Investigation of Object-Related Accidents Affecting Stopping Sight Distances

KAREN B. KAHL AND DANIEL B. FAMBRO

Stopping sight distance (SSD) is an integral part of the highway design process because it is the minimum sight distance required at all points along the roadway. The current SSD model uses a critical sight distance situation in which the driver detects a small object in the roadway, recognizes it as a hazard, and stops before striking it. Some researchers have questioned the assumptions and variables used in the SSD model because they do not appear to represent a realistic, real-world situation when combined in the existing model. The 150-mm (6-in.) object is one of these questionable variables because this height was not based on the probability of encountering such an object in the roadway environment. The objective of this research was to investigate the characteristics of objects encountered in the roadway that represent a realistic hazard for the driver. A detailed examination of accident data was performed to evaluate the characteristics. Three types of accidents in two states were studied: other-object, animal, and evasive-action. The study results showed that only 0.07 percent of the reportable accidents involved small objects in the roadway. More than 90 percent of these objects accidents occurred at night on straight, flat roadways (conditions in which sight distance is not limited by the roadway's geometry), and they did not result in serious injuries. These findings suggest that accidents with small objects are neither frequent enough nor severe enough to justify their use as the critical situation in the SSD model. The authors recommend that the object height used in the design should represent the smallest object that poses a hazard to the driver: the minimum legal taillight height of a vehicle.

Stopping sight distance (SSD) is an integral part of the highway design process because it is the minimum sight distance required at all points along the roadway. The current SSD model uses a critical sight distance situation in which the passenger car driver, traveling at or near the design speed on a wet pavement, detects a small object in the roadway, recognizes it as a hazard, performs a locked-wheel brake, and stops before striking the object. The same parameter values are used for all types of roadways and conditions. Over time, several of these model parameters (including the object height) have changed, resulting in longer vertical curve length requirements; however, it has not been proven that longer curve lengths improve safety or that shorter curve lengths increase the potential for accidents (*1*).

The current SSD model is based on detection and recognition of a 150-mm (6-in.) object; however, several researchers have questioned this value and the assumptions in the SSD model because they do not appear to represent a realistic, real-world situation (*2*). The selection of the object height was not based on the frequency or severity of encountering such objects, and the selection appears to have been unrelated to the operational requirements for safe stopping sight distances (*3*). The initial rationale for the object height was a tradeoff between the cost of excavation and the ability of the driver to see the roadway, however in recent years it has been related to the height of the vehicle's undercarriage. Regardless of the rationale, objects of this size do not represent a hazardous situation for motorists if they do not cause accidents. Woods (*4*) found that a driver is 125 times more likely to be in an accident involving another vehicle than in an accident involving a small unknown "object."

In addition to the probability of striking a 150-mm (6-in.) object, research has not considered whether the chosen object height is actually visible to the average, or 85th percentile, driver. At night, the driver's visibility is limited to the headlight illumination distance, which is generally less than the required SSD. If the driver cannot recognize the object as a hazard or even see it at the required SSD, then the design criteria are not compatible with a driver's visual abilities.

The objective of this study was to investigate the characteristics of objects encountered in the roadway environment that could affect safe SSD. A secondary objective of the study was to determine whether any of these characteristics were different for different types of roadways.

HISTORY OF THE OBJECT HEIGHT

The need for sight distance on roadways was recognized in textbooks on highway engineering as early as 1914 (*5*). In 1921, Harger (*6*) was one of the first to attach lengths and heights to sight distance requirements by creating a line of sight between two points 1.7 m (5.5 ft) above the ground. In 1936, Gutmann (*7*) introduced the German standard for sight distance, which used two objects to determine the sight distance over a crest vertical curve: a standard passenger car 1.5 m (4.9 ft) high and an object 200 mm (8 in.) above the roadway surface.

Since the development of the first SSD models, object height has been a controversial topic. Throughout the 1930s, many highway agencies in the United States considered an approaching vehicle to be the critical encounter for evaluating sight distance; in 1940, the AASHO's SSD publication provided a standard by defining the critical object as a 100-mm (4-in.) object (*8*), the so-called "dead cat" rule (*9*). The 1954 AASHO policy (*10*) further supported the choice of the 100-mm (4-in.) object height by concluding that it offered a compromise between the cost of excavation and the ability of the driver to see the road ahead. "A 4-in. control was considered the approximate point of diminishing returns."

In the 1965 AASHO policy (*11*), the object height was increased from 100 to 150 mm (4 to 6 in.); however, the rationale used to

K. B. Kahl, CH2M HILL, 411 East Wisconsin Avenue, Suite 1600, Milwaukee, Wis. 53202. D. B. Fambro, Department of Civil Engineering, Texas A&M University System, Suite 303, CE/TTI Building, College Station, Tex. 77843.

justify the 150-mm 6-in.) object was the same rationale used for the 100-mm (4-in.) object in 1954. It represented the approximate point of diminishing returns between excavation and visibility. The literature at that time did not contain data to support the increase, but it has been suggested that the object height was increased to offset a decrease in driver's eye height and thus keep the required lengths of crest vertical curves relatively constant.

In 1984, the rationale for using the 150-mm (6-in.) object changed. The 1984 and the 1990 Green Books (*12,13*) emphasize that a 150-mm (6-in.) object represents the lowest object that can create a hazardous situation. They state that an object height of 150 mm (6 in.) is "largely an arbitrary rationalization of possible hazardous objects and a driver's ability to perceive and react to a hazardous situation." In summary, neither the original object height of 100 mm (4 in.) nor the current object height of 150 mm (6 in.) has supporting research to show that either represents an object or situation that is hazardous to a driver.

DATA COLLECTION

Accident records and narratives provide the best information for researchers studying what types of objects are encountered on the roadway as well as what circumstances are associated with object-related accidents. This study reviewed the records and narratives of object-related accidents from two large states to determine what types of objects are being struck on the roadways and the characteristics of the resultant accidents. Three types of single-vehicle accidents were examined in this study: other-object, animal, and evasive-action. These accident types were selected because they had the closest representation to the SSD situation: an unsuspecting driver encountering an unexpected object in the roadway. After these three accident data subsets were compiled, the characteristics of the object-related accidents were compared with characteristics of all accidents to investigate whether there were differences associated with object-related accidents.

The object-related accident characteristics were obtained from computerized data bases compiled from state accident reports; therefore, the type and amount of accessible data were limited to the information found in the state accident reports. The accident variables extracted from the data base included the object type, the accident severity, and the roadway type. The narrative accident reports were reviewed to determine the actual objects or animals struck and their approximate heights.

The accident data were separated according to the type of roadway to investigate whether the types of object struck differed by roadway classification. The roadway classification categories were limited by the variables available in the data bases; therefore, the variables were used to create a set of roadway classifications that could be applied to the data in both states. The classification categories were organized according to features that affected the geometric design of the road, such as the type of area (rural or urban), access control, number of lanes, median treatment, and shoulder treatment. Five road classifications were developed in a hierarchical order: freeways, multilane divided, multilane undivided, two-lane with shoulder, and two-lane without shoulder. These classifications were further divided into rural and urban areas, with four annual average daily traffic groups within each category.

Characteristics of unreported object-related accidents could not be investigated and therefore were a concern to the authors. For example, Griffin (*14*) reported that because fewer noninjury accidents are being reported, a larger percentage of the total number of accidents reported is composed of injury accidents. Griffin stated that accident data bases created through local, state, or federal governments tend to only include accidents that resulted in physical injury or property damage. This limitation could also apply to object-related accidents. For instance, if the object in the roadway did not cause physical injury or property damage, then it may not have been reported; however, these unreported accidents did not create a critical situation for the driver. Discounting these accidents would skew the data toward accidents with higher objects and more severe injuries. Thus, although unreported object-related accidents may be missing from the data base, the results will overestimate the percentage of critical situations caused by objects in the road.

State 1 Data Base

The first accident data set was obtained directly from the accident data base in State 1. The data base only included roadway information for the state-maintained highway system (on-system accidents); therefore, only those accidents occurring on state roads could be evaluated. There were 381,446 reported accidents in the state in 1991, but only 187,024 (49 percent) of the accidents were on the state-maintained system and could be included in the data base for this study.

The accidents used in the study were limited to single-vehicle accidents that occurred on the roadway. (If several vehicles were involved, then the accident description focused on the collision and not necessarily on the object that caused it.) The accident also had to occur on the roadway to directly pertain to the SSD critical situation. Single-vehicle, on-roadway accidents represented 9 percent (34,414) of all accidents in 1990. Within the single-vehicle, on-roadway accident subset, there were 523 object-related accidents and 2,619 animal-related accidents. Evasive-action accidents were also investigated; however, the accidents reviewed were not limited to single-vehicle accidents because the analysis focused on the cause of the evasive maneuver. There were 377 evasive-action accidents in which drivers swerved or slowed to avoid objects and 1,042 evasive-action accidents in which they swerved or slowed to avoid animals.

State 2 Data Base

The second set of accident data was taken from a highway safety data base developed by the FHWA Highway Safety Information System (HSIS). HSIS is a location-based accident system that combines accident, roadway, and traffic data in a computer-linkable format (*15*). The five states involved in HSIS have provided different information about their respective accidents; therefore, each data base had to be reviewed to determine which had variables that most closely matched those in the State 1 data base. As with State 1, the selected state data base contained only those accidents that could be linked to a specific location reference; these were usually accidents on higher order roadways that belonged to the state-maintained system.

Approximately 400,000 accidents were reported in State 2 in 1990; however, only 153,796 accidents were entered in the data base because of the location reference requirement. Twenty-one percent (32,233 accidents) of the accidents in the data base were single-vehicle accidents. Within the single-vehicle accident subset, 619 were object-related accidents and 6,237 were animal-related accidents. In summarizing the evasive-action accidents in State 2, there were 164 accidents in which drivers swerved or slowed to avoid objects and 731 accidents where in which drivers slowed or swerved to avoid animals.

DATA ANALYSIS

The three subsets of accidents that involved objects on the roadway were other-object, animal, and evasive-action. All other-object accident reports and a random sample of animal accident reports (14 percent) and evasive-action accident reports (38 percent) were reviewed to determine what objects were struck. The objects that caused these accidents were recorded, and their heights were established. Six height categories were created to help organize the data. If the object height was unknown, then the location of the damage and the vehicle damage severity were used to estimate an object height.

Other-Object Accidents

Other-object accidents occur when the driver strikes something that would not normally be encountered in the roadway environment and the encounter results in an accident. As mentioned previously, only those accidents that occurred on the roadway were examined because they represented situations that could result from limited SSD. Other-object accidents had the closest representation to the critical situation in the SSD model: a driver encountering an unexpected object on the roadway.

All of the single-vehicle, other-object accident reports were reviewed to determine what objects caused the accidents and if the objects or their characteristics differed according to roadway classification. In State 1 there were 238 other-object accidents on rural roads (45 percent) and 285 other-object accidents on urban roads (55 percent). The largest percentage of other-object accidents in State 1 occurred on freeways: 37 percent occurred in rural areas and 79 percent in urban areas. In State 2, 186 of the other-object accidents occurred on rural roads (30 percent) and 433 on urban roads (70 percent). As with State 1, the largest percentage of other-object accidents occurred on freeways: 48 percent in rural areas and 46 percent in urban areas.

Some of the more common objects struck on all types of roads included tires, hay bales, car parts, poles (lights or signs that had fallen across the road), trees or branches, construction barrels, railroad ties, and metal debris. On rural two-lane roads without shoulders, 53 percent of the accidents involved striking trees that had fallen across the road. Some of the more common objects struck on urban freeways appeared to be items that had fallen from moving vans or trucks, as well as poles that had fallen across the roadway.

Animal Accidents

An animal accident occurs when an animal is struck on the roadway. The accident data bases had limited reporting capabilities, which prompted questions about the nature of the animal accidents; the animal could have darted in front of the vehicle just before impact or it could have been standing in the roadway and the driver was unable to stop before striking it. In the first case, SSD was not a problem; however, in the latter case, it might have been a contributing factor to the accident. Because the purpose of this study was to determine the probability of encountering an object or animal in the roadway, all types of animal accidents were considered.

In State 1, 2,619 single-vehicle, animal accidents were reported in 1990. A random sample of 270 (10 percent) of these accident reports were reviewed. Ninety percent of the animal accidents occurred on rural roads and 10 percent occurred on urban roads. In State 2 there were more than 6,616 single-vehicle, animal accidents; 96 percent of them involved deer, and 4 percent involved other animals. Seventy-three percent of the animal accidents occurred on rural roads, 21 percent on urban roads, and 6 percent were not classified. One noticeable difference between the two states was the significantly higher number of deer accidents in State 2 than in State 1.

The animals were identified from the accident reports and separated according to size. Large animals were taller than 600 mm (24 in.) and included cows, horses, deer, or goats. Ninety-four percent of the animals struck in State 1 and more than 96 percent of the animals struck in State 2 were large animals. A medium-sized animal had an average height of between 450 and 600 mm (18 and 24 in.). They included dogs, pigs, and sheep and represented 5 percent of the animal-related accidents in State 1. Small animals had average heights of between 50 and 150 mm (2 to 6 in.) and included rabbits, raccoons, squirrels, skunks, armadillos, or other small animals. Small animals represented 1 percent of the animal accidents in State 1. The height of the animals from the random sample of 270 accidents was considered representative of all animal accidents. In State 2, however, the animal heights were heavily weighted toward large animals because of the large number of accidents with deer.

Evasive-Action Accidents

Evasive-action accidents occur when a driver attempts to avoid a hazard on the roadway. The drivers are usually successful in their attempt to avoid the hazard but subsequently strike another roadway element. In a study by Ketvirtis (*16*), subjects were given the choice to stop completely, go around, or pass over an object in the roadway; most chose to pass over almost all objects up to 100 mm (4 in.) in height. When the object was 150 mm (6 in.) high, approximately half chose to pass over and half chose to go around the hazard. Most subjects elected to perform an evasive maneuver and go around an object higher than 200 mm (8 in.).

The accidents that occurred because the driver attempted to avoid an object in the roadway were reviewed because they could be related to SSD. These accidents are relevant because they describe drivers' actions when faced with a situation similar to the one described by the SSD model: a driver encountering an unexpected object in the roadway. In State 1, pertinent evasive-action accident categories included: swerved to avoid object, swerved to avoid animal, slowed to avoid object, and slowed to avoid animal. These accidents represented 0.8 percent (1,419 accidents) of the total number of on-system accidents in State 1. Objects were avoided more often on urban roads and animals were avoided more often on rural roads. In State 2, evasive-action accidents were labeled "avoided foreign object" and "avoided animal." These accidents represented approximately 0.06 percent (895 accidents) of all accidents in the data base.

Accident Severity

The severity of the object accidents was determined using severity ratings based on human injury. These severity ratings did not necessarily have a direct correlation to the cause of the accident because the severity could have been influenced by other factors, including the use of seat belts or the size and type of the vehicle. In addition, the accident severity depended on the size of the object struck and the impact location on the vehicle. If the vehicle struck a piece of tire, lost control, and rolled over, then it probably sustained more damage than if it had simply struck the tire and pulled onto the shoulder. The five levels of severity included: no injury, possible injury, nonincapacitating injury, incapacitating injury, and fatality. Low-severity accidents included those in which there was no injury, possible injury, and nonincapacitating injury. Severe-injury accidents included those that resulted in fatalities and incapacitating injuries.

When considering the percentage of accidents resulting in severe injuries for the different types of accidents in State 1, other-object and animal accidents had two of the three lowest percentages of severe injury accidents. In State 2, other-object and animal accidents also had some of the lowest percentages of severe injury accidents. Animal-related accidents had the lowest percentage of injury accidents on rural roads.

To further investigate differences in accident severity, the occupant severity for object-related accidents in State 1 was compared with the occupant severity for all accidents. Table 1 shows that object and animal accidents on rural roads resulted in more low-severity accidents than all other types of accidents in 1990. On urban roads, the percentage of moderate-severity accidents was similar for all types of accidents. These results suggest that accidents with objects or animals on rural roads do not represent the most severe or the most hazardous situations for drivers.

Accident Characteristics

The accident characteristics may have contributed to the cause of the accident; therefore, they offer a comparison of the object-related accidents in this study with all types of accidents. The object-related accidents were an average of the other-object, animal, and evasive-action accidents reviewed from State 1. The characteristics that were reviewed included light, surface, and road conditions; weather; and alignment. Table 1 presents the percentage of accidents that occurred under the given conditions for all accidents and for object-related accidents. The percentages in the tables were an average of all 1990 accidents in State 1. The following situations were chosen for comparison from each accident condition: dry surfaces; clear weather; straight, level alignment; no roadway defects; and dark lighted and unlighted roadways.

A large percentage of object-related accidents occurred in clear weather on dry pavements; therefore, the roadway surface condition was the same for object-related accidents as it was for all accidents. The roadway alignment was also not a significant factor for most object-related accidents; thus, there was not a large difference between all accidents and object-related accidents. In addition, there were slightly fewer roadway defects in object-related accidents than in all accidents.

The light condition was an important contributory factor for the object-related accidents reviewed in this study. On rural and urban roads, approximately 30 to 40 percent more object-related accidents occurred under dark, unlighted conditions. Under dark, lighted conditions on urban roads, there also were more object-related accidents than other types of accidents. Although light conditions may have been important for all types of accidents, it was a more critical feature for accidents involving objects in the road.

RESULTS

The critical situation assumed by AASHTO is that the driver encounters a small unexpected object, recognizes it as a hazard, and then stops within the available SSD. The results of this study discuss the frequency at which these small obstacles result in a reported accident. This section also analyzes the accident conditions as they relate to the SSD critical encounter.

TABLE 1 Comparison of Critical Accident Characteristics in State 1 (by Percentage)

Accident Characteristics	Rural		Urban	
	All Accidents	Object Accidents[a]	All Accidents	Object Accidents[a]
Occupant Severity				
Low Severity	89.2	94.6	95.6	96.2
Light Condition				
Dark Unlit	27.2	70.0	7.4	33.7
Dark Lit	7.7	4.7	20.2	25.1
Surface Condition				
Dry	81.1	85.3	80.5	88.2
Weather				
Clear/Cloudy	86.4	87.7	86.0	90.4
Alignment				
Straight, Level	85.4	89.3	96.6	97.5
Road Condition				
No Defects	89.2	95.5	80.5	92.7

[a] Object-related accidents are an average of other-object, animal, and evasive-action accidents.

TABLE 2 Number of Rural Accidents in State 1 According to Height

Roadway Classification	Object Heights, mm[b]					
	0-50	50-150	150-300	300-450	450-600	> 600
Freeway	4	26	27	19	65	204
Multilane Divided	1	4	3	6	54	185
Multilane Undivided	0	4	4	5	42	176
Two-Lane High	0	8	16	9	129	754
Two-Lane Low	1	9	4	7	304	1091
Summary	6	51	54	46	594	2410
	0.2%	1.6%	1.7%	1.5%	18.8%	76.2%

[a] There were 82,705 rural accidents in the State 1 data base in 1990. This table summarizes other-object, animal, and evasive-action accidents.
[b] 1 inch = 25.4 mm.

Critical Object Heights

The object accident study has considered three types of accidents in which the driver could encounter a situation similar to that assumed by the SSD model: object, animal, and evasive-action. A breakdown of the results of the object heights in State 1 is presented in Tables 2 and 3. When considering all reported accidents in State 1, only 2 percent involved objects or animals; of those 2 percent, less than 4 percent involved an object smaller than 150 mm (6 ins.). More than 96 percent involved objects taller than 150 mm (6 ins.). Therefore, approximately 0.07 percent of the accidents in the State 1 data base involved objects less than 150 mm (6 ins.) high. Similar tables are not presented for State 2 because the accident reports for evasive-action accidents were not available. Thus, the distribution of actual object heights could not be determined.

The study also showed that many of the object-related accidents occurred at night when better roadway geometry would not have improved the drivers' sight distance because their visibility was limited by the headlight illumination distance and not the roadway geometry. Therefore, the only accidents that might be eliminated by increasing SSD would be those that took place during the day. In State 1, the percentage of total accidents involving small objects during the day was only 0.026 percent. Furthermore, it was assumed that a severe injury accident would represent the most critical occurrence to be avoided. The data showed that accidents involving small objects resulted in severe injuries only 0.004 percent of the time.

Considering these percentages, an accident with a small object that occurs in the daylight and results in a severe injury represents less than 0.001 percent of all accidents. In addition, the accident must also occur on or near a curve to apply to the SSD critical situation. Thus, the encounter becomes even less probable because only 0.7 percent of the small-object accidents occurred on vertical or horizontal alignment.

The results of this study were extrapolated to the 11.5 million accidents that occurred in the United States in 1990 (*17*) to determine the number of accidents that might be eliminated by increasing the curve length (i.e., decreasing the object height). Using the preceding percentages there would be approximately 3,000 accidents in the United States in 1 year in which an object 150 mm (6 ins.) or smaller would have been struck during daylight (11.5 million × 0.00026 = 3,000). Only 460 small object accidents would result in severe occupant injuries (11.5 million × 0.00004 = 460).

TABLE 3 Number of Urban Accidents in State 1 According to Height

Roadway Classification	Object Heights, mm[b]					
	0-50	50-150	150-300	300-450	450-600	> 600
Freeway	10	59	90	27	107	118
Multilane Divided	0	3	5	1	45	63
Multilane Undivided	1	4	2	2	32	62
Two-Lane High	0	3	1	3	24	50
Two-Lane Low	0	1	1	1	24	35
Summary	11	70	99	34	232	328
	1.4%	9.0%	12.8%	4.4%	30.0%	42.4%

[a] There were 298,741 urban accidents in the State 1 data base in 1990. This table summarizes other-object, animal, and evasive-action accidents.
[b] 1 inch = 25.4 mm.

Thus, the probability of an accident resulting from an encounter with a small object during the day on vertical alignment that caused a severe injury would be quite small.

Roadway Functional Classification

When the accidents were grouped into different roadway classification categories, no significant differences were observed among the types of objects struck in each category. However, some roadway classifications did not have enough data to make general conclusions about all roadways of that type; a future study using larger samples might yield different results.

The roadway classifications did show a difference among the heights of objects struck on rural and urban roads. On urban roads, 10.4 percent of the objects struck were below 150 mm (6 ins.) in height, but on rural roads only 1.8 percent were below 150 mm (6 ins.) in height. The visibility conditions would not explain this difference because urban roadways tend to be better lighted than rural roadways; however, drivers in urban areas may not be able to swerve to avoid an object in their lane because of high traffic volumes or the conditions of the roadway environment outside their lane. Drivers in rural areas with less traffic may have more opportunity to avoid an object. Given that urban and rural areas represent unique environments, perhaps SSD should be related to the area type.

CONCLUSIONS

The objective of this study was to analyze a representative sample of accidents to evaluate the characteristics of objects encountered on the roadway that would affect SSD. Currently, the SSD model uses a 150-mm (6-in.) object as the critical object height. The critical situation is the moment at which the driver detects an object on the roadway as a hazard just in time to stop before striking it. The conclusions, as stated below, do not support the current object height of 150 mm (6-in.) nor the critical situation used in the SSD model.

1. Two percent of all reported accidents involved objects or animals on the roadway, and only 0.07 percent of all reported accidents involved objects or animals less than 150 mm (6 in.) high. Therefore, small objects and animals were not struck often enough to justify their use as the critical encounter in the SSD model.
2. More than 90 percent of the object-related accidents occurred on straight, level roads where the driver's visibility was not limited by the geometry of the roadway. Therefore, available SSD was not a major contributory factor in the object-related accidents.
3. Most of the object-related accidents occurred at night when longer SSD and curve lengths would not necessarily increase the driver's visibility in these situations.
4. More than 95 percent of the accidents studied resulted in low-severity injuries; therefore, a small object is not the most critical, hazardous encounter in the SSD situation.
5. The study results did not substantiate the use of roadway classifications for identifying different critical object heights for different roadway classes; however, the study did suggest a difference in objects struck between roads in rural and urban areas.

The results of this study do not support the continued use of the existing 150-mm (6-in.) object height; therefore, the following recommendations are made.

1. The object height should represent the smallest realistic hazard encountered in the roadway; therefore, it appears that the height should be greater than 150 mm.
2. The taillight height of a vehicle is an object height that is frequently encountered and can be seen during both daytime and nighttime. Future research on the object height should focus on a 380-mm (15-in.) vehicle taillight because it represents a realistic hazard to the driver.
3. Research also should consider the drivers' visual abilities and limitations because the object height should represent an object that the driver can see.

ACKNOWLEDGMENTS

This research was performed at the Texas Transportation Institute, Texas A&M University.

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The findings and conclusions of the paper are those of the authors and do not necessarily represent the views of TRB or FHWA.

Publication of this paper sponsored by Committee on Geometric Design.