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FIELD TEST OF THE GRADE SEVERITY RATING SYSTEM

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Research, Development, and Technology

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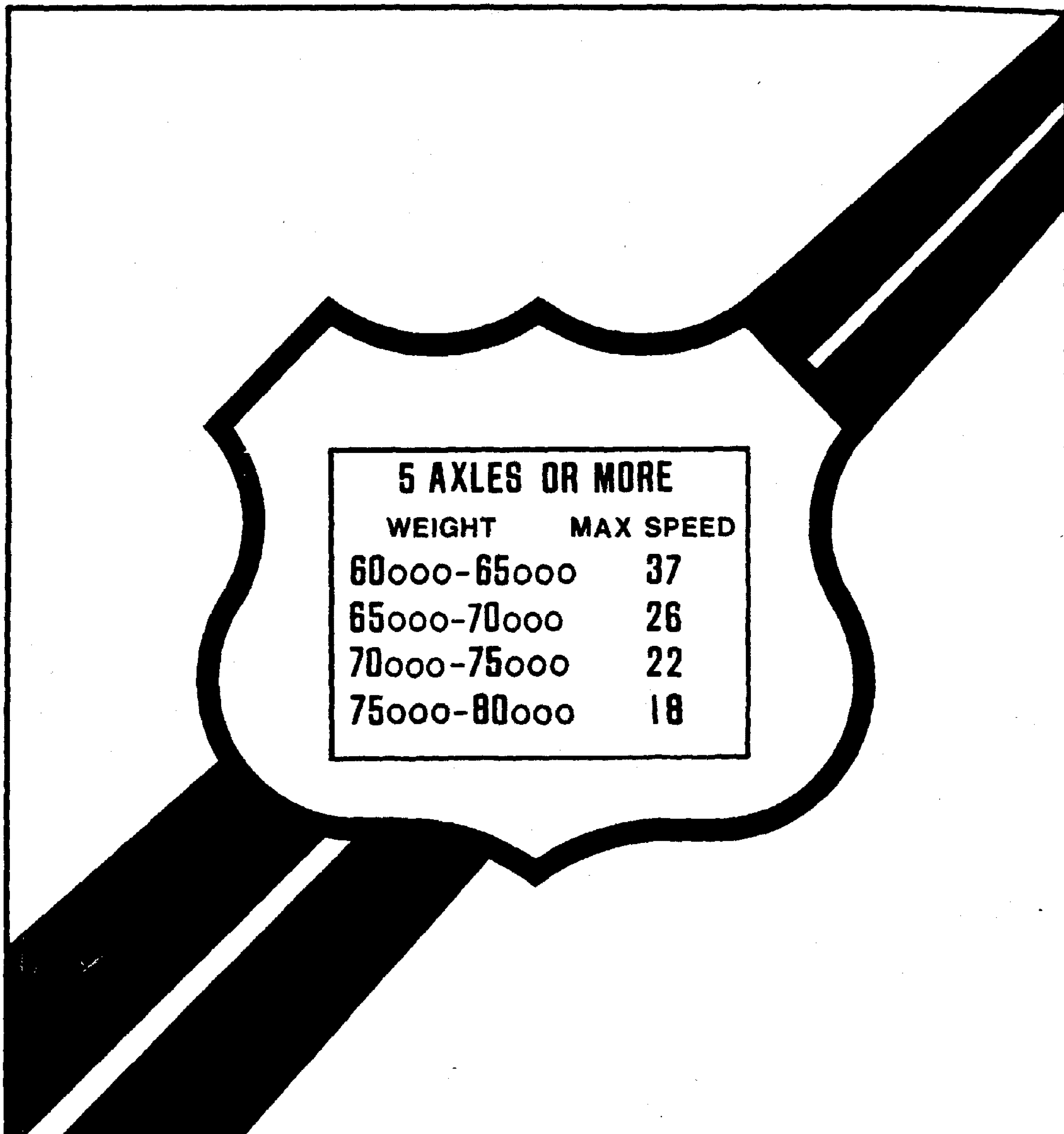

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16. Abstract

The objective of this study was to test the field effectiveness of the 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 nationwide 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, this study examined the feasibility of state highway agencies conducting an accident study to assess GSRS safety impact.

Weight-specific signing (WSS) was determined to elicit a favorable before-after effect at high severity sites. Three truck behavioral measures which provided the basis for this result were 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 (1) corresponding speed increases at one matched control site and (2) the absence of speed changes for trucks weighing less than 70,000 pounds (31.8 Mg) at the other site. Percentages of trucks exceeding WSS-posted speeds were reduced for 70,000-80,000 pound (31.8-36.3 Mg) trucks at one site and for 60,000-70,000 pound (27.2-31.8 Mg) trucks at the other. The proportion of trucks characterized by smoking brakes was reduced by one-half at the single high-severity site where this measure was observed.

Application of the GSRS was viewed to improve States' liability positions as it represents the state of the art. Weight-specific signing was recommended for use at high severity grade locations.

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SUMMARY AND RECOMMENDATION

The Grade Severity Rating System (GSRS) is designed to increase truck safety on downgrades. The GSRS prescribes truck descent speeds which are based on gross truck weight and grade severity. Weight-specific signs (WSS) provide advisory speed information based on weight. This field study examined before-after effects of the signs in terms of two measures: (1) truck speed characteristics, and (2) incidences of smoking brakes. Smoking brakes comprise a valid predictor of actual brake loss and brakefade accident potential.

Before-after reductions in mean speed were observed following installation of the WSS at two out of three high grade-severity locations. That the signs were responsible for the speed reductions (as opposed to other factors) was substantiated in the following manner. At the first site, corresponding speed increases were observed for a matched control site (i.e. geometrically similar in the same region of the country). At the second site, speeds of lighter trucks (not targeted by the WSS) remained unaffected. Moreover, at the third site where the WSS proved ineffective, higher speeds were shown for sub-sample of trucks with very good braking capability and whose drivers were quite familiar with the grade.

A favorable recommendation regarding applicability of the WSS is based on two considerations. First, significant speed reductions were observed for heavy trucks at the majority of the test sites. Second, it was concluded that the GSRS would improve a State's liability position as its use demonstrated prudent application of the state-of-the-art in brakefade accident reduction. Therefore, application of weight-specific signing is recommended at high severity locations. Typical geometric conditions comprising appropriate severity are as follows:

5 percent	-	12.0 miles (19.3 Km)
7 percent	-	3.8 miles (6.1 Km)
8 percent	-	3.0 miles (4.8 Km)
9 percent	-	2.4 miles (3.9 Km)

The WSS design recommended by the FHWA's Office of Traffic Operations and used at all sites is shown in Appendix A of this report.

BACKGROUND

Introduction

The Grade Severity Rating System (GSRS) is a technique for reducing the incidence and severity of truck downgrade accidents. Recent work conducted for the Federal Highway Administration (FHWA) has examined GSRS feasibility via the development and prototype application of a weight-based truck speed selection model. (1,2) 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 describes the GSRS by: (1) defining grade severity ratings (GSR 1 through 10) and (2) prescribing safe downgrade speeds for 80,000 pound (36.6 Mg) combinations according to grade geometry.

Approach

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

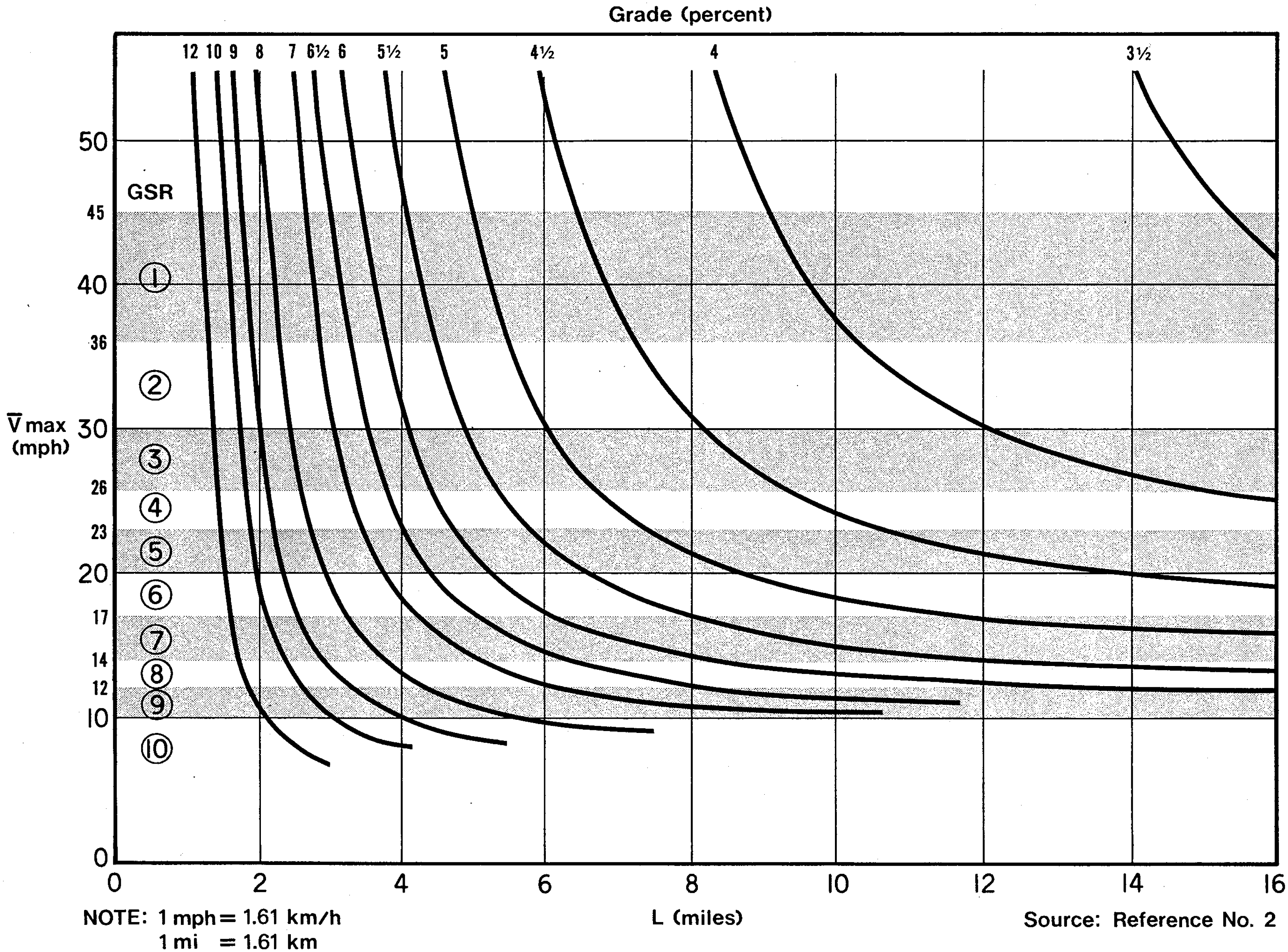

Figure 1. Description of GSRS in terms of grade severity ratings (GSR number) and prescribed speeds for 80,000 pound (36.3 Mg) trucks according to grade characteristics.

STUDY PROCEDURE

The applied procedure in this field evaluation of the GSRS is discussed under the following headings: Designation of Measures of Effectiveness, study design, site/sign characteristics, State highway agency participation, field data collection, and data analysis.

Designation of Measures of Effectiveness

Measures of effectiveness (MOEs) refer to that which is measured in an evaluative study. Designation of MOEs is 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 due to the nature of brake-fade truck accidents. These are smoking brakes and 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 class, 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.

While runaway truck accident occurrences also exhibit high face value as an effectiveness measure, the required study time exceeded that available in the current contract. Therefore, this effort developed requirements for State-conducted accident studies over a suitable study period. Findings based on two MOE categories (i.e., smoking brakes and speed effects) are discussed in the Results section of this report. Appendix B contains the recommended procedure for an accident-based GSRS evaluation.

Study Design

To the extent possible based on available site characteristics (e.g., required downgrade steepness, available truck weight data), the current study employed a <u>before-after with control</u> site paradigm. Sites were designated so as to support multi-regional data within the United States. While the majority of required geometric conditions were located in the Western U.S., data were also gathered at one east coast site. In order to render a precise geographic effect response to the GSRS, the site paradign included a closely matched geometric site pair comprised of the Eastern and a Western site. In order to observe any novelty effect associated with WSS sign responses, acclimation data were gathered immediately following sign installation at three sites in various areas of the U.S.

Site/Sign Characteristics

In order to achieve the required multi-regional effect, the following states were represented in the data base:

California
Colorado
Idaho
Oregon
West Virginia

Both low- and high-grade severity sites were included in the sample. Figure 2 contains studied weight-specific signing characteristics, site designations, and highway geometric conditions which characterized each study site.

State Highway Agency Participation

The five State highway agencies assisted in locating required grade characteristics, collecting weight data, and providing access to accident statistics relative to the test grades. In addition, States designed and installed the weight-specific signing via application of the procedure contained in The Development and Evaluation of a Prototype Grade Severity Rating System, FHWA/RD-81/185. (2)

Field Data Collection

Manual observation techniques were applied to gather matched truck speed and weight data. While there was an initial attempt to use a portable weigh-in-motion system, the system proved to be unreliable due to the fact that such portable systems are still in the developmental stage. While there was consideration of alternate weight-gathering methods (e.g., loadometer surveys), applicable at virtually any location, a sufficient number of grade sites were found in close proximity to permanent weigh scales. Therefore, State-operated weigh stations became the primary source of truck weight data.

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. An example data collection form used to record both speed and weight information is shown as Figure 3.

5 AXLES OR MORE	
WEIGHT	MAX SPEED
75000-80000	45

SITE NUMBER: 1
GSR-1, 4.1 mi @ 5.5%

5 AXLES OR MORE	
WEIGHT	MAX SPEED
74000-80000	40 MPH

SITE NUMBER: 2
GSR-1, 4.3 mi @ 5.6%

5 AXLES OR MORE	
WEIGHT	MAX SPEED
70000-75000	51
75000-80000	32

SITE NUMBER: 3
GSR-2, 12.9 mi @ 3.8%

TRUCK TEST	
5 AXLES OR MORE	
WEIGHT	MAX SPEED
65000-70000	24
70000-75000	19
75000-80000	16

SITE NUMBER: 4
GSR-6, 5.9 mi @ 6.3%

5 AXLES OR MORE	
WEIGHT	MAX SPEED
60000-65000	44
65000-70000	30
70000-75000	23
75000-80000	18

SITE NUMBER: 5
GSR-7, 7.5 mi @ 4.3%

5 AXLES OR MORE	
WEIGHT	MAX SPEED
60000-65000	37
65000-70000	26
70000-75000	22
75000-80000	18

SITE NUMBER: 6
GSR-7, 7.9 mi @ 4.6%

Metric Equivalence
1,000 lbs = 0.454 Mg
1 mph = 1.61 km/h

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

Site:____________

Observer:_________

Date:____________

Weather/Road Conditions:________

Marker spacing:_____

Description Codes

CB - cab behind
CO - cab over
Dbl- double
Tr - triple
FB - flatbed
LB - lowboy
DU - dumper
A - livestock
T - tanker
H - house
L - logger

Color Codes

Bl - blue
Bk - black
Br - brown
Gl - gold
S - silver/grey
O - orange
M - maroon
R - red
Y - yellow
G - green
W - white

Time of Day	Cab Color Solid	Stripe	Description	Carrier	Cab #	Time Clocked/Weight	Match #	Log #
:								1
:								2
:								3
:								4
:								5
:								6
:								7
:								8
:								9
:								10
:								11
:								12
:								13
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:								25

Figure 3. Example field data collection sheet.

The following techniques were applied for each of three data types: truck descriptions, weights, and speeds.

Truck descriptions - A procedure was developed whereby field observers could quickly extract sufficiently detailed visual truck characteristics so as to uniquely identify target trucks. The following characteristics (along with precise time-of-day to aid in data matching) were encoded both at truck weighing and speed measurement points.

1. Tractor-Color - solid, multi-color body; stripe color

2. Cab Description - cab over, cab behind

3. Trailer Description - single; double; flatbed, etc.

4. Carrier Name

5. Unit Identification Number

Carrier name (and unit identification number, in cases when multiple trucks from a given line were traveling in close time proximity) was the most helpful information in the matching procedure. This procedure 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 weight data source provided a high level of accuracy.

Speeds. Observers worked in teams with primary responsibility of one member to manually time speeds and the other to record truck descriptive data. This procedure was effective in terms of producing a high capture rate. That is, when clusters of trucks would appear 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 largely due to its being less obtrusive than radar which is frequently detected by truckers. Further, manual timing enabled precise measurement of target trucks when a number traveled in close proximity. Radar lacks the capability to distinguish between vehicles in such instances.

The applied speed measurement technique involved manually timing target trucks between pavement markings spaced at 268 feet (81.7 m). This spacing did provide a sufficiently long measurement time as to minimize any timing error due to coder reflexes. Measurement accuracy was enhanced via the use of digital stopwatches capable of displaying measured time to 1/100 second.

The issue of manually timed speed accuracy was addressed as follows. First, the project team had validated the applied procedure against a variety of other techniques during a concurrent research project (DTFH61-C-82-00064) and was convinced of its accuracy. Second, all data collectors were subjected to training sessions which involved the conduct of inter-coder reliability determinations. An example of such an exercise is shown as Appendix C. In the example conducted at the Idaho grade, comparative speeds on 109 vehicles are illustrated for two observers. The reliability coefficient was 0.96 and the intercoder difference in mean speeds was 0.5mi/h (0.8 km/h).

Data Reduction and Analysis

Encoded field data were computerized and then subjected to an edit procedure in order to correct any field coding errors. The purpose of the edit was to ensure against either field coding errors or improper data entry into the computer. Data editing involved the identification of specific trucks in the computerized data base which appeared to be traveling unusually slow, unusually fast, or exhibited an atypical weight-speed relationship. When suspect information was identified, it was checked against original field logs and modified if necessary.

Data analysis involved grouping truck samples according to weight categories displayed on the weight-specific signing. For each grouping, sample speed parameters (e.g., means, standard deviations, statistical confidence intervals) were computed as well as the proportion of trucks which exceeded the posted speed. Figure 4 is a sample output from the data analysis. Edited data appears at the top of the page. In this case, trucks are shown which exceed 82,000 pounds (37.2 Mg) gross weight or a speed of 65 mi/h (105 km/h). Also shown is results of the statistical analysis of speed and weight for each weight-specific sign category.

Subsequent data analysis to determine sign impact on truck speeds involved application of student's t-tests (including homogenuity of varience testing) to mean speeds and the z-test to speed violation truck proportions.

```
I=  14  SPEED=  29.8  WEIGHT=   82200
I=  18  SPEED=  67.2  WEIGHT=   29000
I=  33  SPEED=  18.1  WEIGHT=   88500
I=  45  SPEED=  67.2  WEIGHT=   29000
I=  46  SPEED=  65.3  WEIGHT=   58700


 GSRS SPEED/WEIGHT SUMMARY

TOTAL SAMPLE=  69

WT. CLASS  1
     0  TO  65000  POUNDS
POSTED SPEED:  55
SAMPLE SIZE=  53
MEAN SPEED= 50.3
STD DEV=12.2
95TH C.I.= +/- 1.68
AVG WEIGHT=  36573.58
PROPROTION FASTER=  .38

WT. CLASS  2
     65000  TO  70000  POUNDS
POSTED SPEED:  45
SAMPLE SIZE=  3
MEAN SPEED= 45.4
STD DEV= 8.6
95TH C.I.= +/- 4.98
AVG WEIGHT=  65466.67
PROPROTION FASTER=  .33

WT. CLASS  3
     70000  TO  75000  POUNDS
POSTED SPEED:  30
SAMPLE SIZE=  6
MEAN SPEED= 27.1
STD DEV= 6.4
95TH C.I.= +/- 2.60
AVG WEIGHT=  73483.33
PROPROTION FASTER=  .33

WT. CLASS  4
     75000  TO  88500  POUNDS
POSTED SPEED:  20
SAMPLE SIZE=  7
MEAN SPEED= 32.0
STD DEV= 3.9
95TH C.I.= +/- 1.48
AVG WEIGHT=  77271.43
PROPROTION FASTER= 1.00


HEAVIEST TRUCK =  88500
```

Figure 4. Sample output from data analysis.

RESULTS

Separate discussions are contained for each study area: speed effects and smoking brake effects.

Speed Effects

Tables 1 through 9 summarize matched speed and truck weight data analysis results for each of the eight study sites. These tables contain sample size, mean speed, 95th percentile confidence interval about the mean, and proportion of truck sample exceeding the appropriate speed [i.e., 55 mi/h (89 km/h) or that specified on the WSS] for each weight category posted on the WSS. In cases where statistical differences were found, these are noted in the "Effects" column in each table. Study conditions are encoded as follows: "B", before; "Ac", acclimation (data collected immediately following sign installation); and "A", after. Differences noted in the "effects" column utilize a format whereby the faster mean speed or proportion trucks exceeding the posted speed is placed in the numerator and the lower in the denominator. For example, in Table 1, increased speeds for the after condition are noted by A/B.

Sample sizes varied between sites depending upon truck volume and availability of weighing facilities. Where possible, weights were gathered in nearby permanent scales which afforded large samples. At the eastern site, limited loadometer samples were obtained through the cooperation of the respective highway agency. However, sufficient samples were obtained for each tested speed category across all sites to support statistical confidence well within GSR-established speed ranges. A total of 13,205 trucks comprise the data base.

The applied field study paradigm supported the following analysis conditions:

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

Findings are separately discussed for each of these analysis conditions.

Before-after effects

Table 9 summarizes observed effects for each GSR category at all six* test sites. Each cell in this table contains after-minus-before values for both mean speed and violation percentage; i.e., trucks exceeding the posted speed limit. Statistical significance, noted by arrows depicting directionality (e.g., up 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 .01 level of significance in most cases (two exceptions are noted in site-specific tables 3 and 6).

*Data collected at a seventh site did not afford a statistically suitable sample due to weighing difficulties. For the sake of reporting completeness, results obtained at this site are included as Appendix D.

Site #1

Weight Class Posted Speed		Before	After	Effect
<75,000 pounds 55 mph	N	384	826	
	Mean Speed	53.8	55.4	A/B
	(0.05 Confidence)	0.8	0.6	
	% Exceeding	50	59	A/B
75,001-80,000 45 mph	N	294	523	
	Mean Speed	49.0	53.3	A/B
	(0.05 Confidence)	1.2	0.6	
	% Exceeding	73	88	A/B

Note: Speeds and 0.05 Confidence Intervals in mph.

Metric Equivalence
1 lb. = 0.454 kg
1 mph = 1.61 km/h

Table 1 - Summary results for Site #1 (low severity, GSR-1)

Site #2

Weight Class Posted Speed		Before	Acclimation	After	Effect
<74,000 pounds 55 mph	N	253	74	198	
	Mean Speed	58.9	55.9	56.8	$\frac{B}{A}$ $\frac{B}{Ac}$
	(0.05 Confidence)	1.0	2.0	1.8	
	% Exceeding	77	62	71	$\frac{B}{Ac}$
74,000–80,000 40 mph	N	10	10	9	
	Mean Speed	51.5	59.4	56.5	
	(0.05 Confidence)	7.8	3.6	3.2	
	% Exceeding	70	100	100	$\frac{A}{B}$ $\frac{A}{B}$

Note: Speeds and 0.05 Confidence Intervals in mph.

<u>Metric Equivalence</u>
<u>1 lb. = 0.454 kg</u>
1 mph = 1.61 km/h

Table 2 – Summary results for Site #2 (low severity, GSR-1)

Site #3

Weight Class Posted Speed		Before	Acclimation	After	Effect
<70,000 pounds 55 mph	N	605	200	588	
	Mean Speed	53.6	54.7	52.2	$\frac{B}{A}$
	(0.05 Confidence)	1.0	1.6	0.8	
	% Exceeding	57	64	48	$\frac{Ac}{B}$ $\frac{B}{A}$
70,001-75,000 51 mph	N	78	24	85	
	Mean Speed	35.7	35.5	38.0	
	(0.05 Confidence)	3.6	4.0	2.6	
	% Exceeding	21	8	16	
75,001-80,000 32 mph	N	91	40	111	
	Mean Speed	34.7	33.3	36.5	
	(0.05 Confidence)	2.8	3.6	2.4	
	% Exceeding	48	48	59	

$\alpha = .05$

Note: Speeds and 0.05 Confidence Intervals in mph.

<u>Metric Equivalence</u>
1 lb. = 0.454 kg
1 mph = 1.61 km/h

Table 3 - Summary results for Site #3 (moderate severity, GSR-2)

Site #3 (Control)

Weight Class Posted Speed		Before	After	Effect
<70,000 pounds 55 mph	N	316	249	
	Mean Speed	59.6	53.1	B/A
	(0.05 Confidence)	1.0	1.0	
	% Exceeding	78	43	B/A
70,000-75,000 51 mph	N	36	44	
	Mean Speed	57.9	49.5	B/A
	(0.05 Confidence)	2.4	3.8	
	% Exceeding	86	43	B/A
75,001-80,000 32 mph	N	38	41	
	Mean Speed	52.9	49.3	B/A
	(0.05 Confidence)	3.2	3.2	
	% Exceeding	95	95	

$\alpha = .01$

Note: Speeds and 0.05 Confidence Intervals in mph.

<u>Metric Equivalence</u>
1 lb. = 0.454 kg
1 mph = 1.61 km/h

Table 4 - Summary results for Site #3 (Control)

Site #4

Weight Class Posted Speed		Before	After	Effect
<65,000 pounds 55 mph	N	252	232	
	Mean Speed	42.2	41.6	
	(0.05 Confidence)	1.6	1.6	
	% Exceeding	17	1.7	
65,000-70,000 24 mph	N	31	26	
	Mean Speed	26.2	28.9	
	(0.05 Confidence)	3.6	3.4	
	% Exceeding	58	62	
70,001-75,000 19 mph	N	32	32	B/A
	Mean Speed	29.7	24.4	
	(0.05 Confidence)	3.4	1.9	
	% Exceeding	97	81	B/A
75,001-80,000 16 mph	N	275	176	B/A
	Mean Speed	32.4	29.0	
	(0.05 Confidence)	1.2	1.5	
	% Exceeding	98	95	B/A

Note: Speeds and 0.05 Confidence Intervals in mph.

Metric Equivalence
1 lb. = 0.454 kg
1 mph = 1.61 km/h

Table 5 - Summary results for Site #4 (high severity, GSR-6)

Site #5

Weight Class Posted Speed		Before	After	Effect
<60,000 pounds 55 mph	N	320	200	
	Mean Speed	54.4	50.7	B/A
	(0.05 Confidence)	0.8	1.4	
	% Exceeding	51	37	B/A
60,000-65,000 44 mph	N	62	39	
	Mean Speed	51.8	48.5	B/A α =.05
	(0.05 Confidence)	2.0	2.8	
	% Exceeding	87	69	B/A
65,001-70,000 30 mph	N	72	42	
	Mean Speed	52.0	42.3	B/A
	(0.05 Confidence)	1.8	3.2	
	% Exceeding	99	90	B/A
70,001-75,000 23 mph	N	170	139	
	Mean Speed	50.1	44.1	B/A
	(0.05 Confidence)	1.2	2.0	
	% Exceeding	99	97	
75,001-80,000 18 mph	N	367	322	
	Mean Speed	48.7	44.2	B/A
	(0.05 Confidence)	1.0	1.4	
	% Exceeding	99	98	

Note: Speeds and 0.05 Confidence Intervals in mph.

Metric Equivalence
1 lb. = 0.454 kg
1 mph = 1.61 km/h

Table 6 - Summary results for Site #5 (high severity, GSR-7)

Site #5 (Control)

Weight Class Posted Speed		Before	After	Effect
<60,000 pounds 55 mph	N	326	228	
	Mean Speed	52.5	54.5	A/B
	(0.05 Confidence)	2.0	1.0	
	% Exceeding	45	53	A/B
60,000-65,000 44 mph	N	55	40	
	Mean Speed	44.4	53.2	A/B
	(0.05 Confidence)	3.0	2.2	
	% Exceeding	58	90	A/B
65,001-70,000 30 mph	N	71	48	
	Mean Speed	45.9	51.0	A/B
	(0.05 Confidence)	2.6	1.8	
	% Exceeding	93	100	A/B
70,001-75,000 23 mph	N	193	118	
	Mean Speed	46.4	49.1	A/B
	(0.05 Confidence)	1.4	2.0	
	% Exceeding	99	98	
75,001-80,000 18 mph	N	398	287	
	Mean Speed	45.3	49.2	A/B
	(0.05 Confidence)	1.0	1.2	
	% Exceeding	99	99	

Note: Speeds and 0.05 Confidence Intervals in mph.

Metric Equivalence
1 lb. = 0.454 kg
1 mph = 1.61 km/h

Table 7 - Summary results for Site #5 (Control)

Site #6

Weight Class Posted Speed		Before	Acclimation	After	Effect
<60,000 pounds 55 mph	N	270	288	459	
	Mean Speed	51.2	46.8	47.3	$\frac{B}{Ac}$ $\frac{B}{A}$
	(0.05 Confidence)	2.4	1.6	1.2	
	% Exceeding	42	31	33	$\frac{B}{Ac}$ $\frac{B}{A}$
60,000-65,000 37 mph	N	21	23	77	
	Mean Speed	41.7	34.7	40.2	
	(0.05 Confidence)	7.6	5.8	2.6	
	% Exceeding	67	43	61	
65,001-70,000 26 mph	N	26	37	74	
	Mean Speed	36.6	33.5	37.6	
	(0.05 Confidence)	11.6	4.0	2.8	
	% Exceeding	73	78	77	
70,001-75,000 22 mph	N	57	82	203	
	Mean Speed	34.8	31.1	34.6	
	(0.05 Confidence)	5.0	2.2	1.6	
	% Exceeding	78	74	82	
75,001-80,000 18 mph	N	196	187	440	
	Mean Speed	33.4	31.6	32.4	
	(0.05 Confidence)	3.4	1.6	1.2	
	% Exceeding	91	90	90	

Note: Speeds and 0.05 Confidence Intervals in mph.

Metric Equivalence
1 lb. = 0.454 kg
1 mph = 1.61 km/h

Table 8 - Summary results for Site #6 (high severity, GSR-7)

Site Designation
(severity)

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

Legend: ↑= statistically significant

<u>Metric Equivalence</u>
1 lb. = 0.454 kg
1 mph = 1.61 km/h

Table 9 - Observed before-versus after differences in mean speeds and proportions of trucks exceeding WSS speeds

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

Our assessment of WSS effectiveness based on significance testing of the data is as follows. The WSS apparently alerted truckers to downhill brakefade 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 low-GSR sites. We observed no (statistically significant) speed reducing effect 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. While trucks in all weight classes slowed at Site #5, only those heavier than 70,000 pounds (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 mi/h (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 the Site #5 experienced speed increases which further substantiates our interpretation in this instance. While 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 pounds (29.5 Mg)] did not slow on the grade. This fact implies that no extraneous explanation existed to cause slowing.

It is difficult to explain between-site differences which could account for the speed-reducing WSS impact at Sites #4 and #5 and yet result in no affect at Site #6. Sign installations were similar across all three high-severity sites and were constructed in conformity with the FHWA-specified design (see Appendix A). Factors which logically refute any expected sign-related speed effect difference between sites are as follows. Two signs (one at the top and one part way down the grade) were applied at all three sites. While certain preparatory signing (e.g., a series of advance large yellow signs warning of the downgrade) may have competed for driver attention at Site #6, advance large yellow grade warning signs were also present at Site #4. Similarly, due to their close geographic proximity of these two signs, no regional effect exists to explain driver response differences. Nevertheless, three factors unique to the Site #6 grade 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 down-grade ahead) may have diverted driver attention from the initial WSS. Second, the later WSS was slightly laterally displaced from the roadway (due to a fill slope), and driver attention to the sign may have been slightly impaired; however, the initial WSS was highly conspicuous. Finally, we noted a number of logging trucks (operated by a variety of local companies) 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.

Local Logging Truck Speed Effect

A more in-depth examination of Site #6 data was undertaken due to the above noted problem of apparently high-speed local logging trucks, in combination with the fact that Site #6 was the only high-severity site in which favorable WSS mean speed responses were not found. This additional analytic step involved first contacting local weight enforcement personnel in order to identify specific local trucking companies. These personnel were quite knowledgeable of local trucking company practices. A number of cited trucking firms were characterized by: (1) drivers who were very familiar with the grade (e.g., driving the site on the average of five times per week), (2) hauling heavy payloads [average gross weights ranged from 78,000 to 82,000 pounds (35.4 to 37.2 Mg)], and (3) equipment including braking systems which were in generally good operating condition. Following the identification of target carriers, specific trucks were separated within the database and the data were reanalyzed. A wide variation in speed behaviors on the grade was noted between local logging companies, i.e. certain haulers consistently drove at higher speeds than others.

Table 10 contrasts speed behaviors between local logging trucks and other trucks weighing between 75,000 and 82,000 pounds (34.0 and 37.2 Mg). While specific target truck weight (as posted on the WSS) ranged from 75,000 to 80,000 pounds (34.0 to 36.3 Mg), certain loggers were observed to deliberately overload [e.g., up to 82,000 pounds (37.2 Mg)] and pay the fine in order to haul the additional payload. These were the same loggers which consistently drove the Site #6 downgrade at higher speeds.

Study Period		Loggers	Non-Loggers
Before	N	34	144
	Mean Speed (mi/h)	43.7	31.4
	Standard Deviation (mi/h)	10.8	11.0
	% Exceeding	94.1	91.7
Acclimation	N	43	126
	Mean Speed (mi/h)	42.7	29.0
	Standard Deviation (mi/h)	6.9	9.9
	% Exceeding	100.0	89.7
After	N	100	286
	Mean Speed (mi/h)	41.7	29.5
	Standard Deviation (mi/h)	10.8	10.8
	% Exceeding	99.0	87.4

Metric Equivalence
1 lb. = 0.454 kg
1 mph = 1.61 km/h

Table 10 - Comparisons between logging trucks and non-loggers weighing between 75,000 and 82,000 pounds (34.0 and 37.2 Mg) observed at Site #6.

Table 10 demonstrates significantly faster speeds exhibited by local loggers by comparison to other trucks in the sample. Loggers averaged higher speeds [ranging from 12.2 to 13.7 mi/h (19.6 to 22.0 km)] during the before, acclimation, and after study periods. Nevertheless, mean speed responses to the WSS were similar for both groups. Non-significant mean speed reductions (from "before" condition averages) were as follows:

	Speed Reduction (mi/h)	
	Loggers	Non-loggers
Acclimation	1.0	2.4
After	2.0	1.9

1 mi/h = 1.61 km/h

However, statistically significant differences between the two groups were observed in terms of their compliance to posted WSS speeds. A greater proportion of local logging trucks exceeded the posted speed following WSS installation. Comparisons between the two groups for change in violation percentage are as follows:

	Speed Violation Difference (Percentage)	
	Loggers	Non-loggers
Acclimation	+5.9	-2.0
After	+4.9	-4.3

As seen above, a greater percentage of local logging trucks exceeded WSS posted speeds in both the "acclimation" and "after" study periods by contrast with the remaining trucks which exhibited a decrease in speed violators.

Of particular importance, however, in the GSRS evaluation is the speed response exhibited by the truck sample which was unaffected by the high-speed logging trucks. Before-acclimation-after speed comparisons for non-loggers are shown in Table 10. While reduced mean speeds and percentages of speed violators did result following WSS installation, these differences are statistically non-significant.

Results of this separate analysis of Site #6 data revealed atypically high speed behavior for a sub-sample of trucks, characterized by apparently good braking systems, and driven by local drivers. Local logging trucks were shown to drive significantly faster than other trucks of comparable weight in the sample. Moreover, they demonstrated a greater likelihood of exceeding WSS posted speeds.

However, the primary result of this separate analysis was to reveal WSS impact on the remaining truck samples unaffected by the high-speed loggers. The resulting before-after effect is a 1.9 mi/h (3.1 km/h) mean speed decrease and a 3.1 percent speed violation decrease for trucks in the 75,000 to 80,000 (34.0 to 36.3 Mg) weight category. These values compare favorably to the total sample values of 1.0 mi/h (1.6 km/h) and 1.0 percent, respectively, previously shown in the lower right-hand cell of Table 9. Thus, an improved WSS response was evident. While the resulting before-after speed reductions demonstrate a tendency toward safer driving behaviors, lack of associated statistical significance does, however, confirm the previous Table 9 interpretation that the WSS was ineffective at Site #6.

Acclimation Effect

In order 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 11) are briefly discussed for each site.

Site #2- While 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 pounds (33.6 Mg) (not affected by the sign) 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 pounds (33.6 Mg). Speed increases for the heavier trucks were not significant due to inadequate sample. Nevertheless, an interpretation of these data indicate 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 percent versus 57 percent) of trucks weighing less than 70,000 pounds (31.8 Mg) (thus not affected by the WSS) which exceeded 55 mi/h 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 pounds (27.2 Mg)] exhibited lower mean speeds and a smaller proportion exceeded the 55 mi/h limit immediately following installation of the WSS. While trucks in the intermediate weight classes [e.g., 60,000-75,000 pounds (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 [75,000-80,000 pounds (34.0 to 36.3 Mg)] in which nearly the same proportion (91 and 90 percent) exceeded the GSR-posted speed between the before and acclimation periods. Therefore, no WSS-related acclimation speed effect was evident.

Table 11. Before- versus acclimation-differences in mean speeds and sample percentages exceeding posted speed.

GSR Weight Category	Site #2	Site #3	Site #6
Non-WSS Affected	-3.0 mph ↓ -15% ↓	+1.1 mph +7% ↑	-4.4 mph ↓ -11% ↓
#1	+7.9 mph +30% ↑	-.2 mph -13%	-7.0 mph -24%
#2		-1.4 mph 0%	-3.1 mph +5%
#3			-3.7 mph -4%
#4			-1.8 mph -1%

Legend: ↓ = statistical significance

Metric Equivalence
1 mph = 1.61 km/h

In summary, consistent observations at three grades (low-, intermediate-, and high-grade severity sites) indicate that the WSS elicited no "novelty" speed-reducing effect. Those before-after speed differences noted above (with control for season of the year) were apparent effects resulting from a learned response due to the fact that 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 designated due to the fact that, 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 and incidence of smoking brakes was conducted at this site. Comparisons of before-after results were based on a sample of 1,476 trucks over an observation period of nine 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. While a slight increase in proportion of 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, we would expect to find a slight increase in Jake brake usage and a significant reduction in smoking brake occurrences. The obviously more significant measure, in this case, consists of smoking brake occurrences. The observed increase in smoking brake percentage indicates a poor response to the WSS. This finding is consistent with the above noted speed effect asserting that the Site #3 WSS installation was not effective.

Site #4

Due to specialized personnel requirements to assess Jake brake usage, we were unable to obtain this measure at Site #4. However, smoking brake observations indicated a dramatic reduction as indicated below.

	Before N=595	After N=590
Smoking brake	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 very minimal smoking brake reduction in the after condition. Therefore, we attribute the observed before-after reduction in smoking brake proportion as 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 grades.

CONCLUSION

Weight-specific signing (WSS) was determined to elicit a favorable before-after effect at most tested high severity sites. Three truck behavioral measures which provided the basis for this result were 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 (1) corresponding speed increases at one matched control site, and (2) the absence of speed changes for trucks weighing less than 70,000 pounds (31.8 Mg) at the other site. Percentages of trucks exceeding WSS-posted speeds were reduced for 70,000-80,000 pound (31.8 to 36.3 Mg) trucks at one site and for 60,000-70,000 pound (27.2 to 31.8 Mg) trucks at the other. At the third high-severity site, higher speeds were observed for a sub-sample of truckers who were quire 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 State's liability. While 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 brakefade accidents. Two related but conflicting viewpoints held by States were brought to our 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, due to its greater specificity and conspicuity, it is more likely to result in a safety benefit. Therefore, a State's legal position would be improved due to WSS application. The second is that, assuming compliance to 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 due to WSS application.

Consideration of WSS liability implications is as follows. While before-after speed reductions were frequently observed following WSS application, the overall slowing effect was not of sufficient magnitude to increase intervehicle speed differentials. More importantly, we feel that the liability issue could best be resolved by assessing whether the State acted prudently when signing the downgrade. In view of the fact that the GSRS comprises the state of the art in reduction of brakefade accidents, and has in this study proven to be somewhat operationally effective, the conclusion is that State's liability position would be improved via WSS usage.

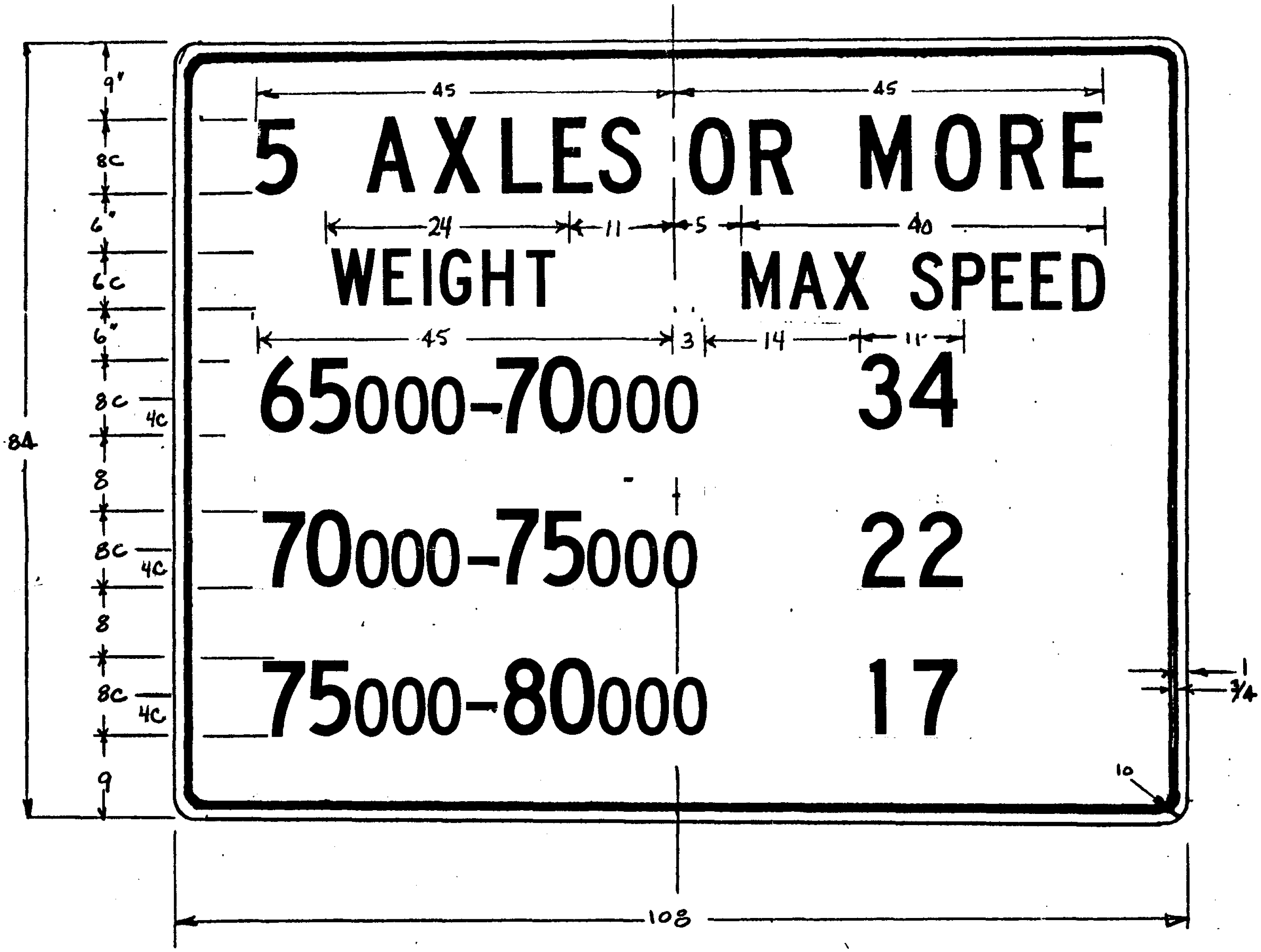
RECOMMENDATIONS

This study observed reductions in truck speeds and smoking brake occurrences at certain high-severity grade sites. Further, it was concluded that GSRS application would improve a State's liability position due to the fact that the GSRS comprises the state of the art in brakefade accident prevention.

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

4 1/2 percent	- 14.0 miles	(22.5 km)
5 percent	- 12.0 miles	(19.3 km)
5 1/2 percent	- 6.6 miles	(10.6 km)
6 percent	- 5.2 miles	(8.4 km)
6 1/2 percent	- 4.4 miles	(7.1 km)
7 percent	- 3.8 miles	(6.1 km)
8 percent	- 3.0 miles	(4.8 km)
9 percent	- 2.4 miles	(3.9 km)
10 percent	- 2.0 miles	(3.2 km)

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



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Appendix B

Data were collected at one additional site not reported in the body of this report. Due to the absence of suitable permanent scale or weigh-in-motion truck weight facilities, an attempt was made to utilize a limited sample of loadometer weights. The resulting sample proved to be unsuitable for a meaningful statistical analysis, so we chose not to include these results as being supportive of any conclusion. However, for sake of completeness in reporting, this data set is appended to the main report.

Exhibit B-1. Summary results for low volume site.

Weight Class Posted Speed		Before	Acclimation	After	Effect
<65,000 pounds 55 mph	N	24	36	53	
	Mean Speed	39.6	36.2	50.3	A/B
	(.05 Confidence)	4.0	6.6	3.4	
	% Exceeding	4	11	38	A/B A/Ac
65,001-70,000 45 mph	N	0	4	3	
	Mean Speed		19.0	45.4	A/Ac
	(.05 Confidence)		9.0	10.0	
	% Exceeding		0	33	*
70,001-75,000 30 mph	N	4	3	6	
	Mean Speed	26.0	21.0	27.1	
	(.05 Confidence)	3.0	21.6	5.2	
	% Exceeding	25	33	33	*
75,001-80,000 20 mph	N	5	7	7	
	Mean Speed	26.8	22.6	32.0	
	(.05 Confidence)	7.4	12.2	3.0	*
	% Exceeding	80	43	100	

$\alpha = .05$
* inadequate sample size

Note: Speeds and .05 Confidence Intervals in m.p.h.

Metric Equivalence
1 lb. = 0.454 kg
1 mph = 1.61 km/h

Appendix C

The field evaluation of the Grade Severity Rating System relied heavily on a manual speed-gathering procedure. Considerable effort was undertaken to ensure accuracy of the technique (e.g., selection and training of speed coders). Further, as a measure of its reliability, we conducted an inter-rater comparison as shown in table C-1. Two coders independently measured speeds on selected vehicles and one of the fast grades (Lewiston Hill). Results indicated that the measurement technique was accurate to .5 mi/h for sample mean speed values. The high correlation value (r=.96) indicates little variance in speed measurement as a function of individual coder.

Table C-1. Results of Speed Measurement Inter-coder Reliability Determination.

	Obs. 1	Obs. 2		Obs. 1	Obs. 2
1.	48.0	48.3	41.	55.7	55.4
2.	53.0	54.9	42.	60.5	63.9
3.	57.3	57.3	43.	58.9	59.0
4.	48.9	49.5	44.	53.0	51.9
5.	63.4	63.7	45.	48.9	49.9
6.	60.5	61.3	46.	54.4	55.9
7.	57.8	58.6	47.	60.5	59.7
8.	50.9	50.9	48.	42.8	41.8
9.	68.4	64.6	49.	55.2	53.9
10.	60.5	60.9	50.	47.1	46.0
11.	50.2	52.4	51.	53.1	52.1
12.	56.4	56.1	52.	50.3	51.9
13.	59.1	61.1	53.	62.2	61.7
14.	62.4	64.3	54.	52.8	53.0
15.	51.0	52.5	55.	54.5	54.9
16.	53.0	52.7	56.	53.7	55.7
17.	50.8	51.6	57.	49.4	50.9
18.	58.4	58.2	58.	59.7	60.3
19.	59.1	59.3	59.	62.8	60.3
20.	59.3	58.0	60.	46.3	48.5
21.	60.1	61.5	61.	59.1	58.6
22.	55.4	54.4	62.	53.3	53.7
23.	63.9	61.9	63.	64.1	64.6
24.	56.2	58.0	64.	51.2	52.7
25.	58.9	59.9	65.	58.2	59.9
26.	45.0	45.8	66.	57.8	60.7
27.	55.9	55.5	67.	67.9	64.4
28.	58.8	58.4	68.	57.1	58.9
29.	64.3	65.3	69.	52.2	54.4
30.	59.9	62.4	70.	53.1	54.1
31.	57.1	59.3	71.	56.7	59.3
32.	59.7	58.6	72.	61.3	64.1
33.	60.3	58.8	73.	58.2	58.8
34.	54.1	52.1	74.	60.5	61.1
35.	55.2	55.9	75.	58.4	57.1
36.	59.1	58.4	76.	59.7	61.3
37.	59.1	57.1	77.	51.8	52.4
38.	55.5	54.4	78.	54.4	56.2
39.	55.0	58.4	79.	59.5	61.3
40.	55.0	56.2	80.	50.5	50.1

Table C-1. Results of Speed Measurement Inter-coder Reliability Determination.

	Obs. 1	Obs. 2
81.	53.6	56.1
82.	56.7	56.6
83.	45.0	46.6
84.	62.6	61.7
85.	51.6	53.7
86.	54.5	54.9
87.	56.6	57.8
88.	44.2	46.0
89.	50.6	52.7
90.	58.4	61.9
91.	65.5	65.0
92.	31.3	31.9
93.	55.0	56.2
94.	60.9	58.4
95.	49.5	51.9
96.	58.0	56.4
97.	62.8	62.4
98.	57.1	55.7
99.	51.8	51.9
100.	54.7	55.9
101.	56.2	59.3
102.	55.2	56.9
103.	56.7	55.7
104.	55.0	56.2
105.	55.0	53.6
106.	59.1	57.1
107.	47.7	50.9
108.	52.1	52.1
109.	53.6	53.3

Summary Statistics

	Mean Speed	Standard Deviation	95-percent Confidence Interval
Observer #1	55.7	5.54	1.05
Observer #2	56.2	5.29	1.01

Correlation r = .96

Appendix D

ACCIDENT-BASED EVALUATION of the GRADE SEVERITY RATING SYSTEM:

A Procedural Approach

by
Forrest Council
and
Richard Knoblauch

TABLE OF CONTENTS

Introduction and Background

The Grade Severity Rating System (GSRS) has shown considerable promise for increasing the safety of heavy vehicles operating on downgrades. Laboratory and simulator testing, in addition to the operational evaluation conducted under the current contract, have indicated that weight-specific signing can provide the operators of heavy vehicles with useful information on the nature of approaching downhill locations. Accident-based GSRS evaluations were considered as a parallel effort to this operational study. This manual is intended to provide state highway personnel with the methodology and procedures to conduct a sound evaluation of the GSRS, based on accidents occurring in their states.

Experimental Design

There are two experimental design alternatives that are appropriate for the GSRS evaluation:

- Pre/Post with randomized control group
- Pre/Post with comparison group

Pre/Post with Randomized Control Group

The randomized control group design requires that all locations where GSRS signing might be installed be identified. This listing of locations is then randomly divided into two groups. One group will have the signs installed and the other will serve as the control group. This design involves examining the before/after effect at sites where the GSRS signs were installed and comparing changes with those that occurred at locations where no GSR signs were installed. The sites where no signs were installed serve as the control group. The control group provides an indication of any changes that might have occurred in the accident experience that were not due to the signs, but were due to other variables (i.e., weather, traffic patterns, etc.)

The randomized control group design is the strongest and most appropriate experimental paradigm for this type of evaluation. The use of a truly randomly determined control group allows much stronger conclusions to be reached. For example, the following type of data might be produced by this design:

	Number of Accidents	
Group	Before	After
Experimental (sign)	100	90
Control (no sign)	100	110

Both groups had 100 accidents in the before period, but the experimental group showed only 90 in the after period. If we did not have a control group, we would state that the sign produced a 10% reduction in accidents. However, the control group, due to unknown factors such as weather and traffic, showed a 10% increase in accidents. By comparing the experimental and control groups' accident experience in the after period, we see an actual accident reduction of 20%. Obviously, things don't always work out this nicely but the control group does allow us to "control" for the other factors that might affect the accident rate. Without a control groups, we don't know if the changes are due to the GSRS signs or due to other factors over which we have no control.

From a practical standpoint, this design is sometimes difficult to live with. We must identify all the potentially hazardous locations and then only treat a randomly selected part. This raises several legal and ethical issues. If all of the sites are dangerous, shouldn't something be done at all of them? Since the GSRS is still an experimental system, and its accident reducing potential has yet to be proved, you may be perfectly comfortable with this design. If not, several experimentally valid modifications are acceptable. A random stratification procedure can be used. All of the potential sites are rank-ordered according to accident rates and divided into two or three categories based on their accident history (i.e., low, medium, and high accident frequencies). These subgroups are then randomly divided into experimental (sign) and control (no sign) groups. This will ensure that at least half of the high accident locations receive the GSRS treatment, something that is not guaranteed unless stratification is used.

A staggered installation procedure may also be used. Because sign installation takes time and money, it is reasonable to schedule the sign installations over a two- or three-year period. Thus, you can schedule the sign installations at all sites according to the randomized control group design and still leave sufficient time for the collection of "after" data at the control locations. This is done by simply randomly assigning a sign installation date to each site. Half of the sites would be randomly selected for sign installation in 1983 and half for installation in 1985. This would allow two years of "control" data to be collected before the signs are installed at the remaining locations in 1985.

Pre/Post with Comparison Group

Like the randomized control group design, this design looks at before/after effects where GSRS signs were installed and other similar comparison locations where they were not installed. Unlike the randomized control group design, the comparison group is not randomly selected from the same population of sites. The comparison locations could be part of the same state (i.e., install signs in the northern part and not in the southern part) or a neighboring state. If a neighboring state is used, it must have compatible weather, terrain, and truck traffic and be willing and able to provide comparable accident data for both the before and after period.

This is a strong experimental design only if the comparison group is truly compatible in terms of all the factors that might affect truck accidents. If the comparison group is not comparable, a true effect may be masked or an apparently true effect produced by factors not related to the GSRS sign.

Which experimental design should be used depends on the number of sites available in a state and the number of accidents occurring at those sites. The randomized control group design is the most desirable, but many states do not have enough sites to divide into two groups and still have enough accidents in each group to conduct a proper evaluation. For these states, the comparison group design is an acceptable alternative.

Data Requirements

The more specifically we can determine that the accidents being counted are runaway truck accidents occurring on a steep downgrade -- and thus treatable by the GSRS sign -- the more likely we are to identify a real effect. We would not expect, for example, the GSRS signs to produce a measurable effect on all motor vehicle accidents or even all truck accidents occurring in a state. However, if we can identify the runaway track accidents occurring at a number of specific locations, we can realistically expect to measure an effect. Two types of data are needed for the GSRS evaluation:

- Accident Data
- Exposure Data

Accident Data

There are three steps involved in obtaining the accident data needed. First, downhill locations where the GSRS can be applied need to be identified. Then, truck accidents occurring at those locations need to be identified. Finally, we need to determine which of those truck accidents involve brake failure or runaway trucks.

In order to implement the GSRS, downhill roadway tangents must meet the following criteria:

- Grade severity: 5% or greater
- Length of grade: 0.5 mi or longer
- Reasonably high truck volumes
- History of truck accidents

State roadway logs should be examined to identify locations that have these characteristics.

Once the roadway sections have been identified, it is necessary to identify the truck accidents occurring at these locations. Typically, this involves sorting data files on vehicle type (truck), roadway segment (from milepost X to Y) and direction (downhill). Obviously, this will produce a relatively large number of accidents, only a small subset of which will be affected by GSR signing.

The final process is to identify which of the truck accidents occurring at these locations involve brake failure or are runaway trucks. To do this, it is necessary to review the hardcopy accident report or the microfilm to see if the accident narrative specifies that the truck was a runaway. A standardized definition needs to be used so that the same type of accidents are identified in both the "before" and "after" phases of the evaluation.

If the accident report narrative mentions either defective or "lost" brakes or that the truck entered an escape ramp or arrester bed, the accident can be considered a runaway. If the report mentions any two or more of the following, the accident is considered to be a runaway:

- Ran off road
- Exceeded speed limit
- Transmission or engine defect
- Failure to downshift

Although arrester bed and escape ramp uses are considered to be runaway truck accidents, it will be necessary to keep sites with escape ramps separate from sites without such facilities. The sites with ramps should be randomly divided between the experimental (sign) and control (no sign) groups and a separate series of analyses performed.

Exposure Data

Although the GSRS evaluation could be conducted by looking simply at the number of accidents that occur; the experimental design is greatly strengthened if accident rates are used. Accident rates are computed by dividing the number of runaway truck accidents occurring at each site by the number of target vehicles (trucks) passing through the site. In order to compute rates, it is necessary to determine the truck ADT at those downhill sites previously identified as experiencing runaway truck accidents.

Accident Sampling Plan

This section describes the step-by-step procedures for determining accident rates, identifying experimental and control groups, and preparing for the data analysis. The preceding discussions explained what is needed for an accident-based evaluation. This section describes how to proceed. The following topics are addressed:

- Identifying Locations
- Determining Accident History (identifying runaway truck accidents)
- Determining Truck Traffic Volume
- Computing Accident Rates
- Identifying Experimental and Control Groups
- Use of Escape Ramp Data

Identify Locations

The first step is to identify all downhill locations that meet the criteria previously described: steepness, length, truck traffic, and truck accident experience. An arbitrary runoff distance of 0.25 mi beyond the end of the grade should be used to define the site length.

Determine Accident History

After all potential downhill locations have been identified, it is necessary to determine how many runaway truck accidents occur at the locations. This is done by examining hardcopy accident reports or microfilm and applying the criteria previously described. Sites with less than one downhill truck accident during the past three years should be eliminated at this point. The remaining downhill accident sites should be used in the next and subsequent steps. At the end of this step, a table such as the following should be prepared.

	Number of Accidents		
Site	1979	1980	1981
1			
2			
3			
.			
.			
.			
N			

Determine Truck Volume

For each downhill truck accident site, it will be necessary to determine the truck ADT so that the number of trucks passing through the site for the past three years can be determined (truck ADT x 365 = trucks per year). If the ADT is a two-way total, it must be divided by 2 to determine downhill volume (i.e., assure that half of the ADT modes uphill and half downhill). At the end of this step, a table like the following should be prepared.

	Trucks per Year		
Site	1979	1980	1981
1			
2			
3			
.			
.			
.			
N			

Determine Truck Accident Rate

For each downhill truck accident site, the number of accidents is divided by the number of trucks per year to determine the accident rate. The accident rate should be expressed in accidents per 100,000 trucks (ACC/HTT).

	Accidents per 100,000 Trucks			
Site	1979	1980	1981	Three-Year Average
1				
2				
3				
.				
.				
.				
N				

The accident rates are then averaged across each site to find the average accident rate at each site. The sites should then be rank-ordered with the site with the highest accident rate first and the lowest rate last.

Identifying Experimental and Control Groups

The ability to detect a given change (i.e., a 10% reduction versus a 20% reduction) in accident rate is a function of the nature of the data and the number of accident sites used in the evaluation. The following table illustrates how many accidents are needed to determine a 20% and a 30% reduction in accidents (assuming $\alpha = 0.10$ and $\beta = 0.20$).

Number of Accidents Needed per Group

Percent Change in Accidents	Average Number of Accidents/Site 1	2	3	4	5
20%	225	112	75	56	45
30%	100	50	33	25	20

Thus, for example, if we wish to detect a 20% reduction in accidents and there are an average of three accidents per downhill site, we will need 75 accident sites for the experimental group and 75 sites for the control group. If we would be satisfied with detecting a 30% change, we would need only 33 accidents in each group.

If there are enough sites for both an experimental and a control group, the randomized control group design should be used by randomly assigning half of the sites to the experimental group and half to the sign group.

Use of Escape Ramp Data

Although similar to runaway truck accidents, escape ramp uses must be treated separately for analysis purposes. Ramp usages tend to occur far more frequently and their economic impact is considerably less. Each of the steps previously described should be followed at escape locations.

Analysis Procedures

After one year (and each subsequent year) determine the number of runaway truck accidents and the truck ADT at each experimental and each control site. It is imperative that identical procedures be used to identify the runaway truck accidents and to determine the truck traffic volumes. By going through the procedures described in the previous section, determine the accident rate at each site. Tables such as the following should be prepared.

Experimental Sites (GSRS Sign)

Accidents/HTT

Site	Before	After
1		
3		
5		
7		
.		
.		
.		
N		
	$\bar{x}$ = ________	$\bar{x}$ = ________

Control Sites (No GSRS Sign)
Accidents per 100,000 trucks

Site	Before	After
2		
4		
6		
8		
.		
.		
.		
N		
	$\bar{x}$ = ________	$\bar{x}$ = ________

If locations with escape ramps or arrester beds are included, it will be necessary to prepare a similar set of tables for those locations.

The mean or average accident rate for each of the four data sets is then computed: Experimental Sites, Before and After; Control Sites, Before and After. These average accident rates are needed for the statistical analysis.

Statistical Procedures

The Cross-product Chi Square is the appropriate procedure to see if the GSR signing produces a statistically significant effect on the accident rates.

REFERENCES

1. T.M. Myers et al., "Feasibility of a Grade Severity Rating System," Report No. FHWA-RD-79-116, Federal Highway Administration, Washington, DC, August 1980.

2. W. A. Johnson et al., "The Development and Evaluation of a Prototype Grade Severity Rating System," Report No. FHWA-RD-81-185, Federal Highway Administration, Washington, DC, March 1982.