Weight-Specific Highway Sign Effects on Heavy Trucks

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The objective of this study was to test the field effectiveness of the Grade Severity Rating System (GSRS), via application of weight-specific signs to control truck speeds on downgrades. Before-after sign effects were evaluated in terms of speed differences and incidences of smoking brakes for trucks in specific weight categories. A five-state (California, Colorado, Idaho, Oregon, and West Virginia) sample of study sites included grades of varying severity. The study design included a determination of novelty effect as well as concurrent before-observations at selected control sites (i.e., no weight-specific sign present). In addition, the feasibility of state highway agencies' conducting an accident study to assess GSRS safety impact was examined. Weight-specific signing (WSS) was determined to elicit a favorable before-after effect at high-severity sites. Three truck behavioral measures provided the basis for this result: mean truck speed, percentage of trucks exceeding posted WSS speeds, and incidences of smoking brakes. Before-after reductions in mean speed were observed at two out of three high-grade-severity locations following installation of the WSS. Substantiating evidence that the WSS was responsible for the speed reduction evolved from (a) corresponding speed increases at one matched control site and (b) the absence of speed changes for trucks weighing less than 70,000 lb (31.8 Mg) at the other site. Percentages of trucks exceeding WSS-posted speeds were reduced for 70,000 to 80,000 lb (31.8 to 36.3 Mg) trucks at one site and for 60,000 to 70,000 lb (27.2 to 31.8 Mg) trucks at the other. The proportion of trucks characterized by smoking brakes was reduced at the single high-severity site where this measure was observed. Because GSRS represents the state of the art, its application was viewed to improve states' liability positions. Weight-specific signing was recommended for use at high-grade-severity locations.

The Grade Severity Rating System (GSRS) is a technique used for reducing the incidence and severity of truck downgrade accidents. GSRS feasibility has been examined via the development and prototype application of a weight-based truck speed selection model *(1, 2)* in recent work conducted for the Federal Highway Administration (FHWA). The model was based on an empirical determination of brake heating characteristics as a function of gross truck weight, grade length, and steepness. Field application of the GSRS involves use of weight-specific signs (WSS) advising truckers of the appropriate descent speed according to gross truck weight. Figure 1 shows the GSRS by (a) defining grade severity ratings (GSR 1 through 10) and (b) prescribing safe downgrade speeds for 80,000-lb (36.3 Mg) combinations according to grade geometry.

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OBJECTIVE

The objective of this field study was to evaluate the field effectiveness of the GSRS, via application of weight-specific signs, to control truck speeds on downgrades *(3)*. A five-state sample of study sites included grades of varying severity. Before-after sign effects were evaluated for trucks in specific weight categories in terms of speed differences and incidences of smoking brakes. The study design included a determination of novelty effect as well as concurrent observations at selected control sites, that is, no weight-specific sign present. In addition, the study examined the feasibility of state highway agencies' conducting an accident study to assess GSRS safety impact.

STUDY PROCEDURE

Designation of Measures of Effectiveness

Measures of effectiveness (MOEs) refer to that which is measured in an evaluative study. Designation of MOEs derived from the primary intent of the current study: a traffic operational evaluation of WSS sign characteristics as determined by application of the GSRS. In addition, this study examined the feasibility of an accident-based evaluation.

Two operational MOEs possess high face value because of the nature of brake-fade truck accidents: (a) smoking brakes and (b) speed characteristics. Smoking brake occurrences were assessed as a proportion of total truck volume. Speed characteristics were addressed by truck weight class targeted on the weight-specific signs. Within each weight category, the before-after sign impact was determined for both the mean speeds and the proportion of trucks exceeding the posted weight-specific speed. An obviously favorable safety implication would result from reduced overall speeds and fewer violations in the "after" condition.

Study Design

Based on available site characteristics (e.g., required downgrade steepness, available truck weight data), the current study used a before-after with control site paradigm to the extent possible. Sites were designated in order to support multiregional data within the United States. Although the majority of required geometric conditions were located in the Western United States, data were also gathered at one east coast site. In order to render a precise geographic effect response to the

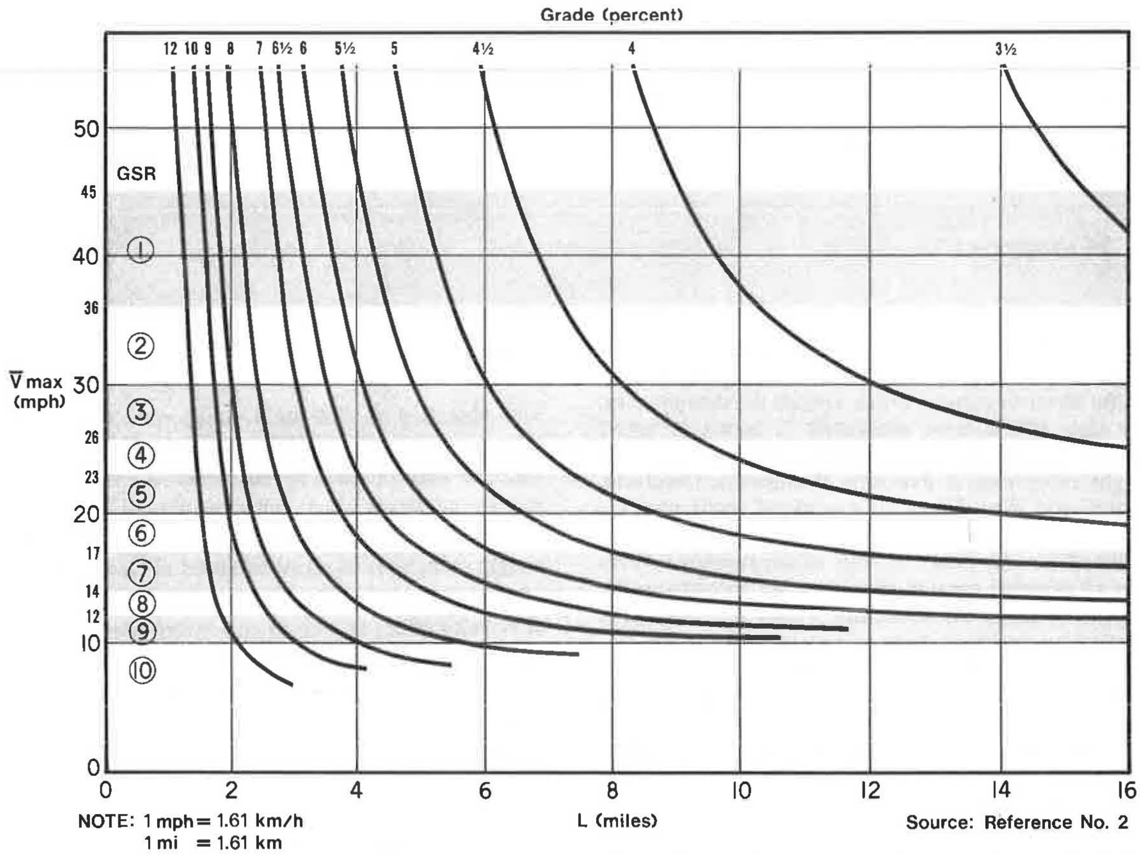

FIGURE 1 Description of GSRs in terms of grade severity ratings (GSR number) and prescribed speeds for 80,000-lb (36.3 Mg) trucks according to grade characteristics.

GSRS, the site paradigm included a closely matched geometric site pair comprised of the eastern site and a western site. Acclimation data were gathered immediately following sign installation at three sites in various areas of the United States to observe any novelty effect associated with WSS sign responses.

Site and Sign Characteristics

To achieve the required multiregional effect, the following sites were represented in the data base:

- I-5: Siskyou County, California.
- I-70: Georgetown, Colorado.
- US 95: Lewiston, Idaho.
- I-84: Cabbage Hill, Oregon.
- I-5: Medford, Oregon.
- US 40: Morgantown, West Virginia.

Both low- and high-severity sites were included in the sample. Site geometrics (e.g., no upgrades nearby) were such that observed speeds were not confounded by factors other than the downgrade. Figure 2 shows studied weight-specific signing characteristics, site designations, and highway geometric conditions that characterized each site.

Field Data Collection

Two field procedures were conducted. Manually timed speed data were collected at a point on each grade where any brake-fade speed effect (e.g., runaway truck) could be observed. In addition, truck weight data were recorded at a nearby weigh station. Each collection procedure involved recording truck-specific descriptive data used to associate individual speeds and weights. The following techniques were applied for each of three data types: truck descriptions, weights, and speeds.

Truck descriptions. A procedure was developed by which field observers could quickly extract sufficiently detailed visual truck characteristics in order to identify target trucks. Carrier name (and unit identification number, in cases in which multiple trucks from a given line were traveling in proximity) was the most helpful information in the matching procedure, which proved to be quite effective; approximately 95 percent of measured speeds and weights were matched.

Weights. Observers stationed at state-operated weigh scales recorded truck descriptions and weight information gathered by state personnel. This source of weight data provided a high level of accuracy.

Speeds. Observers worked in teams; the primary responsibility of one team member was to manually time speeds and the responsibility of another was to record truck descriptive

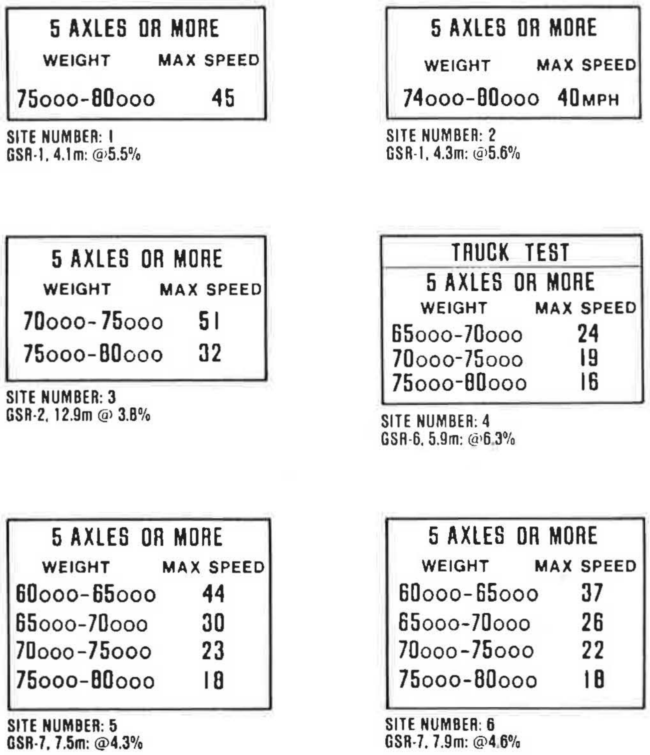

FIGURE 2 Weight-specific sign characteristics, site designations, GSR ratings, and approximate geometrics applied at six study sites.

data. This procedure was effective in producing a high capture rate. That is, when clusters of trucks appeared at the speed site, each observer was capable of gathering both speed and descriptive data; therefore, data attrition was minimized.

Manual timing was designated as the speed collection technique because it was less obtrusive than radar, which is frequently detected by truckers. The applied speed measurement technique involved manually timing target trucks between pavement markings spaced at 268 ft (81.7 m). Measurement accuracy was enhanced by the use of digital stopwatches that were capable of displaying measured time to 1/100 sec. Intercoder reliability determinations verified sample speed measurement accuracy of 0.5 mph.

RESULTS

Speed Effects

The applied field study paradigm supported the following analysis conditions:

- Before-after comparisons for all tested signs, and
- Acclimation (e.g., novelty effect) study at four sites.

Findings for each of these analysis conditions are discussed next.

Before-After Effects

A summary of observed effects for each grade severity rating (GSR) category at all six test sites is given in Table 1. Each cell in the table contains after-minus-before values for both mean speed and violation percentage; that is, trucks exceeding the posted speed limit. Statistical significance, noted by arrows depicting directionality (e.g., arrows indicate observed speeds statistically exceed WSS specified), is based on application of the Student's *t*-test for mean differences and the *z*-test for proportions. Sufficient samples supported use of the 0.01 level of significance to be applied in most cases.

A before-after data comparison (without regard to statistical significant test results) notes a predominant reduction in both mean speeds and violation percentages for heavy trucks in the "after" condition. The single exception is Site 1, the least severe grade. Specific observations of degraded operational performance at the remaining sites are as follows: Increased violation percentage at Site 2, higher mean speed at Sites 3 and 4, and increases in Site 6 data cells. Only one of these conflicting findings (violation percentage at Site 2) may be attributed to a small sample (N = 10).

Statistical significance is noted by arrows within the cells. Arrows indicate changes in mean speeds between before-and-after conditions. The predominant statistical effect is significance associated with lighter weight truck groupings (not affected by the WSS), which comprise a major portion of the sample. With the exception of Site 4, these lighter trucks exhibit lower mean speeds in the after condition. The sustained speed reduction across all weight categories noted at Site 5 is

TABLE 1 OBSERVED BEFORE VERSUS AFTER DIFFERENCES IN MEAN SPEEDS AND PROPORTIONS OF TRUCKS EXCEEDING WSS SPEEDS

	Site Designation (severity)											
	1 GSR-1		2 GSR-1		3 GSR-4		4 GSR-6		5 GSR-7		6 GSR-7	
	mph	%	mph	%	mph	%	mph	%	mph	%	mph	%
Non-GSR speeds	+1.6↑	+9↑	−2.1↓	−6↓	−1.4↓	−9↓	−0.6	0	−3.7↓	−14↓	−3.9↓	−9↓
WSS-affected speeds[a]	+4.3↑	+15↑	−5.0	+30	+2.3	−5	+2.7	+4	−3.3↓	−18↓	−1.5	−6
					−1.8	+11	−5.3↓	−16↓	−9.7↓	−10↓	+1.0	+4
							−3.3↓	−3↓	−6.0↓	−2	−0.2	+4
									−4.5↓	−1	−1.0	−1

NOTES: Arrow (↑) indicates statistically significant. Metric equivalence: 1 lb = 0.454 kg, 1 mph = 1.62 km/h.

[a]Speeds differ between sites; see Figure 2.

associated with the largest sample obtained at any of the sites.

Assessment of WSS effectiveness based on significance testing of the data is as follows. The WSS apparently alerted truckers to downhill brake-fade accident potential, as evidenced by reduced speeds for the lighter trucks as well. However, considering the target heavy-truck population, responses to the WSS were not uniform across all sites. Statistically reduced speeds for GSR-affected trucks were observed at only two of the six test sites. Despite the impressive speed reduction response to the Site 5 sign (control data gathered at a matched site confirm the sign's effectiveness), the Site 1 sign (exposed to virtually the same trucker population) was not shown to be effective. A plausible explanation for this difference is the significantly higher grade severity at Site 5.

The data indicate that the WSS is not effective at lower severity sites. No (statistically significant) speed-reducing effect was observed for heavy trucks at Sites 3 and 4, and an actual speed increase occurred at Site 1.

With regard to the high-severity GSR sites, significant truck speed reductions were observed at two of the three sites. Although trucks in all weight classes slowed at Site 5, only those heavier than 70,000 lb (31.8 Mg) were affected at Site 4. Although observed changes in speed parameters were modest [mean speed reduction ranging from 1.0 to 9.7 mph (1.6 to 15.6 km/h) and decreased speed violations ranging from 1 to 16 percent], associated statistical significance is interpreted as evidence of WSS effectiveness. Further, a matched control site in the vicinity of Site 5 experienced speed increases that further substantiates the interpretation in this instance. Although no matched control site was available in the vicinity of Site 4, it is noteworthy that unaffected trucks [i.e., those with gross weights less than 65,000 lb (29.5 Mg)] did not slow on the grade. This implies that no extraneous explanation existed to cause slowing.

It is difficult to explain between-site difference, which could account for the speed-reducing WSS impact at Sites 4 and 5 and yet result in no effect at Site 6. Sign installations were similar across all three high-severity sites and were constructed in conformity with the FHWA-specified design (see Figure 3). Factors that logically refute any expected sign-related speed-effect difference between sites are as follows. Two signs were installed (one at the top and one part-way down the grade) at all three sites. Although certain preparatory signing (e.g., a series of large yellow signs give advance warning of the downgrade) may have competed for driver attention at Site 6, large yellow grade-advance warning signs were also present at Site 4. Similarly, because of the geographic proximity of these two signs, no regional effect was found to exist in driver response.

Nevertheless, three factors unique to the Site 6 grade were noted, which may have accounted for a reduced WSS speed-reducing effect noted by the principal investigator. First, more advance grade warning signs existed at Site 6 than at any other test site. These signs (e.g., typically "first warning, steep downgrade ahead") may have diverted driver attention from the initial WSS. Second, the later WSS was slightly laterally displaced from the roadway (because of a fill slope), and driver observation of the sign may have been slightly impaired; however, the initial WSS was highly conspicuous. Finally, a number of logging trucks (operated by a variety of local companies) were noted, which consistently descended the grade at high speeds. These trucks appeared to be in good mechanical condition, and the drivers were obviously quite familiar with the roadway.

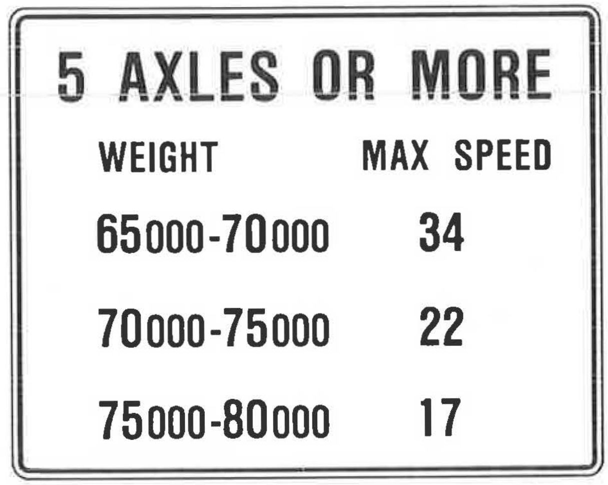

FIGURE 3 FHWA-specified design.

Acclimation Effect

To determine whether weight-specific signs elicited a novelty effect, data were gathered immediately following sign installation at three locations. Acclimation data were gathered at Sites 2, 3, and 6. Observed acclimation speed effects (Table 2) are briefly discussed for each site.

Site 2. Although certain speed differences were observed between the before and acclimation periods, those differences could not logically be attributed to appropriate sign responses. Trucks weighing less than 74,000 lb (33.6 Mg) (not addressed in the sign message) exhibited a significant reduction in mean speed and reduced proportion exceeding the posted speed; however, this effect was offset by speed increases exhibited by trucks weighing more than 74,000 lb (33.6 Mg). Speed increases for the heavier trucks were not significant because of an inadequate sample. Nevertheless, an interpretation of these data indicates no favorable acclimation effect of the weight-specific signing.

Site 3. Very slight speed differences were noted between the before and acclimation conditions. A single statistically significant effect was an increased proportion (64 versus 57 percent) of trucks weighing less than 70,000 lb (31.8 Mg) (thus not affected by the WSS) that exceeded 55 mph during the acclimation period. Therefore, no WSS-related acclimation speed effect was evident.

Site 6. Trucks not affected by the WSS [i.e., those lighter than 60,000 lb (27.2 Mg)] exhibited lower mean speeds, and a smaller proportion exceeded the 55 mph limit immediately following installation of the WSS. Although trucks in the intermediate weight classes [e.g., 60,000 to 75,000 lb (27.2 to 34.0 Mg)] demonstrated a tendency toward lower speeds, the effect was not statistically significant. Particularly noteworthy is the heaviest truck category [75,000 to 80,000 lb (34.0 to 36.3 Mg)] in which nearly the same proportion (91 and 90 percent)

TABLE 2 BEFORE VERSUS ACCLIMATION DIFFERENCES IN MEAN SPEEDS AND SAMPLE PERCENTAGES EXCEEDING POSTED SPEEDS

GSR Weight Category	West Virginia		Colorado		Cabbage Hill		Imperial Grade	
	mph	%	mph	%	mph	%	mph	%
Non-WSS affected	−3.0↓	−15↓	+1.1	+7↑	−4.4↓	−11↓	−3.4	+7
	+7.9	+30↑	−0.2	−13	−7.0	−24		
			−1.4	0	−3.1	+5	−5.0	+8
					−3.7	−4	−4.2	−37
					−1.8	−1		

NOTES: Arrow (↓) indicates statistical significance. Metric equivalence: 1 lb = 0.454 kg, 1 mph = 1.62 km/h.

exceeded the GSR-posted speed between the before and acclimation periods. Therefore, no WSS-related acclimation speed effect was evident.

In summary, consistent observations at three grades (low-, intermediate-, and high-severity sites) indicate that the WSS elicited no novel speed-reducing effect. Those before-after speed differences noted previously (with control for season of the year) were apparent effects resulting from a learned response because the signs had been in place for a sufficient duration.

Smoking Brake Effects

A secondary measure of WSS effectiveness was the incidence of smoking brakes. This behavior was so designated because, as truck brakes heat up, detectable odor and smoking comprise a warning of actual brake loss. Sufficient data samples were obtained at one intermediate-severity site (Site 3) and one high-severity site (Site 4).

Site 3

Extensive observation of Jake brake usage (i.e., utilizing engine compression to reduce speed) and incidences of smoking brakes were conducted at Site 3. Comparisons of before-after results were based on a sample of 1,476 trucks over an observation period of 9 days. The summary result is as follows:

	Before *N = 960* *(%)*	*After* *N = 516* *(%)*
Jake brake usage	30.5	33.7
Smoking brakes	11.8	15.1

Slight but statistically nonsignificant increases were noted for both Jake brake usage and smoking brake occurrence. An explanation of this effect was sought on the basis of possible differences in sampled weight distributions between the before and after conditions. Although a slight increase in heavier trucks (25 percent versus 22 percent targeted by the WSS) characterized the after study sample, this difference alone was insufficient to account for the increase in observed brake effects.

In order to assess WSS effectiveness on the basis of these measures, a slight increase in Jake brake usage and a significant reduction in smoking brake occurrences can be expected. In this case, the obviously more significant measure is smoking brake occurrences. The observed increase in the percentage of smoking brakes indicates a poor response to the WSS. This finding is consistent with the speed effect noted earlier asserting that the Site 3 WSS installation was not effective.

Site 4

Because of specialized personnel requirements to assess Jake brake usage, this measure could not be obtained at Site 4. However, observations of smoking brake incidences indicated a significant reduction as follows:

	Before *N = 595* *(%)*	*After* *N = 590* *(%)*
Smoking brakes	3.5	1.4

A check on before-versus-after weight distribution (i.e., heaviest GSRS category; 47 percent before, and 39 percent after) would account for a minimal reduction in smoking brake incidences in the after condition. Therefore, the observed before-after reduction in the proportion of smoking brake incidences is an indication of WSS effectiveness.

That smoking brake differences revealed an effect at Site 4 but not at Site 3 is consistent with observed speed effects. These findings, based on separate measures, confirm WSS effectiveness on high-severity grade.

SUMMARY AND CONCLUSIONS

Weight-specific signing was determined to elicit a favorable before-after effect at most high-severity sites tested. Three truck behavioral measures that provided the basis for this result were mean truck speed, percentage of trucks exceeding posted WSS speeds, and incidences of smoking brakes.

Modest reductions in before-versus-after mean speed were observed at two out of three high-severity locations following installation of the WSS. Substantiating evidence that the WSS was responsible for the speed reduction evolved from (a) corresponding speed increases at a matched control site, and (b) the absence of speed changes for trucks weighing less than 70,000 lb (31.8 Mg) at the other site. Percentages of trucks exceeding WSS-posted speeds were reduced for 70,000- to 80,000-lb (31.8- to 36.3-Mg) trucks at one site and 60,000- to 70,000-lb (27.2- to 31.8-Mg) trucks at the other. At the third high-severity site, higher speeds were observed for a subsample of truckers who were quite familiar with the grade. The proportion of trucks characterized by smoking brakes was reduced by one-half at the single high-severity site where this measure was observed.

A final consideration is the issue of states' liability. Although detailed study of liability implications of WSS installations was beyond the scope of the existing contract, it is nevertheless a concern. Litigation against states may occur in the event of brake-fade accidents. Two related viewpoints held by states were brought to the author's attention during the course of this study. The first is that weight-specific signing is superior to conventional advisory truck speed limits on downgrades in that, because of its greater specificity and conspicuity, it is likely to result in a safety benefit. Therefore, a state's legal position would be improved as a result of WSS application. The second is that, assuming compliance with WSS-posted speeds, greater stream flow perturbation would result from speed differentials between trucks of varying weight, and safety would be degraded. Therefore, a state's legal position would be weakened as a result of WSS application.

Consideration of WSS liability implications is as follows. Although before-and-after speed reductions were frequently observed following WSS application, the overall slowing effect was not of sufficient magnitude to increase intervehicle speed differentials. More important, the liability issue could best be resolved by assessing whether the state acted prudently when signing the downgrade. Because the GSRS comprises the state of the art in reduction of brake-fade accidents, and has in this study proven to be somewhat operationally effective, the conclusion is that states' liability position would be improved by the use of WSS.

Although actual significant speed reductions were observed at only two of six test sites, this finding is considered a basis for recommending WSS application for the following reasons. First, the signs demonstrated greater effectiveness in the presence of the more severe hazard, a finding that substantiates both sign credibility and safety effects. Second, although actual observed mean speed reductions were slight (3.3 to 9.7 mph), their statistical significance attests to their efficacy at driver behavior modification. Finally, as noted previously, WSS usage provides a liability-protection benefit to state highway agencies.

RECOMMENDATIONS

Reductions in truck speeds and smoking brake occurrences at certain high-severity grade sites were observed in this study. Further, it was concluded that GSRS application would improve a state's liability position because the GSRS comprises the state of the art in brake fade accident prevention.

Therefore, application of weight-specific signing is recommended at high-severity grade locations (i.e., GSR 6 or above). Specific geometric conditions comprising a GSR 6 grade are as follows:

Percent	*mi*	*km*
4.5	14.0	22.5
5	12.0	19.3
5.5	6.6	10.6
6	5.2	8.4
6.5	4.4	7.1
7	3.8	6.1
8	3.0	4.8
9	2.4	3.9
10	2.0	3.2

Further research to improve driver compliance with weight-specific speeds is also recommended. Application of automatic weight sensors in pavements that are integrated with changeable message bulb-matrix signing offers the potential for increased compliance by providing highly conspicuous speed information on a truck-specific basis.

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