Visibility and Speed Estimation of Iowa State Highway Commission Snowplows

A Research Report Prepared for the
Iowa State Highway Commission

by

Bruce M. Boyce

and

D. H. Schuster

Iowa State University

July, 1975

Abstract. Many accidents involving Iowa snowplows have happened in recent years. This study investigated the influence of time of day, sex of subject, type of snowplow sign and snowplow speed on the criteria of oncoming driver reaction time and his estimate of snowplow speed. Film strips were made of a car passing a snowplow under various experimental conditions. These experimental movie strips were viewed in the laboratory by college student drivers who were asked to indicate their reaction time to slow down and to estimate the speed of the snowplow being passed. The generally best sign condition for the snowplow was to have a striped rear sign and a speed-proportional flashing light in addition to the standard rotating beacon on top of the truck. Several recommendations were made.

Purpose. The intent of this study was to determine the relative target values (for drivers of following vehicles) of different rear-end displays on snowplows, and to assess the drivers' perception of snowplow velocity at the mean point of recognition. Both variables were examined under a wide range of actual driving conditions.

Introduction. Collisions to the rear of Iowa State Highway Commission (ISHC) snowplows have caused a problem reflected in personal injuries, damages to the vehicles involved, and an increase in workload if the plow is incapacitated. The commission has speculated that failure to recognize the plows and the inability to judge their speed are prime factors in such mishaps.

Snowplows, like all signs and vehicles, contrast against a given background. The extent of this contrast is the "target value" of the object (Forbes, 1939). Hendricks, Schuster, and Ruffner (1973) have found a snowplow equipped with a diagonally striped ("Z-Bar") sign has a prominent target value compared to other indicators, and hence it is visible at greater distance. This research was conducted under conditions of optimum visibility and establishes a ceiling for perception of snowplows with this signing. Of course, the actual use of plows in such ideal weather is rare. Target value is confounded by the unfavorable weather which usually precedes and accompanies the appearance of snowplows. In a colder, windier situation, swirling clouds of snow driven behind the plow may obscure the sign from view. During a wet snowfall at a relatively high temperature (25° - 30°), visibility may decrease as snow collects and covers the sign. To alleviate this latter problem, the Highway Commission has introduced a flexible plastic sign. The material is designed to flex with the motion of the plow so that snow buildup is prevented. Comparison to standard rigid signing would show its potential for improving snowplow visibility.

It is also likely that target value would be altered by the type of lighting used. Evening headlight illumination might change contrast and reflective surface from daylight, for example. Reduced windshield clarity and concurrent attention to other aspects of the visual environment must also be considered as factors affecting overall target value in a snowfall.

The previous snowplow visibility study by Hendricks et al. (1973) reported that word signs were less conspicuous than symbol signs. King (1975) verified this conclusion with a variety of typical highway signs.

Evans and Rothery (1974) have shown that the perception of a lead vehicle's relative motion from a following car is cautiously biased; there is a tendency to overestimate any gain on the lead vehicle. In spite of a high sensitivity to the direction of relative motion change, they concluded that rear-end collisions are probably caused by inattention and/or inability to correctly estimate the magnitude of relative motion. Because snowplows move at different speeds for different plowing jobs, this latter failing may be critical. A plow moving at 15 miles per hour to remove ice would be especially vulnerable and hazardous, since the approach of a following vehicle would be hastened along a treacherous road surface. An indicator of relative motion would hopefully be effective in helping to reduce the chances of rear-end collision.

Voevodsky (1974) has attempted to communicate relative motion to following drivers. He equipped taxi cabs with a flasher which pulsed exponentially as a direct function of the cab's speed - as it decelerated, the pulse rate slowed. Compared over a 10-month period to unequipped controls, these taxis showed more than a 60% reduction in rear-end collition rate, injuries to their drivers, and cost of repairs. If such an index were found similar in effectiveness for ISHC snowplows, the dangerous rear-end problem might be made substantially less.

Evans (1970) has shown the validity of filmed simulation for research on relative motion, provided the simulation is equalized in perspective for all subjects and imparts no auditory cues. Thus, with appropriate environmental influences included, films of the approach to and passing of snowplows would present a useful tool to assess the comparative target values of the flexible and static Z-Bar signs and the variable-pulse-flasher, singly or in combination. They would also give a means for evaluating relative motion and velocity perception for a given condition and whether an exponential flash pulse rate would be useful index of such motion.

Method. A mixed model analysis of variance (ANOV) was used in this study. The independent variables or factors and their dependent variables or criteria are defined and discussed next.

Time of day (day vs. night) was the first independent variable. Half of the stimulus films were photographed during a daytime snow storm. The other half was filmed at night, but without snow. The films taken first during a night snow storm were seriously underexposed. No further snow storms occurred after this was discovered, so that night time snowplow passing was filmed without the snow in order to get the research done.

The second independent variable was the type of sign or display on the snowplow. These were as follows:

1. Rotating beacon alone. This was the reference or basis of comparison for the other signs. This represented the standard ISHC configuration on snowplows.
2. Plywood stripe. In addition to the rotating top beacon (See #1 above), an additional sign about one foot high by six feet wide with reflective slanted stripes ("Z-Bar") was mounted at eye level on the rear of the snowplow.
3. Plastic stripe and flasher. A 1 X 6 sheet of flexible vinyl plastic with markings identical to #2 above was attached to, and covered, the plywood striped sign. In addition, the top rotating beacon (See #1 above) and the variable pulse flasher (See #4 below) were energized. The vibration of this flexible sign was intended to dislodge any accumulated snow marring sign visibility.
4. Variable pulse flasher.* In addition to the top rotating beacon (See #1 above), an amber light mounted six feet high at the rear flashed at a rate proportional to the truck's velocity: 0 MPH - 1 pulse/2 seconds, 15 MPH - 1 pulse/second, 30 MPH - 2 pulses/second. This flash rate signalled the snowplow's speed. Drivers were not informed of this beforehand; they had to figure it out for themselves.
5. Wood stripe and flasher. This was identical to #3 above, except that the covering plastic sign was removed to bare the wood striped sign (See #2 above).

---

* Thanks go to Ron Peecher for designing and constructing this unit.

Speed of snowplow was the third factor. The snowplow when passed was photographed equally often under these three conditions, 1 - stopped (0 MPH), 2 - moving slowly (15 MPH), and 3 - moving at maximum snowplowing speed (30 MPH).

Sex of subjects was a fourth factor. Subjects were 64 licensed drivers who were taking undergraduate psychology courses at I.S.U. and who volunteered for this study for extra course credit. Half were male and half were female. Such youthful drivers have a very high accident rate despite their excellent perceptual abilities. Considerably more subjects than 64 went through the experiment originally, but data from the excess were randomly discarded to provide a balanced statistical design for economy of analysis. Subjects were nested statistically under the factors of sex of subject and replication or order.

The fifth independent variable was replication or order. The fifteen possible combinations of type of sign and snowplow speed were randomly arranged on a film strip for one order of presentation. This sequence was reversed in the second film strip to control for practice, familiarity and viewing fatigue effects. A given subject saw just one of these two orders or sequences for measuring reaction time. Thus different subjects were exposed to the film orders. Separate day and night strips were made for a total of four films.

There were three criteria or dependent variables in this study, reaction time, speed estimation and accuracy of speed estimation. These are discussed next.

The reaction time criterion was defined as that time in overtaking the snowplow at which the subject was sure he or she had identified the slow moving vehicle and would slow down for it. The exact directions are given in the Appendix. The time in half-seconds before passing was recorded in the upper left of each frame of film. This started at 32 and counted down to zero when the truck had just dissappeared from view as it was being passed. As soon as subjects had made their identification - slow down judgment, they recorded the highest time number just seen on a prepared record sheet.

Approach and passing sequences were filmed through an automobile windshield with a stabilized 16 mm. movie camera. All sequences were equal in length, about 16 seconds. The ordering of passing sequences and sign conditions was accomplished by editing and splicing film. Films were processed and edited by the I.S.U. Film Production Unit.

The second criterion was the subjects' estimate of the speed of the snowplow truck being passed. Subjects were informed that the plow was moving at one of three speeds, 0, 15 or 30 MPH. These estimates were also recorded on prepared data forms.

The third criterion was the dichotomous score as to the correctness of the individual subject's estimate of the speed of the snowplow being passed. This was computer generated as, 0 - subject had guessed the truck's speed wrongly, or 1 - subject had estimated the truck's speed correctly. When analyzed, the averages of these coded numbers directly indicated the percentages of correct speed estimates under the various experimental conditions.

Results. The model used in this study was a mixed analysis of variance (ANOV) design. There were 64 subjects whose data were analyzed in an analysis of variance comprising five factors: time of day, sex of subject, sign type, velocity of snowplow and replication or order. Subjects were nested within sex of subject and replication or order. As such, a separate error term was used to test the effects of sex of subject, replication or order, and their interaction in the analysis of variance tables that follow.

All subjects took all possible treatment combinations of time of day (day-night), type of sign and snowplow velocity. These factors and their interactions with the sex and replication factors made a subject by treatment design. The appropriate error term could have been the pooled subject by treatment variances appropriately, but these variances proved much too heterogeneous to pool. Accordingly, no pooling was done and each within subject treatment effect was tested by that same treatment cell by subject interaction. This is labeled "error" after each cell treatment entry in the ANOV tables.

The results will be discussed for the three criteria or dependent variables in turn, reaction time in seconds, speed estimation, and accuracy of speed estimation in percent. The usual 1% and 5% levels of significance were used throughout. In general, results are discussed only for factors significant beyond the 1% level.

Reaction Time. A serious confounding of replication or order shows up many places in the analysis of variance of reaction time. (See Table 1.) The use of two different orders or replications assumed that practice effects would be uniformly and linearly distributed across all cell treatment combinations of type of sign and snowplow velocity. This was a valid assumption only for the main effect of order or replication. Apparently there was a significant nonlinear effect and counterbalancing by two orders was insufficient. However, since major interest centers on the other factors of time of day, type of sign and snowplow velocity, emphasis is going to be given these factors which are readily interpretable. An additional practical reason is that the sum of all the replication effects accounted for 14.3% of the total variance.

The highest interaction to be discussed from Table 1 is that of the interaction of time of day, type of sign and snowplow velocity. This interaction is graphed in Figure 1. In general, a longer reaction time prevailed for the daytime conditions as compared with nighttime conditions. It is obvious that no single sign was clearly superior under all conditions. Signs #3 and #5 appear to be generally superior under daytime viewing conditions, whereas sign #5 appears to be generally superior under nighttime conditions.

The average reaction times for levels of the factors of time of day, type of sign and snowplow velocity are shown in Table 2. As expected, a longer reaction time prevailed in the day than at night. Also as expected, the faster the snowplow was moving as it was being passed, a longer reaction time was obtained. Some signs provided a longer reaction time than others. Specifically, sign #5 provided significantly the longest time, then #3, #1, #2, and finally sign #4 provided the shortest anticipatory reaction time.

Speed Estimation. The analysis of variance for the factors investigated in speed estimation is given in Table 3. Note that a serious confounding with order or replication obtained for this criterion also. Again major interest centers on the other factors. The average speeds per level are presented and analyzed further in Table 4.

The interaction for the effect of time of day, type of sign and snowplow speed was not significant for the speed estimation criterion. The major significant interaction here was for the effects of time of day and type of sign on estimated snowplow speed. This is graphed in Figure 2. Note that at night there was little differentiation among the signs in their ability to let drivers estimate the snowplow speed. However, in daytime, the best type of signs in order from best to worst were: #5, #2, #3, #1, and #4. This order changed somewhat at night.

Accuracy of Speed Estimation. The analysis of variance for factors effecting snowplow speed estimation is presented in Table 5. As before, there were many significant order interaction effects, but they are not of major interest.

The major interaction of interst here was the significant interaction of time of day, type of sign and snowplow speed on the accuracy of speed estimation. This is graphed in Figure 3. Note that there was very little differentiation between day and night, although some obtained depending on the type of sign. Most of the signs produced noticeably better speed estimation for the vehicle to be overtaken when the overtaken vehicle was proceeding at 15 MPH. Why this happened is not known, but a reasonable guess seems to be that the subjects hedged their bets by guessing the median velocity when uncertain. At night sign #5 provided the most accurate speed perception under the most hazardous condition, when the snowplow to be overtaken was stopped.

The subsequent analyses of average accuracy by factor levels is shown in Table 6.

Discussion. The belated discovery of significant nonlinear practice effects in spite of a supposedly adequate experimental design clouds the interpretation of results in this study. This is especially true for interactions such as time of day, by type of sign, by speed of plow, as their cells are summed over only a few treatment conditions. In contrast, low order interactions, such as type of sign by speed of plow, and the main effects of all factors are relatively free of this confounding cloud; their cells are summed over many treatment conditions and thus are more reliable due to their large frequencies of observation. This should be kept in mind in what follows. If the study were to be repeated or extended, precise control over nonlinear practice effects can be, and should be, exerted with many orders of presentation of passing sequences. A film loop that could be started on any of its passing sequences would facilitate this.

From Table 2 and Figure 1, we can conclude that signs #3 and #5 were generally superior to the rest under many conditions tested in providing longer anticipatory reaction times. These signs were either the wooden or plastic striped sign along with both the variable pulse flasher and truck-top rotating beacon. When the snowplow was stopped during daytime, no practical differences were found between signs. However, when the truck was stopped at night, sign #5 was superior again.

A possible interpretation is that drivers do not expect snowplows to be stopped; they're supposed to be plowing snow slowly. This agrees with the significantly greatest correct plow speed estimation at 15 MPH from Table 6 and Figure 3. This is modified by time of day. During daytime approaches, other visual factors such as the plow's perceived relative motion (or lack) on the road relieve the driver from excessive dependency on the truck's signing. Nighttime approaches are different; under poor visual conditions as in a night snow storm, the driver has to rely primarily on the truck's signing for his perception of its speed and secondarily upon ambient illumination or his own headlights. In this situation the redundant information afforded by rotating beacon, reflectorized striped sign and speed-coded flashing light (sign #3 or #5) is welcome and helpful. Sign #5 was most helpful under the nighttime, plow-stopped condition; here the probability for an accident is greatest as the driver has less time to maneuver than when the plow is moving. A corroborating detail from Figure 2 is that signs #3 and #5 had the lowest nighttime estimated speeds.

The use of sign condition #4, top rotating beacon plus variable pulse flasher, is not recommended. This condition lead to no consistent improvement for any criterion and had a poor showing in many cases.

The speed coding of the variable pulse flasher is an interesting concept in itself. Here a direct velocity to flash rate was used; a higher truck speed was indicated by a higher flash rate. Should the reverse have been used? For one thing, an optimum flash rate for attention getting is two to ten pulses/second and rates above this quickly get confused and can't be discriminated easily (McCormick, 1970). For another, a reverse coded flash rate would warn of immediacy and severity of hazard. Suppose the highest flash rate of two pulses/second indicated a stopped truck (an immediate hazard) and the rate varied progressively to one pulse/two seconds meaning a truck moving at 30 MPH (less of a hazard). Obviously another study would have to be done to look at this question as well as drivers' stereotypes of what they expect the flash frequency to mean.

A final consideration is parsimony and economy of flashing lights. The two generally best sign conditions #3 and #5 had two flashing lights, the top rotating standard beacon plus the experimental variable pulse flasher. Couldn't these be combined? Published work (McCormick, 1970) shows that the use of two flashing lights to mean two different things is bad. Then there are the financial and electrical load reasons to combine the two flashing lights into one. This would be a truck-top mounted beacon whose flash rate varied to indicate vehicle speed. This integration seems highly desirable.

In conclusion, a flashing light whose rate is proportional to snowplow speed, and which is used together with a reflectorized striped sign, appears recommendable as a generally satisfactory way to warn oncoming motorists of the hazards of a slowly moving snowplow. This has been qualified earlier in this report. More research is recommended to clarify the nonlinear practice effects discovered herein and to investigate the integration of the two flashing lights used in this study into one multipurpose flasher.

REFERENCES

Evans, L. Automobile speed estimation using movie film simulation. Erogonomics, 1970, 13 (2), 231-238.

Evans, L. and Rothery, R. Detection of the sign of relative motion when following a vehicle. Human Factors, 1974, 16 (2), 161-173.

Forbes, T. W. A method of analysis of the effectiveness of highway signs. Journal of Applied Psychology, 1939, 23, 669-684.

Hendricks, R., Schuster, D. and Ruffner, J. Iowa Highway Commission Snowplow Visibility. Unpublished report, Iowa State University, 1973.

King, L. E. Recognition of symbol and word traffic signs. Journal of Safety Research, 1975 (June), 7 (2), 80-84.

McCormick, E. J. Human Factors Engineering, 3rd Edition. New York: McGraw-Hill, 1970, 154-155.

Voevodsky, J. Evaluation of a deceleration warning light for reducing rear-end automobile collisions. Journal of Applied Psychology, 1974, 59, (3), 270-273.

APPENDIX - STANDARD INSTRUCTIONS

Please date your data sheets, indicate sex using M or F.

In this study we are interested in determing the ease with which drivers can identify dangerously slow-moving vehicles as they are driving on the highway. On the screen in front of you, you will see 2 films made from a moving car as it passes several vehicles on the highway. Your task is to identify the vehicle as being one that you would approach with caution; that is, as something you would slow down for. As soon as you are certain, you can identify the time in this manner. Note the number in the upper left-hand corner and record on your data card the number which you see there. This procedure will be repeated until all vehicles are passed. After you have completed viewing the films, please make any brief comments you may have in the spaces provided. Do you have any questions?

(Daytime film shown next.)

The next sequences were filmed at night. I will show 2 of them as practice trials. Do not mark responses for them.

(Night film shown.)

Now we wish to assess the accuracy with which drivers perceive the speed of a vehicle they are following. You will see the same film, but at some point before passing occurs the film will be stopped. You are to choose which of three speeds is closest to that which you perceive (0 MPH, 15 MPH or 30 MPH) and record that speed on your data card. This procedure will be repeated for all vehicles filmed. Do you have any questions?

(Alternate order films, day and night, then shown.)

Table 1. ANOV summary for the effects of time of day, sex of subject, type of sign, snow plow velocity and replication on reaction time in seconds.

Source	MS	df	F
T, Time of Day	2625.00	1	44.27**
Error	59.30	13	
X, Sex of Subject	262.44	1	0.89
R, Replication (Order)	152.40	1	0.52
XR, Sex x Rep.	89.61	1	0.30
Error	293.99	52	
S, Sign Type	235.37	4	20.63**
Error	11.41	52	
V, Velocity of Plow	206.45	2	33.79**
Error	6.11	26	
TX, Time x Sex	2.59	1	0.05
Error	54.17	13	
TS, Time x Sign	54.85	4	4.12**
Error	13.30	52	
TV, Time x Velocity	35.94	2	2.56
Error	14.02	26	
TR, Time x Rep.	30.94	1	0.93
Error	33.39	13	
XS, Sex x Sign	10.53	4	0.79
Error	13.27	52	

Table 1. (Continued)

XV, Sex x Velocity	1.89	2	0.10
Error	18.24	26	
SV, Sign x Velocity	127.49	8	14.79**
Error	8.62	104	
SR, Sign x Rep.	261.38	4	29.97**
Error	8.72	52	
VR, Velocity x Rep.	1416.85	2	161.19**
Error	8.79	26	
TXS	11.34	4	0.62
Error	18.37	52	
TXV	41.85	2	4.15*
Error	10.09	26	
TXR	0.68	1	0.01
Error	48.58	13	
TSV	102.38	8	13.40**
Error	7.64	104	
TSR	198.39	4	11.64**
Error	17.04	52	
TVR	39.01	2	2.45
Error	15.91	26	

Table 1. (Continued)

XSV	6.89	8	0.66
Error	10.40	104	
XSR	7.88	4	0.57
Error	13.82	52	
XVR	11.89	2	0.73
Error	16.24	26	
SVR	154.38	8	16.62**
Error	9.29	104	
TXSV	18.70	8	1.87
Error	10.00	104	
TXSR	7.58	4	0.83
Error	9.18	52	
TXVR	3.07	2	0.24
Error	13.06	26	
TXVR	42.22	8	3.89**
Error	10.86	104	
XSVR	9.75	8	0.81
Error	11.98	104	
TXSVR	10.27	8	1.01
Error	10.17	104	
TOTAL:	28.45	1679	

* $p < .05$

** $p < .01$

Table 2. Newman-Keuls analyses of factors effecting reaction time in seconds.

Time of Day	Average
Day	11.69 secs.
Night	10.44 **

Type of Sign

Sign	Seconds Average	Mean Differences			
		3	1	2	4
5, Wood Stripe & #4	11.71	0.51**	0.71**	0.96**	1.05**
3, Plastic Stripe & #4	11.20		0.20	0.45*	0.54*
1, Rotating Beacon alone	11.00			0:25	0.34
2, Wood Stripe	10.75				0.09
4, Variable Pulse Flasher	10.66				

Mean Error/df = $\sqrt{11.41}/336 = 0.13$.

Plow Velocity

Velocity	Seconds Average	Mean Differences	
		2	1
3, 30 MPH	11.36	0.29**	0.60**
2, 15 MPH	11.07		0.31**
1, 0 MPH	10.76		

Mean Error/df = $\sqrt{6.11}/560 = 0.004$.

Table 2. (Continued)

Sign x Velocity

Sign & Speed	Seconds Average	
13, Plastic Stripe & VPF, 30 MPH	12.11	NS
15, Wood Stripe & VPF, 30 MPH	12.07	
10, Wood Stripe & VPF, 15 MPH	11.82	
6, Rotating Beacon, 15 MPH	11.44	
14, Variable Pulse Flasher, 30 MPH	11.42	
5, Plastic Stripe & VPF, 0 MPH	11.24	
1, Rotating Beacon alone, 0 MPH	11.13	
7, Wood Stripe, 15 MPH	10.97	
8, Plastic Stripe & VPF, 15 MPH	10.85	
12, Wood Stripe, 30 MPH	10.81	
3, Plastic Stripe & VPF, 0 MPH	10.64	
2, Wood Stripe, 0 MPH	10.46	
11, Rotating Beacon alone, 30 MPH	10.41	
4, Variable Pulse Flasher, 0 MPH	10.33	
9, Variable Pulse Flasher, 15 MPH	10.24	

Mean Error/df = $\sqrt{8.62}/112$ = .026

VPF: Variable Pulse Flasher

NS : $p > .05$ * $p < .05$ ** $p < .01$

Vertical bar indicates means not different, $p > .05$

Table 3. ANOV summary for the effects of time of day, sex of subject, type of sign, velocity of snow plow and replication on speed estimation.

Source	MS	df	F
T, Time of Day	2048.23	1	17.70**
Error	115.73	13	
X, Sex of Subject	907.87	1	2.02
R, Replication (Order)	509.30	1	1.13
XR, Sex x Rep.	1092.87	1	2.43
Error	450.51	52	
S, Sign Type	580.83	4	7.29**
Error	79.72	52	
V, Velocity of Plow	261.35	2	3.20
Error	81.74	26	
TX, Time x Sex	102.51	1	0.44
Error	235.21	13	
TS, Time x Sign	967.39	4	12.85 **
Error	75.27	52	
TV, Time x Velocity	434.12	2	4.10*
Error	105.76	26	
TR, Time x Rep.	700.73	1	5.55*
Error	126.31	13	
XS, Sex x Sign	78.37	4	0.84
Error	93.80	52	

Table 3. (Continued)

XV, Sex x Velocity	104.57	2	1.23
Error	85.05	26	
SV, Sign x Velocity	127.78	8	1.32
Error	96.54	104	
SR, Sign x Rep.	808.15	4	7.24**
Error	111.66	52	
VR, Velocity x Rep.	5513.14	2	61.81**
Error	89.20	26	
TXS	169.67	4	2.35
Error	72.07	52	
TXV	174.84	2	1.40
Error	124.64	26	
TXR	32.87	1	0.24
Error	134.80	13	
TSV	200.55	8	1.94
Error	103.61	104	
TSR	780.60	4	8.17**
Error	95.60	52	
TVR	1731.98	2	16.83**
Error	102.94	26	
XSV	45.66	8	0.68
Error	67.18	104	

Table 3. (Continued)

XSR	16.94	4	0.23
Error	72.37	52	
XVR	274.57	2	1.58
Error	173.80	26	
SVR	912.04	8	10.97**
Error	83.11	104	
TXSV	134.68	8	1.45
Error	92.72	104	
TXSR	93.77	4	1.01
Error	93.29	52	
TXVR	4.48	2	0.08
Error	57.08	26	
TSVR	625.75	8	6.39**
Error	97.85	104	
XSVR	82.73	8	1.00
Error	82.39	104	
TXSVR	116.44	8	1.75
Error	66.46	104	
TOTAL:	127.98	1679	

* $p < .05$

** $p < .01$

Table 4. Newman-Keuls analysis of factors effecting speed estimation in MPH.

Type of Sign

Sign	MPH Average	2	Mean Differences 1	3	4
5, Wood Stripe & #4	15.67	0.85	2.06	2.80	3.11
2, Wood Stripe	14.82		1.21	1.95	2.26
1, Rotating Beacon alone	13.61			0.74	1.05
3, Plastic Stripe & #4	12.87				0.31
4, Variable Pulse Flasher	12.56				

Mean Error/df = $\sqrt{79.72}/336$ = .026; p < .01 for all comparisons.

Time of Day by Sign

Sign and Time	MPH Average	
5, Wood Stripe & #4, Day	18.84	
2, Wood Stripe, Day	16.70	
3, Plastic Stripe & #4, Day	14.50	
4, Variable Pulse Flasher, Night	13.75	NS
1, Rotating Beacon alone, Day	13.66	NS
1, Rotating Beacon alone, Night	13.57	NS
2, Wood Stripe, Night	12.95	
5, Wood Stripe & #4, Night	12.50	
4, Variable Pulse Flasher, Day	11.37	(bar)
3, Plastic Stripe & #4, Night	11.25	(bar)

Mean Error/df = $\sqrt{75.27}/168$ = .052

NS: Vertical Bar Indicates Not Different, p > .01

Table 4. (Continued)

Time of Day	Average MPH
Day	15.01
Night	12.80**

** $p < .01$

Table 5. ANOV summary for the effects of time of day, sex of subject, type of sign, snow plow velocity and replication on the accuracy of snow plow speed estimation.

Source	MS	df	F
T, Time of Day	0.9524	1	2.15
Error	0.4434	13	
X, Sex of Subject	0.0024	1	0.01
R, Replication (Order)	10.3714	1	38.53**
XR, Sex x Rep.	0.0214	1	0.08
Error	0.2692	52	
S, Sign Type	0.5113	4	3.59*
Error	0.1424	52	
V, Velocity of Plow	9.0071	2	23.61**
Error	0.3815	26	
TX, Time x Sex	1.2595	1	6.01*
Error	0.2095	13	
TS, Time x Sign	0.0179	4	0.07
Error	0.2573	52	
TV, Time x Velocity	1.4952	2	8.95**
Error	0.1670	26	
TR, Time x Rep.	1.8667	1	7.62*
Error	0.2449	13	
XS, Sex x Sign	0.0262	4	0.13
Error	0.2034	52	

Table 5. (Continued)

XV, Sex x Velocity	0.4595	2	1.66
Error	0.2775	26	
SV, Sign x Velocity	0.5399	8	4.06**
Error	0.1330	104	
SR, Sign x Rep.	1.5441	4	7.06**
Error	0.2187	52	
VR, Velocity x Rep.	2.1500	2	7.39**
Error	0.2910	26	
TXS	0.3458	4	1.80
Error	0.1917	52	
TXV	0.0667	2	0.35
Error	0.1897	26	
TXR	0.0024	1	0.01
Error	0.1934	13	
TSV	0.6723	8	3.80**
Error	0.1767	104	
TSR	0.4292	4	2.05
Error	0.2096	52	
TVR	0.7881	2	5.65**
Error	0.1394	26	
XSV	0.0771	8	0.37
Error	0.2067	104	

Table 5. (Continued)

XSR	0.1970	4	1.04
Error	0.1897	52	
XVR	0.4500	2	1.27
Error	0.3551	26	
SVR	1.1932	8	5.77**
Error	0.2068	104	
TXSV	0.4298	8	2.43*
Error	0.1770	104	
TXSR	0.0976	4	1.03
Error	0.0947	52	
TXVR	0.3310	2	2.11
Error	0.1566	26	
TSVR	0.5292	8	3.03**
Error	0.1745	104	
XSVR	0.1613	8	0.95
Error	0.1698	104	
TXSVR	0.2342	8	1.65
Error	0.1424	104	
TOTAL:	0.2317	1679	

---

* $p < .05$

** $p < .01$

Table 6. Newman-Keuls analyses of factors effecting accuracy of speed estimation.

Type of Sign

Sign	Percent Accuracy	Mean Differences 2	3	5	4
1, Rotating Beacon alone	38.4	0,NS	0.30	0.60	8.90
2, Wood Stripe	38.4		0.30	0.60	8.90
3, Plastic Stripe & #4	38.1			0.30	8.60
5, Wood Stripe & #4	37.8				8.30
4, Variable Pulse Flasher	29.5				

Mean Error/df = $\sqrt{.1424/336} = .001$

All comparisons $p < .01$ except NS, $p > .01$

Plow Velocity

Speed	Average Accuracy	Mean Differences 1	3
2, 15 MPH	48.9	12.1	25.3
1, 0 MPH	36.8		13.2
3, 30 MPH	23.6		

Mean Error/df = $\sqrt{.3815/560} = .001$

All comparisons significant, $p < .01$

Table 6. (Continued)

Time by Velocity

Time & Speed	Average Accuracy	Mean Differences 2N	1N	1D	3D	3N
2D, 15 MPH, Day	53.9	10.0	13.5	20.7	24.6	36.0
2N, 15 MPH, Night	43.9		3.5	10.7	14.6	26.0
1N, 0 MPH, Night	40.4			7.2	11.1	22.5
1D, 0 MPH, Day	33.2				3.9	15.3
3D, 30 MPH, Day	29.3					11.4
3N, 30 MPH, Night	17.9					

Mean Error/df = $\sqrt{.1670/280}$ = .001

All comparisons significant , $p < .01$

Table 6. (Continued)

Sign by Velocity

Sign & Velocity	Average Accuracy	
7, Wood Stripe, 15 MPH	52.7%	
6, Rotating Beacon, 15 MPH	50.0	NS
10, Wood Stripe & VPF, 15 MPH	50.0	NS
3, Plastic Stripe & VPF, 0 MPH	47.3	
8, Plastic Stripe & VPF, 15 MPH	46.4	
9, Variable Pulse Flasher, 15 MPH	45.5	
1, Rotating Beacon	38.4	
5, Wood Stripe & VPF, 0 MPH	38.4	
12, Wood Stripe, 30 MPH	34.8	
4, Variable Pulse Flasher, 0 MPH	32.1	
2, Wood Stripe, 0 MPH	27.7	
11, Rotating Beacon, 30 MPH	26.8	
15, Wood Stripe & VPF, 30 MPH	25.0	
13, Plastic Stripe & VPF, 30 MPH	20.5	
14, Variable Pulse Flasher, 30 MPH	10.7	

Mean Error/df = $\sqrt{.1330/112} = .003$

NS: $p > .01$, all other comparisons significant, $p < .01$

Fig. 1. The effects of time of day, type of sign and snow plow velocity on reaction time in seconds.

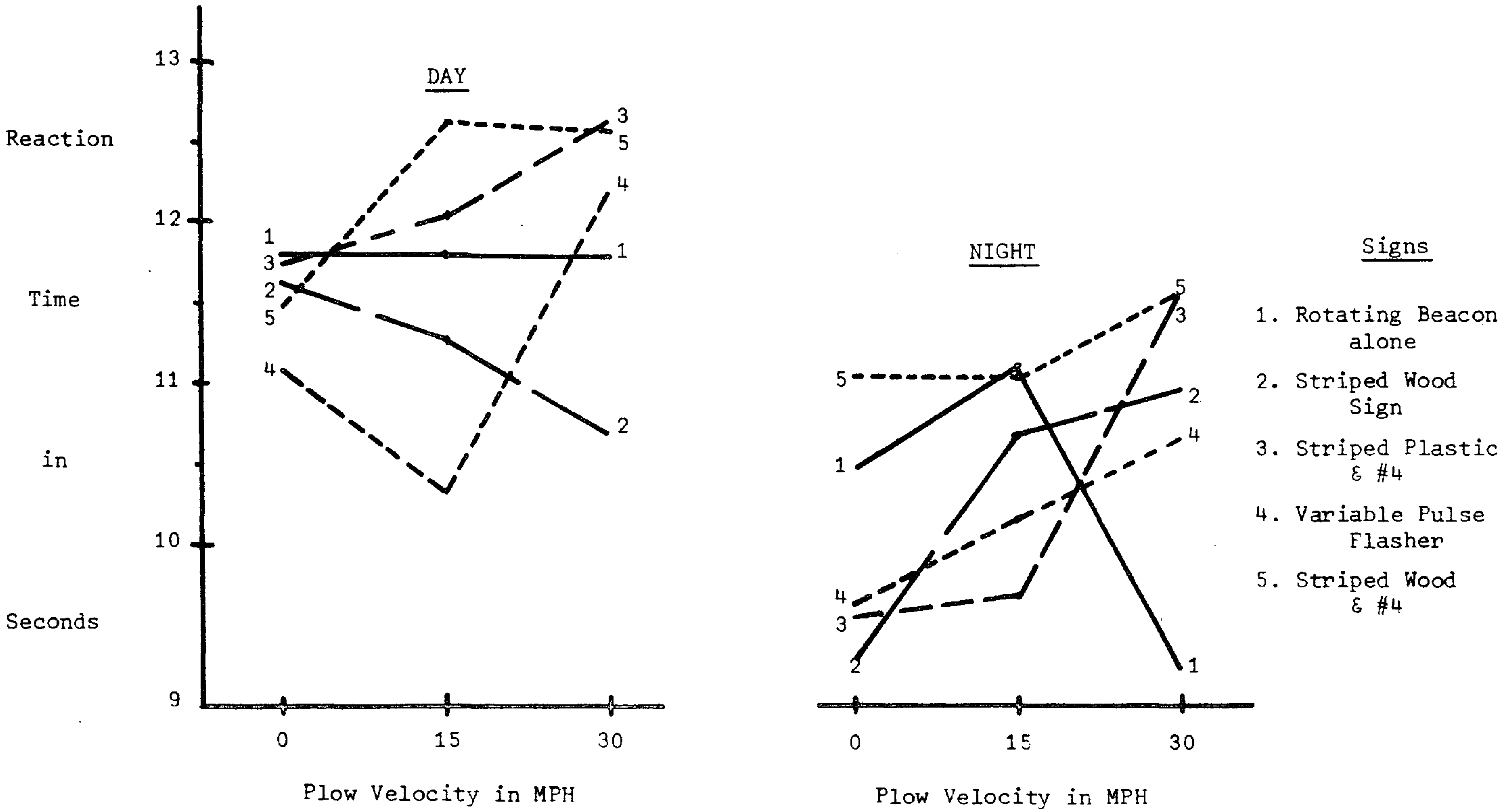

Fig. 2. The effects of time of day and type of sign on estimated snow plow speed.

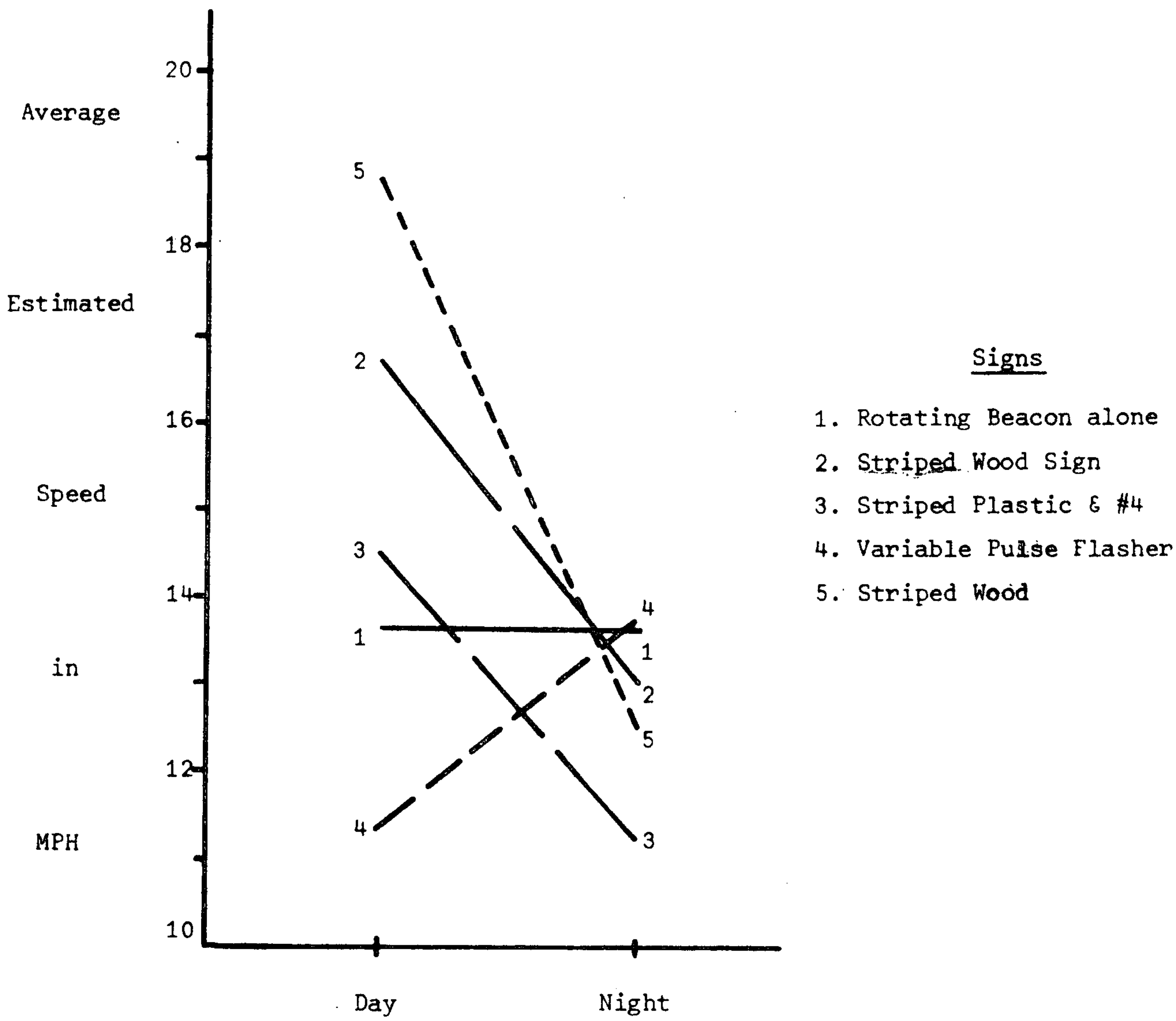

Fig. 3. The effects of time of day, type of sign and snow plow velocity on accuracy of speed estimation.