EVALUATION OF THE NEW VIRGINIA DEPARTMENT OF HIGHWAYS AND TRANSPORTATION SKID TESTING TRAILER

by

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SUMMARY

The purpose of this study was to evaluate the new skid trailer obtained by the Virginia Department of Highways & Transportation and to determine how the survey skid testing program should be conducted in light of the findings. Specifically, those things considered about the new trailer were: (1) testing precision; (2) operational error, defined as unexplained day-to-day variation; (3) the speed-skid number relationships obtained for some customary surface types used in Virginia; and (4) the relationship of the new skid trailer to the Research Council's skid trailer and stopping distance car.

Based on the findings of the study several recommendations were made, including the following:

(1) Normal survey testing should be done at 40 mph (64 km/h).

(2) Corrections to skid numbers obtained at speeds other than the intended test speed should be based on a slope of -.55.

(3) Control site testing should be included as a normal part of survey skid testing, and skid test results should be adjusted based on control site test results.

(4) Survey skid test data collected with the trailer should be reported in terms of predicted stopping distance car skid numbers based on regression results obtained in this study.

(5) The relationships between the three testing devices should be verified at least annually.

(6) The testing rate in the survey program should be five tests per lane mile.

(7) At sites having borderline skid resistance, additional testing should be run with the trailer before taking action or verifying the results with stopping distance car tests when the standard deviation of the trailer results exceeds 2.25.

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INTRODUCTION

After several years of skid testing by the Virginia Highway & Transportation Research Council utilizing a skid trailer designed and constructed by the Research Laboratories for the Engineering Sciences at the University of Virginia, the decision was made for the Materials Division of the Department of Highways & Transportation to obtain a skid trailer for general survey and accident site skid testing. Specifications for the new trailer were developed by personnel from the Materials Division and the Research Council, and invitations for bids were submitted to several prospective manufacturers. Ken Law and Associates were awarded the contract and delivered the new skid trailer in May 1974, minus a digital display unit and printer, which would be available at a later date.

PURPOSE AND SCOPE

The purpose of this study was to evaluate the new skid trailer obtained by the Materials Division to determine what items should be given consideration in the survey skid testing program and accident site testing program. General test procedures based on prior experience in skid testing as well as data input procedures for skid testing have been defined in a previous report by Runkle.[1] This evaluation was intended to either verify the general procedures already adopted, or to indicate what changes might be necessary.

Specifically, those things considered about the new trailer were: (1) testing precision, or the ability to repeat test results at the same site under the same conditions during a short time span (short time span being defined as the period of time necessary to obtain several repeat tests — usually only a few minutes); (2) operational error, or the amount of error associated with repeated testing of the same site over extended time periods (day-to-day) under conditions as near the same as would be encountered and measured during survey skid testing; (3) the speed-skid number relationships obtained for some customary surface types used in Virginia; and (4) the relationship of the new trailer to the skid testing units already in use in Virginia, the Research Council's trailer and stopping distance car.

The study was limited in that only the normal water depth for skid testing (0.02 inch) (0.05 cm) and tires having a good tread depth (7/32" (.56 cm) or more) were used during the testing. A separate study under way by D. C. Mahone will explore the effects of different tread depths and water depths on skid resistance at several sites including several textures. Also, the speed-skid number relationships determined in this study were limited in that not all mix types (and thus textures) used in Virginia were tested, and the coarser mixes tested (I-2 and popcorn) were selected because they had a relatively low skid resistance and are not typical of the average mix of these types.

Finally, no attempt was made in this study to evaluate equipment components of the new trailer, its ease of operation, or its overall performance in terms of breakdowns and required maintenance. Information of this type is being collected by those in charge of the survey testing program and may be available in a later report after the survey testing program has been under way for an extended period of time.

TESTING PROGRAM

Tests were conducted in two phases on 15 sites including five pavement surfaces normally used in Virginia. During the first phase the Research Council skid trailer (VHTRC trailer) and skid car (VHTRC car), as well as the new skid trailer (VDHT trailer) were utilized to test all surfaces, with the two trailers testing sites 1-6 on several separate occasions. During this phase of testing the two trailers were equipped with old type ASTM test tires and the car was equipped with new Uniroyal tires.

During the second phase of testing the VDHT trailer and VHTRC car again tested the 15 sites during phase one, but this time both testing vehicles were equipped with the new type ASTM tires.

In both phases each site was tested at multiple speeds, with five tests being run at each test speed. For the trailers, during test phase one five tests were run in each of five passes (one for each speed) over the test section, thus multiple tests were not obtained at a common test spot within the test section. For phase two, the same procedure was followed, but in addition, five tests at each speed were obtained at a common spot in the test section. During both test phases the car obtained tests at the common test spot within each test section as tested by the VDHT trailer during test phase two.

DATA ANALYSIS

Data obtained in phase one of the testing are summarized in Table 1, and data obtained in phase two are summarized in Table 2 (all tables and figures are appended). Table 1 also indicates the mix type at each site while Table 2 shows the method of test, i.e. five tests at the same spot or five tests over a length of pavement. Both tables show the dates each site was tested. The average skid number and standard deviation shown for each test speed are based on five repeat skid tests.

As mentioned previously, the major items of interest were (1) testing precision, (2) operational variations, (3) speed-skid number relationships (or speed gradients), and (4) relationship of the VDHT trailer to the VHTRC trailer and VHTRC car. Several analyses were performed regarding each of these four items and are discussed in the following four sections.

Testing Precision

Testing precision, or repeatability, is defined as that testing variability experienced within a normal test sequence on a site. A normal test sequence presently involves five tests per mile per lane provided the surface mix, including aggregate materials, remains constant. Thus, precision as defined here includes random errors associated with the tester as well as nonhomogeneity of the site with regard to skid resistance. The testing variability for all three testing devices was examined by running five repeat tests at the fifteen sites shown in Tables 1 and 2, and computing standard deviations for the tests run at each test speed.

Several maximum F-ratio tests were run to determine if significant differences existed between variances.[2] For the results obtained during test phase one, it was found that for the VDHT trailer there were no significant differences between variances within a given site using a $\alpha = 0.5$ level of significance. This indicates that variances were not significantly different for different test speeds, and for those sites tested on more than one date the variances did not differ significantly for date tested. The same results were obtained during test phase two, where the variances at different test speeds within sites were compared for each test method employed. Again, it was found that the differences between variances at different test speeds within a given site were not significant at a $\alpha = 0.5$ level, with the exception of one site. The same analysis was performed for the VHTRC trailer and VHTRC car for the results obtained during both test phases, and in only three cases for the trailer and three cases for the car were significant differences determined between variances. Thus, on the basis of the above it was concluded that testing precision is equivalent within a given test site for different test speeds and test dates for both trailers, and for test speeds for the car. The question remains, however, whether testing precision is different between sites and/or between testing vehicles.

In order to answer that question, the standard deviations obtained at each site were combined to obtain the best estimate of site standard deviations by the method

$$S_{x_s} = (\Sigma_1^n Sx^2/n)^{\frac{1}{2}}$$

where

S_{x_s} = site standard deviation,

Sx = individual standard deviations at each site

and

n = number of standard deviations at each site which S_{x_s} is based on.

This approach is reasonable since usually no significant differences between variances were found within a site. The site standard deviations obtained in this manner are shown in Table 3.

This analysis showed that the two trailers had about the same average testing standard deviation during test phase one, and that both exceeded the average VHTRC car testing standard deviations. It was expected that the trailer variabilities would exceed the car during test phase one since the car tested the same spot while the trailers tested in series along a section, thus the longitudinal variation in the test sections is included in the trailer variabilities. During test phase two the VDHT trailer average standard deviation based on tests run at the same spot within a test section was equivalent to the average VHTRC car standard deviation (1.8 vs. 1.9). Again, the VDHT trailer had a higher average standard deviation based on the test results obtained in series through the test sections. On the basis of these results it is believed that the three test vehicles have about the same testing variability (precision) provided the test conditions are the same. Also, it should be noted that the standard deviations shown for the VDHT trailer testing at the same spot within the test sections are within the range of standard deviations obtained by 12 skid testers during an October 1972 correlation program conducted at the Pennsylvania Transportation and Traffic Safety Center's Pavement Durability Facility.[3]

In order to test if variances differed between sites, F-ratio tests at a α = .05 significance level were applied to the variances determined from the site standard deviations shown in Table 3. Based on this analysis, there was a large number of significant differences in site variances for each of the test vehicles, with the exception of the car in test phase one. These results were expected for those tests run in series since it was felt the sites were not all equally homogeneous with regard to skid resistance, and, in fact, the most occurrences of significant differences did occur when tests were run in series (VDHT trailer approximately 60%). However, the large number of significant differences in the site variances during test phase two for the VDHT trailer testing at the same spot (45%) and the VHTRC car (48%) indicates that some additional factor about the sites other than nonhomogeneity of skid resistance was affecting the variability.

It was felt the most likely effect on testing variability other than the testing method would be that from pavement texture. Again referring to Table 3, it can be seen that those sites having a harsher texture (4, 10, 11, 12, and 13) do tend to have relatively high standard deviations, thus supporting the belief that texture may influence testing variability to some extent.

Operational Variation

Operational variation is defined in this report as differences between average daily skid numbers as obtained from a series of five tests which cannot be attributed to random variation, or, as defined above, testing precision. Operational variation is said to occur if day-to-day differences for the same site are larger than would be expected due to testing error.

In order to determine what, if any, operational error exists, a two-way analysis of variance test was run at each site tested more than once during test phase one (none were tested more than once during test phase two under like conditions). Figure 1 graphically displays the test results on which the analyses of variance were run. The results indicate that for all analyses speed, as expected, was a highly significant factor, i.e., that the skid numbers obtained were significantly different for different test speeds (again testing at a α = .05 significance level).

The results also indicate that for the VDHT trailer the date tested was a significant factor. This significant difference in results obtained day-to-day is illustrated in Figure 1 by the distance between the lines plotted for each day. If no significant difference existed the lines would fall in approximately the same position. For the VHTRC trailer, date tested was a less significant factor than for the VDHT trailer, but still proved to be significant for three of the six sites. However, for the data available the results were not consistent in the sense that both trailers obtained relatively high or low values on the same day, thus indicating that the operational error probably cannot be accounted for by some measured variable such as temperature. It should be noted that the operational error for the VDHT trailer would be greatly decreased if the results of May 24, 1974, which were unusually high at each site, were omitted. However, the important point is that on all days, including May 24, 1974, the trailers and crews were operating as much the same as possible and still different results were obtained. It should also be noted that temperature corrections as described by Meyer, Hegmon and Gillespie[4] were considered, but offered no apparent improvement in the operational error. Finally, the results indicate that for three of the six analyses the interaction effects are significant, i.e., the magnitude of the change in skid numbers from day-to-day is different at different speeds. In Figure 1, this would be shown by non-parallel lines as can be seen at site 3 for both trailers. It is worth noting that while interaction effects were not frequently significant, when they were the greatest differences in skid numbers occurred at either low or high test speeds, thus indicating a middle range speed (40 or 50 mph) (64 or 81 km/h) as the best choice for survey testing.

In order to further indicate what operational variability may be encountered, additional 40 mph (64 km/h) test results at sites 1-6 are plotted in Figure 2. The tire type was changed from old type ASTM to new type ASTM between the tests run in April and those run later, but regardless it is apparent that the operational variation discussed above continued.

No analysis of operational variation was possible for the VHTRC car since it did not test the same site on successive dates, except for site 5 during test phase one.

Speed Gradients

Speed gradients are of interest primarily for the purpose of applying corrections to individual skid tests in order to make them equivalent to the results that would be obtained at the stated test speed, i.e., correcting a skid value obtained at 38 mph (61 km/h) to the value that would be obtained at 40 mph (64 km/h).

Speed gradients are also of use in making predictions of expected skid values at speeds other than the test speed, i.e., predicting the skid values at 70 mph (113 km/h) based on 40 mph (64 km/h) test results.

Because of the intended uses of speed gradients, it was felt that an average slope for each mix type would be the most detailed information that would be usefully applied, and that hopefully an average slope for a group of mix types could be used. Unfortunately, as explained above under "Purpose and Scope", the test sites for the more open mixes (popcorn and I-2) were selected because they had lower than average skid numbers, generally because of flushing conditions, and the speed gradients obtained on these sites probably would not be typical of those normally found for these mix designs. With the above limitations in mind average speed-skid number curves for each mix type are shown in Figure 3 for the VDHT trailer during both test phases and the VHTRC trailer during test phase one. To obtain these average curves the data from site to site were normalized by finding the differences between the average skid numbers obtained at speeds other than 40 mph (64 km/h) and the average skid number obtained at 40 mph (64 km/h) (40 mph (64 km/h) was selected as the zero value since it is the normal survey testing speed).

As can be seen in Figure 3, with the exception of the somewhat erratic results obtained on the popcorn mixes by the VHTRC trailer during test phase one and on the I-2 mixes by the VDHT trailer during test phase two, the slopes (speed gradients) are about the same for the various mix types with perhaps a slight reduction in slopes for the harsher textured surfaces. Figure 4 shows average curves for the smoother textures (S-5 and PCC) and harsher textures (I-2, popcorn, and surface treatment), and again illustrates the approximately same slopes. Based on these average curves, slopes were estimated for each test speed and it was found that little accuracy would be lost if average slopes were used at each test speed. An average error of not more than .5 skid number per 10 mph (16 km/h) change in speed would be expected.

Also evident from Figures 3 and 4 is the fact that the speed-skid number curves are fairly close to being linear for the range of test speeds considered, especially for the smoother textured surfaces. Selecting the average of the estimated average slopes at 40 mph (64 km/h) and 50 mph (81 km/h) (slope = -.55) for prediction purposes produces a maximum average error of 2.5 skid numbers (VHTRC trailer — test phase one, harsh texture) at any test speed for the curves shown in Figure 4, and in most cases the average error is within one skid number.

Relationship of Testing Devices

As mentioned previously, one of the specific purposes of this study was to develop the relationships between the VDHT trailer and the VHTRC trailer and car. The relationship between the VDHT trailer and VHTRC car is of particular interest since traditionally skid data have been reported in Virginia in terms of stopping distance skid numbers (either actual or predicted). It is felt this practice should be continued because the skid numbers as obtained by the stopping distance method are the ones of primary interest since they can be directly related to a car stopping distance, and since this method of reporting data standardizes the data as collected from different testing devices.

One would expect the two trailers to obtain approximately the same average skid number at each site (or at least numbers not statistically significantly different), but previous studies such as the Penn State correlation study have shown that trailer results do differ significantly at the same site. No doubt the differences between the VDHT and VHTRC trailers would be significantly different judged by testing precision only, and probably would not be considered significantly different if operational variation were also considered. Regardless, it was felt the important thing to do was to establish what the relationship was, and this was accomplished through the use of linear regression analysis.

Utilizing data from test phase one when both trailers tested, linear regressions were determined between the two trailers at each test speed. These results are shown in Figure 5, where the dotted line is the computed regression curve and the solid line is the line of equality (one to one relationship). It should be mentioned that each point shown is the average of five repeat tests for each vehicle, and thus utilization of the curves (particularly the confidence limits associated with the curves) should be on the basis of the average of at least five tests. As shown in Figure 5, the relationships are fairly close to being one to one, particularly at the speeds of 40 and 50 mph (64 km/h and 81km/h), with the VHTRC trailer consistently obtaining results somewhat higher than the VDHT trailer. The data spread around the computed regression curve is fairly high (at 40 mph (64 km/h) the standard error is 4.0, which indicates a 95% confidence range of ± 8 skid numbers). It is felt that much of this data spread is due to operational variation (maybe as much as 75% based on the control site data shown in Figure 2).

Several linear regression analyses were also made to better quantify the relationships between each of the trailers and the VHTRC car at all combinations of test speeds. The results of these analyses are summarized in Table 4. Again it should be noted that points in the regression analyses were averages of five repeat tests. It should also be noted that the regression curves with their associated confidence bands as determined from the standard errors shown in the far right column in Table 4 account for operational variation. A predicted car value based on the regression curve would fall within ± 2 standard errors of the predicted value with 95% confidence.

Just prior to concluding this study, additional correlation data were obtained when both trailers and the VHTRC car were used to test several sections of roadway, many of which had been predicted as having an average car skid value less than 50 based on previous results obtained with the VHTRC trailer. Data obtained on these sites tested at 40 mph (64 km/h) only are shown in Table 5. For purposes of correlating the car with the two trailers, the data obtained in opposite directions were averaged for each site since many of the sites were not level. All data obtained for both directions were used in correlating the trailers since the levelness of the site would not affect their results.

Linear regressions were performed on the additional data obtained combined with (1) the 40 mph (64 km/h) data for the trailers collected during test phase one, (2) the 40 mph (64 km/h) data for the VDHT trailer and VHTRC car collected during test phase two, and (3) the 40 mph (64 km/h) data for the VHTRC trailer and car collected in test phase one. The results of these linear regressions are shown in Figures 6 and 7, and, as can be seen, the relationships change very little with the additional data (the new data as shown in the two figures are indicated by triangles).

RECOMMENDATIONS

Based on the results as discussed above, the following recommendations are made.

(1) Normal survey skid testing should be done at 40 mph (64 km/h), unless safety considerations require a lower test speed. Results of this study indicated that a test speed of 40 mph (64 km/h) is as good or better as any other test speed with regard to testing precision, operational variation, and the prediction of skid numbers obtained by the stopping distance car method. In addition, the customary test speed for trailer testing has always been 40 mph (64 km/h).

(2) Corrections to skid numbers obtained at speeds other than the intended test speed (say 38 mph (61 km/h) as opposed to 40 mph) (64 km/h) should be based on a slope of -.55. Data obtained in this study indicate little difference in speed-skid number relationship due to mix type, and also indicate that the speed gradient is very close to linear. This recommendation is subject to change depending on the results obtained in Mahone's study.

(3) Because of the significant operational variation (day-to-day variation) found for both the trailers, control site testing should be included as a normal part of trailer testing as described in the report "Test Procedures and Data Input Techniques for Skid Testing,"[5] and skid data should be adjusted according to control site testing. Basically, the procedure as outlined in the report mentioned is to establish permanent control sites near the home base of the VDHT trailer which will be tested prior to and after each testing program, whether the interval between programs is one day or several days, with permanent control sites being tested a minimum of twice per week (once at the beginning of the week and once at the end of the week). In addition, daily control sites are to be selected when the VDHT trailer is away from its home base, and the trailer will be tested at the end of each day and the beginning of the next day. It is recommended that sites 1 and 2 (portland cement concrete) and sites 5 and 6 (bituminous concrete S-5) be utilized as permanent control sites, with the addition of two slurry seal sites and two sites having a more open texture (such as I-2 or popcorn) when possible. Average skid values should be determined for these sites on the basis of at least eight test runs, with each test run consisting of five repeat tests, and each test run occurring on a separate day. The initial testing to establish an average site skid number should span at least four weeks and preferably be in the summer months, since skid resistance values are probably lowest during summer and results obtained during other periods should be adjusted to this lowest value. The adjustment procedure should be incorporated in the computer programs used to process skid data, and initially should involve a single adjustment value for each day based on the difference between that day's control site average and the base control site value.

It should be emphasized that the automated data system under development to store and retrieve skid data will retain the skid data in their collected form, and any adjustments made will be in output procedures for preparing auxiliary files or reports. Thus, access will always be available to the actual data, which will permit different or no adjustment schemes if desired.

(4) Survey skid test data collected with either trailer should be reported in terms of predicted VHTRC car stopping distance skid numbers (PSDN) as based on the regression results shown in Table 4, except for 40 mph (64 km/h) trailer results versus 40 mph (64 km/h) VHTRC car results, which are shown in Figure 7. Included with the PSDN should be the 95% confidence limits as determined from the standard errors shown in Table 4 and Figure 7. For instance, for the regression analysis shown in Figure 7 for the VDHT trailer and VHTRC car, a predicted VHTRC car skid number of 40 would have a 95% confidence band of $\pm$ 6 skid numbers. Assuming the adjustment of survey skid data based on control site testing is implemented as recommended, the standard errors probably would be reduced. However, the amount of the reduction could be determined only through future correlation programs.

It should be mentioned that predicted stopping distance numbers will be predictions of VHTRC car values that would be obtained on level surfaces. Additional research or literature review is necessary to determine how the predicted numbers would be altered by different grades.

(5) Each control site should be tested with the VHTRC car and VHTRC trailer periodically (at least each summer) together with the VDHT trailer to continually verify the relationships established in this report, and to establish new control site base values.

(6) The rate of testing, or sample size, should continue to be five tests per lane mile per mix type with a minimum of five tests per lane per mix in order to best utilize the regression results obtained in this study. Also, based on the average site standard deviation (testing precision) of 2.5, five tests are required to predict the mean value within 2.25 skid numbers.

(7) At sites having borderline skid resistance, additional testing should be done with the trailer before taking action or verifying the results with the VHTRC car when the standard deviation of the average trailer skid number for the site exceeds 2.25. Since the confidence limits on the PSDN as discussed in recommendation number 4 above are partially dependent on the variation in the trailer skid results, a better estimate of the VHTRC car value can be obtained by increasing the sample size for the trailer. The standard deviation value chosen would exceed roughly 50% of the sites tested in this study and, of course, can be increased if desired.

(8) When testing with the VHTRC car, the sample size or number of tests run should be large enough to predict the mean car skid value within ± 2 skid numbers with 95% confidence where the confidence limits are computed as

$$CL = \pm t\ (s/n)$$

where

CL = 95% confidence limits,

t = student t value required for 95% confidence at a given sample size,

s = site standard deviation as determined from the skid tests, and

n = sample size, or number of skid tests run.

By rearranging the above equation the sample size required to predict the mean value within ± 2 skid numbers can be determined for each site after running an initial series of five tests by

$$n = \frac{(2.776)^2\ S^2}{2^2}$$

which reduces to

$$n = 1.93\ S^2$$

where S is the standard deviation computed from the initial five tests at the site. Thus, assuming an average site standard deviation for the VHTRC car of 2.0 as shown in Table 3, the normal sample size required would be

$$n = 1.93\ (2)^2 = 7.72, \text{ or } 8.$$

Since five initial tests are run, only three additional tests need be required for the average site. The largest sample size required based on the largest standard deviation shown in Table 3 for the VHTRC car of 3.2 would be $n = 1.93\ (3.2)^2 = 19.76$, or 20 tests.

(9) The final recommendation concerns additional research the author feels is desirable. First, the results of Mahone's study on the effect of texture, tread depth, and water depth on skid resistance should be examined closely to determine if varying speed-skid number relationships should be considered, and, if so, how they should be considered. For instance, should different regression curves be established to predict stopping distance skid numbers depending on pavement texture. Second, further study of tester variation and particularly operational variation would be desirable for the trailers and the VHTRC car. It is felt this study could be accomplished by repeat testing of a few sites at 40 mph (64 km/h) at varying time intervals, and may be combined with the periodic control site testing by the VHTRC car and trailer recommended in number 5 above. Third, as mentioned previously, the effect of grade on stopping distance skid numbers should be determined so that adjustments to predicted stopping distance skid numbers based on grade can be made. Finally, the control site testing should be reviewed continually to determine how and if adjustments should be best made, and how seasonal variations should be considered, if they exist.

REFERENCES

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(2) Natrella, M. G., Experimental Statistics, National Bureau of Standards Handbook 91, August 1963.

(3) Meyer, W. E., R. R. Hegmon, and T. D. Gillespie, "Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques," NCHRP Report 151, (Washington, D. C., Transportation Research Board, 1974.

(4) Ibid.

(5) Runkle, op.cit.

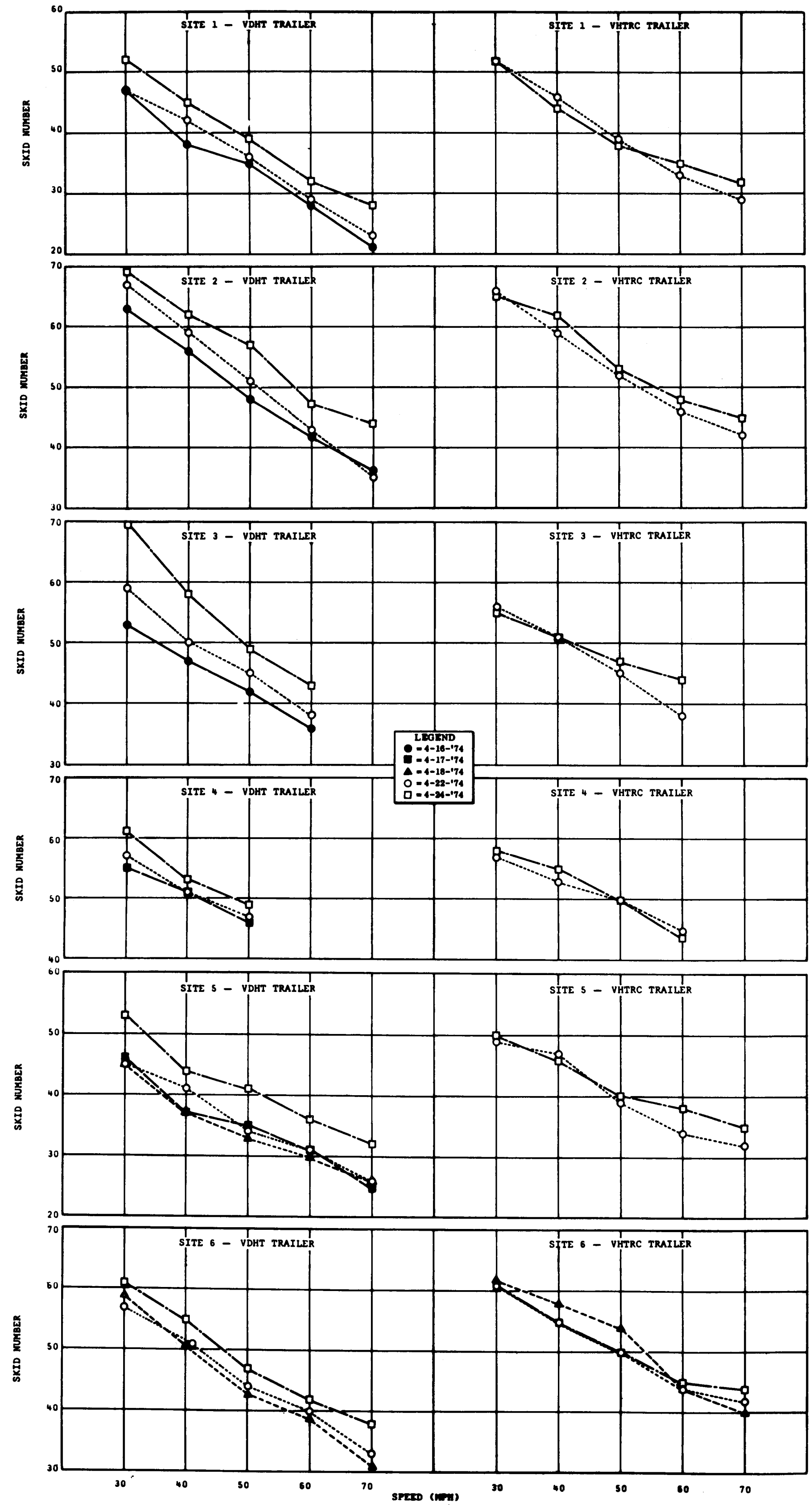


Figure 1. Partial test results — test phase 1, (1 mph = 1.609 km/h).

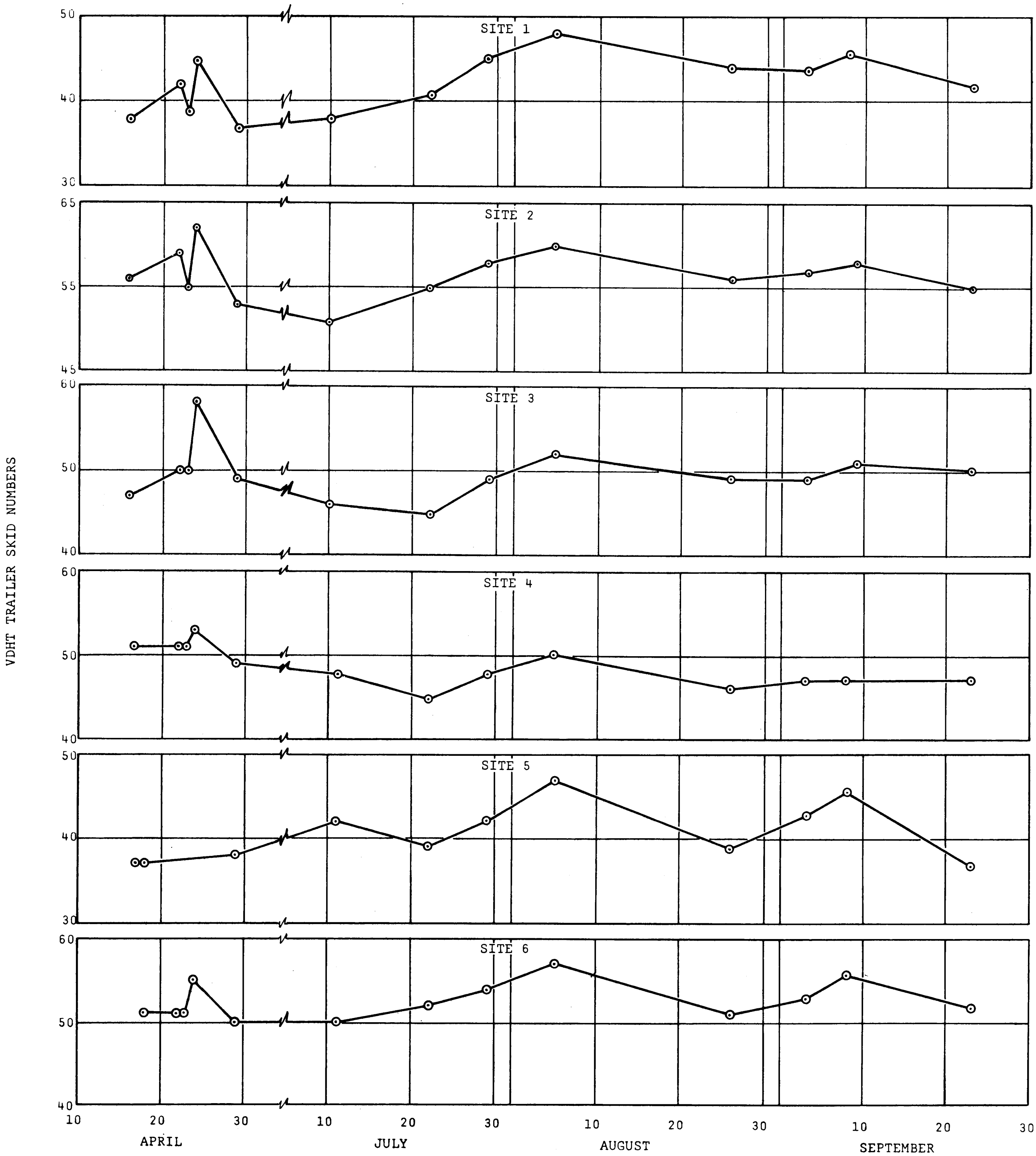
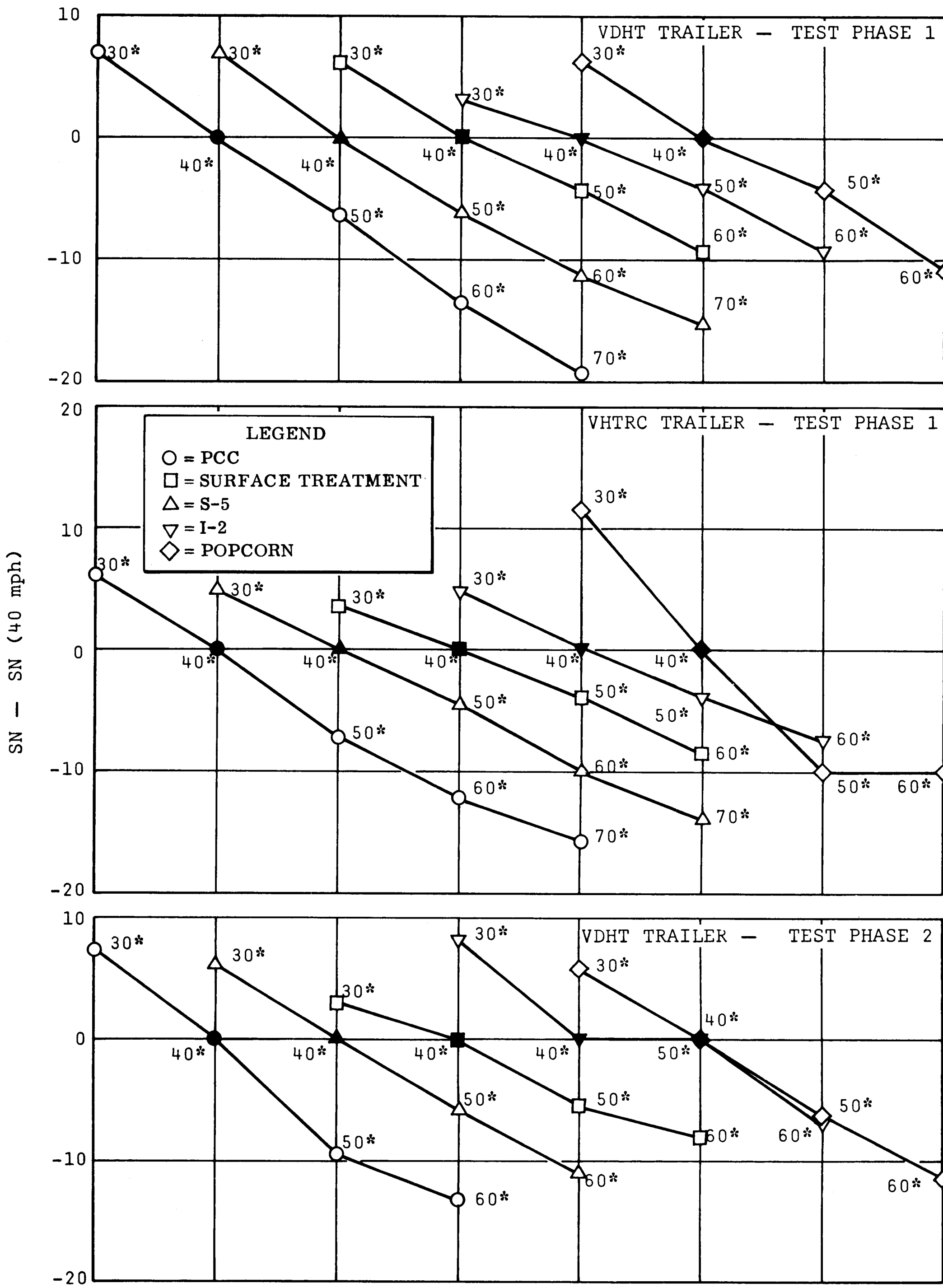


Figure 2. Control site tests.



*Speed in mph is indicated for each of the points plotted.

Figure 3. Skid number — speed relationships by mix, (1 mph = 1.609 km/h).

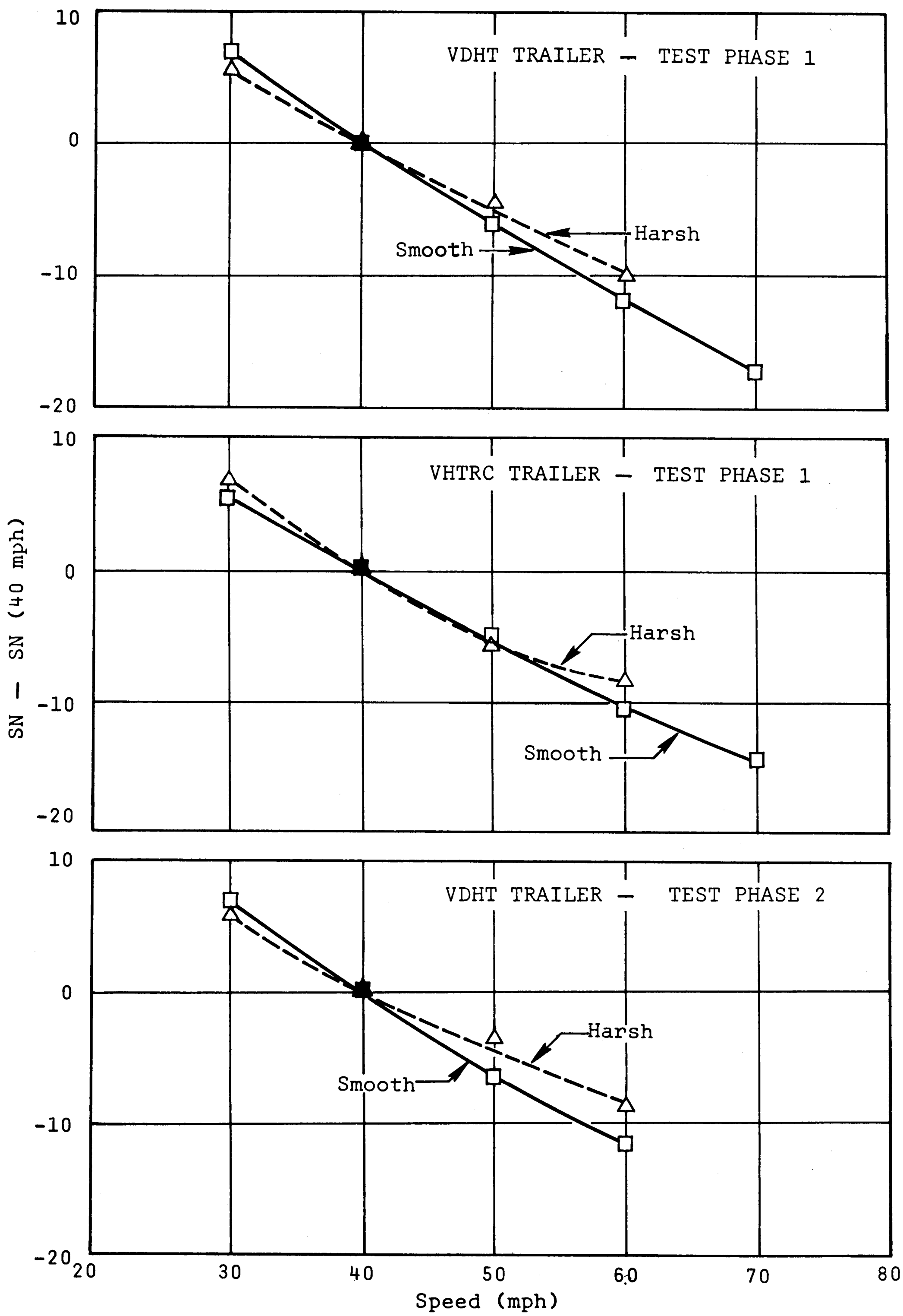


Figure 4. Skid number — speed curves by texture, (1 mph = 1.609 km/h).

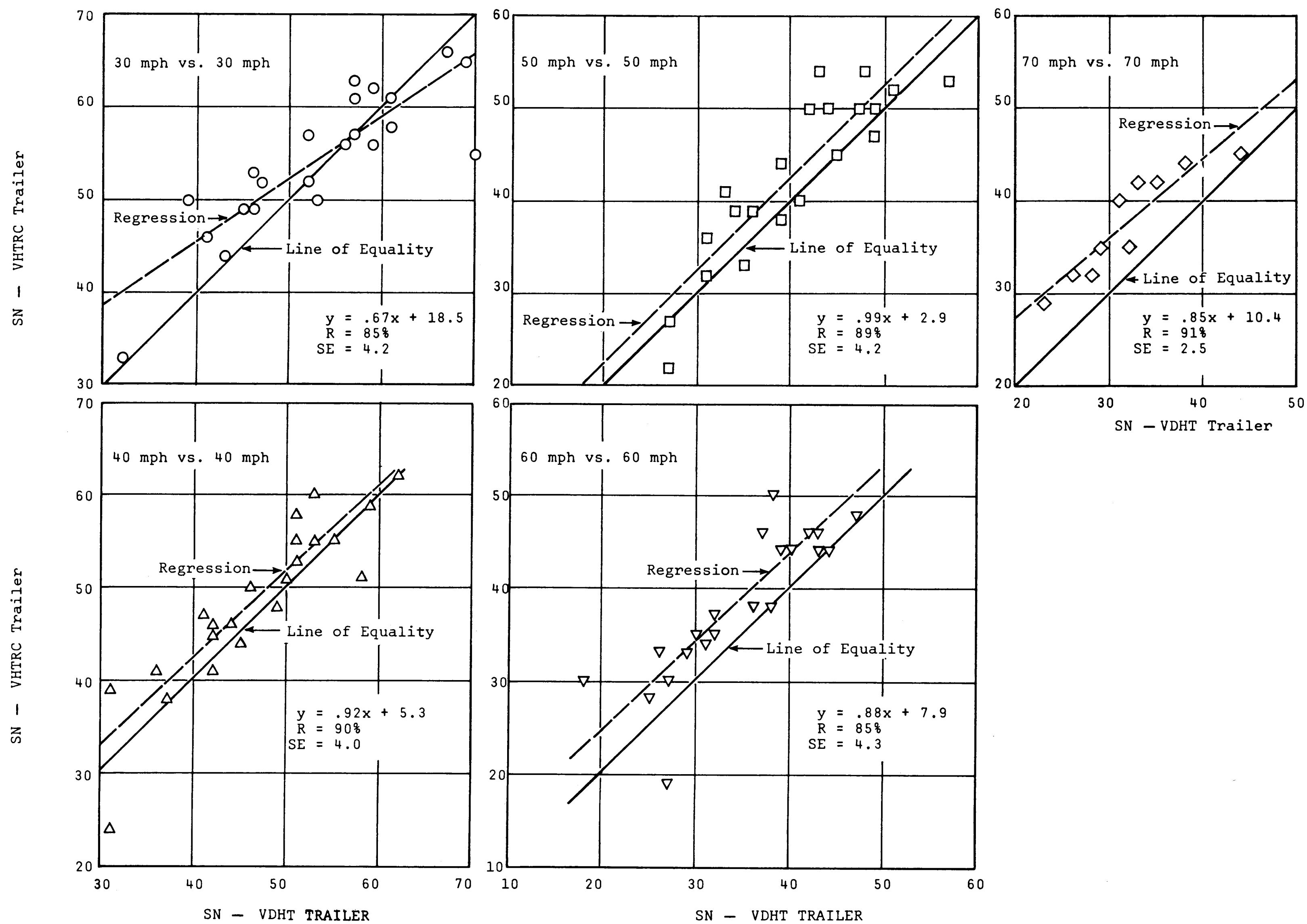


Figure 5. VDHT trailer vs. VHTRC trailer regression results, (1 mph = 1.609 km/h).

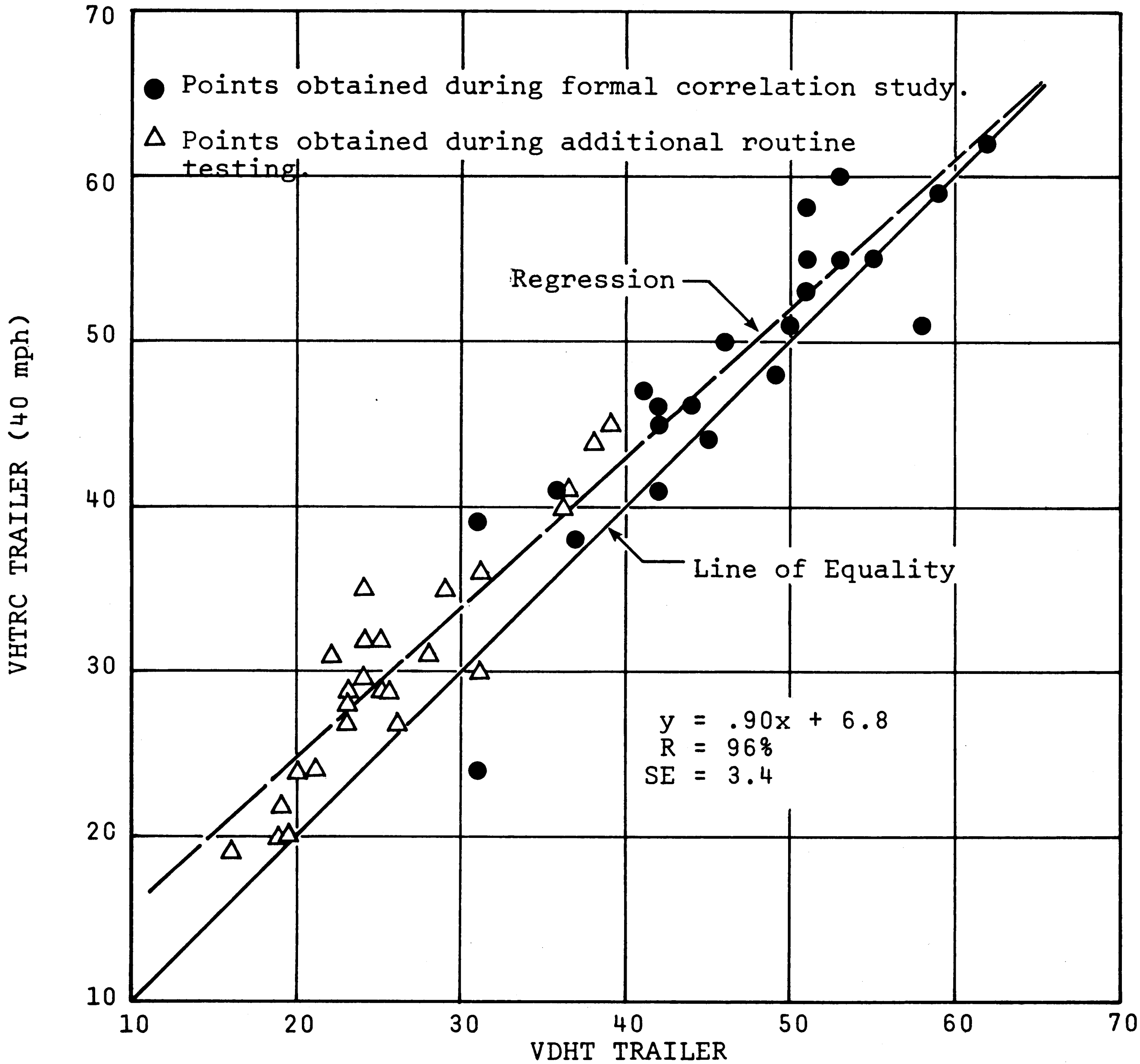


Figure 6. Trailer correlation (40 mph).
(1 mph = 1.609 km/h).

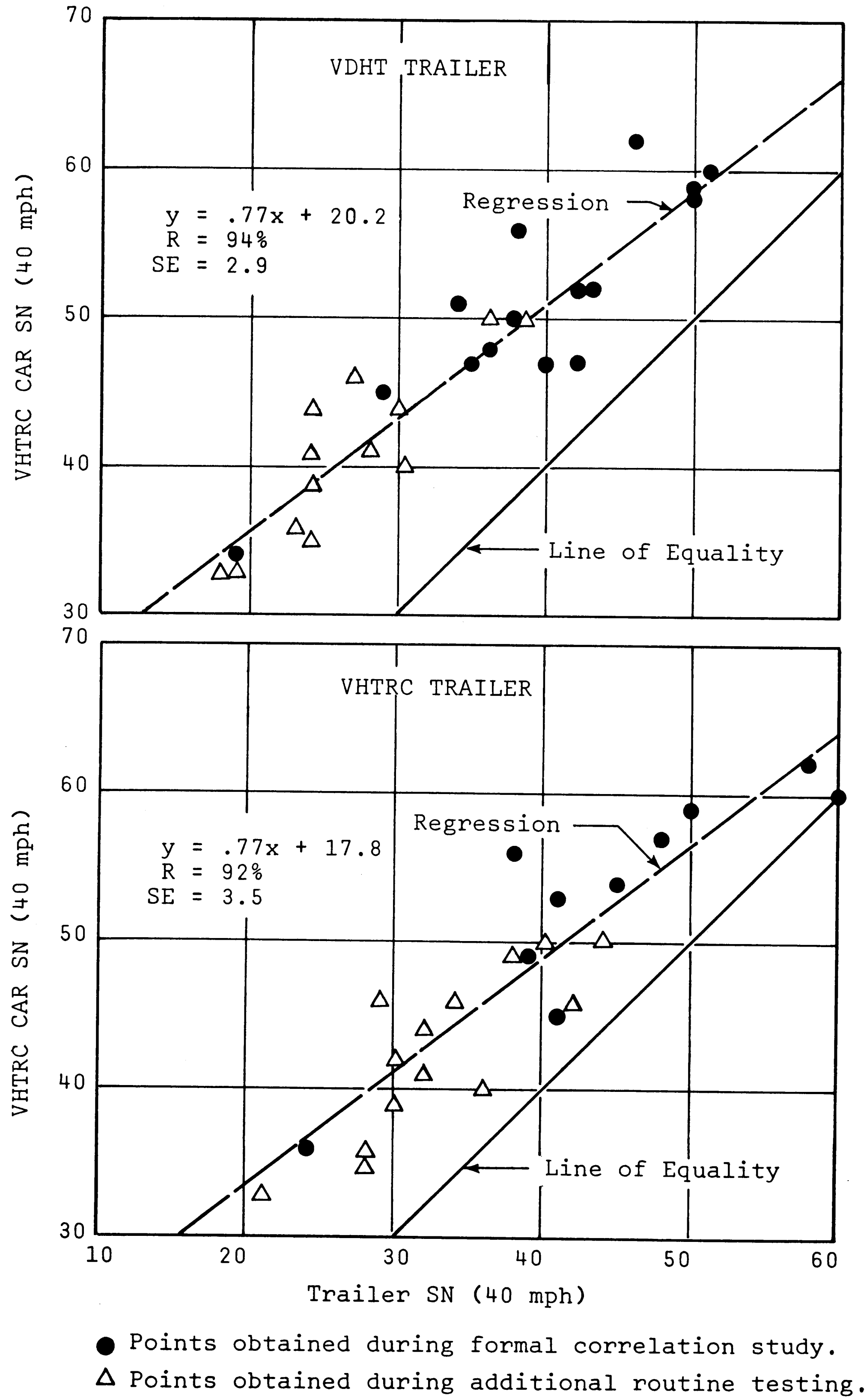


Figure 7. Car-trailer correlations (40 mph), (1 mph = 1.609 km/h).

TABLE 1

Test Results - Test Phase One

(1 mph = 1.609 km/h)

Test Site	Mix Type	Date Tested	VDHT TRAILER										VHTRC TRAILER										VHTRC CAR									
			30 Mph		40 Mph		50 Mph		60 Mph		70 Mph		30 Mph		40 Mph		50 Mph		60 Mph		70 Mph		30 Mph		40 Mph		50 Mph		60 Mph		70 Mph	
			X	Sx	X	Sx	X	Sx	X	Sx	X	Sx	X	Sx	X	Sx	X	Sx	X	Sx	X	Sx	X	Sx	X	Sx	X	Sx	X	Sx	X	Sx
1	Portland Cement	4/16/74	47	4.9	38	2.6	35	3.9	28	1.9	21	1.6											55	1.3	54	1.4	52	1.3	48	2.1	46	0.8
		4/22/74	47	1.3	42	2.7	36	1.5	29	2.7	23	1.9	52	2.3	46	1.8	39	2.0	33	2.3	29	2.7										
		4/24/74	52	1.8	45	1.9	39	1.8	32	1.3	28	4.5	52	1.5	44	3.0	38	1.9	35	1.1	32	2.6										
2	Portland Cement	4/16/74	63	1.3	56	1.5	48	2.2	42	1.8	36	1.7											61	1.3	63	2.1	58	2.0	55	1.5	49	2.2
		4/22/74	67	0.9	59	2.6	51	2.0	43	2.3	35	1.9	66	1.9	59	4.0	52	1.2	46	3.5	42	2.1										
		4/24/74	69	1.5	62	1.7	57	2.2	47	2.2	44	2.7	65	1.5	62	0.0	53	2.4	48	2.4	45	3.8										
3	Bit Conc. Type S-5	4/16/74	53	2.1	47	2.4	42	1.1	36	1.9													61	2.2	59	2.0	55	1.5	54	2.2		
		4/22/74	59	1.8	50	1.7	45	2.2	38	1.9			56	0.9	51	1.8	45	0.9	38	1.1												
		4/24/74	70	3.1	58	3.0	49	1.3	43	1.1			55	1.8	51	1.5	47	1.4	44	2.3												
4	Bit Conc. Surface Treatment	4/17/74	55	2.4	51	1.3	46	3.8	41	3.3													60	3.1	57	1.6	55	1.4	54	1.1		
		4/22/74	57	0.5	51	1.5	47	3.0					57	1.1	53	1.4	50	1.6	45	2.6												
		4/24/74	61	2.0	53	1.6	49	3.7	44	1.7			58	1.1	55	1.6	50	2.4	44	1.8												
5	Bit Conc. Type S-5	4/17/74	46	2.1	37	1.0	35	1.5	31	3.2	25	0.6											57	2.2	55	2.1	49	4.1	46	2.3	44	1.9
		4/18/74	45	1.6	37	0.9	33	1.6	30	2.6	26	3.4											56	1.5	54	2.4	52	1.8	49	0.7	46	1.0
		4/22/74	45	2.8	41	0.9	34	2.4	31	2.7	26	2.0	49	2.4	47	0.9	39	2.3	34	3.0	32	1.7										
		4/24/74	53	2.8	44	0.9	41	2.8	36	1.5	32	2.9	50	1.4	46	3.5	40	4.0	38	2.9	35	4.2										
6	Bit. Conc. Type S-5	4/18/74	59	0.9	51	3.6	43	2.3	39	1.8	31	2.6	62	2.0	58	1.4	54	4.0	44	2.5	40	3.4	63	0.5	62	2.6	59	1.5	54	2.9	50	1.5
		4/22/74	57	3.6	51	2.4	44	3.1	40	1.5	33	2.4	61	1.8	55	2.5	50	2.4	44	3.5	42	3.0										
		4/24/74	61	2.1	55	4.4	47	2.6	42	1.9	38	2.4	61	1.8	55	1.6	50	6.2	45	4.4	44	3.0										
7	Bit. Conc. Type S-5	4/23/74	52	2.6	46	4.5	39	3.7	32	2.3	29	4.8	57	4.0	50	5.8	44	2.8	37	4.2	35	1.0	59	3.6	59	1.5	56	1.7	51	1.6	49	1.2
8	Bit. Conc. Type S-5	6/23/74	43	1.3	37	1.9	31	2.4	25	2.0			44	3.3	38	3.6	32	3.6	29	3.6			57	2.3	56	1.2	52	1.1	45	2.0		
9	Bit. Conc. Type S-5	6/3/74	56	2.4	49	1.0	42	3.5	37	2.7			56	5.6	48	1.7	50	3.2	46	2.0			58	1.5	57	1.3	57	2.6	49	2.3		
10	Bit. Conc. Type I-2	6/3/74	33	7.1	31	7.2	27	5.9	27	9.6			32	2.7	24	1.1	22	1.8	19	0.9			38	2.1	36	2.0	36	2.0	35	1.8		
11	Bit. Conc. Type I-2	6/3/74	57	2.5	53	2.9	48	5.7	38	2.3			63	0.0	60	2.7	54	4.1	50	5.0			63	1.2	60	2.2	58	0.8	52	2.1		
12	Popcorn Mix	6/4/74	39	5.1	31	1.9	27	5.7	18	2.6			50	6.7	39	2.3	27	5.8	30	7.9			53	1.8	49	2.3	48	3.1	43	4.1		
		6/5/74	33	3.6	28	3.2	24	5.4	18	3.4																						
13	Popcorn Mix	6/4/74	46	4.1	42	7.2	35	5.6	27	4.2			53	4.5	41	4.6	33	5.5	30	7.9			58	3.8	53	2.0	50	1.1	35	1.1		
		6/5/74	46	2.9	37	5.0	35	3.6	28	3.1																						
14	Bit. Conc. Type S-5	6/5/74	41	3.6	36	3.6	31	3.7	26	1.7			46	2.4	41	4.1	36	5.0	33	2.5			50	1.4	45	1.6	42	1.5	40	2.5		
15	Bit. Conc. Type S-5	6/5/74	45	7.0	42	5.4	33	4.8	30	4.1			49	7.2	45	8.6	41	3.4	35	5.7			57	2.5	54	1.3	48	2.4	46	1.3		

TABLE 2

Test Results - Test Phase Two
(1 mph = 1.609 km/h

Test Site	Date Tested	Method Tested	VDHT TRAILER								VHTRC CAR							
			30 Mph		40 Mph		50 Mph		60 Mph		30 Mph		40 Mph		50 Mph		60 Mph	
			X	Sx	X	Sx	X	Sx	X	Sx	X	Sx	X	Sx	X	Sx	X	Sx
1	7/10/74	Same Point Series	48 47	0.8 1.8	41 38	0.8 1.7	34 33	0.9 1.9	29 25	0.9 2.1	52	2.7	50	1.3	46	1.1	43	1.1
2	7/10/74	Same Point Series	58 57	1.8 1.1	51 51	0.4 0.9	42 34	1.1 1.2	37 37	1.3 2.2	62	0.4	60	1.2	56	1.5	51	0.7
3	7/10/74	Same Point Series	52 51	0.8 0.9	43 46	1.6 1.3	37 39	0.4 2.2	32 34	1.6 1.5	62	1.5	62	2.0	59	1.7	55	2.4
4	7/11/74	Same Point Series	52 48	1.4 1.5	46 48	1.0 0.8	42 41	3.6 1.9	38 40	1.5 2.3	58	1.6	56	2.8	54	1.8	49	1.8
5	7/11/74	Same Point Series	48 48	0.4 1.3	41 42	1.5 1.1	36 35	1.0 1.9	29 33	0.6 1.5	50	1.6	47	1.4	43	1.8	41	0.9
6	7/11/74	Same Point Series	55 56	2.9 3.1	49 50	4.0 4.0	44 46	2.9 2.9	37 39	2.8 2.8	59	1.6	59	1.1	54	0.5	52	1.4
7	7/11/74	Same Point Series	48 46	1.0 3.9	42 42	1.7 2.5	38 35	0.6 1.2	30 30	2.5 1.7	54	0.9	52	0.4	51	1.0	45	0.8
8	7/15/74	Same Point Series	44 42	0.4 3.2	35 36	1.1 1.1	29 29	0.5 3.1	25 24	1.5 0.9	50	2.9	48	3.7	46	1.5	40	1.8
9	7/15/74	Same Point Series	50 50	0.4 2.7	44 43	1.7 1.3	39 38	1.0 3.5	35 35	0.9 2.8	55	1.6	52	5.2	54	0.4	49	1.9
10	7/17/74	Same Point Series	28 29	3.0 4.6	19 19	1.6 2.6	27 22	4.0 5.5	15 18	2.5 4.3	43	4.8	34	1.5	35	1.2	33	2.3
11	7/17/74	Same Point Series	57 57	1.3 0.5	51 50	1.3 1.2	45 45	2.2 2.3	40 39	0.9 1.5	59	0.9	58	0.9	57	1.5	52	1.3
12	7/17/74	Same Point Series	36 30	1.9 3.0	29 29	0.6 5.2	21 24	1.6 7.8	19 18	3.5 1.8	47	3.7	45	3.7	37	2.7	36	2.3
13	7/17/74	Same Point Series	51 48	3.4 5.7	46 40	1.6 5.0	41 32	0.8 3.4	34 27	2.5 7.0	55	2.6	47	2.8	46	0.6	45	1.1
14	7/15/74	Same Point Series	39 39	3.8 5.3	34 35	1.0 3.6	28 28	1.6 3.9	21 23	1.2 5.3	46	0.9	47	2.4	40	1.1	33	2.9
15	7/15/74	Same Point Series	39 42	1.7 2.5	34 34	1.2 3.1	26 30	1.4 3.7	20 27	2.2 4.1	51	2.3	51	1.9	47	1.4	44	3.1

TABLE 3

Best Estimate Computations of Standard Deviations

(n = 20 except where shown otherwise in parentheses following standard deviations)

Site	TEST PHASE ONE			TEST PHASE TWO		
	VDHT Trailer	VHTRC Trailer	VHTRC Car	VDHT TR. Same Spot	VDHT TR. Series	VHTRC Car
1	2.6 (75)	2.2 (50)	1.4 (25)	0.9	1.9	1.7
2	2.0 (75)	2.5 (50)	1.9 (25)	1.3	1.4	1.0
3	2.1 (60)	1.4 (40)	2.0	1.2	1.5	1.9
4	2.5 (55)	1.8 (40)	2.0	2.1	1.7	2.0
5	2.2 (100)	2.9 (50)	2.2 (50)	1.2	1.5	1.5
6	2.7 (75)	3.2 (75)	2.0 (25)	3.2	3.2	1.2
7	3.7 (25)	3.9 (25)	2.1 (25)	1.6	2.5	0.8
8	1.9	3.5	1.7	1.0	2.3	2.6
9	2.6	3.5	2.0	1.1	2.7	2.9
10	7.6	1.8	2.0	2.9	3.3	2.8
11	3.6	3.5	1.7	1.5	1.5	1.2
12	4.1 (40)	6.0	3.0	2.2	5.0	3.2
13	4.7 (40)	5.8	2.3	2.3	5.4	2.0
14	3.3	3.7	1.8	2.2	4.6	2.0
15	5.4	6.5	2.0	1.7	3.4	2.3
$\bar{X}$	3.4	3.5	2.0	1.8	2.9	1.9

TABLE 4

Linear Regression Results
VDHT Trailer vs VHTRC Car, Test Phase 2 at Same Point
VHTRC Trailer vs VHTRC Car, Test Phase 1
(1 mph = 1.609 km/h)

(x) Independent Variable	(Y) Dependent Variable	Regression Equation	Correlation Coefficient	Standard Error
VDHT Trailer 30 mph	VHTRC Car 30 mph	Y = .61 x + 25.6	89%	2.7
	40 mph	Y = .72 x + 18.2	85	3.9
	50 mph	Y = .77 x + 12.9	89	2.5
	60 mph	Y = .68 x + 13.8	90	2.9
VDHT Trailer 40 mph	VHTRC Car 30 mph	Y = .60 x + 29.3	91	2.5
	40 mph	Y = .75 x + 21.1	91	3.0
	50 mph	Y = .76 x + 17.9	89	3.5
	60 mph	Y = .66 x + 18.4	91	2.8
VDHT Trailer 50 mph	VHTRC Car 30 mph	Y = .68 x + 30.3	82	3.4
	40 mph	Y = .84 x + 22.4	82	4.3
	50 mph	Y = .91 x + 17.2	86	4.0
	60 mph	Y = .81 x + 17.4	88	3.1
VDHT Trailer 60 mph	VHTRC Car 30 mph	Y = .67 x + 33.4	86	3.0
	40 mph	Y = .80 x + 27.2	83	4.1
	50 mph	Y = .88 x + 21.9	88	3.6
	60 mph	Y = .76 x + 22.1	89	3.0
VHTRC Trailer 30 mph	VHTRC Car 30 mph	Y = .73 x + 18.4	92	3.1
	40 mph	Y = .76 x + 14.3	89	3.9
	50 mph	Y = .73 x + 13.2	91	3.3
	60 mph	Y = .56 x + 16.1	77	4.6
VHTRC Trailer 40 mph	VHTRC Car 30 mph	Y = .63 x + 27.6	89	3.4
	40 mph	Y = .67 x + 23.4	88	3.9
	50 mph	Y = .63 x + 22.8	88	3.8
	60 mph	Y = .55 x + 20.3	86	3.7
VHTRC Trailer 50 mph	VHTRC Car 30 mph	Y = .52 x + 35.0	80	4.7
	40 mph	Y = .58 x + 30.2	82	4.7
	50 mph	Y = .56 x + 28.7	84	4.3
	60 mph	Y = .52 x + 24.6	86	3.7
VHTRC Trailer 60 mph	VHTRC Car 30 mph	Y = .63 x + 33.5	80	4.7
	40 mph	Y = .67 x + 29.5	80	5.1
	50 mph	Y = .66 x + 27.2	84	4.3
	60 mph	Y = .60 x + 24.0	83	4.0

TABLE 5

Additional Correlation Data
40 Mph Tests
(1 mph = 1.609 km/h)

Site No.	County	Route	Lane	VHTRC Car	VDHT Trailer	VHTRC Trailer	Avg. Car Value	Predicted Car Value
1	Lee	58	EBTL	50	38	44	50	53
			WBTL	50	39	45		
2	Lee	A58	EBTL	47	36	41	50	48
			WBTL	53	36	40		
7	Wise	A58	EBTL	50		37	42	40
			WBTL	34		23		
9	Wise	72	NBTL	40	29	35	40	42
			SBTL	39	31	36		
11	Wise	58	EBTL	41	24	35	44	42
			WBTL	48	25	29		
13	Wise	23	NBTL	31	24	30	35 (TL)	
			NBPL	37	25	29	39 (PL)	
			SBTL	39	23	27		
			SBPL	41	22	31		
14	Wise	T-646	EBTL	34	23	28	36	37
			WBTL	39	23	29		
18	Wise	23	NBTL	50	31	30	40	43
			SBTL	30	28			
19	Wise	23	NBTL	41	33		44	43
			SBTL	48	27			
20	Wise	23	NBTL	36	29		41	43
			SBTL	46	26			
21	Dickenson	63	NBTL	49	28	31	46	44
			SBTL	44	26	27		
22	Dickenson	80	EBTL	42	24	32	41	40
			WBTL	40	25	32		
26	Buchanan	460	EBTL	33	40	24		
			EBPL	51		46		
			WBTL		21	24		
			WBPL			45		
25	Buchanan	460	EBTL	36	19	20	33	35
			WBTL	30	16	19		
24	Buchanan	460	EBTL	34	19	22	33	36
			WBTL	31	19	20		
27	Tazewell	67	NBTL	45				
			SBTL	36		30		
28	Tazewell	61	EBTL	45		34	46	47
			WBTL	46		35		
29	Tazewell	16	NBTL	45		36	49	
			SBTL	53		41		
32	Smith	11	NBTL	45		41	46	47
			SBTL	47		42		