restarted between starter engagements. If engine speed did not reach 500 rpm between attempted starts, then the computer treated the first engagement as a false start and assigned no demerits. The computer and rater comparisons of total stall demerits by test is shown in Figure 8 and in Table VI. From the figure it is easy to see that the computer and trained rater stall demerits agreed very closely. The cases of disagreement were caused by various factors but primarily they resulted from improper data input by the trained rater or instrumentation failure during the test. These procedures for detecting engine stalls are perfected for future use.

Engine Idle Roughness Measurement by Computer

Engine idle roughness is the degree of smoothness perceived by a driver while the engine is idling. The method developed for measuring engine idle roughness is also based upon engine speed fluctuations. In this case only the start and idle maneuvers are computer-inspected for idle roughness. Each of these maneuvers is divided into a series of concurrent five-second intervals. Within each interval the computer searches for the minimum and maximum value of engine speed. From these speed ranges the computer selects the broadest one for the start and each idle maneuver. A least squares regression was run using the speed range and rater observed demerits from the few maneuvers when the rater noticed idle roughness. The resulting equation is:

$$\text{Idle Roughness Demerits} = -1.0 + 0.038\ (\text{Max speed range})$$

Figure 8

Stall Demerits for Phase I Tests

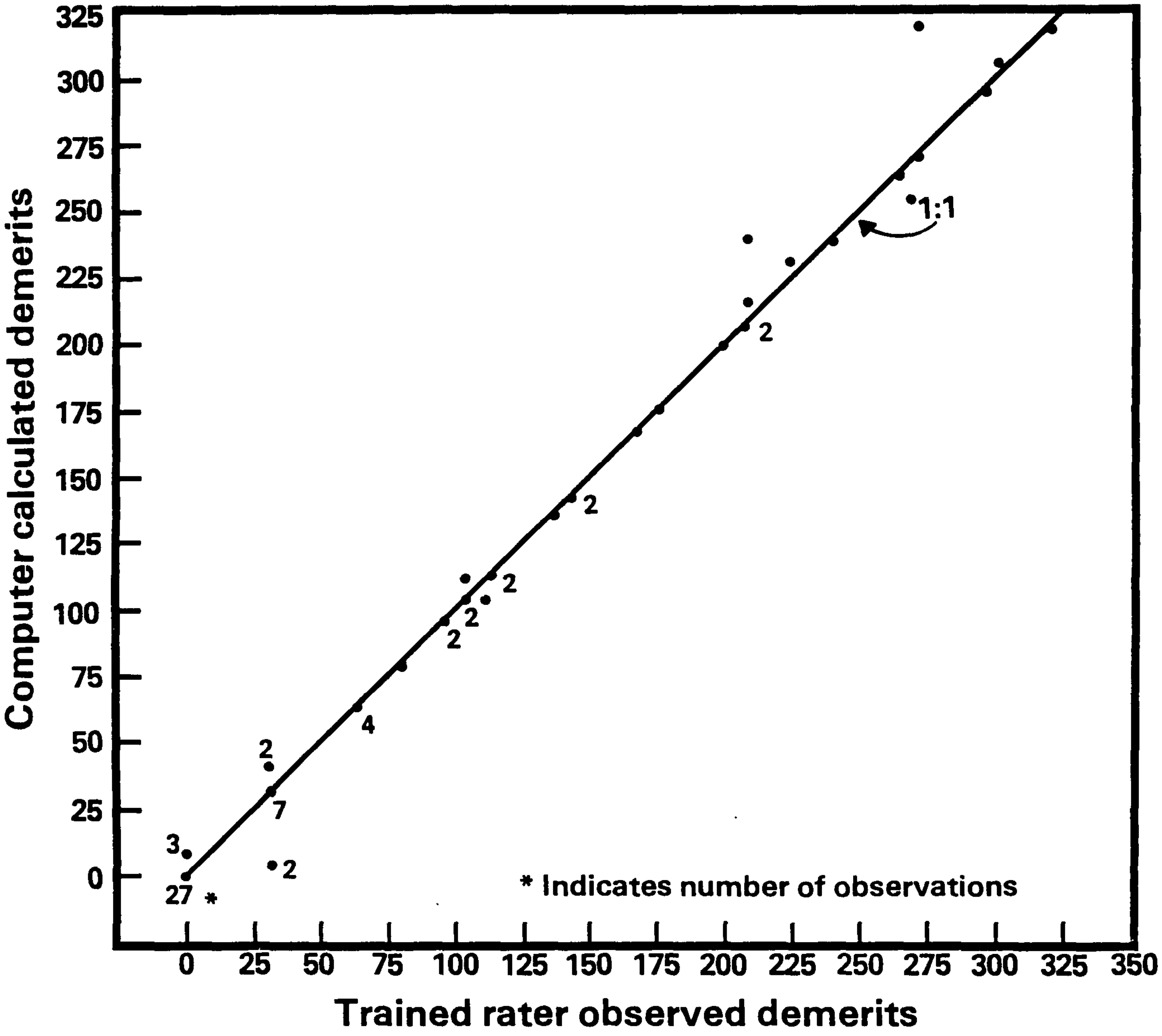


TABLE VI

STALL DEMERITS BY TEST FUEL
(Test Phase I)

Fuel 1			Fuel 2A			Fuel 3		
	Stall Demerits			Stall Demerits			Stall Demerits	
Test Number	Rater	Comp.	Test Number	Rater	Comp.	Test Number	Rater	Comp.
1	272	312	4	0	0			
2	224	232	5	0	0	16	96	96
3	136	136	7	0	0	20	104	112
6	208	216	8	0	0	21	32	32
9	272	256	11	64	64	23	96	96
10	208	208	14	32	32	24	64	64
12	176	176	17	0	0	25	32	40
13	0	0	18	0	0	27	64	64
19	320	320	22	0	0	32	32	32
26	304	304	28	0	0	36	0	0
30	272	272	29	0	0	37	0	8
31	240	240	33	0	0	44	0	0
34	208	240	39	0	8	48	32	32
35	144	144	41	0	0	49	0	8
38	168	168	46	0	0	51	32	32
40	112	104	54	0	0	55	0	0
42	144	144	54	0	0	57	0	0
43	200	200	56	32	0	62	32	32
47	112	112	58	0	0	70	32	40
50	104	104	61	0	0	76	64	64
53	112	112	64	32	32	79	0	0
59	296	296	66	32	0			
65	264	264	69	0	0			
68	80	80	72	0	0			
73	208	208	74	0	0			
77	104	104	80	0	0			
			81	0	0			
**Mean	188.0	190.5		7.1	5.0		35.6	37.6
Std. Dev., % of Mean	43	43		228	292		98	93

** Means and Standard Deviations are calculated from all available observations.

Rules are applied to eliminate data collected during engine stalls or when the transmission is placed in gear because either one creates very large speed ranges and abnormally large idle roughness demerits. Comparisons between computer and trained rater demerits for idle roughness are shown in Table VII and Figure 9. Average demerits by the computer compare favorably with the trained rater evaluations (Table VIII), but totals for individual tests do not agree well as shown in Figure 9. Because idle roughness contributes very little to total demerits, the method developed is adequate for this car but more effort is required using additional cars.

Hard Starting Measurement by Computer

Hard starting is excessive cranking during start-up. To measure this problem, only the start maneuver is investigated by the computer. The computer records the amount of time (seconds) the starter is engaged and after subtracting 2 seconds, the result is hard starting demerits. Because this is such a straight-forward measurement, the raters only measured crank times during the first few Phase I tests to ensure the computer was making the proper calculations. Hard starting demerits are listed in Table VIII. No comparison between rater-observed and computer-calculated demerits is possible, but this method is perfected for future use.

Total Demerit Measurement - Phase I Tests

Figure 10 and Table IX show comparisons of computer-calculated and rater-observed demerits totaled across the five driveability problems for which objective measurement methods were developed. The figure shows that total rater and computer demerits follow the same trend but the computer demerits are generally higher. Table IX supports this conclusion for Fuels 2A and 3, but not for Fuel 1 because of the 6 tests listed in the table which are not shown on the figure (tests 1, 2, 3, 9, 26, and 31 could not be computer-analyzed). Excluding these would lower the mean rater demerits from 425.6 to 359.6 and reduce the standard deviation from 48 to 41 percent of the mean.

As expected from results on the 5 individual driveability problems, the computer calculation methods yield lower standard deviations than the rater observations although the reduction is negligible for Fuel 1. Furthermore, the computer methods apparently can distinguish between performance differences of fuels.

Demerit Measurement - Phase II, III and IV Tests

In Appendix F the rater-observed and computer-calculated demerits are tabulated for each driveability test conducted in Phases II, III and IV. In general, these data further support the above conclusions about adequacy of the computer methods. For brevity, only total demerits in Phases II-IV will be discussed; these data are presented in Table X.

TABLE VII

IDLE ROUGHNESS DEMERITS BY TEST FUEL
(Test Phase I)

Fuel 1			Fuel 2A			Fuel 3		
	Idle Roughness Demerits			Idle Roughness Demerits			Idle Roughness Demerits	
Test Number	Rater	Comp.	Test Number	Rater	Comp.	Test Number	Rater	Comp.
1	7	- *	4	1	0.4			
2	9	-	5	0	2.5	16	1	3.2
3	1	2.6	7	1	6.4	20	6	9.1
6	5	-	8	3	0.9	21	0	2.1
9	18	-	11	0	-	23	3	$\boxed{18.9}$
10	13	5.5	14	0	1.3	24	3	3.1
12	6	9.5	17	1	1.9	25	0	$\boxed{12.3}$
13	0	10.0	18	2	2.1	27	1	3.1
19	5	$\boxed{76.7}$	22	1	1.1	32	0	0.7
26	4	-	28	1	0.4	36	0	1.7
30	3	5.8	29	1	1.8	37	0	1.4
31	0	-	33	2	1.6	44	0	0.6
34	1	3.6	39	1	1.1	48	0	1.7
35	3	2.3	41	0	3.0	49	0	0.6
38	3	8.5	46	0	1.9	51	0	6.8
40	1	5.4	52	0	2.6	55	0	1.6
42	9	10.9	54	0	2.0	57	0	1.3
43	10	6.7	56	0	1.2	62	1	0.8
47	7	10.2	58	0	1.3	70	0	0.0
50	0	4.7	61	1	0.8	76	0	1.7
53	7	8.4	64	0	2.9	79	0	1.0
59	1	0.1	66	0	0.8			
65	6	4.6	69	0	1.1			
68	0	4.8	72	0	1.4			
73	8	6.3	74	0	1.5			
77	5	6.3	80	1	7.8			
			81	0	2.5			
**Mean	5.3	6.1		0.6	2.0		0.8	2.2
Std. Dev., % of Mean	81	48		133	83		194	104

---

* Dashes indicate that the test data could not be computer analyzed.

** Means and Standard Deviations are calculated from all available observations except boxed values which appear to be outliers.

Figure 9

Idle Roughness Demerits for Phase I Tests

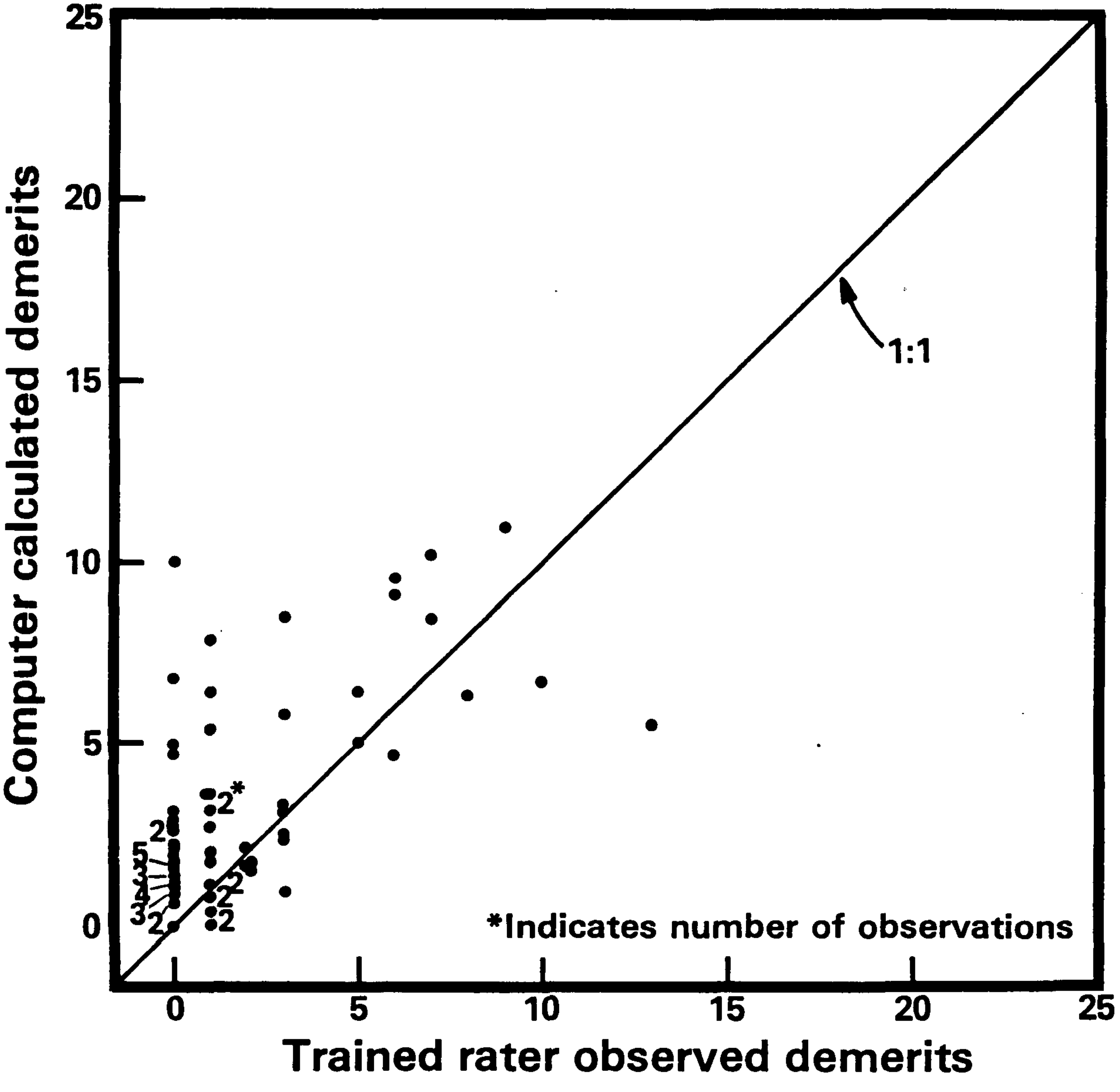


TABLE VIII

HARD STARTING DEMERITS* BY TEST FUEL
(Test Phase I)

Fuel 1		Fuel 2A		Fuel 3	
Test Number	Hard Starting Demerits	Test Number	Hard Starting Demerits	Test Number	Hard Starting Demerits
1	4.6	4	15.8		
2	4.4	5	0.0	16	0.2
3	2.4	7	4.4	20	3.0
6	16.6	8	0.0	21	0.8
9	4.4	11	0.0	23	0.2
10	1.4	14	0.8	24	0.0
12	3.4	17	0.0	25	7.6
13	0.0	18	0.0	27	0.2
19	3.0	22	0.0	32	0.0
26	7.4	28	0.0	36	0.0
30	2.8	29	0.0	37	15.6
31	13.6	33	0.0	44	0.2
34	3.0	39	14.2	48	0.2
35	2.6	41	0.0	49	16.0
38	4.6	46	0.0	51	0.2
40	2.2	52	0.0	55	0.2
42	2.4	54	0.0	57	0.0
43	2.0	56	0.0	62	0.2
47	3.0	58	0.6	70	0.0
50	2.2	61	0.0	76	1.0
53	2.6	64	0.8	79	0.2
59	1.8	66	0.4		
65	1.8	69	0.0		
68	3.6	72	0.0		
73	2.4	74	1.2		
77	1.8	80	0.0		
		81	1.0		
**Mean	3.8		1.4		2.3
Std. Dev., % of Mean	95		286		215

---

* Starting time used for calculating hard starting demerits was not measured by the trained rater -- only by the computer. The hard starting demerits shown are included in the total for both the trained rater and computer.

** Means and Standard Deviations are calculated from all available observations.

Figure 10

Total Demerits for Phase I Tests

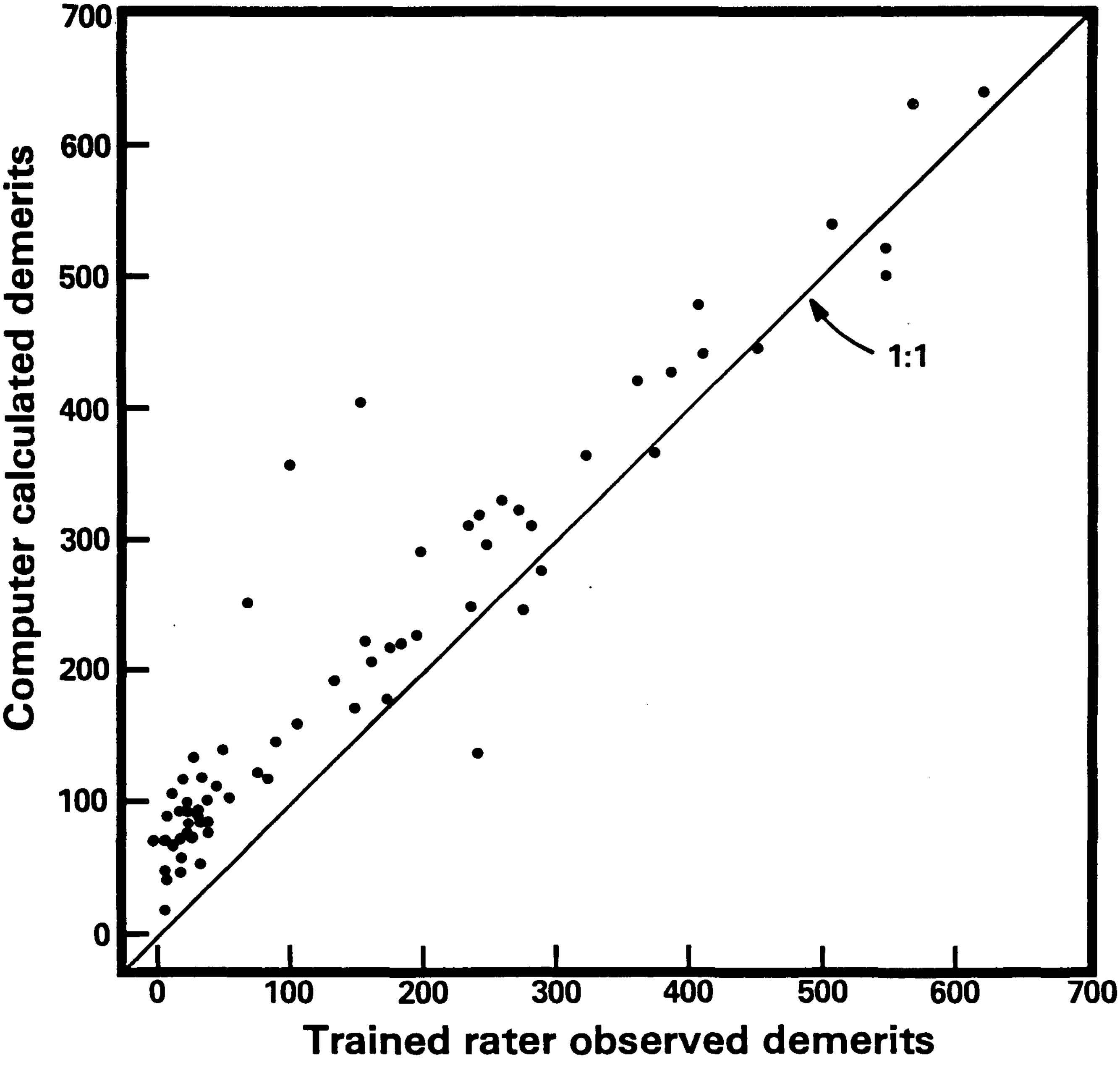


TABLE IX

TOTAL DEMERITS* BY TEST FUEL
(Test Phase I)

Fuel 1			Fuel 2A			Fuel 3		
	Total Demerits			Total Demerits			Total Demerits	
Test Number	Rater	Comp.	Test Number	Rater	Comp.	Test Number	Rater	Comp.
1	487.6	-**	4	34.8	117.4			
2	483.4	-	5	18.0	91.2	16	199.2	290.5
3	571.4	-	7	149.4	171.4	20	323.0	364.6
6	565.6	630.6	8	177.0	217.6	21	182.8	220.6
9	1086.4	-	11	100.0	356.3	23	237.2	246.8
10	546.4	503.2	14	242.8	138.9	24	175.0	178.5
12	509.4	540.4	17	13.0	106.2	25	159.6	208.4
13	90.0	145.2	18	20.0	116.2	27	275.2	249.2
19	622.0	647.1	22	37.1	100.2	32	134.0	193.8
26	615.4	-	28	31.0	90.6	36	54.0	103.9
30	547.8	523.2	29	31.0	87.6	37	75.6	120.1
31	625.6	-	33	32.0	52.0	44	24.2	99.1
34	362.0	420.8	39	21.2	75.0	48	62.4	-
35	287.6	277.2	41	6.0	47.0	49	28.0	133.6
38	271.6	334.3	46	6.0	69.9	51	50.2	138.9
40	259.2	330.5	52	12.0	65.9	55	6.2	88.0
42	383.4	427.1	54	0.0	71.3	57	24.0	91.5
43	374.0	368.2	56	38.0	83.9	62	81.2	118.3
47	236.0	311.8	58	18.6	57.5	70	68.0	250.9
50	196.2	226.8	61	25.0	74.0	76	107.0	159.2
53	283.6	312.2	64	44.8	110.7	79	36.2	79.3
59	406.8	478.7	66	38.4	78.1			
65	451.8	444.9	69	18.0	47.0			
68	155.6	221.5	72	24.0	83.8			
73	410.4	441.5	74	7.2	17.6			
77	248.8	296.3	80	19.0	73.1			
			81	7.0	41.1			
***Mean	426.1	394.1		43.4	97.8		115.2	175.5
Std. Dev., % of Mean	48	34		133	67		79	45

---

* Total demerits for stumble, hesitation, stalls, idle roughness and hard starting.

** Dashes indicate that the test data could not be computer analyzed for one or more driveability problems.

*** Mean and Standard Deviations are calculated from all available observations.

TABLE X

TOTAL DEMERITS BY TEST FUEL
(Test Phases II-IV)

	Fuel 1			Fuel 2B			Fuel 3		
	Test	Total Demerits		Test	Total Demerits		Test	Total Demerits	
Test Phase	Number	Rater	Comp.	Number	Rater	Comp.	Number	Rater	Comp.
II	4	590.2	-	1	6.0	103.8	3	18.0	215.8
	5	377.4	390.5	2	92.0	127.6	6	36.0	90.2
	8	202.4	338.3	7	97.0	51.8	10	24.0	107.1
	11	152.0	290.4	9	108.0	54.1	12	23.0	33.3
	13	102.0	165.6	14	23.0	57.3	16	6.0	143.1
	15	90.0	123.9	18	0	63.1	19	15.0	115.2
	17	78.6	135.1	21	6.0	123.0	22	0	-
	20	31.0	107.9	25	29.0	60.6	24	36.0	30.4
	23	39.0	-	27	39.0	56.2	26	65.0	60.5
*Mean		184.7	222.0		44.4	77.5		24.8	99.5
Std. Dev., % of Mean		100	52		97	40		78	62
III	28	339.4	-	29	37.0	120.7	30	79.8	125.2
	31	245.6	312.2	32	45.0	48.3	33	89.4	-
	34	338.0	234.7	38	84.0	131.6	35	64.0	114.6
	36	412.4	-	41	74.0	133.3	37	111.0	112.8
	40	387.2	-	44	46.0	111.6	39	57.4	145.7
	43	305.0	-	47	63.4	140.9	42	80.0	133.9
	46	302.2	321.4	51	81.0	143.8	45	93.0	135.4
	49	148.4	-	54	92.0	-	48	88.8	140.3
	50	222.4	278.1	56	57.2	140.2	52	82.0	125.4
	53	309.4	-				55	101.0	-
	58	177.4	133.2				57	39.4	112.1
	59	307.8	-						
*Mean		291.3	255.9		64.4	121.3		80.5	126.3
Std. Dev., % of Mean		27	30		30	26		25	10
IV	61	127.0	162.5	60	79.0	46.1	63	24.0	75.5
	65	482.0	602.8	62	190.4	201.3	67	60.2	83.6
	68	224.0	272.4	64	253.4	232.3	69	18.2	60.1
	70	566.4	549.7	66	212.4	175.5	74	106.2	140.8
	72	318.6	407.7	71	309.0	266.9	76	90.4	157.5
	77	249.6	293.5	73	94.0	130.7	79	89.0	186.8
	80	179.0	257.8	75	90.2	121.5	82	146.4	167.4
	83	370.6	413.0	78	96.0	153.1	84	84.4	236.9
	86	350.0	329.8	81	76.6	130.5			
				85	93.0	133.7			
*Mean		318.6	365.5		149.4	159.2		77.4	138.6
Std. Dev., % of Mean		45	39		57	39		55	48

---

* Means and Standard Deviations are calculated from all available observations.

Figures 11, 12 and 13 are comparisons of rater and computer total demerits for Phases II, III and IV, respectively. As with the Phase I results (Figure 10) each of these show that total demerits calculated by computer generally increase with rater-observed values and at low demerit levels the computer tends to calculate higher demerits than observed by the rater. Insufficient data are available for Phases II and III to draw firm conclusions about the relative magnitude of computer and rater demerits at higher demerit levels. However, the Phase IV data agree with Phase I in that generally the computer demerits are larger than rater demerits over a broad range of demerits.

Consolidation of Computer Methods

The five computer methods described thus far (one for each driveability problem) were developed independently. The data were first analyzed for stumble then reanalyzed for hesitation and so on. This requires about 1-1/2 hours* of computer time to completely analyze each driveability test of only 20 minutes duration. To reduce the needed computer time and to compile the various computer schemes into a single "package," the individual analyses were consolidated into one large computer program capable of analyzing an entire driveability test with one pass through the data. This reduces the analysis time to only about 20 minutes per test.

Only the Phase I data were analyzed using the consolidated program -- results are tabulated in Appendix G. The one major drawback of the consolidated program is that relative to the independent analysis method, computer-calculated and rater-observed stumble demerits do not agree well, as can be seen by comparing Figures 6 and 14. When the data were independently analyzed for the five driveability problems, it was possible for the computer to assign both hesitation and stumble demerits to a short interval of data at the start of an acceleration. It was decided that this should be prohibited in the consolidated program by giving preference to hesitation. Stumble demerits were only assigned to segments of data where hesitation was not detected. Compared with the independent analysis methods, it was expected that the consolidated program would calculate fewer stumble demerits, but the magnitude of the reduction (nearly 50 demerits average) was larger than expected. A similar reduction in total demerits also results from using the consolidated program. Additional time is necessary to perfect the consolidated program.

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* The computer being used for these analyses has memory capability of only 64K bytes. Analysis time could be reduced by at least one order of magnitude if a computer with more memory (e.g. an IBM 370) were used.

Figure 11

Total Demerits for Phase II Tests

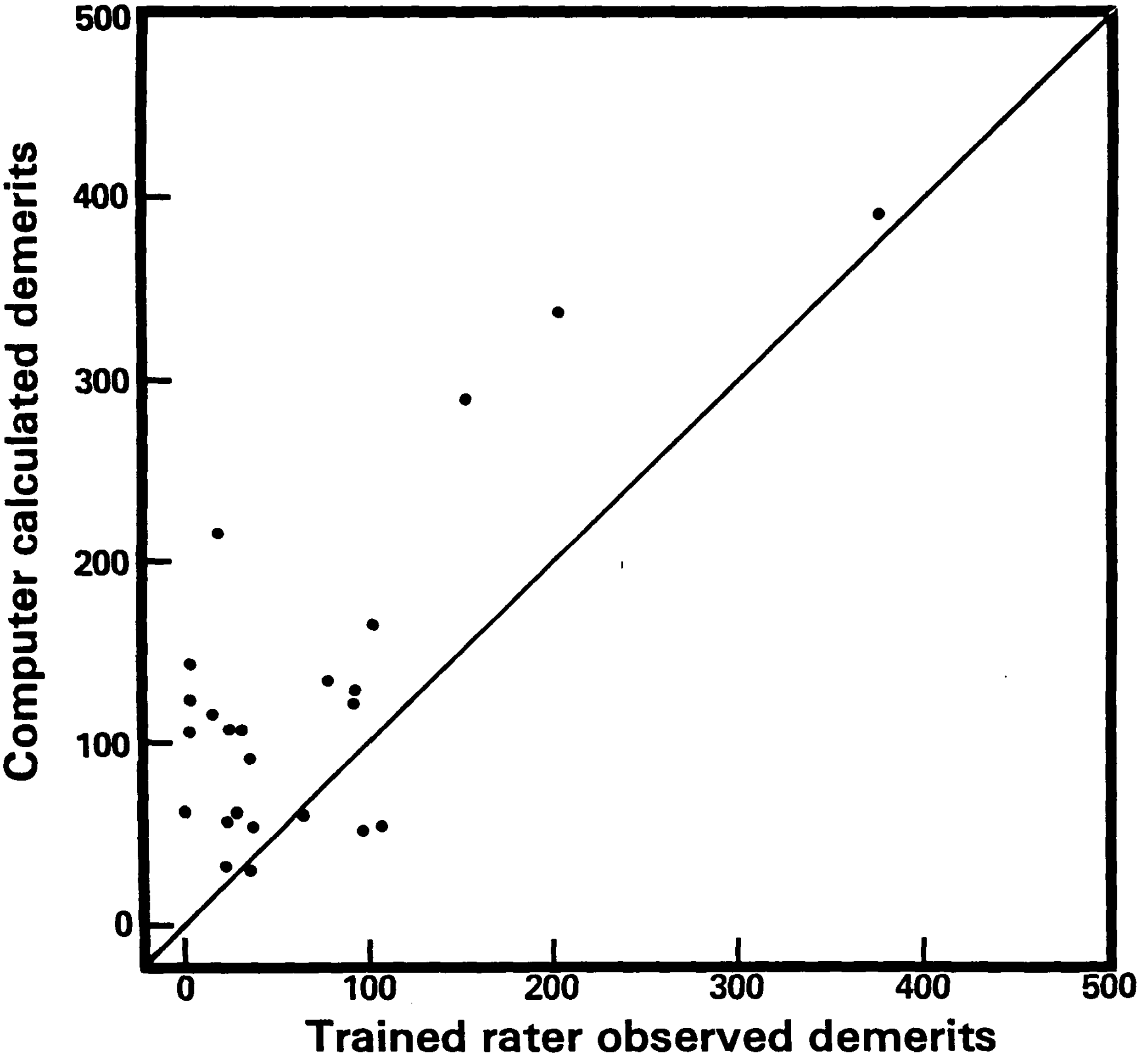


Figure 12

Total Demerits for Phase III Tests

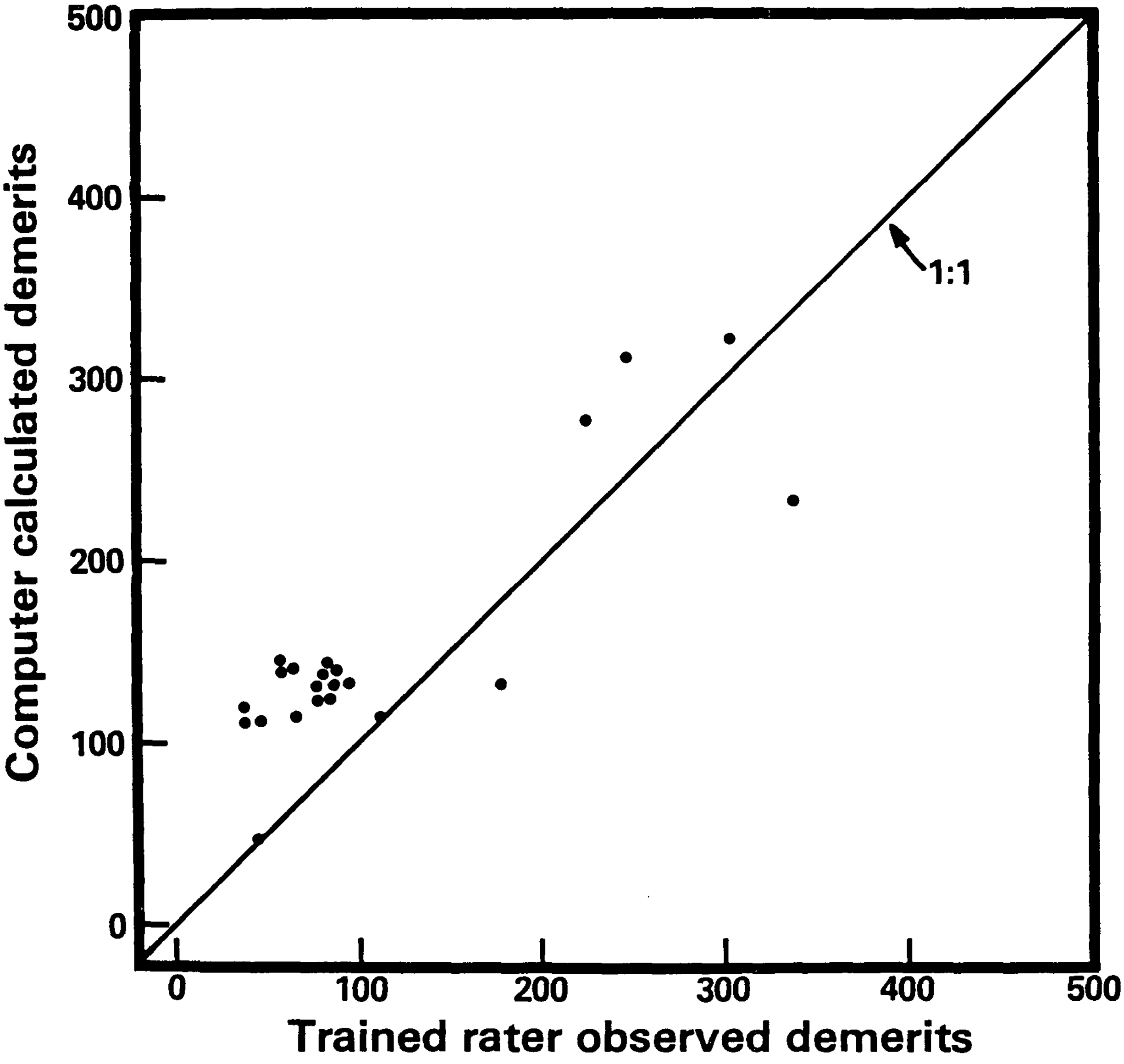


Figure 13

Total Demerits for Phase IV Tests

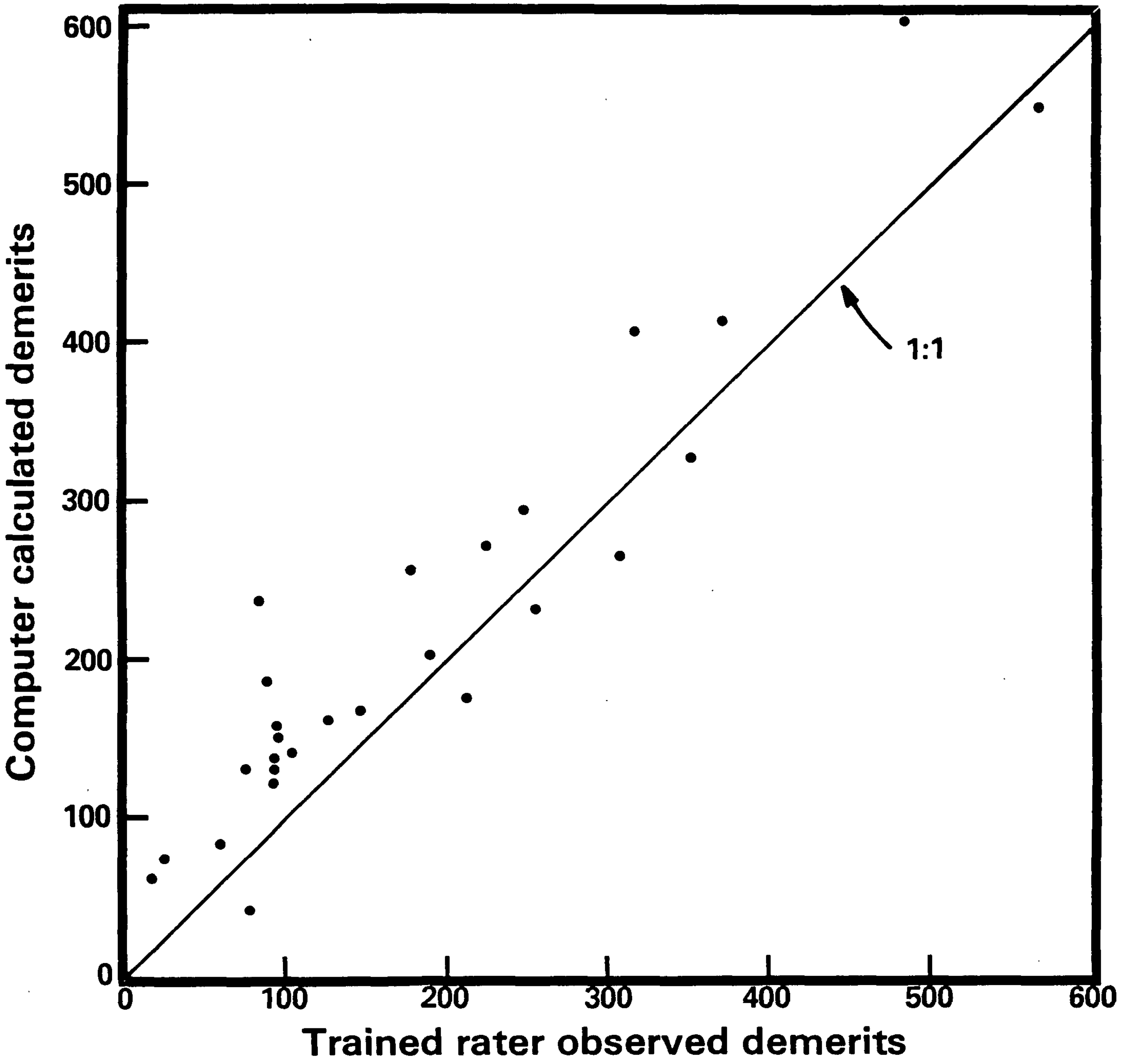
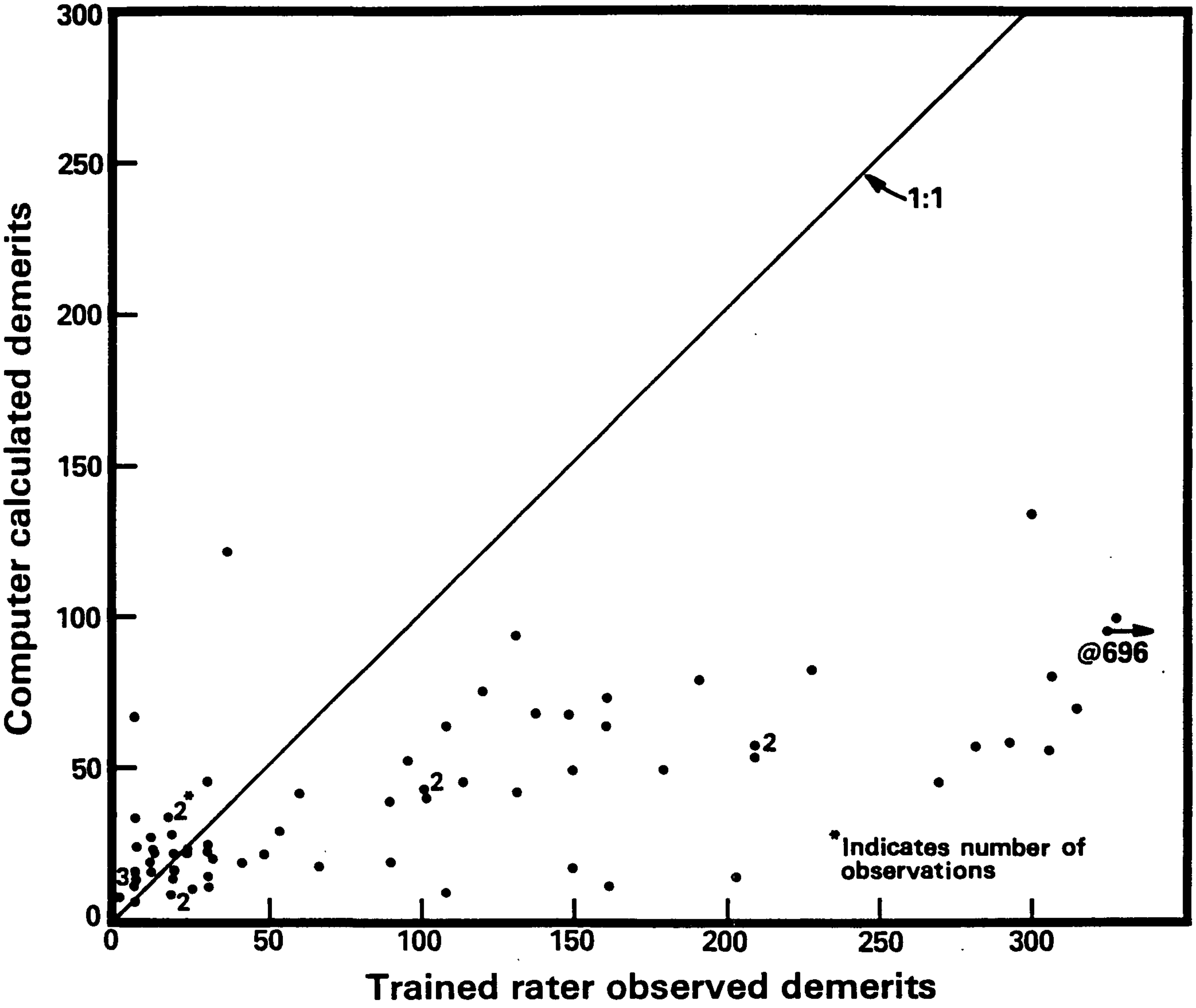


Figure 14

Stumble Demerits Using Consolidated Computer Program (Phase I Tests)



REFERENCES

1. "Evaluation of a High Temperature Driveability Test Procedure - 1971 Yuma Program," Coordinating Research Council Report No. 455, June, 1973.

2. "Driveability Performance of 1975 Passenger Cars at Intermediate Ambient Temperatures - Paso Robles," Coordinating Research Council Report No. 486, May, 1976.

3. "Driveability Performance of 1975 Passenger Cars at High Ambient Temperatures," Coordinating Research Council Report No. 490, November, 1976.

4. "Driveability Performance of 1977 Passenger Cars at Intermediate Ambient Temperatures - Paso Robles," Coordinating Research Council Report No. 499, September, 1978.

5. "Light Duty Vehicle Driveability Investigation," Environmental Protection Agency Report 460/3-78-012, Toulmin, H. A., Jr., Suntech, Inc., December, 1978.

6. "Code of Federal Regulations, Title 40 - Protection of Environment, Parts 81-99," Office of the Federal Register, U.S. General Services Administration, July 1, 1980.

7. "1973 Driveability Instrumentation Tests," Coordinating Research Council Report No. 489, November, 1976.

8. "Comparison of Vehicle/Fuel Test Procedures with Customer Driving," Klen, D. S., Amoco Oil Company, SAE paper 810491, presented at SAE Congress and Exposition -- Detroit, Michigan, February 23-27, 1981.

APPENDIX A

I. CRC Cold Start and Driveaway Test Procedure

II. Motorist Driving Cycle

I. CRC COLD START AND DRIVEAWAY TEST PROCEDURE

TEST PROCEDURE AND DATA RECORDING

A. Start engine per Owner's Manual Procedure. Record start time.

B. If engine fails to start after 15 seconds of cranking, stop cranking and depress accelerator pedal to the floor once and release. Repeat procedure until engine starts. Record total cranking time.

C. Record idle quality in "Neutral" or "Park" immediately after start; foot should be removed from accelerator pedal.

D. If engine stalls, repeat Steps A and B. Record number of stalls.

E. Allow engine to idle 15 seconds. Apply brakes (right foot), shift transmission to normal drive range, and record idle quality. If engine stalls, restart immediately. Record number of stalls. Idle 5 seconds in "Drive".

This completes the start-up portion of the procedure. Note that space on only three restarts at idle are to be noted. After the third stall, manipulate throttle to keep engine running. Proceed to next maneuver.

F. Drive through the cycle shown in Figure A-I-1.

G. During each maneuver observe and record the severity of any of the following malfunctions (see definitions):

1. Hesitation
2. Stumble
3. Surge
4. Stall
5. Backfire
6. Idle Roughness

DEFINITIONS AND EXPLANATIONS

A. Maneuver

A specified single vehicle operation or change of operating conditions (such as idle, acceleration or cruise) that constitutes one segment of the driveability driving schedule.

B. Cruise

Operation at a prescribed constant vehicle speed with a fixed throttle position on a level road.

C. Wide Open Throttle (WOT) Acceleration

"Floorboard" acceleration through the gears from prescribed starting speed. Rate at which throttle is depressed is to be as fast as possible without producing tire squeal or appreciable slippage.

D. Part Throttle (PT) Acceleration

An acceleration made at any defined throttle position, or consistent change in throttle position, less than WOT. Several PT accelerations are used. They are:

1. Light Throttle (Lt Th) - All light throttle accelerations are made by holding throttle position constant throughout the acceleration. The throttle position selected is one which allows the car to accelerate 0-25 mph in 0.1 mile when car engine is warm.

2. Crowd - An acceleration made at a constant intake manifold vacuum. To maintain constant vacuum, the throttle opening must be continually increased with increasing engine speed. Crowd accelerations are performed at the manifold vacuum which initially exists for the light throttle acceleration.

3. Detent - All detent accelerations are made at constant throttle position. The throttle opening is the downshift position.

E. Malfunctions

1. Stall - Any occasion during a test when the engine stops with the ignition on. The three types of stall, indicated by maneuver being attempted, are:

    a. Stall; idle - Any stall experienced when the vehicle is not in motion, or when a maneuver is not being attempted.

    b. Stall; maneuvering - Any stall which occurs during a prescribed maneuver or attempt to maneuver.

    c. Stall; decelerating - Any stall which occurs while decelerating between maneuvers.

2. Idle Roughness - An evaluation of the idle quality or degree of smoothness while the engine is idling.

3. Backfire - An explosion in the induction or exhaust system.

4. Hesitation - A temporary lack of vehicle response to opening of the throttle.

5. Stumble - A short, sharp reduction in acceleration after the vehicle is in motion.

6. Surge - Cyclic power fluctuations occurring during acceleration or cruise.

F. Malfunction Severity Ratings

The number of stalls encountered during any maneuver are to be noted by the rater. Each of the other malfunctions must be rated by severity. The following definitions of severity are to be applied in making such ratings:

1. Slight - A level of malfunction severity that is just discernible to a test driver but not to most laymen.

2. Moderate - A level of malfunction severity that is probably noticeable to the average layman.

3. Heavy - A level of malfunction severity that is pronounced and obvious to both test driver and layman.

The rater enters his evaluations into computer storage by depressing the appropriate keys on the keyboard.

DEMERIT CALCULATIONS

Driveaway malfunctions rated during this program and the manner in which total demerits were calculated are as follows:

Demerits for Poor Starting:
Demerits = starting time(s) - 2

Demerits for Stalls: (decelerating stalls are not assigned demerits)
Demerits = (no. of idle stalls) x 8 + (no. of maneuvering stalls) x 32

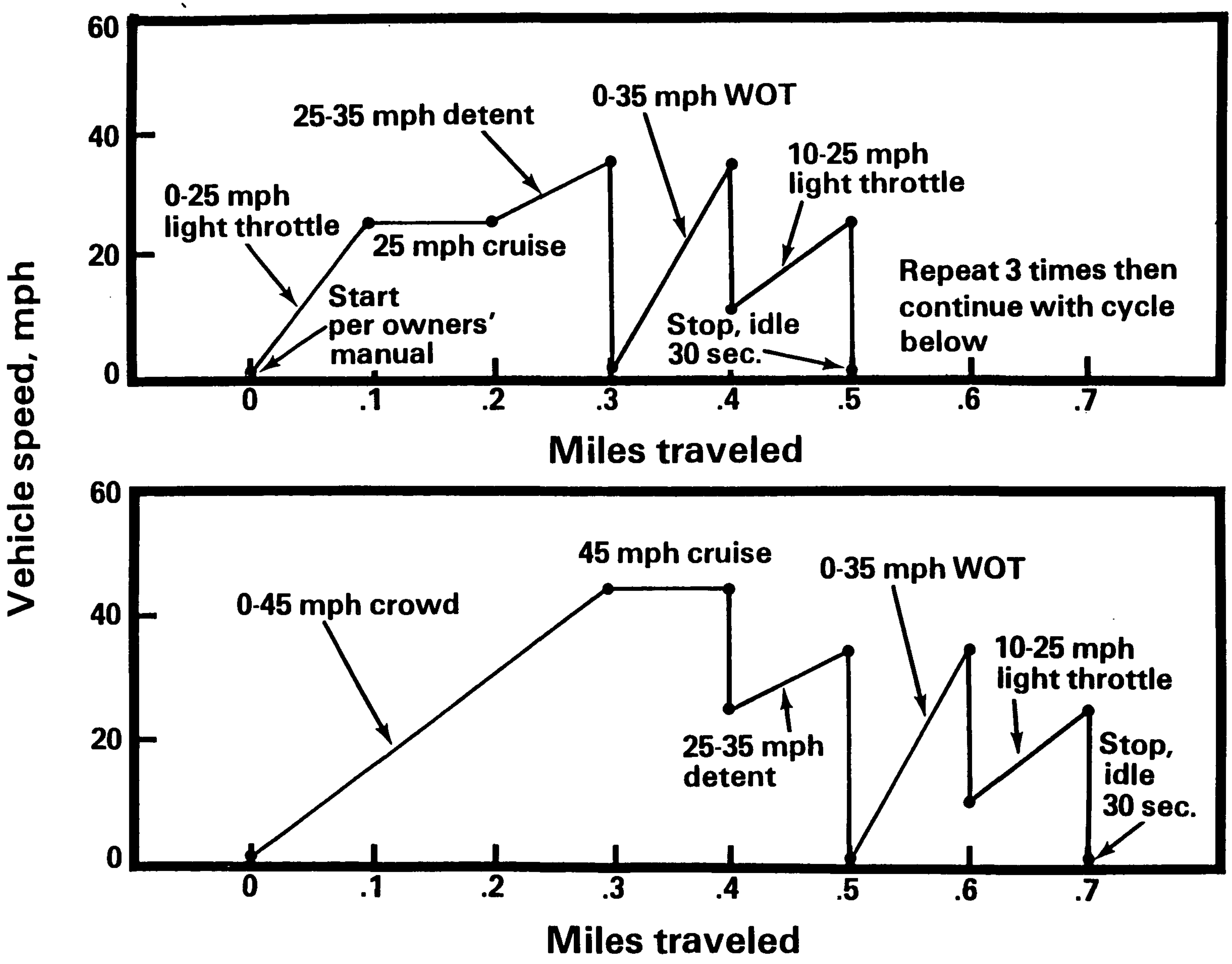
Demerits for Subjective Ratings
  Trace = 1
  Moderate = 2
  Heavy = 4
Weighting Factors for Each Malfunction
  Idle Roughness = 1
  Surge = 4
  Backfire, Stumble, Hesitation = 6
Weighted Demerits = Demerits x Weighting Factor

Calculation:
  Total Demerits = Weighted Demerits + Demerits for Stalls + Demerits for Poor Starting

Demerits for each run were summed, counting all malfunctions that occurred.

Figure A-I-1

CRC driving cycle



II. MOTORIST DRIVING CYCLE

The motorist driving data collected by Amoco and used for developing the cycle, are detailed in SAE paper, 810491 (8). The motorist cycle was adapted from the current CRC cycle by redefining the throttle positions to use for the various maneuvers. The CRC cycle uses four types of accelerations; light-throttle, crowd, detent, and wide-open-throttle. The throttle positions used for each of these are described in Appendix A-I. For the motorist cycle, the CRC accelerations are replaced by the following motorist accelerations (definitions are given in SAE paper 810491):

CRC Acceleration	Motorist Acceleration
Light-Throttle	Random and cold-start driving -- 50th percentile acceleration** (Random-50)
Crowd	Random and cold-start driving -- modified 50th percentile acceleration
Detent	Random and cold-start driving -- 90th percentile acceleration (Random-90)
Wide-Open-Throttle	Toll plaza driving -- 90th percentile acceleration (Toll-Plaza-90)

Figure A-II-1 shows the relationship between vehicle acceleration and vehicle speed for "Random-50, "Random-90", and "Toll-Plaza-90" accelerations. Throttle positions are selected which yield vehicle accelerations closely matching the appropriate profile in Figure A-II-1. For example, the Chrysler LeBaron being used in this program required 25 percent, 40 percent, and 50 percent throttle openings to approximate the motorist Random-50, Random-90, and Toll-Plaza-90 accelerations, respectively. The modified Random-50 acceleration replaces the crowd acceleration and is made by initially opening the throttle to 25 percent followed by a very slow increase to 30 percent.

In addition to changes in throttle positions, the rate of throttle movement is slower for the motorist cycle than for the CRC cycle. For example, when making the wide-open-throttle CRC acceleration, the rater is instructed to open the throttle as rapidly as possible without causing tire squeal or slippage. When using the motorist cycle, however, raters are to take about 1 second to open the throttle to the desired position.

The last changes between the CRC and motorist cycles are that a "stabilization" period is allowed between maneuvers and that speed ranges for the maneuvers are slightly different. A graphic description of the motorist cycle is shown in Figure A-II-2. When using the motorist cycle, the start-up procedure and driveability problem ratings are the same as when using the CRC cycle.

** The 50th percentile acceleration was exceeded in 50% of the motorists' accelerations.

The 90th percentile acceleration was exceeded in 10% of the motorists' accelerations.

Figure A-II-1

Motorist Driving Data Used for Cycle Development

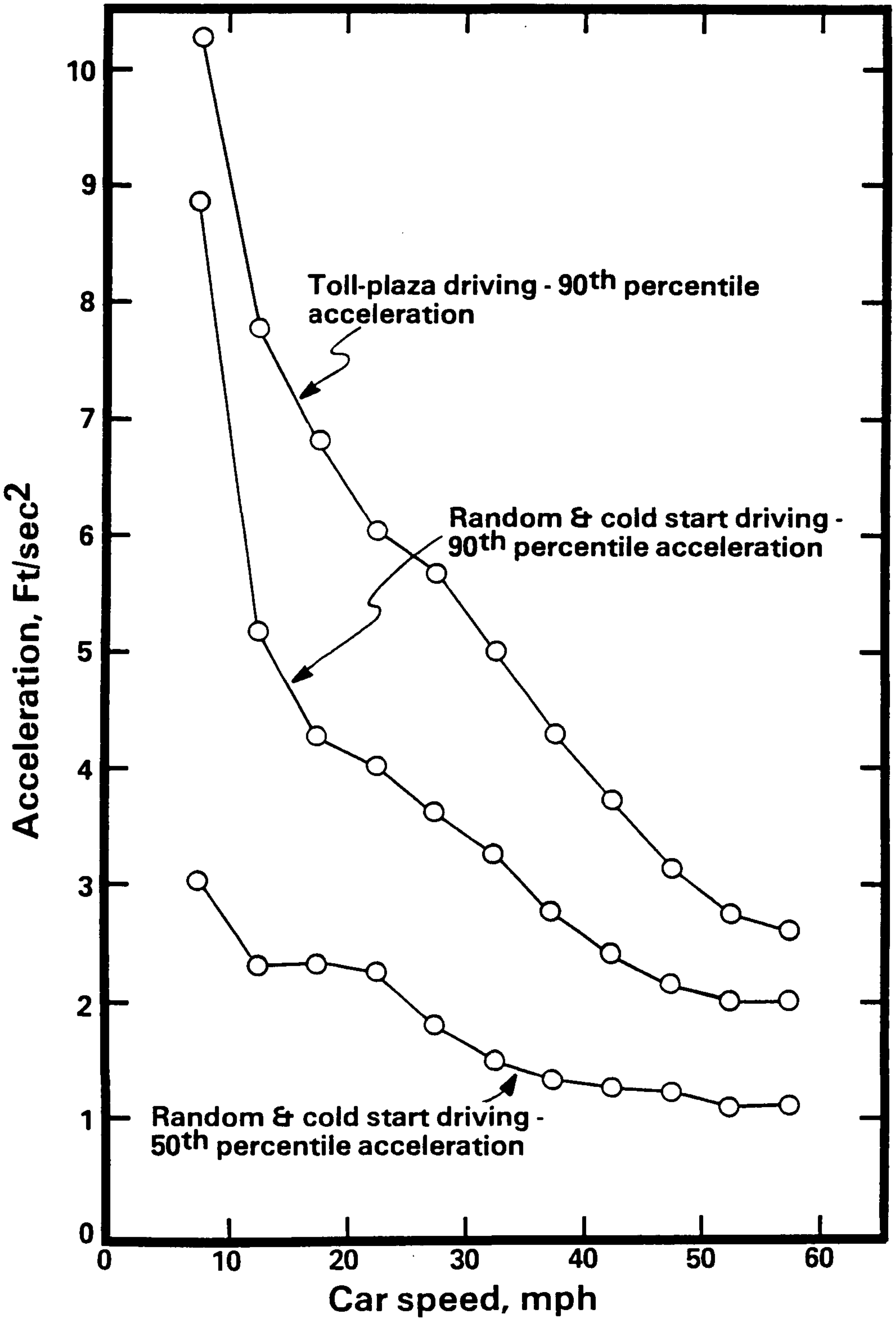
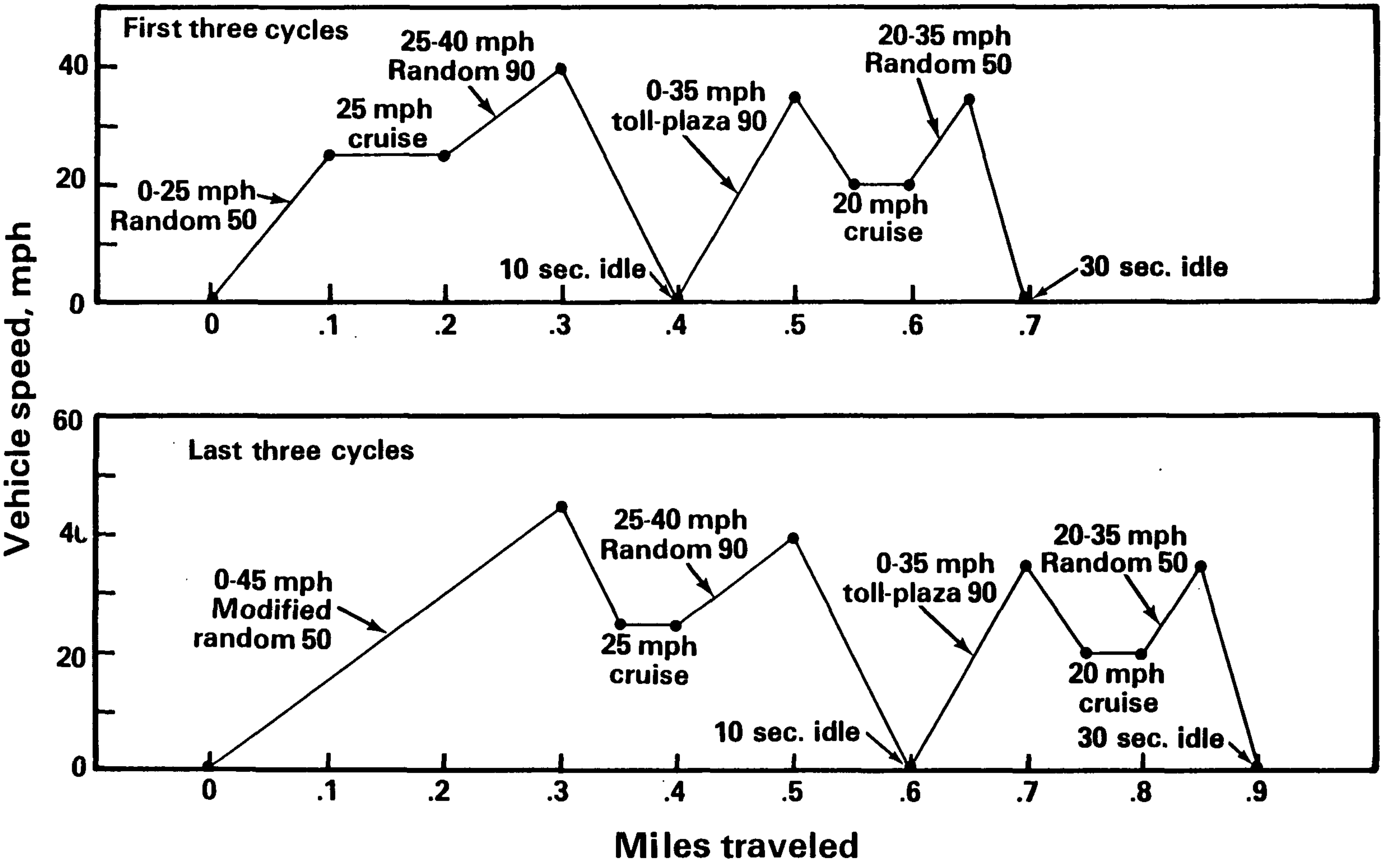


Figure A-II-2

Motorist driving cycle



APPENDIX B

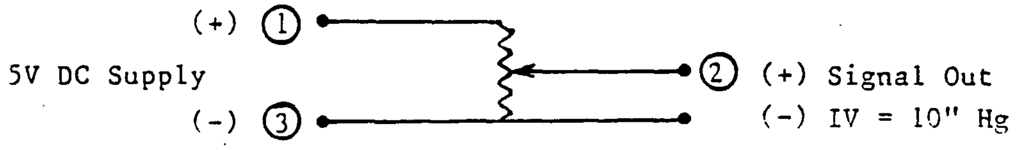
Instruments for Measuring Engine/Vehicle Operating Parameters

INSTRUMENTS FOR MEASURING ENGINE/VEHICLE OPERATING PARAMETERS

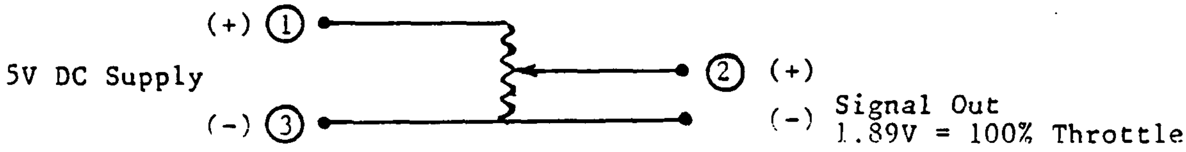
1. Start Time - This was measured by activation of a Potter-Brumfield KRP 110 6V DC relay. The activation voltage for the relay was provided by connecting two wires across the starter solenoid and then to the relay coil. When the car is initially started, the relay coil closes the relay contacts and activates the event marker on the Gould 6-channel recorder (Model 15-6367-00). A 6V DC relay was used because there may not always be a full 12V DC at the solenoid.

2. Oil Temperature - This was sensed by use of a 24" long, 1/8" sheathed, Type K thermocouple, inserted into the oil dipstick hole. The thermocouple signal was then fed into a Type K digital pyrometer (Newport Model 268).

3. Intake Manifold Vacuum - This was sensed by use of a Robinson-Halpern P61-995-31, 0-30" Hg vacuum, 1000 ohm potentiomatic transducer.



4. Throttle Position - This was sensed by mechanically linking a New England Instruments Company Model #78CBA102-C1B, 1 turn, 1200 ohm potentiometer, to the throttle linkage on the carburetor.



5. Vehicle Speed - This is driveshaft speed and is taken, as a pulsetrain, from the Himmelstein Torque/RPM head. This pulsetrain is then converted, by electronics on the cart built by ESD, to a voltage of 1.33V per 50 mph, or .0266V/mph, and displayed on the appropriate digital meter.

6. Driveshaft Torque - This parameter is measured by use of the S. Himmelstein Torquemeter and speed pick-up. This unit is located in the vehicle's driveshaft. The calibration and installation of the unit is as per the manual.

7. Engine Speed - The tachometer signal from the vehicle distributor was converted to a voltage output via a Gould Model 13-4618-30 converter. The resulting output is lmv/rpm to a maximum engine speed of 10,000 rpm. Engine speed was then monitored with a Gould strip chart recorder.

8. Vehicle Acceleration - This was monitored by an ESD accelerometer. This device is mechanically linked in series with the speedometer cable. The sine wave output of this transducer is then fed into ESD's accelerometer. This signal conditioning device converts the sine wave signal into a 0-5V analog signal which is proportional to the change in vehicle speed. This analog signal is then recorded by a Gould 260 recorder.

9. Drawbar Pull - This condition was sensed by using a Transducer, Inc. strain gauge, Model BTC-FF63H-CS-500. The transducer was bolted to the bed plate soak room floor, the other end of this assembly was attached to the frame of the vehicle. The transducer output was fed into a Transducer, Inc. signal conditioner, Model 75C-42-0003E. The analog signal produced was then recorded by a Gould 260 recorder.

10. Engine Vibration - This condition was monitored by a P.M.C. standard vibration velocity transducer, Model 260C. The output of this unit was recorded by a Gould 260 recorder.

11. Engine Rotation - A 1000 phm potentiometer was mounted to the fenderwell, the other end was connected to the engine block by means of a moment arm. The mechanical advantage of this moment arm and associated gears was approximately 10 to 1. A 5 volt signal was placed across this potentiometer. The resulting output was fed to a Gould 260 recorder.

12. Signal Conditioning Cart - All signals were converted from analog form to digital form for computer recording. The cart utilizes a microprocessor for actual data transmission.

APPENDIX C

Trained Rater Observed Demerits
by Driveability Problem Type

TRAINED RATER OBSERVED DEMERITS BY DRIVEABILITY PROBLEM TYPE

				Demerits										
					Stalls									
Test Phase	Test Number	Rater	Fuel	Hard Starting*	Idle	Accel	Decel	Roughness	Stumble	Extension	Hesitation	Surge	Backfire	Total
I	1	A	1	4.6	16	256	0	7	168	0	36	24	66	577.6
	2	A	1	4.4	0	224	0	9	180	0	66	0	6	489.4
	3	A	1	2.4	8	128	0	1	330	0	102	0	42	613.4
	4	B	2A	15.8	0	0	0	1	18	0	0	0	0	34.8
	5	B	2A	0	0	0	0	0	18	0	0	0	0	18.0
	6	B	1	16.6	16	192	0	5	336	0	0	16	36	617.6
	7	A	2A	4.4	0	0	0	1	126	0	18	0	0	149.4
	8	A	2A	0	0	0	0	3	162	0	12	0	0	177.0
	9	A	1	4.4	16	256	0	18	738	0	54	180	108	1374.4
	10	B	1	1.4	16	192	0	13	306	0	18	8	18	572.4
	11	B	2A	0	0	64	0	0	24	0	12	0	6	106.0
	12	B	1	3.4	16	160	0	6	312	0	12	4	30	543.4
	13	A	1	0	0	0	0	0	90	0	0	0	0	90.0
	14	A	2A	0.8	0	32	0	0	210	0	0	0	84	326.8
	15	Data Destroyed by Computer Malfunction												
	16	B	3	0.2	0	96	0	1	102	0	0	0	0	199.2
	17	B	2A	0	0	0	0	1	12	0	0	0	0	13.0
	18	B	2A	0	0	0	0	2	18	0	0	4	0	24.0
	19	A	1	3.0	0	320	0	5	294	0	0	0	78	700.0
	20	A	3	3.0	8	96	0	6	204	0	6	0	12	335.0
	21	A	3	0.8	0	32	0	0	150	0	0	0	6	188.8
	22	B	2A	0	0	0	0	1	30	0	6	0	18	37.0
	23	B	3	0.2	0	96	0	3	132	0	6	0	0	237.2
	24	B	3	0	0	64	0	3	102	0	6	0	0	175.0
	25	A	3	7.6	0	32	0	0	120	0	0	0	24	183.6
	26	A	1	7.4	16	288	0	4	300	0	0	40	168	823.4
	27	A	3	0.2	0	64	0	1	210	0	0	0	18	293.2
	28	B	2A	0	0	0	0	1	30	0	0	0	0	31.0
	29	B	2A	0	0	0	0	1	30	0	0	0	0	31.0
	30	B	1	2.8	16	256	0	3	270	0	0	0	30	577.8

TRAINED RATER OBSERVED DEMERITS BY DRIVEABILITY PROBLEM TYPE

- Continued -

Test Phase	Test Number	Rater	Fuel	Demerits										
				Hard Starting*	Stalls			Roughness	Stumble	Extension	Hesitation	Surge	Backfire	Total
					Idle	Accel	Decel							
I	31	A	1	13.6	16	224	0	6	354	0	12	8	84	717.6
	32	A	3	0	0	32	0	0	102	0	0	0	18	152.0
(Cont'd)	33	A	2A	0	0	0	0	2	30	0	0	0	0	32.0
	34	B	1	3.0	16	192	0	1	150	0	0	0	36	398.0
	35	B	1	2.6	16	128	0	3	138	0	0	0	24	311.6
	36	B	3	0	0	0	0	0	54	0	0	4	12	70.0
	37	A	3	15.6	0	0	0	0	60	0	0	0	0	75.6
	38	A	1	4.6	8	160	0	3	96	0	0	4	0	275.6
	39	A	2A	14.2	0	0	0	1	6	0	0	4	0	25.2
	40	A	1	2.2	16	96	0	1	144	0	0	0	36	295.2
	41	B	2A	0	0	0	0	0	6	0	0	4	0	10.0
	42	B	1	2.4	16	128	0	9	228	0	0	8	48	439.4
	43	A	1	2.0	8	192	0	10	162	0	0	16	54	444.0
	44	A	3	0.2	0	0	0	0	18	0	6	4	0	28.2
	45	A	1	2.2	8	128	0	4	168	0	0	4	18	332.2
	46	B	2A	0	0	0	0	0	6	0	0	0	6	12.0
	47	B	1	3.0	16	96	0	7	114	0	0	8	24	268.0
	48	B	3	0.2	0	32	0	0	30	0	0	4	6	72.2
	49	A	3	16.0	0	0	0	0	12	0	0	0	12	40.0
	50	A	1	2.2	8	96	0	0	90	0	0	4	30	230.2
	51	B	3	0.2	0	32	0	0	18	0	0	4	0	54.2
	52	B	2A	0	0	0	0	0	12	0	0	0	0	12.0
	53	B	1	2.6	16	96	0	7	162	0	0	8	12	303.6
	54	A	2A	0	0	0	0	0	0	0	0	4	6	10.0
	55	A	3	0.2	0	0	0	0	6	0	0	4	18	28.2
	56	A	2A	0	0	32	0	0	6	0	0	4	0	42.0
	57	B	3	0	0	0	0	0	18	0	6	0	6	30.0
	58	A	2A	0.6	0	0	0	0	6	0	12	0	0	18.6
	59	A	1	1.8	8	288	0	1	108	0	0	0	102	508.8
	60 **	A	1	0	0	0	0	0	0	0	0	0	0	0

TRAINED RATER OBSERVED DEMERITS BY DRIVEABILITY PROBLEM TYPE

- Continued -

Test Phase	Test Number	Rater	Fuel	Demerits										
				Hard Starting*	Stalls			Roughness	Stumble	Extension	Hesitation	Surge	Backfire	Total
					Idle	Accel	Decel							
I	61	A	2A	0	0	0	0	1	24	0	0	0	0	25.0
	62	B	3	0.2	0	32	0	1	48	0	0	0	0	81.2
(Cont'd)	63 **	B	9	0	0	0	0	0	0	0	0	0	0	0
	64	B	2A	0.8	0	32	0	0	12	0	0	0	0	44.8
	65	B	1	1.8	8	256	0	6	180	0	0	16	48	515.8
	66	A	2A	0.4	0	32	0	0	6	0	0	0	0	38.4
	67 **	A	9	0	0	0	0	0	0	0	0	0	0	0
	68	A	1	3.6	16	64	0	0	66	0	6	0	12	167.6
	69	A	2A	0	0	0	0	0	18	0	0	0	0	18.0
	70	B	3	0	0	32	0	0	36	0	0	0	6	74.0
	71 **	B	9	0	0	0	0	0	0	0	0	0	0	0
	72	B	2A	0	0	0	0	0	24	0	0	4	0	28.0
	73	B	1	2.4	16	192	0	8	192	0	0	12	24	446.4
	74	A	2A	1.2	0	0	0	0	6	0	0	0	0	7.2
	75 **	A	9	0	0	0	0	0	0	0	0	4	0	4.0
	76	A	3	1.0	0	64	0	0	42	0	0	0	6	113.0
	77	B	1	1.8	8	96	0	5	138	0	0	4	18	270.8
	78 **	B	9	0	0	0	0	1	0	0	0	8	0	9.0
	79	B	3	0.2	0	0	0	0	36	0	0	4	18	58.2
	80	B	2A	0	0	0	0	1	18	0	0	0	6	25.0
	81	A	2A	1.0	0	0	0	0	6	0	6	0	0	13.0
	83	A	2A											
	84	B	2A											
	85	B	2A											
	86	A	2A											
	87	A	2A											

Each of these tests was a series of 0-45 mph accelerations at various throttle openings. The data were used in determining throttle positions for the Motorist-cycle tests.

TRAINED RATER OBSERVED DEMERITS BY DRIVEABILITY PROBLEM TYPE

(Phases II thru VI Results)

				Trained Rater Observed Demerits										
				Hard	Stalls									
Test Phase	Test Number	Rater	Fuel	Starting*	Idle	Accel	Decel	Roughness	Stumble	Extension	Hesitation	Surge	Backfire	Total
II	1	A	2B	0	0	0	0	0	0	0	6	0	0	6.0
	2	A	2B	1.2	8	0	0	0	6	0	0	0	0	15.2
	3	A	3	0	0	0	0	0	18	0	0	0	0	18.0
	4	A	1	2.2	16	320	0	6	234	0	12	48	12	650.2
	5	B	1	0.4	0	256	0	1	96	0	24	4	0	381.4
	6	B	3	0	0	0	0	0	36	0	0	8	0	44.0
	7	B	2B	0	0	0	0	1	24	0	0	12	0	37.0
	8	A	1	2.4	8	96	0	0	96	0	0	0	6	208.4
	9	A	2B	0	0	0	0	0	6	0	0	0	0	6.0
	10	A	3	0	0	0	0	1	24	0	0	0	0	25.0
	11	A	1	4.0	8	32	0	0	108	0	0	0	0	152.0
	12	B	3	0	0	0	0	5	18	0	0	28	0	51.0
	13	B	1	0	0	0	0	6	84	0	12	24	0	126.0
	14	B	2B	0	0	0	0	5	18	0	0	24	0	47.0
	15	B	1	0	0	0	0	6	84	0	0	32	0	122.0
	16	A	3	0	0	0	0	0	6	0	0	0	0	6.0
	17	A	1	0.6	8	64	0	0	6	0	0	4	6	88.6
	18	A	2B	0	0	0	0	0	0	0	0	0	0	0
	19	A	3	1.0	8	0	0	0	6	0	0	0	0	15.0
	20	A	1	1.0	0	0	0	0	30	0	0	4	0	35.0
	21	A	2B	0	0	0	0	0	6	0	0	0	0	6.0
	22	A	3	0	0	0	0	0	0	0	0	0	0	0
	23	B	1	0	0	0	0	3	36	0	0	32	0	71.0
	24	B	3	0	0	0	0	6	30	0	0	20	0	56.0
	25	B	2B	0	0	0	0	5	24	0	0	12	0	41.0
	26	B	3	0	0	0	0	5	60	0	0	20	0	85.0
	27	B	2B	0	0	0	0	9	30	0	0	20	0	59.0
III	28	A	1	1.4	0	128	0	0	210	0	0	4	6	349.4
	29	A	2B	1.0	0	0	0	0	36	0	0	0	0	37.0
	30	A	3	1.8	8	0	0	0	42	0	36	0	24	111.8

TRAINED RATER OBSERVED DEMERITS BY DRIVEABILITY PROBLEM TYPE

(Phases II thru VI Results)
- Continued -

Test Phase	Test Number	Rater	Fuel	Trained Rater Observed Demerits										
				Hard Starting*	Stalls			Roughness	Stumble	Extension	Hesitation	Surge	Backfire	Total
					Idle	Accel	Decel							
III	31	A	1	4.6	16	96	0	3	102	0	24	48	72	365.6
(Cont'd)	32	B	2B	0	0	0	0	3	42	0	0	4	0	49.0
	33	B	3	0.4	0	0	0	5	84	0	0	0	0	89.4
	34	B	1	2.0	8	32	0	8	288	0	0	8	54	400.0
	35	B	3	0	0	0	0	4	60	0	0	4	0	68.0
	36	B	1	1.4	8	128	0	5	246	0	24	4	6	422.4
	37	B	3	0	0	0	0	3	96	0	12	8	6	125.0
	38	B	2B	0	0	32	0	4	48	0	0	8	0	92.0
	39	A	3	1.4	8	0	0	0	30	0	18	8	24	89.4
	40	A	1	1.2	16	160	0	0	168	0	42	24	84	495.2
	41	A	2B	0	0	32	0	0	42	0	0	0	6	80.0
	42	A	3	0	0	0	0	0	66	0	24	0	36	126.0
	43	B	1	0	8	64	0	5	156	0	72	12	84	401.0
	44	B	2B	0	0	0	0	4	42	0	0	0	6	52.0
	45	B	3	0	0	0	0	3	90	0	0	0	0	93.0
	46	B	1	1.2	8	96	0	5	162	0	30	0	42	344.2
	47	A	2B	1.4	8	0	0	0	36	0	18	16	0	79.4
	48	A	3	2.8	8	0	0	0	72	0	6	8	24	120.8
	49	A	1	4.4	16	32	0	0	90	0	6	76	102	326.4
	50	A	1	6.8	8	64	0	0	138	0	6	0	192	414.8
	51	B	2B	0	0	0	0	3	66	0	12	0	12	93.0
	52	B	3	0	0	0	0	4	72	0	6	4	6	92.0
	53	B	1	1.4	8	32	0	4	240	0	24	0	36	345.4
	54	B	2B	0	0	0	0	2	90	0	0	4	24	120.0
	55	B	3	0	0	32	0	3	66	0	0	4	12	117.0
	56	A	2B	1.2	8	0	0	0	42	0	6	0	36	93.2
	57	A	3	1.4	8	0	0	0	24	0	6	4	24	67.4
	58	A	1	1.4	8	0	0	0	168	0	0	8	6	191.4
	59	A	1	3.8	8	32	0	0	174	0	90	8	54	369.8
IV	60	A	2B	0	0	0	0	1	30	0	48	36	36	151.0

TRAINED RATER OBSERVED DEMERITS BY DRIVEABILITY PROBLEM TYPE

(Phases II thru VI Results)
- Continued -

Test Phase	Test Number	Rater	Fuel	Trained Rater Observed Demerits										
				Hard Starting*	Stalls Idle	Stalls Accel	Stalls Decel	Roughness	Stumble	Extension	Hesitation	Surge	Backfire	Total
IV (Cont'd)	61	B	1	0	0	0	0	7	120	0	0	0	30	157.0
	62	A	2B	0.4	0	64	0	0	84	0	42	32	36	258.4
	63	A	3	0	0	0	0	0	24	0	0	0	0	24.0
	64	A	2B	1.4	0	96	0	0	138	0	18	16	24	293.4
	65	B	1	1.6	8	288	0	11	126	0	48	8	72	562.6
	66	A	2B	0.4	0	0	0	0	168	0	54	16	6	244.4
	67	A	3	0.2	0	0	0	0	6	0	54	0	0	60.2
	68	A	1	7.0	8	64	0	1	114	0	30	12	48	284.0
	69	A	3	0.2	0	0	0	0	12	0	6	0	0	18.2
	70	A	1	2.4	8	256	0	0	174	0	126	8	96	670.4
	71	B	2B	0	0	96	0	5	126	0	12	0	36	275.0
	72	B	1	2.6	8	192	0	8	84	0	24	0	114	432.6
	73	B	2B	0	0	0	0	4	66	0	24	0	42	136.0
	74	B	3	0.2	0	32	0	2	72	0	0	0	24	130.2
	75	A	2B	0.2	0	0	0	0	60	0	30	0	12	102.2
	76	A	3	0.4	0	0	0	0	78	0	12	4	18	112.4
	77	B	1	2.6	8	96	0	5	102	0	36	0	84	333.6
	78	B	2B	0	0	0	0	0	84	0	12	0	42	138.0
	79	B	3	0	0	32	0	5	84	0	0	0	18	139.0
	80	A	1	3.0	8	96	0	0	66	0	6	0	114	293.0
	81	A	2B	0.6	0	0	0	0	30	0	36	4	18	88.6
	82	A	3	0.4	0	32	0	0	78	0	36	0	78	224.4
	83	A	1	2.6	8	128	0	4	114	0	114	24	198	592.6
	84	B	3	0.4	0	32	0	4	48	0	0	0	24	101.4
	85	B	2B	0	0	32	0	1	60	0	0	0	36	129.0
	86	B	1	2.0	16	128	0	0	102	0	102	24	222	596.0
	87	B	3	0.4	0	32	0	3	42	0	0	0	24	101.4
V	88	A	1	1.6	0	0	0	0	18	0	24	0	0	43.6
	89	A	3	0	0	0	0	0	30	0	6	0	0	36.0
	90	A	2B	0.2	0	0	0	0	0	0	12	0	0	12.2

TRAINED RATER OBSERVED DEMERITS BY DRIVEABILITY PROBLEM TYPE

(Phases II thru VI Results)
- Continued -

				Trained Rater Observed Demerits											
				Hard	Stalls										
Test Phase	Test Number	Rater	Fuel	Starting*	Idle	Accel	Decel	Roughness	Stumble	Extension	Hesitation	Surge	Backfire	Total
V	91	A	1	3.0	16	32	0	0	30	0	18	0	0	99.0
(Cont'd)	92	B	2 B	0	0	0	0	0	0	0	0	0	0	0
	93	B	1	0.2	0	32	0	10	138	0	0	16	0	196.2
	94	B	1	0.6	0	32	0	8	102	0	0	20	12	174.6
	95	A	2 B	0.2	0	0	0	0	12	0	30	0	0	42.2
	96	A	1	3.8	16	0	0	0	18	0	90	0	0	127.8
	97	A	3	0	0	0	0	10	0	0	0	4	0	14.0
	98	A	2 B	0.4	0	0	0	0	24	0	12	0	0	36.4
	99	A	3	2.0	8	0	0	0	6	0	0	0	0	16.0
	100	B	1	1.4	8	32	0	5	138	0	0	20	0	204.4
	101	B	3	0	0	0	0	9	0	0	0	0	0	9.0
	102	A	2 B	1.2	8	0	0	0	0	0	6	0	0	15.2
	103	A	3	0	0	0	0	0	12	0	18	0	0	30.0
	104	B	2 B	0	0	0	0	6	0	0	0	0	0	6.0
	105	B	1	1.8	8	0	0	4	18	0	0	0	0	31.8
	106	B	3	0	0	0	0	15	6	0	0	0	0	21.0
	107	A	1	0.2	8	0	0	0	24	0	12	0	0	44.2
	108	A	3	0	0	0	0	0	0	0	6	0	0	6.0
	109	B	2 B	0	0	0	0	4	6	0	0	0	0	10.0
	110	B	3	0	0	0	0	7	0	0	0	0	0	7.0
	111	B	2 B	0	0	0	0	8	6	0	0	4	0	18.0
VI	112	A	1	0	0	0	0	2	0	0	6	0	0	8.0
	113	B	2 B	0	0	0	0	4	18	0	0	0	0	22.0
	114	B	3	0	0	0	0	2	6	0	0	0	0	8.0
	115	B	1	0	0	32	0	6	90	0	0	20	0	148.0
	116	A	2 B	0	0	0	0	0	12	0	30	0	0	42.0
	117	A	3	0	0	0	0	0	6	0	18	0	0	24.0
	118	B	1	0	0	0	0	6	36	0	0	0	0	42.0
	119	B	3	0	0	0	0	5	18	0	0	0	0	23.0
	120	B	2 B	0	0	0	0	11	42.0	0	0	0	0	53.0

TRAINED RATER OBSERVED DEMERITS BY DRIVEABILITY PROBLEM TYPE

(Phases II thru VI Results)
- Continued -

				Trained Rater Observed Demerits										
				Hard	Stalls									
Test Phase	Test Number	Rater	Fuel	Starting*	Idle	Accel	Decel	Roughness	Stumble	Extension	Hesitation	Surge	Backfire	Total
VI	121	A	3	0	0	0	0	0	0	0	12	0	0	12.0
	122	A	2B	0.2	0	0	0	1	0	0	0	0	0	1.2
	123	A	1	0	0	0	0	0	0	0	0	0	0	0
	124	B	1	0	0	0	0	10	24	0	0	8	0	42.0
	125	A	2B	0	0	0	0	2	18	0	12	0	0	32.0

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* Starting time used for calculating hard starting demerits was not measured by the trained rater -- only by the computer.

** These tests were made with the car engine fully warmed-up. The data were used in developing the hesitation measurement method.

APPENDIX D

Unsuccessful Attempts to Objectively Measure Stumble and Hesitation

UNSUCCESSFUL ATTEMPTS TO OBJECTIVELY MEASURE STUMBLE AND HESITATION

STUMBLE

A. General

From past experience the investigators were confident that vehicle stumble could be related to fluctuations in engine or vehicle operating parameters. Throughout the program, efforts to measure stumble dealt with:

1. ways to identify all fluctuations
2. ways to eliminate fluctuations not noticed by the rater
3. ways to associate fluctuations with trained rater observed stumble, and
4. ways to predict trained rater observed stumble demerits from properties of the fluctuations.

Various attempts to accomplish items 1, 2 and 3 are described below in section B, and item 4 is discussed in section C.

B. Stumble Identification

1. Cubic - Initially, attempts were made to identify dips by fitting cubic equations to short segments of engine speed and driveshaft torque data. The cubic equation form was selected because it has a local maximum and minimum value. These equations were then analyzed by computer to find the time duration (Δt) and amplitude (Δa) of dips in the data. We next attempted to eliminate meaningless dips by placing a lower limit on the multiple regression coefficient squared for each equation; the thought being that if a stumble occurred and was recognized by the rater, then the dip should be large enough to provide good equation fit. The Δt and Δa values were then used in an optimization routine. The types of optimization routines considered throughout the program are described in section C. However, regardless of the type of optimization used, several items were universal. First, rules were applied to the Δt and Δa information to see whether consecutive dips should be grouped together. Second, decisions had to be made as to which dip or dip-groups should be paired with the trained rater observed stumble. (Explanations of dip grouping and pairing are included in the main body of this report.) Third, demerits had to be calculated for each dip or group, and fourth, a score had to be calculated for the data being optimized. The rules for dip grouping and pairing were quite complex when using the cubic equation approach. It is sufficient to say that some of the rules included variables to be optimized. When using the cubic equation approach, the following equation was used for calculating total stumble demerits for an entire driveability test:

Stumble Demerits $= \Sigma_i (R_i^2 - R_T^2) (b_0 + b_1 (\Delta t_i) + b_2 (\Delta a_i))_T + \Sigma_j (R_j^2 - R_S^2) (b_3 + b_4 (\Delta t_j) + b_5 (\Delta a_j))_S$

where i and j denote the i^{th} driveshaft torque dip or j^{th} engine speed dip respectively.

R_i^2 and R_j^2 denote the multiple-correlation-coefficient squared for the equation fitted to the i^{th} driveshaft torque dip or j^{th} engine speed dip respectively.

R_T^2 and R_S^2 denote minimum cutoff values for the multiple-correlation-coefficient squared on equations fitted to driveshaft torque or engine speed dips respectively.

b_x's are coefficients for calculating computer demerits of individual dips

After calculating demerits, the computer calculated a score that described a discrepancy between rater observed and computer calculated demerits. It was:

$$\text{Score} = D_R + D_C + 1/2\ D_B$$

where D_R = sum of demerits for stumbles observed by the trained rater that are not paired with a dip.

D_C = sum of demerits for dips found by computer which are not paired with trained rater-observed stumbles.

D_B = sum of the absolute difference in demerits for computer-observed dips that are paired with trained rater-observed stumbles.

The optimization programs always attempted to minimize the score by adjusting the values of the variables. These variables included: 1) the rules for grouping and pairing dips, 2) the multiple correlation coefficient cutoffs (R_S^2 and R_T^2), and 3) the demerit equation coefficients (b_x's). The cubic approach was abandoned because the number of consecutive data points for equation fitting had to be held constant for each variable. This damaged the equation's ability to accurately measure Δt and Δa for all dips.

2. Smoothing - First Try

The only difference between the smoothing and cubic methods are: 1) the system used for finding Δt and Δa, and 2) the demerit calculation equations. The smoothing method is so named because to find Δt and Δa

the engine and vehicle operating parameter data were smoothed slightly and then searched to find actual maximum and minimum values. The smoothing function was:

$$X_{iS} = .25X_{i-1} + .5X_i + .25X_{i+1}$$

where: X_{iS} is the smoothed value of the i^{th} data point
X_i is the un-smoothed value of the i^{th} data point
X_{i-1}, X_{i+1} are the un-smoothed values of the data points on either side of the i^{th} point

Along with this new method of finding dips, it was also decided that the time interval between maximum and minimum values of the engine speed or torque may not be the appropriate interval to use. Therefore, to allow data immediately prior to the maximum to be included a slope cutoff variable was established. This defined a dip as beginning when the speed or torque slope (as a function of time) dropped below this cutoff. The new demerit calculation equation became:

$$\text{Stumble Demerits} = {}_i(b_1(\Delta t_i) + b_2(\Delta a_i)) + {}_j(b_3(\Delta t_j) + b_4(\Delta a_j))$$

where: i is driveshaft torque dips
j is engine speed dips
b_x's are coefficients for calculating computer demerits of individual dips

The variables now manipulated by the optimization to minimize the score were 1) the rules for grouping and pairing dips, 2) the slope cutoffs, and 3) the demerit equation coefficients (b_x's).

3. Smoothing - Second Try

The difference between first and second attempts using the smoothing methods are in the demerit calculation equation and the addition of more rules for the optimization. The demerit equation became:

$$\text{Stumble Demerits} = \Sigma_i(b_1(\Delta t_i) + b_2(\Delta a_i) + b_3(\frac{\Delta a_i}{\Delta t_i}))$$
$$+ \Sigma_j(b_4(\Delta t_j) + b_5(\Delta a_j) + b_6(\frac{\Delta a_j}{\Delta t_j}))$$

The rules added to the optimization were that the values of certain terms of the demerit equation had to exceed a cutoff value to be included in the data. Neither of the smoothing attempts were successful for various reasons including the fact that they were too complex. At this time the stumble identification method was changed to the one described in the main body of this report.

C. Optimization Routines

1. General

The function of the optimization routines was to find values for several variables which resulted in the best possible agreement between trained rater observed and computer calculated demerits (minimize the score). Before deciding upon the final optimization method three other schemes were investigated.

2. Random Lines

When using this method simultaneous optimization of eleven variables was being attempted. The procedure followed by the computer was to select two points in the eleven variable space, project a line between these points, and find the best optimum between them. Next, project a second random line through this best point, find a better optimum, and so on until no better optimum could be found. Since this is a random approach, there was no guarantee that repeat optimizations of identical data would yield matching results. In fact, they yielded widely varying results. Another optimization approach was then tried.

3. Partan

The computer projects two parallel lines through the n-space and finds the best optimum along each line. Through these two best points a third line is projected. A fourth line parallel to the third is then projected and the process starts again. As with the random line approach, this method tended to converge to local rather than universal optimum and it was therefore abandoned.

4. Exhaustive Search

With this method the computer found the optimum value for each variable by exhaustively investigating all possible values of each variable. By the time this third optimization procedure was being considered, several variables had been discarded from the optimization which reduced the required computer time to a manageable level. Using the exhaustive method the computer always converged to a unique optimum but the optimum values for the variables varied widely between individual driveability tests.

Because none of these optimization methods were satisfactory, the optimization described in the report was finally used -- linear-least-squares regression.

HESITATION

In developing a system for measuring hesitation, it was theorized that a lack of "proper" engine speed response to throttle opening could be used. To do this required defining an ideal rate of engine speed increase and comparing this rate with the actual rate. A simple equation was developed to predict ideal engine speed slope during the initial 1 or 2 seconds of an acceleration as a function of throttle opening. The equation form was:

$$\text{Ideal Engine Speed Slope} = 10^{(b_0 + b_1(\text{TTL}))}$$

where: TTL was the throttle opening 2.0 seconds after the beginning of the acceleration
b_x's are regression coefficients

Next, a relationship to predict hesitation demerits was developed as a function of the difference between the ideal slope and the actual slope existing during the acceleration. This provided very poor correlation between trained rater observed and computer calculated demerits.

The next attempt was to predict hesitation demerits as a function of: 1) time required for engine speed to increase by a constant amount (e.g. 50 or 100 RPM), and 2) throttle position 2.0 seconds after the beginning of an acceleration. This too provided poor correlation between observed and calculated demerits.

The first two hesitation methods may have failed because they placed too little emphasis on the time immediately after the acceleration began, and they did not recognize the possible effect of throttle opening rate upon engine speed increase. Therefore, coefficients were developed for the following regression equation through linear-least-squares techniques:

$$\text{Hesitation Demerits} = b_0 + b_1 \left(\frac{\text{WRPM}}{\text{WTTL}}\right)$$

where: WRPM and WTTL are weighted engine speed increase and throttle opening increase, respectively, during the first 1.0 second of an acceleration:

$$\text{WRPM} = 0.5(\Delta\text{RPM}_1)+.25(\Delta\text{RPM}_2)+.13(\Delta\text{RPM}_3)+.06(\Delta\text{RPM}_4)+.06(\Delta\text{RPM}_5)$$
$$\text{WTTL} = 0.5(\Delta\text{TTL}_1)+.25(\Delta\text{TTL}_2)+.13(\Delta\text{TTL}_3)+.06(\Delta\text{TTL}_4)+.06(\Delta\text{TTL}_5)$$

ΔRPM_i is the engine speed increase during the i^{th} 0.2 second interval of the acceleration
ΔTTL_i is the throttle opening increase during the i^{th} 0.2 second interval of the acceleration

The coefficients for this equation resulted in calculated demerits being very sensitive to the independent variable (WRPM over WTTL) and again correlation was poor between observed and calculated demerits. In addition, this method yielded nearly identical hesitation demerits for all three test fuels.

The attempts described above cover only the basic equations considered; in most cases several alternate equation forms were considered but found to be of little benefit. The final scheme for hesitation demerit measurement is described in the body of this report.

APPENDIX E

Data Used for Developing
Hesitation Measurement Method

HESITATION DATA

Test Number	Maneuver	Initial TTL, % Open	ΔTTL_i					Initial RPM	ΔRPM_i					MPH_0	WTTL	WRPM	Trained Rater Observed Hesitation Demerits
			1	2	3	4	5		1	2	3	4	5				
60	1st 0-25	5.8	2.1	4.3	7.4	3.7	3.7	710	20	50	70	200	100	19.5	3.5	44.6	0
	2nd 0-25	2.6	4.8	2.7	2.6	3.7	3.2	645	140	50	140	30	120	0	3.8	109.7	0
	1st 25-35	6.9	4.2	6.9	7.9	10.6	2.1	850	50	80	210	60	70	25.1	3.9	160.0	0
	2nd 25-35	5.3	3.2	7.4	30.1	3.7	0	880	30	130	320	30	70	27.8	9.3	95.1	0
	1st 0-35	3.7	82.5	10.6	0	0	0	550	450	350	10	10	50	1.1	44.0	317.0	0
	2nd 0-35	2.6	7.5	75.1	11.6	0	0	550	425	350	0	50	30	1.1	24.0	3050.0	0
63	1st 0-25	12.7	7.4	.5	.6	1.0	-1.0	580	110	390	20	0	-5	0	3.9	155.0	0
	2nd 0-25	2.6	12.7	12.2	-1.0	1.0	-1.0	590	100	340	30	-60	-60	0	9.3	182.0	0
	1st 25-35	9.0	26.4	6.4	2.6	0	.6	920	350	140	50	20	-5	25.5	15.2	217.4	0
	2nd 25-35	21.2	19.5	1.6	1.6	1.1	0	760	520	90	20	20	-5	27.0	4.4	286.0	0
	2nd 0-35	3.7	45.0	48.1	0	0	0	550	320	425	-25	20	50	2.6	34.5	11.1	0
67	1st 0-25	4.2	2.7	1.6	2.1	0.5	2.1	780	30	20	30	30	130	0	2.2	335.0	0
	2nd 0-25	4.2	3.7	6.9	3.7	3.2	4.2	620	30	60	120	160	130	0	4.5	63.0	0
	1st 25-35	7.4	2.1	6.9	11.6	17.5	2.6	910	60	220	140	100	20	25.5	7.6	110.4	0
	2nd 25-35	5.7	1.7	7.4	9.0	14.3	3.8	830	70	60	120	200	60	26.6	5.0	81.2	0
	1st 0-35	3.2	6.3	72.0	15.3	0	0	560	625	175	-30	30	30	1.1	23.0	356.0	0
	2nd 0-35	2.6	7.5	68.8	15.3	0	0	540	550	250	-25	50	70	1.1	23.0	341.0	0
71	2nd 0-25	3.2	24.8	-1.5	0	-0.6	-2.6	640	180	230	90	-50	-40	0	11.8	64.3	0
	1st 25-35	12.2	29.6	5.8	0	0	0	900	390	140	50	5	5	25.9	16.3	237.0	0
	2nd 25-35	4.2	24.9	7.4	5.3	4.2	0	800	120	390	60	50	10	27.8	15.2	169.0	0
	1st 0-35	2.6	4.3	82.0	7.9	0	0	550	375	425	20	25	40	1.5	24.0	300.0	0
	2nd 0-35	5.8	39.2	50.2	1.1	0.5	0	550	400	375	10	50	20	2.3	32.0	299.0	0
75	1st 0-25	4.2	4.8	1.6	1.6	2.6	1.1	950	20	50	40	0	20	0.4	3.2	28.9	0
	2nd 0-25	3.7	1.1	10.0	8.0	2.1	0	615	50	50	120	330	10	0.4	4.2	73.5	0
	1st 25-35	10.6	27.5	9.0	2.1	0	0	940	220	190	80	40	-5	26.2	13.0	170.0	0
	2nd 25-35	2.6	4.8	6.9	11.6	12.2	3.7	940	50	80	120	200	80	27.0	6.6	77.4	0
	1st 0-35	2.6	10.1	89.9	4.2	0	0	540	725	50	60	10	40	1.1	28.0	386.0	0
	2nd 0-35	2.6	3.2	82.0	9.0	0	0	540	750	-30	40	75	20	1.5	23.3	378.0	0

HESITATION DATA

Test Number	Maneuver	Initial TTL, % Open	ΔTTL_i					Initial RPM	ΔRPM_i					MPH_0	WTTL	WRPM	Trained Rater Observed Hesitation Demerits
			1	2	3	4	5		1	2	3	4	5				
78	1st 0-25	2.6	2.7	24.3	-4.7	-1.1	-0.5	520	30	390	210	20	-30	0.4	6.5	139.2	0
	1st 25-35	10.1	8.9	23.3	1.6	0	0	790	90	380	60	0	-20	27.0	10.5	147.0	0
	2nd 25-35	7.9	33.9	5.3	0	0.6	0	930	450	150	10	30	0	27.0	18.3	266.0	0
	1st 0-35	37.6	53.2	0	0	0	0	520	660	230	0	20	30	1.9	26.6	390.0	0
	2nd 0-35	10.6	77.2	9.0	0	0	0	540	560	250	-20	50	20	3.4	10.9	344.0	0
3	2nd 0-35	6.3	19.6	69.9	-0.5	0	0	890	-60	50	30	10	80	0	27.0	-8.2	24
	3rd 0-25	8.5	3.7	5.3	2.6	1.1	1.0	710	60	100	-10	-80	-50	0	3.6	45.9	24
	4th 0-45	6.9	2.1	2.1	7.4	6.4	4.7	740	20	160	170	-10	-25	0	3.2	70.0	12
	5th 0-35	3.2	24.3	64.0	0	0	0	825	260	270	60	-25	-80	1.5	28.0	199.0	24
	6th 0-45	2.6	4.3	1.2	4.8	2.6	8.0	645	70	260	110	20	-20	0	3.7	114.3	12
7	2nd 0-35	7.4	53.4	34.4	1.1	0	0	940	280	40	180	65	10	0.8	35.4	178.0	12
	6th 0-35	3.7	54.0	38.6	0	0	0	1000	530	40	10	-10	-15	0.4	37.0	275.0	6
8	3rd 0-35	6.3	12.2	77.8	0	0	0	850	320	320	50	-5	-80	1.5	26.0	243.0	12
9	2nd 0-25	10.1	2.6	4.5	4.2	0	0	620	30	5	-80	100	230	0	2.9	25.6	6
	4th 0-35	6.3	36.0	50.8	2.7	0.5	0	530	200	50	50	-50	-60	0.8	31.0	112.4	12
	5th 0-45	2.6	22.3	65.6	5.8	0	0	510	110	100	-30	40	-30	1.5	28.0	76.7	12
10	4th 0-45	3.7	6.4	6.3	6.4	-1.1	1.1	540	30	140	-40	-60	-70	0	4.3	37.0	12
	4th 25-35	6.9	34.8	8.5	-0.6	-4.7	0.5	950	-70	160	60	-80	-100	27.4	20.0	2.0	12
11	3rd 0-25	4.8	3.7	10.0	0.5	0.6	0	690	240	-70	-40	-10	5	0	3.7	97.0	6
	4th 0-45	6.3	12.7	8.5	1.6	16.3	-13.2	850	160	-160	-80	0	320	0	8.9	48.8	6
12	1st 25-35	6.3	41.3	2.1	-5.3	-0.5	0	1190	-130	-30	240	50	140	27.0	16.0	-29.9	12
20	2nd 0-25	14.8	2.7	1.0	1.1	3.7	0.5	810	70	20	110	30	50	0	2.9	59.0	6
22	1st 0-35	11.1	27.5	57.2	0.5	0	0	770	260	-100	450	65	10	2.3	28.0	168.0	6
23	3rd 0-25	11.1	0.5	6.9	0.5	0.6	0	660	130	-50	-70	-20	0	0	4.5	42.2	6
24	1st 10-25	6.3	15.9	0	-0.5	0	0	860	-30	-20	120	80	-5	13.9	5.5	0.1	6
31	4th 0-35	10.1	-3.7	3.7	9.0	2.7	2.6	630	160	160	20	-40	-50	0	2.4	117.2	6
	6th 0-45	7.4	-2.6	5.3	3.7	3.2	2.1	660	60	120	140	50	-40	0	2.1	78.8	6
44	2nd 0-35	4.8	11.6	57.1	15.3	0	0	780	250	290	60	0	-5	2.3	21.0	205.0	6
58	3rd 0-25	6.3	2.2	3.7	4.7	7.4	4.8	680	30	90	20	60	-150	0	3.7	34.7	6
	4th 0-45	3.2	4.2	6.4	2.6	1.6	3.2	600	90	240	30	20	-40	0	4.3	108.0	6
81	2nd 0-35	6.9	27.5	60.8	1.6	0	0	660	360	370	120	10	-20	0	29.0	287.5	6

APPENDIX F

Rater-Observed and Computer-Calculated Demerits

(Test Phases II-IV)

TEST FUEL 1 DEMERITS
(Phases II thru IV Results)

			Fuel 1 Demerits											
	Test Number	Rater	Hard Starting*	Idle Roughness		Hesitation		Stumble		Stall		Total	
				Rtr	Comp	Rtr	Comp	Rtr	Comp	Rtr	Comp	Rtr	Comp
TEST PHASE II	4	A	2.2	6	-	12	74.8	234	-	336	320	590.2	-
	5	B	0.4	1	8.2	24	52.2	96	73.7	256	256	377.4	390.5
	8	A	2.4	0	4.7	0	83.5	96	79.7	104	168	202.4	338.3
	11	A	4.0	0	28.8	0	121.1	108	88.5	40	48	152.0	290.4
	13	B	0	6	21.0	12	79.6	84	65.0	0	0	102.0	165.6
	15	B	0	6	6.0	0	44.9	84	73.0	0	0	90.0	123.9
	17	A	0.6	0	3.1	0	26.2	6	33.2	72	72	78.6	135.1
	20	A	1.0	0	3.3	0	55.0	30	48.6	0	0	31.0	107.9
	23	B	0	3	1.9	0	-	36	39.5	0	0	39.0	-
	**Mean		1.2	2.4	9.6	5.3	67.2	86	62.7	90	96	184.7	222.0
	Std. Dev., % of Mean		116	118	103	164	43	77	32.0	138	128	100	52
TEST PHASE III	28	A	1.4	0	1.0	0	77.1	210	-	128	128	339.4	-
	31	A	4.6	3	0.0	24	30.1	102	165.5	112	112	245.6	312.2
	34	B	2.0	8	2.4	0	5.3	288	185.0	40	40	338.0	234.7
	36	B	1.4	5	4.8	24	57.9	246	-	136	136	412.4	-
	40	A	1.2	0	14.3	42	86.8	168	-	176	168	387.2	-
	43	B	0	5	2.1	72	86.0	156	-	72	64	305.0	-
	46	B	1.2	5	3.8	30	92.9	162	119.5	104	104	302.2	321.4
	49	A	4.4	0	16.0	6	84.2	90	-	48	48	148.4	-
	50	A	6.8	0	0.8	6	63.9	138	126.6	72	80	222.4	278.1
	53	B	1.4	4	0.0	24	92.0	240	-	40	40	309.4	-
	58	A	1.4	0	7.0	0	25.0	168	91.8	8	8	177.4	133.2
	59	A	3.8	0	6.8	90	40.0	174	-	40	48	307.8	-
	**Mean		2.5	2.5	7.9	26.5	61.8	178.5	137.7	81.3	81.3	291.3	255.9
	Std. Dev., % of Mean		79	114	109	110	48	33	27	61	59	27	30
TEST PHASE IV	61	B	0	7	4.7	0	46.0	120	111.8	0	0	127.0	162.5
	65	B	1.6	11	6.5	48	144.0	126	154.7	296	296	482.6	602.8
	68	A	7.0	1	3.6	30	77.9	114	111.9	72	72	224.0	272.4
	70	A	2.4	0	8.9	126	155.0	174	119.4	264	264	566.4	549.7
	72	B	2.6	8	4.5	24	99.0	84	101.6	200	200	318.6	407.7
	77	B	2.6	5	2.2	36	72.0	102	112.7	104	104	249.6	293.5
	80	A	3.0	0	1.2	6	65.1	66	84.5	104	104	179.0	257.8
	83	A	2.6	4	6.2	114	130.5	114	105.7	136	168	370.6	413.0
	86	B	2.0	0	3.6	102	105.9	102	82.3	144	136	350.0	329.8
	**Mean		2.6	4	4.6	54	99.5	111	109.4	146.7	149.3	318.6	365.5
	Std., Dev., % of Mean		72	102	51	88	38	27	19	64	63	45	39

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* Starting time used for calculating hard starting demerits was not measured by the trained rater -- only by the computer. The hard starting demerits shown are included in the total for both the trained rater and computer.

** Means and Standard Deviations are calculated from all available observations.

TEST FUEL 2B DEMERITS

(Phases II thru IV Results)
- Continued -

	Test Number	Rater	Fuel 2B Demerits										
			Hard Starting*	Idle Roughness		Hesitation		Stumble		Stall		Total	
				Rtr	Comp	Rtr	Comp	Rtr	Comp	Rtr	Comp	Rtr	Comp
TEST PHASE II	1	A	0	0	4.9	6	74.8	0	24.1	0	0	6.0	103.8
	2	A	1.2	0	6.0	0	77.2	0	35.2	8	8	92.0	127.6
	7	B	0	1	6.9	0	13.2	96	31.7	0	0	97.0	51.8
	9	A	0	0	21.5	0	11.7	108	20.9	0	0	108.0	54.1
	14	B	0	5	4.1	0	22.0	18	31.2	0	0	23.0	57.3
	18	A	0	0	35.7	0	27.4	0	0	0	0	0	63.1
	21	A	0	0	33.4	0	52.9	6	36.7	0	0	6.0	123.0
	25	B	0	5	2.7	0	38.1	24	19.8	0	0	29.0	60.6
	27	B	0	9	0	0	7.7	30	48.5	0	0	39.0	56.2
	**Mean		0.1	2.2	12.8	0.7	36.1	31.3	27.6	0.9	0.9	44.4	77.5
	Std. Dev., % of Mean		400	149	107	286	74	133	49	300	300	97	40
TEST PHASE III	29	A	1.0	0	0.0	0	13.7	36	98.0	0	8	37.0	120.7
	32	B	0	3	0.0	0	0	42	48.3	0	0	45.0	48.3
	38	B	0	4	0.8	0	45.8	48	53.0	32	32	84.0	131.6
	41	A	0	0	6.6	0	53.3	42	41.4	32	32	74.0	133.3
	44	B	0	4	0.0	0	67.1	42	44.5	0	0	46.0	111.6
	47	A	1.4	0	0.7	18	76.2	36	54.6	8	8	63.4	140.9
	51	B	0	3	0.0	12	68.2	66	75.6	0	0	81.0	143.8
	54	B	0	2	0.0	0	83.4	90	-	0	0	92.0	-
	56	A	1.2	0	3.2	6	67.0	42	60.8	8	8	57.2	140.2
	**Mean		0.4	1.8	1.3	4.0	52.7	49.3	59.5	8.9	8.9	64.4	121.3
	Std. Dev., % of Mean		152	100	174	168	54	36	32	152	152	30	26
TEST PHASE IV	60	A	0	1	1.8	48	0	30	44.3	0	0	79.0	46.1
	62	A	0.4	0	6.4	42	49.0	84	81.5	64	64	190.4	201.3
	64	A	1.4	0	4.8	18	68.0	138	94.0	96	64	253.4	232.2
	66	A	0.4	0	2.3	54	59.0	168	113.8	0	0	212.4	175.5
	71	B	0	5	1.4	12	63.0	196	106.5	96	96	309.0	266.9
	73	B	0	4	0.2	24	39.0	66	91.5	0	0	94.0	130.7
	75	A	0.2	0	1.5	30	52.0	60	67.8	0	0	90.2	121.5
	78	B	0	0	0.4	12	65.6	84	87.1	0	0	96.0	153.1
	81	A	0.6	0	0.7	36	82.3	30	46.9	0	0	76.6	130.5
	85	B	0	1	0.8	0	38.5	60	62.4	32	32	93.0	133.7
	**Mean		0.3	1.1	2.0	27.6	51.6	91.6	79.6	28.8	28.8	149.4	159.2
	Std. Dev., % of Mean		148	168	101	63	44	62	30	143	143	57	39

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* Starting time used for calculating hard starting demerits was not measured by the trained rater -- only by the computer. The hard starting demerits shown are included in the total for both the trained rater and computer.

** Means and Standard Deviations are calculated from all available observations.

TEST FUEL 3 DEMERITS
(Phases II thru IV Results)
- Continued -

			Fuel 3 Demerits										
	Test Number	Rater	Hard Starting*	Idle Roughness		Hesitation		Stumble		Stall		Total	
				Rtr	Comp	Rtr	Comp	Rtr	Comp	Rtr	Comp	Rtr	Comp
TEST PHASE II	3	A	0	0	3.9	0	119.7	18	60.2	0	32	18.0	215.8
	6	B	0	0	5.9	0	51.7	36	32.6	0	0	36.0	90.2
	10	A	0	1	24.4	0	44.4	24	38.3	0	0	24.0	107.1
	12	B	0	5	5.9	0	7.1	18	20.3	0	0	23.0	33.3
	16	A	0	0	3.9	0	60.3	6	46.9	0	32	6.0	143.1
	19	A	1.0	0	29.4	0	56.6	6	20.2	8	8	15.0	115.2
	22	A	0	0	-	0	42.4	0	20.9	0	0	-	-
	24	B	0	6	3.7	0	5.8	30	20.9	0	0	36.0	30.4
	26	B	0	5	4.2	0	4.8	60	51.5	0	0	65.0	60.5
	**Mean		0.1	1.9	10.2	0	43.6	22	34.6	0.9	8.0	24.8	99.5
	Std. Dev., % of Mean		300	139	102	0	83	84	44	296	173	78	62
TEST PHASE III	30	A	1.8	0	0.0	36	7.1	42	108.3	8	8	79.8	125.2
	33	B	0.4	5	0.1	0	6.6	84	-	0	0	89.4	-
	35	B	0	4	0.0	0	0	60	114.6	0	0	64.0	114.6
	37	B	0	3	1.2	12	49.4	96	62.2	0	0	111.0	112.8
	39	A	1.4	0	17.3	18	68.7	30	50.3	8	8	57.4	145.7
	42	A	0	0	9.1	24	52.6	66	72.2	0	0	80.0	133.9
	45	B	0	3	12.3	0	52.3	90	70.8	0	0	93.0	135.4
	48	A	2.8	0	9.8	6	46.6	72	73.1	8	8	88.8	140.3
	52	B	0	4	0.5	6	59.3	72	65.6	0	0	82.0	125.4
	55	B	0	3	0.7	0	56.7	66	-	32	32	101.0	-
	57	A	1.4	0	9.4	6	47.0	24	46.3	8	8	39.4	112.1
	**Mean		0.7	2	5.5	9.8	40.6	63.8	73.7	5.6	5.6	80.5	127.3
	Std. Dev., % of Mean		140	100	113	120	59	37	32	179	179	25	10
TEST PHASE IV	63	A	0	0	7.6	0	26.0	24	41.9	0	0	24.0	75.5
	67	A	0.2	0	2.3	54	52.0	6	29.1	0	0	60.2	83.6
	69	A	0.2	0	0.7	6	20.0	12	39.2	0	0	18.2	60.1
	74	B	0.2	2	0.6	0	21.0	72	87.0	32	32	106.2	140.8
	76	A	0.4	0	2.4	12	52.0	78	102.7	0	0	90.4	157.5
	79	B	0	5	2.5	0	65.6	84	86.7	32	32	89.0	186.8
	82	A	0.4	0	5.8	36	60.5	78	68.7	32	32	146.4	167.4
	84	B	0.4	4	8.1	0	130.5	48	65.9	32	32	84.4	236.9
	**Mean		0.2	1.4	3.8	13.5	53.5	50.3	65.2	16	16	77.4	138.6
	Std. Dev., % of Mean		73	150	80	152	67	64	41	107	107	55	44

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* Starting time used for calculating hard starting demerits was not measured by the trained rater -- only by the computer. The hard starting demerits shown are included in the total for both the trained rater and computer.

APPENDIX G

Results of Analyzing Phase I Tests with Consolidated Program

DEMERITS CALCULATED USING CONSOLIDATED COMPUTER PROGRAM
Phase I

	Fuel 1 Demerits										
Test Number	Hard Starting*	Stall		Idle Roughness		Stumble		Hesitation		Run	Total
		Rtr	Comp	Rtr	Comp	Rtr	Comp	Rtr	Comp	Rtr	Comp
1	2.8	272	312	5	-	168	-	36	-	484	-
2	4.4	224	232	6	-	168	-	60	-	462	-
3	2.4	136	136	1	2.6	330	69	102	62	571	272
6	15.6	208	216	6	10.4	336	80	0	54	566	376
9	2.4	272	288	14	10.6	696	95	42	70	1026	465
10	0.2	208	304	12	11.5	282	57	18	75	520	448
12	2.0	176	208	7	9.0	306	55	12	50	503	324
13	0	0	0	0	9.9	90	18	0	12	90	40
19	3.0	320	320	5	15.5	294	58	0	52	622	448
26	4.0	304	304	4	9.6	300	128	0	32	612	477
30	1.8	272	272	3	5.8	270	95	0	27	547	401
31	12.4	240	240	5	7.2	354	97	12	48	623	405
34	1.8	208	240	1	3.6	150	48	0	28	361	322
35	1.4	144	144	3	2.3	138	67	0	27	286	242
38	4.6	168	168	3	8.5	96	52	0	37	272	271
40	2.2	112	104	1	5.4	148	67	0	58	263	236
42	1.2	144	144	10	11.2	228	82	0	41	383	279
43	2.0	200	200	8	6.5	162	64	0	40	372	312
47	1.8	112	120	7	9.8	114	45	0	40	235	217
50	2.2	104	104	0	4.7	90	39	0	34	196	184
53	1.8	112	112	8	8.7	162	73	0	41	284	237
59	1.8	296	296	1	0.1	108	64	0	41	407	404
65	1.8	264	264	6	4.7	180	49	0	47	452	366
68	2.2	80	80	0	4.8	66	17	6	57	154	161
73	1.4	208	240	8	6.5	192	79	0	35	409	362
77	1.8	104	104	5	5.7	138	94	0	51	249	256
**Mean	3.1	188	198	5.0	7.3	214	66	12	44	421	313
Std. Dev., % of Mean	110	43	44	74	48	61	39	200	33	46	35

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* Starting time used for calculating hard starting demerits was not measured by the trained rater -- only by the computer. The hard starting demerits shown are included in the total for both the trained rater and computer.

** Means and Standard Deviations are calculated from all available observations.

DEMERITS CALCULATED USING CONSOLIDATED COMPUTER PROGRAM

Phase I

- Continued -

Fuel 2A Demerits

Test Number	Hard Starting*	Stall		Idle Roughness		Stumble		Hesitation		Run	Total
		Rtr	Comp	Rtr	Comp	Rtr	Comp	Rtr	Comp	Rtr	Comp
4	15.8	0	8	1	0.5	18	28	0	26	35	78
5	0	0	0	0	0.7	18	14	0	27	18	42
7	4.4	0	0	0	7.2	108	8	18	25	130	45
8	0	0	0	3	0.9	162	10	6	28	171	38
11	0	72	72	-	-	24	21	12	57	-	-
14	0.8	32	32	0	1.2	210	57	0	76	243	168
17	0	0	0	1	1.9	12	23	0	28	13	53
18	0	0	0	2	2.1	18	8	0	57	20	68
22	0	0	0	1	1.0	30	24	6	34	37	59
28	0	0	0	1	0.4	30	13	0	49	31	62
29	0	0	0	1	1.5	30	22	0	29	31	53
33	0	0	0	2	1.6	30	11	0	11	32	24
39	14.2	0	8	1	1.0	6	13	0	30	21	66
41	0	0	0	0	3.0	6	24	0	11	6	38
46	0	0	0	0	4.6	6	33	0	26	6	64
52	0	0	0	0	2.6	12	27	0	18	12	48
54	0	0	0	0	2.0	0	7	0	62	0	71
56	0	32	0	0	1.4	6	66	0	48	38	76
58	0.6	0	0	0	1.3	6	15	12	45	19	62
61	0	0	0	1	3.3	24	10	0	45	25	59
64	0.8	32	32	0	2.8	12	18	0	25	45	78
66	0.4	32	0	0	1.1	6	11	0	57	38	69
69	0	0	0	0	1.5	18	8	0	29	18	39
72	0	0	0	0	1.4	24	22	0	35	24	58
74	1.2	0	0	0	1.4	6	6	0	0	7	9
80	0	0	0	1	8.6	18	33	0	19	19	61
81	1.0	0	8	0	2.6	6	11	6	19	13	41
**Mean	1.6	7.4	5.9	.6	2.2	31	20	2	34	40	59
Std. Dev., % of Mean	252	234	267	134	88	162	72	238	52	139	47

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* Starting time used for calculating hard starting demerits was not measured by the trained rater -- only by the computer. The hard starting demerits shown are included in the total for both the trained rater and computer.

** Means and Standard Deviations are calculated from all available observations.

DEMERITS CALCULATED USING CONSOLIDATED COMPUTER PROGRAM
Phase I

- Continued -

	Fuel 3 Demerits										
Test Number	Hard Starting*	Stall Rtr	Stall Comp	Idle Roughness Rtr	Idle Roughness Comp	Stumble Rtr	Stumble Comp	Hesitation Rtr	Hesitation Comp	Run Rtr	Total Comp
15	0.8	32	32	0	1.2	210	57	0	76	243	168
16	0.2	96	96	1	14.2	102	42	0	58	199	211
20	1.8	104	112	6	9.4	204	13	6	74	322	210
21	0.8	32	64	0	2.0	150	17	0	60	183	143
23	0.2	96	104	3	16.2	132	41	6	46	237	207
24	0	64	64	3	7.9	102	40	6	40	175	151
25	7.6	32	40	0	12.5	120	75	0	69	160	204
27	0.2	64	64	1	4.0	210	53	0	57	275	179
32	0	32	32	0	0.8	102	41	0	52	134	126
36	0	0	0	0	-	54	29	0	30	54	-
37	15.6	0	8	0	1.5	60	42	0	44	76	111
44	0.2	0	0	0	0.5	18	16	6	68	24	85
48	0.2	32	32	0	5.9	30	45	0	30	62	113
49	16.0	0	8	0	0.4	12	15	0	71	28	110
51	0.2	32	32	0	9.0	18	34	0	46	50	121
55	0.2	0	0	0	1.6	6	11	0	53	6	66
57	0	0	0	0	1.3	18	22	6	47	24	70
62	0.2	32	32	1	0.8	48	21	0	24	81	78
70	0	32	32	0	0	36	121	0	35	68	188
76	1.0	64	64	0	1.7	42	18	0	37	107	121
79	0.2	0	0	0	4.3	36	20	0	26	36	51
**Mean	2.2	35	39	0.7	4.8	81	37	2	50	121	136
Std. Dev., % of Mean	219	98	91	217	105	83	69	173	32	77	38

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* Starting time used for calculating hard starting demerits was not measured by the trained rater -- only by the computer. The hard starting demerits shown are included in the total for both the trained rater and computer.

** Means and Standard Deviations are calculated from all available observations.