

Speed selection at sites with restrictive alignment: the US-191 case study

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Abstract

An investigation into the driver's choice of speed at roadway sites with restrictive alignment is presented in this study. Specifically, the study focused on the effect of horizontal curve radii and sight distance on speed selection. Seven sites were examined in this study that are located along a 10-mile stretch of a rural high crash corridor, US 191 north of Big Sky in southwest Montana. Two of the study sites have no restrictive geometry representing base conditions, another two have restrictive curve radii, and the other three have restrictive radii and sight distances. Vehicle speeds, classification, and headways were collected at each site. The selected speeds for free-moving vehicles were compared to the legal speed limit, advisory speed, and the speeds dictated by curve radius and sight distance when applicable. Study results found that the vast majority of observed selected speeds are notably higher than the speeds found using the alignment and sight distance design equations. Results also showed that the perceived safe speeds selected by drivers are likely to be determined by the most restrictive geometric feature.

Keywords – speed, alignment, horizontal curves, sight distance, design speed

1. Introduction

Speed is known to be a major contributory factor in many traffic crashes. It is also a major input for highway design and therefore has a determining effect on most highway geometric features. One recent study reported that “in 2002, 13713 fatalities - about one third of all fatalities that occurred in motor vehicle traffic crashes were speeding-related, i.e., at least one of the drivers involved in the crash was speeding” [13]. The same study stated, “The geometry of the road plays a vital role in the occurrence of speeding-related crashes. In 2002, about 40 percent of speeding-related fatal crashes occurred while negotiating a curve, while slightly less than 20 percent of non-speeding related fatal crashes occurred under similar roadway geometry” [13].

Understanding how drivers select their speeds given road geometry and traffic control devices is important in creating a safe driving environment in the highway system. From a safety perspective, this understanding is even more critical at high-speed facilities, which exist mostly in rural and suburban environments where drivers have less interaction with other drivers in the traffic stream and more interaction with geometric features. Liu et al. [13] reported that a major

proportion of fatal, speeding-related single-vehicle crashes occur on rural roadways. Another study found that the risk of a serious or fatal run-off-the-road crash clearly tended to increase as speed increased based on crash data from Australia and Minnesota [4]. Also, it is strongly believed that the vast majority of single vehicle run-off-the-road crashes occur in rural areas and that those crashes are overrepresented at curve locations where geometry is restricted.

2. Background

Several relevant studies that were identified in the course of performing this research project are summarized in this section.

Discetti [5] examined 46 curves on mountainous Italian roads with regard to sight distance, interior radius, approach grade and length of tangent approach. For conditions of limited sight distance and sharp curvature, a model was constructed, in order to characterize drivers speed selection. This study found that drivers select their speeds based primarily on physical characteristics present on the road in combination with sight distance.

Schurr et al. [16] looked at 56 horizontal curves with radii varying from 716 ft to 5730 ft to analyze free-flowing passenger car speeds in relation to posted speed limits and design speeds. The study found that “inferred design speed ... does not appear to have an influence on 95th percentile operating speeds in Nebraska” and that when the posted speed limit increases, the mean speed increases. They also found that the majority of drivers tend not to significantly increase or decrease their speeds when traveling from a tangent segment to a horizontal curve when the radius is equal to or greater than 1150 ft.

Tate and Turner [19] investigated the crash rate of New Zealand drivers based on 488 horizontal curves. They found that 85th percentile operating speeds decrease as bendiness (the sum of the absolute value of highway deviations, expressed as degrees per kilometer) increases. The radius of curve was also determined to be the best predictor of 85th percentile speeds. This implies that geometric features with design speeds that are lower than the driver selected speed, which is closely related to the posted speed limit, are expected to have increasing accident rates as the difference between these two speeds increases.

Piras and Pinna [14] examined 22 sites with varying curve designs to create a model that more accurately predicts the 85th percentile speeds on Italian roads built with a spiral transition to the curve. Their single parameter model, based on curvature change rate, found that transitory structures have a large influence on the predicted 85th percentile speeds. The most highly correlated results from their models were based on curve radii and covered both curves with and without transitory structures.

Steyer [17] investigated 8 curves with high accident frequencies. Speeds were measured at the beginning, midpoint, and end of the curve. High operating speeds were observed at all of the sites. The lowest speeds on the curve were found at the midpoint of the curve. Sharper curves with good sight distance resulted in higher operating speeds. The study also found that inappropriate speed selection led to centerline encroachment.

A few studies were found in the literature that investigated speed selection as it relates to environmental conditions such as light and weather conditions. Taylor and McGee [20] as well as Stimpson et al. [18] found no statistical difference in driver's speed selection during the night when compared to daylight speeds when evaluated at the 95% confidence level. A later study found a significant difference of 1-6 mph in passenger cars' speeds during the night as compared to the day at several horizontal curves, while other curves showed no significant difference [8].

More recently, Rose and Carlson [15] found significant differences between the night and day mean speeds at two of three study sites.

In regards to weather conditions, Blackburn et al. [3] found a statistical difference in 38% of the investigation sites between dry and rainy conditions, but the difference was no more than 3 mph. Similarly, Ibrahim and Hall [10] found that driver's speed varied with rain intensity and varied in the range of 1-6 mph. Another study found no significant difference in mean speeds between wet and dry pavement [12].

Speed selection may also differ by vehicle type, i.e. heavy vehicles versus passenger cars. A study by Fitzpatrick et al. [7] concluded that on horizontal curves, passenger car and heavy vehicle speed behaviors are similar, with the 85th percentile speed of heavy vehicles being slightly less than that of passenger cars. Other studies stated that data collected on heavy vehicles is often disregarded due to a sample size that is too small to be statistically significant [9, 15, 16].

In summary, the research on how drivers select their speeds in relation to highway geometric features is limited. This is given the fact that some of the aforementioned studies did not examine the effect of alignment on speed selection, while others investigated operating speeds which could be notably different from free-flow speeds that are usually associated with drivers' speed selection.

3. Research motivation

The objective of the current research is to gain a better understanding of how drivers select their speeds under free-flow conditions at locations with restrictive geometric features. Specifically, the effect of horizontal alignment and sight distance on drivers' speed selection is the focus of this study. This understanding is critical given that speed is believed to be a contributory factor in many crashes at locations where geometry is restricted. Furthermore, such an understanding is essential in developing design guidelines and practices that are consistent with drivers' behavior and in developing speed management strategies and countermeasures.

4. Approach

Speeds of free flowing vehicles were examined at several study sites that have restricting geometric features as related to horizontal curvature and/or sight distance. Time headway data was used in selecting free-flow speeds, i.e. speeds selected based on roadway and environmental conditions and no interaction with other vehicles in the traffic stream. The design speed was estimated using information gathered from the field as well as the construction blueprints at each individual site. In the process, the AASHTO's formulae for minimum radius of curve and for minimum safe stopping distance were used in the estimation (AASHTO 2004). Speed data at each particular site was characterized and used later for comparison with the design speed, advisory speed (if any), and the speed limit.

5. Study sites

Six study sites were selected along a 10-mile stretch of US 191 Highway between Gallatin Gateway and Big Sky in southwest Montana. This two-lane highway segment was designed in 1954 to accommodate the natural contours of the Gallatin River, within the Gallatin Canyon, creating many sharp curves with limited sight distance for drivers at a few locations. This particular stretch was chosen because it contains the most restrictive sight distance and curve radii within the canyon. Currently, it has a posted speed limit of 60 mph with advisory speed limits on many of its restricting curves and an average daily traffic (ADT) of around 6000 vehicles per day.

This stretch of rural road is considered by the Montana Department of Transportation (MDT) as one of the high-crash corridors in the state. Sites were chosen after examining the geometric features using the construction blueprints and on-site visual inspection.

Of the six sites examined in this study, one is on a straight stretch of road with no restrictions (both in the northbound and southbound directions), chosen to represent base conditions, two have restrictive horizontal alignment (sharp radii), and three have restrictive features in regards to horizontal alignment and sight distance.

Study site 1 is on a straight highway segment representing base conditions. The site, located just south of mile marker 55, practically involves two sites; one in the northbound and one in the southbound directions. This section has no restrictive alignment features, ample sight distance, and no advisory speed.

Study site 2 is in the southbound direction near mile marker 61. This site has the most restrictive curve radius among all study sites. There is ample sight distance for vehicles in both directions. The site also had an advisory speed of 35 mph. Study site 3 is in the southbound direction and is located right at mile marker 52. This site is located at a horizontal curve with ample sight distance with a posted advisory speed of 45 mph.

Study site 4 is in the northbound direction located halfway between mile markers 61 and 62. This site has both restricting alignment and sight distance with a posted advisory speed of 35 mph. The site is also adjacent to a turnout for cars to pull in and out of for passing and recreation purposes. This site is considered to be the most restrictive with respect to sight distance. Study site 5 is in the northbound direction and is located ¼ mile north of mile marker 58. It has a restrictive alignment and sight distance. There is a posted advisory speed of 45 mph. Study site 6 is in the northbound direction and is located ¼ mile north of mile marker 53. This site also has restrictive sight distance and alignment. There is a posted advisory speed of 45 mph. While all sites are generally located in what is considered level terrain, this site has the highest grade value of 2.5 percent. Table 1 shows a summary of the geometric characteristics and data collected at each study site.

6. Data collection and processing

After the sites were selected, automatic traffic recorders were installed at each site for a minimum of one week of data collection. At those sites with horizontal curvatures, the recorder was installed within the curve to make sure that speeds were measured when the restriction is in effect. Specifically, speeds were measured well into the curve and before the mid-point. Speed, headway, and vehicle classification for individual vehicles were among the major data provided by traffic recorders for use in this study.

Tab. 1 - Geometric characteristics and data collected at study sites

<i>Location (travel direction)</i>	<i>Radius (ft)</i>	<i>Curve length (ft)</i>	<i>Sight Distance (ft)</i>	<i>Grade (%)</i>	<i>Collection period (days)</i>	<i>Sample Size (vehicles)</i>
No Restrictions						
<i>Site 1-Base (NB)</i>	NA	NA	NA	-1.0	9	22028
<i>Site 1-Base (SB)</i>	NA	NA	NA	1.0	9	22331
Restriction on Horizontal Curvature						
<i>Site 2</i>	376	301	NA	-1.3	7	15403
<i>Site 3</i>	710	182	NA	1.4	7	17199
Restrictions on Sight Distance and Horizontal Curvature						
<i>Site 4</i>	668	864	290	-0.9	7	15077
<i>Site 5</i>	631	529	340	-0.3	7	14957
<i>Site 6</i>	949	223	360	2.5	7	14709

In order to examine the selected speeds (free moving vehicles) while controlling on the effect of other vehicles in the traffic stream, only vehicles with headways equal or greater than 8 seconds were included in the analyses. The selection of this cut-off value is deemed conservative in light of the results of other studies that investigated the interaction between successive vehicles on two-lane highways, which suggest that such interaction generally ceases when headway exceeds 6 seconds [1, 11]. While all sites are located in areas where traffic flow is primarily uninterrupted, a few speed observations were extremely low. This may be due to the presence of private driveways or a turnout near a study site. To control the effect of those few observations on the analysis, it was deemed appropriate to discard speed observations that were more than four standard deviations from the mean speed. The Federal Highway Administration vehicle classification was used in classifying passenger cars and heavy vehicles [6]. Specifically, smaller vehicles (classes 2, 3, 5, 6, and 7) were considered passenger cars while buses and larger trucks (classes 4, 8, 9, 10, 11, 12, and 13) were considered heavy vehicles. Motorcycles (class 1) were excluded from the analysis.

7. Analysis of results

7.1. Speed characterization under base conditions

In order to be able to discern the effect of restricting geometry on speed selection of the free moving vehicles, it is necessary to characterize speed in the absence of these restrictions.

Study site 1 - Northbound:

The mean speed at this study site for all vehicles is 60.4 mph, which is slightly higher than the posted speed limit. The median and mode speeds were found to be 60.5 mph and 61 mph respectively. These values are very close to the mean speed value suggesting a highly normal and symmetric speed distribution. The standard deviation is 5.4 mph, which is a typical value on high-speed uninterrupted-flow facilities. The coefficient of variation is around 9 percent.

The straight and cumulative frequency distributions of aggregate speed observations at this site are shown in Figure 1. The 85th percentile speed is 65.3 mph, which is 5.3 mph higher than the speed limit. This suggests that the operating speed at this site is relatively high given the geometric features and the overall winding nature of the road within the Gallatin Canyon. As shown in this figure, the frequency distribution indicates a symmetrical bell-shaped distribution while the cumulative frequency distribution indicates an S-shaped distribution. The numerical values for the measures of central tendency (mean, median and mode) and the distributions shown in Figure 1 strongly suggest the possibility of speed observations following the normal distribution. To test this hypothesis, a Chi-square test was conducted and, unexpectedly, the test did not confirm the speeds to follow the normal distribution at 95% confidence level.

It is believed that speed observations at the two ends of the distribution (very low or very high speeds) may be blamed for the speed distribution not passing the Chi-square test.

Study site 1 - Southbound:

Similar analysis was done for study site 1 southbound to characterize speed observations. The mean speed, the median speed and the mode were found to be 55.6 mph, 55.9 mph, and 57.4 mph respectively. The three measures of central tendency are relatively close. The lower mean value for traffic in this direction may be partly attributed to the roadside features in this direction of travel with steeper side slopes and guardrail in close proximity to the roadway at some parts on

this side of the Gallatin River. The standard deviation is 5.25 mph, which is a typical value on high-speed uninterrupted highways. The coefficient of variation is around 9.5 percent, which is close to that in the northbound direction.

The straight and cumulative frequency distributions of aggregate speed observations at this site are shown in Figure 2.

The 85th percentile speed is 60.2 mph, which is very close to the speed limit on this highway. This indicates that speeds in this direction of travel are reasonable and consistent with the posted speed limit. Similar to the northbound direction, the frequency distribution indicates an overall symmetrical bell-shaped distribution while the cumulative frequency distribution indicates an S-shaped distribution. Again, at this site, there are adequate reasons to consider a normal distribution for speed observations. However, the Chi-square test did not support the theory of speed observation following the normal distribution at a 95% confidence level.

Speed observations by day and night

As many factors other than site geometry may influence speed selection at a particular location, it was deemed important to test some of these factors for their effect on speed. Table 2 shows the measures of central tendency, the standard deviation, and the 85th percentile speed at study site 1 by day and night. Overall, the mean and median speeds during the day are close to those during the night, with the higher difference in mean value estimated at 2.7% at site 1 northbound. The *t*-test results support the hypothesis that the mean speed during the night is significantly lower than that during the day at a 95% confidence level in the two directions of travel. The mode speed increased 1 mph and decreased 2 mph in the northbound and southbound directions respectively. The standard deviation showed an increase during the night in the two directions of travel. This indicates more variation in speeds during the night compared to that during daytime. The *F*-test for difference in variance was conducted and the results confirmed the hypothesis of higher variance during the night at a 95% confidence level in the two directions of travel. The 85th percentile speeds are generally consistent with that of the total speed observations with minor changes between day and night in the two directions of travel.

Speed observations during dry and rainy weather

Another factor that may affect speed selection at a particular site is weather conditions. Speed data was collected during dry as well as rainy weather conditions. Rain may have an effect on the traction between tires and pavement surface as well as potential effects on visibility. Table 3 shows the measures of central tendency, the standard deviation, and the 85th percentile speed at study site 1 during dry and rainy weather.

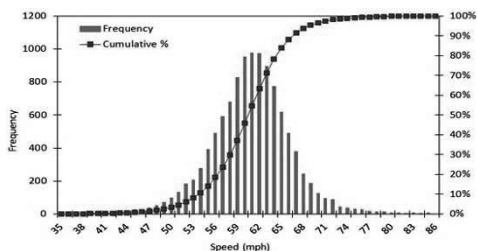


Fig. 1 - Frequency and cumulative frequency distributions at study site 1 northbound

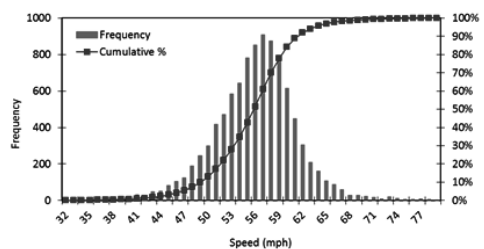


Fig. 2 - Frequency and cumulative percentage distributions at study site 1 southbound

Tab. 2 - Driver selected speeds for base conditions by day and night

<i>Location & Travel Direction</i>	<i>Light Condition</i>	<i>Mean (mph)</i>	<i>Median (mph)</i>	<i>Mode (mph)</i>	<i>Standard Deviation (mph)</i>	<i>85th Percentile Speed (mph)</i>	<i>Number of Observations</i>
<i>Site 1-NB</i>	Day	60.6	60.6	61	5.27	65.4	9637
	Night	59.0	59.4	62	6.04	64.7	1515
<i>Site 1-SB</i>	Day	55.6	56.0	57	5.11	60.0	8280
	Night	55.3	55.4	55	5.97	61.0	1430

Tab. 3 - Driver selected speeds for base conditions under dry and rainy weather

<i>Location & Travel Direction</i>	<i>Weather Condition</i>	<i>Mean (mph)</i>	<i>Median (mph)</i>	<i>Mode (mph)</i>	<i>Standard Deviation (mph)</i>	<i>85th Percentile Speed (mph)</i>	<i>Number of Observations</i>
<i>Site 1-NB</i>	Dry	60.4	60.5	62	5.40	65.3	10933
	Rain	59.7	60.1	60	5.97	65.5	219
<i>Site 1-SB</i>	Dry	55.6	55.9	57	5.24	60.1	9555
	Rain	55.1	55.7	58	5.69	60.2	155

The mean speed showed a slight decline during the rain which is somewhat expected. However, the amount of change seems small and may not be significant. The *t*-test was conducted and the results confirmed that there is a significant decrease in the mean speed during rainy weather in the northbound direction at a 95% confidence level. On the other hand, *t*-test results at a 95% confidence level did not find the decrease in mean speed to be significant in the southbound direction. The three measures of central tendency, mean, median, and mode speeds are reasonably close during dry and wet weather conditions. The standard deviation exhibited an increase during rainy weather, which suggests more variation in speeds during rain in the two directions of travel. The *F*-test for difference in variance was performed and the results suggest that the increase in variance during rainy weather is significant at the 95% confidence level in the northbound direction only. The 85th percentile speed did not show notable change during rainy weather with values being very consistent with the overall speed observations discussed earlier.

Speed observations by vehicle type

Vehicle type may have an influence on speed selection due to different vehicle performance characteristics or driver population. In this analysis, vehicles were classified into two classes: passenger cars (PCs) and heavy vehicles (HVs). Table 4 shows the measures of central tendency, the standard deviation, and the 85th percentile speed at study site 1 for passenger cars and heavy vehicles. As shown in this table, the mean speed for heavy vehicles is lower than that for passenger cars in the two directions of travel with the difference being in the order of 1 mph. The difference in mean speed was found significant using the *t*-test at a 95% confidence level in the two directions of travel. The median speeds are generally very close to the mean speed values while the mode speeds are all higher than the mean speed values, however, they are still reasonably close to the mean speeds. The standard deviation for heavy vehicle speeds is higher than that for passenger cars in the two directions of travel. This may be attributed to the wide range in vehicle performance of heavy vehicles based on size and loading status. The *F*-test confirmed that the speed variance for heavy vehicles is higher than that for passenger cars at a 95% confidence level in the southbound direction only.

Tab. 4 - Driver selected speeds for base conditions for passenger car and heavy vehicle

<i>Location & Travel Direction</i>	<i>Vehicle Type</i>	<i>Mean (mph)</i>	<i>Median (mph)</i>	<i>Mode (mph)</i>	<i>Standard Deviation (mph)</i>	<i>85th Percentile Speed (mph)</i>	<i>Number of Observations</i>
<i>Site 1-NB</i>	PCs	60.5	60.6	61	5.39	65.4	10363
	HVs	59.2	59.5	62	5.60	64.1	789
<i>Site 1-SB</i>	PCs	55.6	56.0	57	5.18	60.2	9030
	HVs	54.4	54.3	56	6.03	59.0	680

7.2. Examination of observed speeds

In this section, the free-flowing driver selected speeds will be analyzed in reference to the posted speed limit, advisory speeds, and other speeds dictated by geometric design features.

Base conditions

Under base conditions, no restrictions exist on the selected speeds due to horizontal curvature or sight distance as the speeds were measured on a straight highway segment with ample sight distance in both directions. Therefore, the only reference speed that is used is the posted speed limit. Table 5 shows the mean, median, and the 85th percentile speeds for base conditions in relevance to the posted speed limit. In this table, it is clear that the 85th percentile speed in the northbound direction is notably higher than the speed limit. Traffic engineers may rely on the 85th percentile speed to establish speed limits. The premise behind this rule is to have 85% of drivers traveling at or below the posted speed limit. Table 5 shows that this percentage is only around 46% in the northbound direction while it is very close to 85% in the southbound direction. This attests to the fact that drivers may not follow the legal speed limit if they perceive the conditions to be safe to travel at a higher speed.

Sites with restrictive alignment

At these sites (sites 2 and 3), there is ample sight distance and therefore the curve radii are the main factor in driver's speed selection. Table 6 provides basic speed measurements at the study sites with restricting alignment while showing major reference speeds, namely, the posted speed limit, the posted advisory speed, and the speed dictated by alignment design (per design equations).

At study site 2, the mean speed and the 85th percentile speed are well below the posted speed limit of 60 mph. However, the two speeds are notably higher than the posted advisory speed or the speed dictated by alignment design. The speed dictated by alignment design (the radius of curve) is of particular interest here as it provides an indicator of the safe operating speed while negotiating the horizontal curve. Only 9.3% of the drivers followed the advisory speed in negotiating the curve while only 8.8% of speed observations were within the speed dictated by alignment design. This goes to show that the observed speeds at this site are extremely high for the conditions, and that the posted advisory speed has little effectiveness if any in enforcing safe speeds at this particular location. Due to restrictive alignment, nearly all (99.9%) drivers were within the posted speed limit.

At study site 3, the horizontal curvature is less restricting than that of site 2 and therefore the posted advisory speed, the speed dictated by alignment, and measured speeds are all higher than those of site 2. Nonetheless, the observations at study site 2 are still applicable to this site.

Tab. 5 - Observed free-flow speeds at site 1–no restrictions on alignment

<i>Location & Travel Direction</i>	<i>Posted speed limit (mph)</i>	<i>Mean (mph)</i>	<i>Median (mph)</i>	<i>85th Percentile Speed (mph)</i>	<i>Percentage at or below posted Speed Limit</i>	<i>Number of Observations</i>
<i>Site 1-NB</i>	60	60.4	60.5	65.3	45.8%	11152
<i>Site 1-SB</i>	60	55.6	55.9	60.2	84.3%	9710

Tab. 6 - Observed speeds at sites with restrictive horizontal alignment

<i>Location</i>	<i>Speed Limit (mph)</i>	<i>Advisory Speed (mph)</i>	<i>Speed Dictated by Radius (mph)</i>	<i>Mean (mph)</i>	<i>85th Percentile Speed (mph)</i>	<i>Percentage at or below</i>		
						<i>Posted Speed Limit</i>	<i>Advisory Speed</i>	<i>Speed Dictated by Radius</i>
<i>Site 2</i>	60	35	34.8	41.9	46.8	99.9%	9.3%	8.8%
<i>Site 3</i>	60	45	46.7	49.8	54.4	98.6%	14.2%	19.6%

Specifically, the percentage of drivers who followed the advisory speed are only 14.2% while the percentage of speeds that were found at or below the speed dictated by alignment was only 19.6%. The previous figures suggest that the posted advisory speed signs may not be very effective in promoting lower speeds if drivers perceive higher speeds being safe for the conditions. On the other hand, the observed speeds are well below the legal speed limit, which leads one to conclude that, even in the absence of legal speed requirements, drivers would select speeds that they perceive as safe for the conditions. Furthermore, the average “safe” speed selected by drivers is notably higher than that suggested as a maximum safe speed using design equations. These equations stipulate wet pavement conditions. Specifically, the percentage of drivers who traveled at speeds higher than the speed dictated by alignment during rainy weather conditions is more than 89% at study site 2. No adequate observations of wet weather data is available at site 3.

Sites with restrictive alignment and sight distance

Three sites were selected with restrictive radii and sight distance relative to the posted speed limit. Table 7 provides basic speed measurements at those sites while showing major reference speeds, namely, the posted speed limit, the posted advisory speed, the speed dictated by alignment, and the speed dictated by available sight distance.

A quick examination of Table 7 reveals several very interesting insights into the relationship between selected speeds and the geometric features. At study site 4, the mean speed is slightly less than the speed dictated by radius, which is inconsistent with the observations from sites 2 and 3 where the observed mean speeds were notably higher. This clearly suggests that the restricted sight distance at this site is the main factor in determining selected speeds. However, it is also true that what the drivers perceive as safe speeds at this site is higher than the maximum safe speed found from design equations. Specifically, the mean speeds at the three sites were notably higher than the speeds dictated by sight distance. At study site 5, the speed dictated by radius is very close to that dictated by sight distance. Therefore, it is expected that the two restrictive geometric features may have the same influence on selected speeds. The mean speed at this site is around 20% higher than those dictated by radius or sight distance. This is somewhat consistent with the observed speeds at site 2 and 4.

Tab. 7 - Observed speeds at sites with restrictions on curve radii and sight distance

Location	Speed Limit (mph)	Posted Advisory Speed (mph)	Speed Dictated by Radius (mph)	Speed Dictated by Sight Distance (mph)	Mean Speed (mph)	85th Percentile Speed (mph)	Percentage at or below			
							Posted Speed Limit	Advisory Speed	Speed Dictated by Radius	Speed Dictated by Sight Distance
Site 4	60	35	45.3	38.6	44.2	49.0	99.9%	4.1%	57.8%	12.4%
Site 5	60	45	44.0	43.3	53.1	59.2	87.9%	8.8%	6.5%	4.8%
Site 6	60	45	52.6	46.5	51.9	56.6	96.9%	8.8%	47.9%	11.8%

Study site 6 is very similar to site 4 in that sight distance is more restrictive than alignment when it comes to estimating maximum safe speed. Again, the mean speed at this site is slightly less than the maximum safe speed dictated by curvature radius, but is notably higher than that dictated by sight distance.

The results here affirm the observations made at study site 4 despite the more severe restrictive geometric features at study site 4 as shown in Table 7.

Similar to study sites 2 and 3, observed speeds at the study sites shown in Table 7 confirm the fact that the percentage of drivers traveling at speeds higher than those dictated by geometric features could be extremely high, which raise doubts about the safety of traffic operations in this corridor.

This may also explain the high crash rate at several locations within this important corridor in southwestern Montana.

8. Summary of findings

The current study aims at examining the way drivers select their safe speeds as they negotiate roadways with restrictive geometric features. Six sites were selected in one of the challenging high crash corridors in southwest Montana for this study.

One study site (in two directions of travel) served to represent base conditions in the absence of alignment and sight distance restrictions, another two with restrictive horizontal alignment, and three with restrictive alignment and sight distance. Selected speeds were characterized under base conditions to gain a better understanding of the observed speeds in this corridor. Speeds at all sites were then analyzed to discern the effect of restrictive geometric features on the selected speeds. The major findings of the study are:

- In the absence of effective enforcement, drivers tend to travel at speeds they perceive as safe for the conditions regardless of the posted legal speed limit or the advisory speed.
- The vast majority of observed selected speeds are notably higher than the safe speeds found using the alignment and sight distance design equations.

The above findings clearly emphasize the urgency to rethink the speed management policies currently in use at the location of curves.

This is particularly important for roadways in mountainous terrain, where winding alignment becomes a common feature, such as the corridor investigated in this study. The situation becomes even more critical for roads that are located in cold regions where pavement is usually exposed to snow and ice for extended periods during the winter season.

The occasional deterioration of the tire-pavement friction during the winter season could compromise traffic safety even at speeds that correspond closely to the posted advisory speeds. Study results also stress the need to better manage speeds at the locations of restrictive alignment using site-specific speed reduction tools and measures.

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